

Risk-based meat inspection and integrated meat safety assurance

WG 3 - Abattoir level controls and risk categorisation of abattoirs

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WG3 P23: Pig abattoir interventions in a risk-based meat safety assurance system: A systematic review and meta-analysis of the efficacy of interventions to reduce microbiological contamination on pig carcasses

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WG3 Introduction

- Interventions at abattoir level to control microbiological hazards are an essential part of meat safety assurance systems
- Interventions:
 - GHP-based (pre-requisites at the pre-slaughter stage (e.g. lairage holding time and feed withdrawal) and during slaughter and carcass dressing (e.g. scalding, singeing, rectum sealing, head removal, knife trimming, carcass washing);
 - Hazard-based known efficacy (hot water washing, steam pasteurisation, organic acid washes, other chemical washes)
- Priority hazards for control in pigs: Salmonella and Yersinia
- Indicator microorganisms for process hygiene assessment: aerobic colony count (ACC), Enterobacteriaceae count (EBC), generic E. coli count (ECC)
- No work has been performed to pool efficacy results of pig interventions on indicator organisms (ACC, EBC, ECC) and *Yersinia*.

WG3 specific objectives

- 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
- 3.3 Assessment of the performance of food safety management systems
- 3.4 HEI in risk categorisation of abattoirs



Years 3 & 4

Task 3.2.3. Systematic review and Meta-analysis **pig** interventions

The task is finished

WG3

- Literature searched 1990-2021 (>30 years)
- Systematic review and meta-analysis performed
- Work spanned 2019-2021

Contributors

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WG3 Methodology

- Systematic review:
 - 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.



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WG3 Results – systematic review

WG3-P23

Salines

- 74 relevant studies were identified (including Salmonella); 54 on non-Salmonella outcomes
- Salmonella excluded further due to recently published meta-analysis (Young et al., 2016)
- Only 25 with extractable data; 22 (88%) were of low risk of bias and available for meta-analysis.

4-Apr-22

Article characteristic	No of articles (%)
Study design	
Challenge trial	7 (24%)
Before-and-after trial	12 (41%)
Controlled trial	9 (31%)
Cohort study	1 (3%)
Study conditions	
Laboratory conditions	6 (23%)
Commercial abattoir conditions	18 (69%)
Research/pilot plant	2 (8%)
Intervention category/subcategory	
Pig handling in lairage	2 (5%)
Scalding	4 (10%)
Singeing Other standard processing procedures/GHP	4 (10%) 8 (20%)
Carcass pre-chill interventions	12 (31%)
Chilling, spray chilling, blast chilling	9 (23%)
Outcomes investigated	
Aerobic colony count	17 (38%)
Enterobacteriaceae	9 (20%)
Generic <i>E. coli</i>	12 (27%)
Yersinia enterocolitica	6 (13%)
Yersinia pseudotuberculosis	1 (2%)



WG3 Results – Risk of Bias

- 22 papers low risk of bias
- Three or more trials forest plots generated:
 - 48 forest plots, 40 with meta-analysis summary effects, 13 low/moderate heterogeneity
- Test for heterogeneity:
 - homogenous (p>0.05 on the test for heterogeneity),
 - moderately heterogeneous (p<0.05, I²<=60%),
 - highly heterogeneous (p<0.05, I²>60%).
- Meta-analysis grade:
 - Significant positive effect
 - No effect
 - Significantly homogenous studies







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WG3 Results – pre-slaughter, lairage interventions

Only 2 papers available

 Enterobacteriaceae counts in pig caecal content increased with both feed withdrawal and lairage holding time (MD 0.48, 95% CI: -0.10 to 1.06, I² = 77%)



 Misting live pigs with disinfectant reduced *Enterobacteriaceae* counts on pig skin significantly when compared to water misting alone in only one trial (MD -1.36, 95% CI: -2.91 to - 0.19)



WG3 Results – standard processing procedures: 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

Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight
Pearce (2004)	Scalding	8 min at 61°C, a linear scald tank	+ i	-3.76 [-	4.07; -3.45]	7.1%
Pearce (2004)	Scalding	8 min at 61°C, a linear scald tank	• •	-3.81 [-	4.12; -3.50]	7.1%
Pearce (2004)	Scalding	8 min at 61°C, a linear scald tank		-3.72 [-	4.03; -3.41]	7.1%
Rivas (2000)	Scalding		+	-2.14 [-	2.22; -2.06]	7.2%
Rahkio (1992)	Scalding			0.07 [-	0.15; 0.29]	7.1%
Rahkio (1992)	Scalding		-	-0.78 [-	1.02; -0.54]	7.1%
Spescha (2006)	Scalding	5 min immersion at 59°C-62°C	•	-3.05 [-	3.16; -2.94]	7.2%
Spescha (2006)	Scalding	5 min immersion at 59°C-62°C	+	-3.21 [-	3.32; -3.10]	7.2%
Spescha (2006)	Scalding	5 min immersion at 59°C-62°C	+	-3.19 [-	3.32; -3.06]	7.2%
Spescha (2006)	Scalding	5 min immersion at 59°C-62°C	+	-3.37 [-	3.48; -3.26]	7.2%
Spescha (2006)	Scalding	8.5 min immersion at 59°C-62°C	+	-3.23 [-	3.35; -3.11]	7.2%
Spescha (2006)	Scalding	8.5 min immersion at 59°C-62°C	+	-3.25 [-	3.38; -3.12]	7.2%
Spescha (2006)	Scalding	8.5 min immersion at 59°C-62°C	+	-3.16 [-	3.30; -3.02]	7.2%
Spescha (2006)	Scalding	8.5 min immersion at 59°C-62°C	+	-3.16 [-	3.30; -3.02]	7.2%
Random effects mode Heterogeneity: $l^2 = 99\%$,	$\tau^2 = 1.2829, p =$	0 T		2.84 [-4	3.50; -2.18]	100.0%

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 (log₁₀ CFU) on pig carcasses

WG3 Results – standard processing procedures: **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



Study	Intervention	Description	Mean Dif	ference	MD	95%-Cl	Weight
Pearce (2004)	Singeing	1200°C for 15 s			-2.55	[-2.91; -2.19]	10.5%
Pearce (2004)	Singeing	1200°C for 15 s			-2.21	[-2.57; -1.85]	10.5%
Pearce (2004)	Singeing	1200°C for 15 s			-2.85	[-3.21; -2.49]	10.5%
Rahkio (1992)	Singeing		+		-2.17	[-2.37; -1.97]	11.3%
Rahkio (1992)	Singeing				-2.18	[-2.41; -1.95]	11.2%
Spescha (2006)	Singeing	Standard singeing	-+		-0.99	[-1.14; -0.84]	11.5%
Spescha (2006)	Singeing	Standard singeing	+		-1.73	[-1.85; -1.61]	11.5%
Spescha (2006)	Singeing	Standard singeing			-1.35	[-1.53; -1.17]	11.4%
Spescha (2006)	Singeing	Standard singeing	+		-1.65	[-1.81; -1.49]	11.5%
Random effects model Heterogeneity: $I^2 = 96\%$, τ	² = 0.3251, p <	0.01			-1.95	[-2.40; -1.50]	100.0%
			-3 -2 -1 0	123			

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 (log₁₀ CFU) on pig carcasses



WG3 Results – standard processing procedures: water wash

Study	Interventio	on Ris	sk Ratio		RR	95	%-CI	Weig	ht	
Gill (2000) Gill (2000)	Water was	h b			1.33	[1.03;	1.72]	20.9	%	
Gill (2000)	Water was	41 .b	18 °		1.20	10.00	1.70	10.0	/0 0/	
GIII (2000)	water was	11 L	E.		1.00	[0.69,	1.12]	41.1	70 0/	
GIII (2000)	vvater was	in .	_		1.14	[0.72;	1.80]	9.1	%o	
Gill (2000)	Water was	in —			0.79	[0.45;	1.38]	6.3	%	
Gill (2000)	Water was	h — —	•		0.67	[0.21;	2.08]	1.7	%	
Gill (2000)	Water was	h	-	+	3.00	[0.67; 1	3.46]	1.0	%	
Gill (2000)	Water was	h –	1		0.92	[0.53;	1.61]	6.5	%	
Random effects mode	el		÷		1.09	[0.94;	1.27]	100.09	%	
Heterogeneity: $I^2 = 26\%$,	$\tau^2 = 0.0110, p$	= 0.22		I						
		0.1 0.5	1 2	10						Weigh
Rivas (2000)	Water wash	25 s, high pressure	e				-0.30	[-0.49;	-0.11]	5. 2 %
Gill (2000)	Water wash			<u>+</u> ++	_		0.13	[-0.14;	0.40]	5.0%
Gill (2000)	Water wash				_		-0.01	[-0.43;	0.41]	4.5%
Gill (2000)	Water wash						-0.25	[-0.59;	0.09]	4.8%
Gill (2000)	Water wash		-	<u></u>			-0.58	[-0.95;	-0.21]	4.7%
Gill (2000)	Water wash						-0.06	[-0.27;	0.15]	5.2%
Gill (2000)	Water wash				_		-0.74	[-1.07;	-0.41]	4.8%
Gill (2000)	Water wash		_	-	•		0.52	[0.17;	0.87]	4.8%
Gill (2000)	Water wash			- !		_	-1.16	[-1.55;	-0.77]	4.6%
Yu (1999)	Water wash	Final wash					1.28	[0.91;	1.65]	4.7%
Yu (1999)	Water wash	Final wash				-	0.52	[0.05;	0.99]	4.3%
Yu (1999)	Water wash	Pre-evisceration	-				-0.50	[-0.92;	-0.08]	4.5%
Spescha (2006)	Water wash	10°C for 15 s					-0.33	[-0.49;	-0.17]	5.3%
Spescha (2006)	Water wash	10°C for 15 s		1			-0.03	[-0.15;	0.09]	5.4%
Spescha (2006)	Water wash	10°C for 15 s					0.00	[-0.14;	0.14]	5.3%
Spescha (2006)	Water wash	10°C for 15 s					0.08	[-0.05;	0.21]	5.3%
Spescha (2006)	water wash	10°C for 15 s					-0.19	[-0.27;	-0.11]	5.4%
Spescha (2006)	vvater wash	10°C for 15 s					-0.39	[-0.49;	-0.29]	5.4%
Spescha (2006)	Water wash	10°C for 15 s					-0.18	[-0.28;	-0.08]	5.4%
Spescha (2006)	Water wash	10°C for 15 s					-0.20	[-0.30;	-0.10]	5.4%
Random effects model	- 0.0000 0	04		`			-0.12	[-0.35;	0.11]	100.0%
Heterogeneity: $I = 90\%, \tau^{-1}$	= 0.2260, p < 0.	.01	-1.5 -1	-0.5 0	0.5	1 1.5				

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

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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 (log₁₀ CFU) on pig carcasses

WG3 Results – SPP: rectum sealing

Study	Intervention	Description		Risk Ratio		RR	95%-Cl	Weight
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				1.26	[0.08; 19.32]	2.0%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.94	[0.23; 3.91]	7.3%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				1.51	[0.38; 6.04]	7.7%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.58	[0.27; 1.24]	25.8%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.60	[0.10; 3.49]	4.8%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag			-	1.05	[0.11; 10.31]	2.8%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				1.60	[0.07; 36.32]	1.5%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.42	[0.12; 1.44]	9.8%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.63	[0.29; 1.39]	23.9%
Laukkanen (2010)	Rectum sealing Ma	anual bagging with plastic bag				0.42	[0.05; 3.87]	3.0%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag				0.11	[0.01; 2.02]	1.8%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag		•		0.09	[0.01; 1.61]	1.8%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag		• • •		0.33	[0.01; 8.02]	1.5%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag						0.0%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag				0.11	[0.01; 2.02]	1.8%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag		•		0.33	[0.01; 8.02]	1.5%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag				0.20	[0.01; 4.08]	1.6%
Nesbakke (1994)	Rectum sealing Ma	anual bagging with plastic bag				3.00	[0.12; 72.19]	1.5%
Random effects mode Heterogeneity: $I^2 = 0\%$, τ^2	$p^2 = 0, p = 0.88$		Γ]	0.60	[0.41; 0.89]	100.0%
			0.01	01 1 1	0 100			

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



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WG3 Results – hazard-based, pre-chill carcass interventions: **hot water wash**



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

Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight	
Hamilton (2010)	Hot water wash	83.5°C, 15 s		-2.25	[-3.61; -0.89]	7.4%	
Hamilton (2010)	Hot water wash	83.5°C, 15 s		-0.90	[-2.60; 0.80]	5.7%	
Gill (1997)	Hot water wash Post-polishing	, pre-evisceration, 85°C, 15 s	-	-1.94	[-2.20; -1.68]	14.9%	
Gill (1997)	Hot water wash Post-polishing	, pre-evisceration, 85°C, 15 s		-1.78	[-2.06; -1.50]	14.8%	
Gill (1997)	Hot water wash Post-polishing	, pre-evisceration, 85°C, 15 s		-0.09	[-0.45; 0.27]	14.4%	
Gill (1997)	Hot water wash Post-polishing	, pre-evisceration, 85°C, 15 s		-0.65	[-1.01; -0.29]	14.4%	
Gill (1998)	Hot water wash 85°C, 10	0 s, carcass split before		-1.38	[-1.83; -0.93]	13.8%	
Gill (1998)	Hot water wash 85°C, 1	0 s, carcass split after		-1.70	[-2.01; -1.39]	14.7%	
Random effects mode Heterogeneity: / ² = 93%, t	l 2 ² = 0.4338, <i>p</i> < 0.01			-1.32	[-1.93; -0.71]	100.0%	
			-3 -2 -1 0 1 2 3				

Forest plot of the results of combined controlled trials and before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of hot water wash in reducing aerobic colony count (log₁₀ CFU) on pig carcasses



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 (log₁₀ CFU) on pig carcass meat

Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight	
Van Netten (1997)	Lactic acid 1% wash	55°C for 90 s	-	-0.40	[-0.58; -0.22]	9.0%	
Van Netten (1997)	Lactic acid 2% wash	55°C for 90 s	-	-1.20	[-1.38; -1.02]	9.0%	
Van Netten (1997)	Lactic acid 5% wash	55°C for 90 s	-	-1.20	[-1.38; -1.02]	9.0%	
Van Netten (1997)	Lactic acid 1% wash	55°C for 90 s		-0.70	[-0.88; -0.52]	9.0%	
Van Netten (1997)	Lactic acid 2% wash	55°C for 90 s		-1.40	[-1.58; -1.22]	9.0%	
Van Netten (1997)	Lactic acid 5% wash	55°C for 90 s		-1.70	[-1.88; -1.52]	9.0%	
Van Netten (1997)	Lactic acid 1% wash	55°C for 120 s	<u> </u>	-1.10	[-1.51; -0.69]	7.3%	
Van Netten (1997)	Lactic acid 2% wash	55°C for 120 s		-1.20	[-1.61; -0.79]	7.3%	
Van Netten (1997)	Lactic acid 5% wash	55°C for 120 s		-1.50	[-1.91; -1.09]	7.3%	
Van Netten (1997)	Lactic acid 1% wash	55°C for 120 s		-0.40	[-0.72; -0.08]	8.0%	
Van Netten (1997)	Lactic acid 2% wash	55°C for 120 s		-1.10	[-1.42; -0.78]	8.0%	
Van Netten (1997)	Lactic acid 5% wash	55°C for 120 s		-1.00	[-1.32; -0.68]	8.0%	
Random effects mode	el			-1.07	[-1.33; -0.81]	100.0%	
Heterogeneity: $I^2 = 93\%$,	$\tau^2 = 0.1464, p < 0.01$						
			-1.5 -1 -0.5 0 0.5 1 1.5				

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** (log₁₀ CFU) on pig carcasses

WG3 Results – hazard-based, pre-chill carcass interventions: **novel interventions (pulsed light)**

Study	Intervention	Description	Mean Differ	ence MD	95%-CI	Weight
Koch (2019)	Pulsed light	PL fluence 0.52 J/cm2, 13.4cm, 1s	-	-1.97	[-2.54; -1.40]	2.8%
Koch (2019)	Pulsed light	PL fluence 2.08 J/cm2, 13.4cm, 5s		-2.53	[-3.29; -1.77]	2.6%
Koch (2019)	Pulsed light	PL fluence 4.03 J/cm2, 13.4cm, 10s	+	-2.43	[-2.69; -2.17]	3.0%
Koch (2019)	Pulsed light	PL fluence 5.98 J/cm2, 13.4cm, 15s		-3.12	[-3.90; -2.34]	2.6%
Koch (2019)	Pulsed light	PL fluence 7.93 J/cm2, 13.4cm, 20s	+-	-2.30	[-2.60; -2.00]	3.0%
Koch (2019)	Pulsed light	PL fluence 11.83 J/cm2, 13.4cm, 30s		-2.37	[-2.99; -1.75]	2.7%
Koch (2019)	Pulsed light	PL fluence 0.64 J/cm2, 10.8cm, 1s		-1.47	[-1.98; -0.96]	2.8%
Koch (2019)	Pulsed light	PL fluence 2.56 J/cm2, 10.8cm, 5s	-	-2.00	[-2.45; -1.55]	2.9%
Koch (2019)	Pulsed light	PL fluence 4.96 J/cm2, 10.8cm, 10s	+	-2.07	[-2.40; -1.74]	3.0%
Koch (2019)	Pulsed light	PL fluence 7.36 J/cm2, 10.8cm, 12s		-2.36	[-2.77; -1.95]	2.9%
Koch (2019)	Pulsed light	PL fluence 9.76 J/cm2, 10.8cm, 20s		-3.42	[-5.27; -1.57]	1.5%
Koch (2019)	Pulsed light	PL fluence 14.56 J/cm2, 10.8cm, 30s		-2.07	[-2.47; -1.67]	2.9%
Koch (2019)	Pulsed light	PL fluence 0.84 J/cm2, 8.3cm, 1s	+	-1.99	[-2.21; -1.77]	3.0%
Koch (2019)	Pulsed light	PL fluence 3.36 J/cm2, 8.3cm, 5s		-2.54	[-3.42; -1.66]	2.5%
Koch (2019)	Pulsed light	PL fluence 6.51 J/cm2, 8.3cm, 10s		-1.94	[-2.56; -1.32]	2.7%
Koch (2019)	Pulsed light	PL fluence 9.66 J/cm2, 8.3cm, 15s		-4.37	[-6.09; -2.65]	1.6%
Koch (2019)	Pulsed light	PL fluence 12.81 J/cm2, 8.3cm, 20s		-4.20	[-5.84; -2.56]	1.6%
Koch (2019)	Pulsed light	PL fluence 19.11 J/cm2, 8.3cm, 30s		-4.19	[-5.86; -2.52]	1.6%
Koch (2019)	Pulsed light	PL fluence 0.52 J/cm2, 13.4cm, 1s	•	-0.37	[-0.43; -0.31]	3.1%
Koch (2019)	Pulsed light	PL fluence 2.08 J/cm2, 13.4cm, 5s	+	-0.58	[-0.69; -0.47]	3.1%
Koch (2019)	Pulsed light	PL fluence 4.03 J/cm2, 13.4cm, 10s	+	-0.86	[-0.97; -0.75]	3.1%
Koch (2019)	Pulsed light	PL fluence 5.98 J/cm2, 13.4cm, 15s	+	-0.86	[-0.98; -0.74]	3.0%
Koch (2019)	Pulsed light	PL fluence 7.93 J/cm2, 13.4cm, 20s	+	-0.95	[-1.07; -0.83]	3.0%
Koch (2019)	Pulsed light	PL fluence 11.83 J/cm2, 13.4cm, 30s	+	-0.99	[-1.20; -0.78]	3.0%
Koch (2019)	Pulsed light	PL fluence 0.64 J/cm2, 10.8cm, 1s	+	-0.84	[-1.00; -0.68]	3.0%
Koch (2019)	Pulsed light	PL fluence 2.56 J/cm2, 10.8cm, 5s	-+	-1.06	[-1.39; -0.73]	3.0%
Koch (2019)	Pulsed light	PL fluence 4.96 J/cm2, 10.8cm, 10s	+	-1.16	[-1.30; -1.02]	3.0%
Koch (2019)	Pulsed light	PL fluence 7.36 J/cm2, 10.8cm, 12s	-+	-1.42	[-1.72; -1.12]	3.0%
Koch (2019)	Pulsed light	PL fluence 9.76 J/cm2, 10.8cm, 20s		-1.69	[-2.01; -1.37]	3.0%
Koch (2019)	Pulsed light	PL fluence 14.56 J/cm2, 10.8cm, 30s	+	-1.37	[-1.59; -1.15]	3.0%
Koch (2019)	Pulsed light	PL fluence 0.84 J/cm2, 8.3cm, 1s	+	-0.78	[-0.88; -0.68]	3.1%
Koch (2019)	Pulsed light	PL fluence 3.36 J/cm2, 8.3cm, 5s	+	-1.02	[-1.14; -0.90]	3.0%
Koch (2019)	Pulsed light	PL fluence 6.51 J/cm2, 8.3cm, 10s	+	-0.84	[-1.05; -0.63]	3.0%
Koch (2019)	Pulsed light	PL fluence 9.66 J/cm2, 8.3cm, 15s	-+	-1.14	[-1.39; -0.89]	3.0%
Koch (2019)	Pulsed light	PL fluence 12.81 J/cm2, 8.3cm, 20s	+	-1.18	[-1.29; -1.07]	3.1%
Koch (2019)	Pulsed light	PL fluence 19.11 J/cm2, 8.3cm, 30s		-1.33	[-1.64; -1.02]	3.0%
Random effects model				-1.68	[-1.99; -1.37]	100.0%
Heterogeneity: $I^2 = 97\%$, τ^2	⁺ = 0.8057, <i>p</i> <	0.01				
			n / 2 ()	1 1 6		

Forest plot of the results of challenge trials performed under laboratory conditions to investigate the efficacy of pulsed light treatment in reducing *Yersinia enterocolitica* counts (log₁₀ CFU) on pig carcass meat.

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WG3 Results – chilling: conventional dry chilling



Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight
Langkabel (2014)	Dry chilling	Conventional chiller	- -	-0.20	[-0.48; 0.08]	6.6%
Langkabel (2014)	Dry chilling	Mobile chilling unit		-0.10	[-0.35; 0.15]	6.7%
Langkabel (2014)	Dry chilling	Conventional chiller		-0.20	[-0.49; 0.09]	6.5%
Langkabel (2014)	Dry chilling	Mobile chilling unit		-0.10	[-0.29; 0.09]	7.0%
Langkabel (2014)	Dry chilling	Conventional chiller		-0.40	[-0.63; -0.17]	6.8%
Langkabel (2014)	Dry chilling	Mobile chilling unit	— · • •	-0.70	[-0.96; -0.44]	6.7%
Pearce (2004)	Dry chilling	2°C - 4°C, 24 h		0.14	[-0.17; 0.45]	6.4%
Pearce (2004)	Dry chilling	2°C - 4°C, 24 h		-0.01	[-0.32; 0.30]	6.4%
Pearce (2004)	Dry chilling	2°C - 4°C, 24 h		0.33	[0.02; 0.64]	6.4%
Gill (2000)	Dry chilling	Dry chilling		-0.38	[-0.83; 0.07]	5.7%
Gill (2000)	Dry chilling	Dry chilling		0.05	[-0.31; 0.41]	6.2%
Spescha (2006)	Dry chilling	4.0 m/s at 2°C		-0.65	[-0.78; -0.52]	7.2%
Spescha (2006)	Dry chilling	4.0 m/s at 2°C		-0.96	[-1.11; -0.81]	7.1%
Spescha (2006)	Dry chilling	4.0 m/s at 2°C	-	-1.17	[-1.32; -1.02]	7.1%
Spescha (2006)	Dry chilling	4.0 m/s at 2°C	-	-0.89	[-1.03; -0.75]	7.1%
Random effects mo	del			-0.36	[-0.61; -0.12]	100.0%
Heterogeneity: 1 ² = 94%	6, τ ² = 0.1789, <i>p</i> <	0.01	1 1 1 1 1			
			-1 -0.5 0 0.5 1			

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 (log₁₀ CFU) on pig carcasses

WG3 Results – chilling: blast chilling

Study	Intervention	Description	Risk Ratio	RR	95%-CI Weight
Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006)	Blast and conventional chilling Blast and conventional chilling Blast and conventional chilling Blast and conventional chilling	Blast for 45 min (8.0 m/s at -8° C) then dry chill 1.0 m/s at 2° C Blast for 45 min (8.0 m/s at -8° C) then dry chill 1.0 m/s at 2° C Blast for 45 min (8.0 m/s at -8° C) then dry chill 1.0 m/s at 2° C Blast for 45 min (8.0 m/s at -8° C) then dry chill 1.0 m/s at 2° C -		0.39 0.04 0.08 0.03	[0.22; 0.68] 33.5% [0.01; 0.32] 22.5% [0.02; 0.32] 27.3% [0.00; 0.42] 16.6%
Random effects model Heterogeneity: $I^2 = 78\%$, τ^2	² = 1.8444, <i>p</i> < 0.01		0.01 0.1 1 10 100	0.10	[0.02; 0.47] 100.0%

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

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Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight
Gill (2000)	Blast and conventional chilling	Blast chilling at -20°C for 1h, then dry chill	- <u>-</u>	0.08	[-0.18; 0.34]	9.9%
Gill (2000)	Blast and conventional chilling	Blast chilling at -20°C for 1h, then dry chill		0.29	[-0.03; 0.61]	9.4%
Gill (2000)	Blast and conventional chilling	Blast chilling at -20°C for 1h, then dry chill		-0.26	[-0.60; 0.08]	9.2%
Gill (2000)	Blast and conventional chilling	Blast chilling at -20°C for 1h, then dry chill		- 0.61	[0.11; 1.11]	7.7%
Rahkio (1992)	Blast chilling	Blast at -22°C for 1 h		-0.04	[-0.24; 0.16]	10.4%
Rahkio (1992)	Blast chilling	Blast at -22°C for 1 h	÷	-0.05	[-0.20; 0.10]	10.6%
Spescha (2006)	Blast and conventional chilling Blas	t for 45 min (8.0 m/s at -8°C) then dry chill 1.0 m/s at 2°C	-	-0.20	[-0.38; -0.02]	10.5%
Spescha (2006)	Blast and conventional chilling Blas	t for 45 min (8.0 m/s at -8°C) then dry chill 1.0 m/s at 2°C		-0.79	[-0.93; -0.65]	10.7%
Spescha (2006)	Blast and conventional chilling Blas	t for 45 min (8.0 m/s at -8°C) then dry chill 1.0 m/s at 2°C		-0.59	[-0.73; -0.45]	10.7%
Spescha (2006)	Blast and conventional chilling Blas	t for 45 min (8.0 m/s at -8°C) then dry chill 1.0 m/s at 2°C	-	-0.51	[-0.64; -0.38]	10.8%
Random effects mo	odel % τ ² = 0.1515 ρ < 0.01			-0.17	[-0.47; 0.12]	100.0%
inclose genergy in the	, · · · · · · · · · · · · · · · · · · ·		-1 -0.5 0 0.5	1		

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 (log₁₀ CFU) on pig carcasses.

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WG3 Results – multiple interventions

Study	Intervention	Description	Risk Ratio	RR	95%-CI	Weight
Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006) Spescha (2006)	Multiple interventions So Multiple interventions So Multiple interventions So Multiple interventions So Multiple interventions Multiple interventions Multiple interventions Multiple interventions	calding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill calding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill calding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill calding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill Scalding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill Scalding, dehairing, singeing, polishing, trimming, water wash, dry chill		0.14 0.01 0.02 0.00 0.43 0.18 0.17 0.21	$\begin{matrix} [0.09; \ 0.23] \\ [0.00; \ 0.07] \\ [0.01; \ 0.08] \\ [0.00; \ 0.08] \\ [0.35; \ 0.54] \\ [0.12; \ 0.28] \\ [0.11; \ 0.26] \\ [0.15; \ 0.31] \end{matrix}$	14.7% 9.0% 10.9% 4.8% 15.5% 15.0% 14.9% 15.1%
Random effects mod Heterogeneity: $I^2 = 94\%$	del $_{6}$, τ^{2} = 0.8798, ρ < 0.01		0.001 0.1 1 10	0.11	[0.05; 0.23]	100.0%

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

Study	Intervention	Description	Mean Difference	MD	95%-CI	Weight
Pearce (2004)	Multiple interventions	Scalding, dehairing, singeing, polishing, water wash, dry chill 24 h, 2°C		-3.22	[-3.55; -2.89]	6.6%
Pearce (2004)	Multiple interventions	Scalding, dehairing, singeing, polishing, water wash, dry chill 24 h, 2°C		-2.70	[-3.03; -2.37]	6.6%
Pearce (2004)	Multiple interventions	Scalding, dehairing, singeing, polishing, water wash, dry chill 24 h, 2°C		-2.60	[-2.93; -2.27]	6.6%
Van Ba (2019)	Multiple interventions	Scalding, dehairing, singeing, water wash, lactic acid 2% spray, dry chill 24 h, 2°C		-4.25	[-4.86; -3.64]	6.1%
Van Ba (2019)	Multiple interventions	Scalding, dehairing, singeing, water wash, lactic acid 4% spray, dry chill 24 h, 2°C +	•	-4.81	[-5.42; -4.20]	6.1%
Rahkio (1992)	Multiple interventions	Scalding, dehairing, singeing, blast chill -22°C for 1 h		-1.34	[-1.61; -1.07]	6.7%
Rahkio (1992)	Multiple interventions	Scalding, dehairing, singeing, blast chill -22°C for 1 h		-1.38	[-1.63; -1.13]	6.7%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill	+	-2.32	[-2.47; -2.17]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill		-3.08	[-3.20; -2.96]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill	*	-2.84	[-2.97; -2.71]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, blast chill, dry chill	+	-2.76	[-2.89; -2.63]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, dry chill	+	-2.51	[-2.64; -2.38]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, dry chill	-	-3.06	[-3.21; -2.91]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, dry chill	+	-3.23	[-3.38; -3.08]	6.8%
Spescha (2006)	Multiple interventions	Scalding, dehairing, singeing, polishing, trimming, water wash, dry chill	+	-2.95	[-3.10; -2.80]	6.8%
Random effects model				-2.85	[-3.33; -2.37]	100.0%
Heterogeneity: $I^{2} = 97\%$, $\tau^{2} = 0.7383$, $p < 0.01$						

-4 -2 0 2 4

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 (log₁₀ CFU) on pig carcasses.



WG3 Discussion & Conclusions

 >30 years of literature reviewed, 4 microorganisms, all possible interventions from lairage to carcass chilling

however

- Only 22 eligible papers and 40 meta-analysis summary effects generated: significant gaps in the literature about pig interventions
- Not all studies had extractable data (<50% !)</p>
- High heterogeneity of studies (>2/3)
- Sufficient data for scalding, singeing, but
- Lack of data for carcass steam pasteurisation, organic acid washes (acetic acid, and lack of data on lactic acid from commercial trials)
- Lack of sufficient data on most interventions, to reduce heterogeneity

WG3 Discussion & Conclusions

- Scalding, singeing 2-3 logs ACC, RR 0.05 0.25 Enterobacteriaceae prevalence
- Rectum sealing RR 0.60 for Yersinia enterocolitica
- Hot water wash up to 1.3 logs ACC and E. coli
- Multiple interventions up to 3 logs ACC, RR 0.11 Enterobacteriaceae prevalence
- Recommendations:
 - Standard processing procedures and hot water wash recommended
 - More research is needed
 - Methodologies and data recording needs to be harmonised



WG3 Systematic review and Meta-analysis of pig interventions

 Big thanks to all contributors in this task (2019-2022) and co-authors of this work and future manuscript

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WG3 specific objectives: what next ?

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

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