Targeted low cost solutions for control of Salmonella in pig production

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Priority Area (s) | I - Sustainable Food Production and Processing

Key words: Pigs, Salmonella, organic acids, feed
1. Rationale for Undertaking the Research

Carriage of *Salmonella* in pigs is a significant food safety issue. In the EU in 2014, 225 food-borne outbreaks related to *Salmonella* were reported and ~21 (or 9.3%) were linked to the consumption of pork. Ireland has been shown to have a high prevalence of *Salmonella* on pig carcasses (20% based on the 2008 EU Baseline survey). Further research on *Salmonella* in pigs and pork in Ireland highlighted risk factors for *Salmonella* contamination on pork, with high carriage at primary production and cross contamination in the lairage noted as key problem areas (Duggan et al., 2010; McCarthy et al., 2011). With a view to addressing *Salmonella* in pigs, an Irish National *Salmonella* Pig Control Programme (SPCP) was relaunched by the Dept of Agriculture, Food and the Marine (DAFM) in January 2010 which renewed efforts to link control of *Salmonella* back to farm level. However, serological prevalence levels for herds have still not declined. In addition, recent unpublished bacteriological data (DAFM) suggest that while some progress has been made in reducing *Salmonella* levels at slaughter, it has been extremely limited. This highlights the need to take on board recent national and international research on *Salmonella* control in pigs at primary production, in particular practical, commercially viable, low cost interventions and to assess and validate their efficacy on Irish pig farms with a high *Salmonella* prevalence. Feed additives and hygiene control measures have shown promise in controlling *Salmonella* (Berge and Wierup, 2011). Studies to date have looked at using interventions at finisher stage only; however, recent thinking suggests that elimination of *Salmonella* carriage at an early stage of production, i.e. in weaners, is desirable (Wales et al., 2010). Sows could also be targeted, as they are a recognised source of infection for both weaner and finishing pigs (Nollet et al., 2005). In addition, as sows make up a relatively small proportion of the herd, feed interventions at this stage would likely be cost-effective, as are feed additives for first stage weaned pigs in which feed intake is low. Carriage of *Salmonella* by finishing pigs is a significant source of contamination of the lairage and subsequently carcasses at slaughter. As the lairage of pig abattoirs are a significant source of *Salmonella* contamination for carcasses (Duggan et al 2010, Mannion et al., 2012) control measures here are likely to be of significant benefit and are in line with EU recommendations that control programmes implement measures at the processing level as well as primary production (EFSA, 2008). This project therefore aimed to investigate the role of breeding sows and gilts in the transmission of *Salmonella* to piglets and its shedding pattern and to investigate the effect of dietary supplementation with 3 organic acids during 2 stages of growth, second stage weaning and late finishing (24-28 days before slaughter). With a view to controlling *Salmonella* in pig lairage, several cleaning and disinfection regimes were evaluated for their ability to eliminate *Salmonella* and reduce levels of *Enterobacteriaceae* within the lairage pen environment. The cost benefit of proposed controls was also investigated.

2. Research Approach

A range of field trials and associated laboratory studies employing microbial and molecular tools were used to study various strategies for control of *Salmonella* in pig production.

**Shedding patterns in breeding pigs (Task 2)**

This was one of the first studies and it aimed to provide new insights into the epidemiology of *Salmonella* in pig production, focusing on potential shedding patterns in breeding pigs throughout a full production cycle and the risk of transmission of infection from the sow to her offspring. A longitudinal study was conducted on five farrow-to-finish commercial pig farms. In each herd, shedding of *Salmonella* in faeces was monitored in breeders through service, gestation and lactation. Swabs of the farrowing room floor and pools of faeces from piglets were collected on two occasions during lactation. Environmental pen swabs were also taken in the weaning and finisher
houses. *Salmonella* isolates were serotyped, tested for antimicrobial resistance (AMR) and typed by Multiple-Locus Variable number tandem repeat Analysis (MLVA).

**Control of Salmonella in grower pigs (Task 3)**
The objective of this research was to investigate the usefulness of a sodium butyrate-supplemented diet on *Salmonella* prevalence in grower pigs. However, due to low levels of *Salmonella* encountered throughout the trial, differences in *Salmonella* prevalence or shedding were not detected. Therefore, a new protocol for experimental *Salmonella* infection was developed which could then be used as a tool in the investigation of control measures. The approach used was successful in infecting pigs with *Salmonella* and was used to examine the effect of 3 organic acid-based products on *Salmonella* levels in grower pigs.

**Control of Salmonella in finisher pigs (Task 4)**
Pre-harvest *Salmonella* control strategies directed towards finishing pigs were also investigated at farm level. Two strategies focusing on dietary supplementation with feed additives: (1) sodium butyrate; and (2) an encapsulated blend of formic acid, citric acid, and essential oils (FormaXOL™) were investigated for their effectiveness in controlling *Salmonella* shedding and seroprevalence in pigs 24-28 days prior to slaughter.

**Control of Salmonella in lairage (Task 5)**
In the abattoir, two strategies: a) cleaning and disinfection of lairage pens with a quaternary ammonium compound- or chlorocresol-based disinfectant; and (b) misting pigs with a peroxygen disinfectant at 0.5% were evaluated for their ability to eliminate *Salmonella* in the lairage environment and to reduce topical contamination levels on pigs prior to slaughter, respectively.

**Assessment of integrated control strategies to reduce Salmonella in a full pig production cycle (Task 6)**
This case study was undertaken following research in previous tasks, which showed that duration of treatment and concomitant infections are key factors in the efficacy of pre-harvest *Salmonella* control measures in finishing pigs. This reflects the situation that many farmers are faced with, wherein multiple diseases are common among pigs; posing challenges for *Salmonella* control. This study investigated the effectiveness of three interventions on *Salmonella* shedding and seroprevalence on a commercial farm with a history of high *Salmonella* seroprevalence and secondary infections: (1) cleaning and disinfecting finisher pens with an peroxygen agent and a chlorocresol-based disinfectant followed by a drying step, (2) supplementing finisher feed with sodium butyrate (3 kg/t) for 63 days prior to slaughter, or (3) supplementing finisher feed with sodium butyrate (3 kg/t) for 28 days prior to slaughter. Two trials were conducted to investigate the three interventions. In Trial A, interventions I and 2 above were investigated, in combination, while Trial B investigated intervention 3 alone. Pooled faeces were collected from each pen on the same days and examined for the presence of concurrent infections with pathogens such as Rotavirus, *Lawsonia intracellularis* and *Brachyspira*. When pigs reached their target slaughter weight they were transported to a commercial abattoir and carcass quality parameters were recorded.

**Cost benefit analysis on use of Salmonella-control strategies in commercial pig operation (Task 7)**
Data from Irish pigs farms since 2010 was collated in order to compare their production parameters and their *Salmonella* prevalence. Factors that can be affected by salmonellosis were included in a model and logistic regression was used to estimate which factors were related to the
presence/absence of *Salmonella* and the economic impact of *Salmonella* in Irish pig herds. The approach taken was to

- Estimate the impact of the infection on production
- Calculate the cost of the infection for the farmer
- Determine any negative impact on growth and carcass yield
- Calculate the cost of the control interventions (acids, disinfectants)
- Estimate potential benefits (i.e. improvement of growth)
- Measure the cost-benefit

### 3. Research Achievements/Results

**Shedding patterns in breeding pigs (Task 2)**

Shedding by breeding pigs was low in all stages of the production cycle; 5% of sows shed at service, the production stage with highest risk of shedding (*p* < .01), 1.6% shed during gestation and 2.5% after farrowing. *Salmonella* was detected in 4% of piglet faecal pools in the second week post-farrowing and 5% in the fourth week. Serotyping and AMR profiles of *Salmonella* isolates revealed that strains in sows and gilts were mostly different from strains isolated in weaner and finisher facilities. MLVA typing confirmed that the source of infection in piglets was in most instances the contaminated environment rather than their dam. Based on the typing results, it appears that sows did not pose a major risk in the maintenance and transmission of *Salmonella* to their progeny in the farms studied but instead the contaminated pen environment was more significant in the perpetuation of the organism on-farm.

**Control of *Salmonella* in grower pigs (Task 3)**

A new protocol of *Salmonella* infection based on exposure to an artificially contaminated environment that closely mimics natural exposure to the organism was developed. The aim of the study was to evaluate the effectiveness of this protocol, which could then be used as a tool in the investigation of control measures. In addition, *Salmonella* shedding pattern and growth performance of the pigs were examined. All pigs in the contaminated pens shed *Salmonella* within the first 2 days of exposure with values ranging from 100 to 10⁴ CFU/g. The non-infected pigs had significantly higher final body weights on day 28 and significantly higher average daily weight gain over the 28-day period compared to those exposed to the *Salmonella* contaminated environment (*p* < 0.001). Although not significant, numerical improvements in average daily feed intake and feed conversion efficiency were observed in the *Salmonella*-free pigs when compared to the contaminated pigs. Thus, it was concluded that the approach of exposing pigs to a contaminated environment was successful in infecting pigs with *Salmonella* without the need for direct inoculation or exposure to seeder pigs. This "natural" method of infection in which pigs are exposed to low levels of environmental contamination with *Salmonella* may be an effective tool that could be utilized by researchers when investigating control measures.

Dietary supplementation with organic acids has previously been shown to reduce shedding and transmission of *Salmonella*. Therefore, this study aimed to examine the effect of three commercially available organic acid-based products on *Salmonella* levels in grower pigs, using the method of experimental infection described above. Trial pigs received one of four diets for 28 days: 1, control diet; 2, sodium butyrate-supplemented diet; 3, benzoic acid-supplemented diet and 4, formic-citric acid (*FormaXOL™*)-supplemented diet. Within the first two days of exposure to the contaminated environment, 96% (77/80) of pigs became infected. Most pigs shed *Salmonella* at levels of between 100-10⁵ CFU/g faeces for at least 7 days post-exposure. A significant reduction in *Salmonella* faecal concentration was observed after supplementation with sodium butyrate (*p* =
and a formic-citric acid blend (p < 0.0001). Average daily weight gain (ADWG) was significantly increased in all groups fed the supplemented feed when compared to the positive control group.

The use of sodium butyrate or a blend of formic and citric acid in feed could be considered a cost-effective control measure to reduce Salmonella faecal shedding and improve ADWG in Salmonella-infected herds.

Control of Salmonella in finisher pigs (Task 4)

1) Sodium butyrate

This study investigated the effectiveness of dietary supplementation with sodium butyrate administered to finisher pigs for ∼4-weeks prior to slaughter to control Salmonella shedding on highly contaminated farms. Two trials (A and B) were conducted on two commercial pig farms, which had a history of high Salmonella seroprevalence. In Trial A, Salmonella shedding was reduced in the treatment compared to the control group at the end of the trial (30% versus 57% probability of detecting Salmonella in faeces, respectively; p < 0.001). This reflected the serology results, with detection of a lower seroprevalence in the treatment compared to the control group using the 20% optical density cut-off (69.5% versus 89%; p = 0.001). However, no effect on faecal shedding or seroprevalence was observed in Trial B, which may be explained by the detection of a concomitant infection with Lawsonia intracellularis. No significant differences in Salmonella recovery rates were observed in the caecal digesta or lymph nodes in either trial. Furthermore, feed intake, weight gain, and feed conversion efficiency (FCE) did not differ between groups (p > 0.05) in either trial. Numerical improvements in weight gain and FCE were found with sodium butyrate treatment, which gave a cost benefit of €0.04/kg of live-weight gain. Overall, results suggest that strategic feeding of sodium butyrate, at 3 kg/t of feed, to finishing pigs for 24–28 days prior to slaughter was effective in reducing Salmonella shedding and seroprevalence but perhaps only in the absence of co-infection with other pathogens. However, sodium butyrate supplementation at this rate did not influence intestinal carriage, nor did it reduce seroprevalence to below the cut-off used for the high Salmonella risk category in Ireland (50%), or significantly improve growth performance. These findings further confirm the multifactorial nature of the problem of Salmonella in pig production.

2) FormaXOL™

This study investigated the efficacy of an encapsulated blend of formic acid, citric acid, and essential oils (FormaXOL™) administered to finisher pigs for 28 days prior to slaughter in controlling Salmonella shedding on a commercial farm with a history of high Salmonella seroprevalence. Fourteen pens of 8–10 pigs/pen were randomly assigned to a control (finisher diet without additive) or a treatment group (the same diet with 4 kg/t of FormaXOL™) for 28 days. On day 14, Salmonella shedding was reduced in the treatment compared to the control group (27.9% versus 51.7% probability of detecting Salmonella in faeces, respectively; p = 0.001). However, on day 28, no reduction was observed (20.6% versus 35.9% probability of detecting Salmonella in faeces, respectively; p = 0.07). Interestingly, Salmonella shedding rates in the treated pigs remained stable throughout the trial compared to the control group. This suggests that the feed additive prevented additional pigs from acquiring the Salmonella infection. A lower Salmonella seroprevalence was detected at slaughter in the treatment compared to the control group using the 40% optical density cut-off (64.5% versus 88.5%, respectively; p = 0.01). However, no significant differences in Salmonella recovery rates were observed in the caecal digesta or lymph nodes between treated and control groups. Treated pigs had a lower feed intake than pigs fed the control diet (p = 0.001); however, average daily gain and feed conversion efficiency were not affected by treatment (p = 0.45 and 0.55, respectively). Consequently, supplementing the diet with FormaXOL™ for 28 days increased the feed cost per kg of live-weight gain by €0.08. Overall, results suggest that strategic administration of an encapsulated blend of formic acid, citric acid, and essential oils,
to finishing pigs for 28 days prior to slaughter has potential to prevent increased *Salmonella* shedding at certain time points as well as reducing seroprevalence. However, this additive did not lower intestinal carriage, nor did it reduce seroprevalence to below the cut-off used for the high *Salmonella* risk category in Ireland (50%) or improve growth performance.

**Control of *Salmonella* in lairage (Task 5)**

1) **Cleaning and disinfection**

Several cleaning and disinfection protocols were tested for their ability to eliminate *Salmonella* and to reduce levels of *Enterobacteriaceae*, within the lairage pens of a commercial pig abattoir. Eight protocols were evaluated in each of 12 lairage pens at the end of the slaughtering day on 3 occasions (36 pens/protocol):

- (P1) high-pressure cold water wash (herein referred to as high-pressure wash);
- (P2) high-pressure wash followed by a quaternary ammonium compound (QAC)-based disinfectant without rinsing;
- (P3) high pressure wash followed by a chlorocresol-based disinfectant without rinsing;
- (P4) high-pressure wash followed by a sodium hydroxide/sodium hypochlorite detergent with rinsing;
- (P5) P4 followed by P2;
- (P6) P4 followed by P3;
- (P7) P5 with drying for 24–48 h; and
- (P8) P6 with drying for 24–48 h.

Two floor swabs and one wall swab were taken from each lairage pen before and after each protocol was applied, and examined for the presence of *Salmonella* and enumeration of *Enterobacteriaceae*. The results showed that high-pressure washing alone (P1) did not reduce the prevalence of *Salmonella* in the lairage pens. When high pressure washing, the probability of detecting *Salmonella* following application of the chlorocresol-based disinfectant (P3) was lower than with the QAC-based disinfectant, P2 (14.2% versus 34.0%, respectively; *p* < 0.05). The probability of detecting *Salmonella* after the combined use of detergent and the chlorocresol-based disinfectant (P6) was also lower than application of detergent followed by the QAC-based disinfectant, P5 (2.2% versus 17.1%, respectively; *p* < 0.05). Drying of pens (P7 and P8) greatly reduced the probability of detecting *Salmonella*. Only 3.8% of swabs were *Salmonella*-positive 48 h after cleaning with detergent and the QAC-based disinfectant (P7) while an eradication of *Salmonella* was achieved 24h after cleaning with detergent and the chlorocresol-based disinfectant, P8. A reduction in *Enterobacteriaceae* counts to below the limit of detection (LOD: 10 CFU/cm²) was achieved following cleaning with detergent and disinfection with the chlorocresol-based disinfectant, regardless of drying (p < 0.05), whereas, applying detergent and the QAC-based disinfectant (P7) did not reduce *Enterobacteriaceae* counts to below the LOD. Therefore, ensuring that lairage pens are allowed to dry after intensive cleaning with detergent and a chlorocresol-based disinfectant is recommended as the most effective hygiene routine to eliminate *Salmonella* and reduce *Enterobacteriaceae* counts.

2) **Misting**

Water misting/showers are used in abattoir lairages to improve meat quality, and to cool and calm pigs after transport and during hot weather. The novel approach investigated here was to add a disinfectant to the misting water as a means of topically reducing *Salmonella* on pigs prior to slaughter, thereby potentially controlling this organism in the abattoir. The study evaluated misting with water or with Virkon® S (an approved disinfectant for use in the presence of animals), for their ability to topically reduce *Salmonella* on high seroprevalence pig herds before stunning and to reduce *Enterobacteriaceae*. Three experimental groups were investigated: control group (i.e., no misting); water group (misting with cold, 15-17 °C, water, herein referred to as water); and a
disinfectant group (misting with 0.5% Virkon® S). As pigs entered the abattoir, each animal was swabbed along its back before being allocated to its experimental group. Each group was randomly assigned to one of 3 lairage pens that were separated by non-trial pens. After 30 min of misting with water or disinfectant, pigs were moved to the stunning area, where each pig was again swabbed, as above. Swabs were analyzed for the presence of Salmonella and enumeration of Enterobacteriaceae. The study showed that Salmonella prevalence on the pigs was 79.0%, 72.1% and 83.6% for the control, water and disinfectant groups, respectively. After misting, Salmonella prevalence increased to 94.3% in the water group; whereas for the disinfectant group, the prevalence increased marginally to 85.9%. No change in Salmonella prevalence was detected for the control group. In line with the Salmonella results, no significant differences were observed in Enterobacteriaceae counts in the control group at either time point (4.37 and 5.01 log_{10} CFU/cm², respectively) or in the disinfectant group before and after misting (4.02 and 4.26 log_{10} CFU/cm², respectively). However, a 2.3 log_{10} CFU/cm² increase in Enterobacteriaceae was recorded for the water group after misting as compared to before misting (p < 0.05). Since misting with water alone increased topical Salmonella contamination on pigs before slaughter, a risk assessment based on known Salmonella data, meat quality and welfare is recommended to determine whether its use is justifiable. On the other hand, the findings from this study suggest that misting with Virkon® S at 0.5% could have a role in topical antisepsis of pigs contaminated with Salmonella prior to slaughter and as such this warrants further investigation.

**Assessment of integrated control strategies to reduce Salmonella in a full pig production cycle (Task 6)**

This study investigated the efficacy of three interventions on Salmonella shedding and seroprevalence on a commercial farm with a history of high Salmonella seroprevalence and concurrent infections: (1) cleaning and disinfecting finisher pens with an peroxygen agent and a chlorocresol-based disinfectant followed by a drying step, (2) supplementing finisher feed with sodium butyrate (3 kg/t) for 63 days prior to slaughter, or (3) supplementing finisher feed with sodium butyrate (3 kg/t) for 28 days prior to slaughter. Two trials (A and B) were conducted to investigate the three interventions. Testing of pigs faeces showed pigs were co-infected with rotavirus throughout both studies. In Trial A, all pen swabs were Salmonella-positive on days 28 and 52, while only half were Salmonella-positive on day 63. Salmonella prevalence increased from 17.5% faecal samples being Salmonella-positive on day 28, to 22.5% and 30.0% samples positive on days 52 and 63, respectively. On the other hand, in Trial B, only 2% of faecal samples and 20% of pens swabs were Salmonella-positive on day 28. All isolates recovered from both trials were identified as Salmonella Typhimurium. In line with the bacteriological results, for Trial A, the seroprevalence at slaughter was higher at 55.0% using the 40% OD cut-off value used in the Irish Salmonella control programme, while for Trial B the seroprevalence was 41.1%. Numerical improvements in live weight before slaughter and carcass weight (4.8% and 4.2% increase, respectively) were observed for pigs supplemented with sodium butyrate for 63 days rather than 28 days. Overall, dietary supplementation with sodium butyrate for 63 days was not successful in reducing faecal shedding of Salmonella or Salmonella seroprevalence. The concurrent rotavirus infection was most likely a key factor in the lack of effect observed with the feed additive, despite a thorough initial cleaning, disinfection and drying of the finisher pens. Since numerical improvements in live weight before slaughter and carcass weight were observed in the finisher pigs supplemented with sodium butyrate for 63 days, further investigation to determine the cost-benefit of this is warranted.

**Cost benefit analysis on use of Salmonella-control strategies in commercial pig operation (Task 7)**

This research focused on the cost-benefit analysis of on-farm interventions including
- Novelty of the approach
- The cost of the infection for the farmer
- Cost-benefit analysis of use of organic acids in growers
- Cost-benefit analysis of use of organic acids in finishers

and included
- Estimation of the impact of the infection on production
- Calculation of the cost of the infection for the farmer
- Determination of any negative impact on growth and carcass yield
- Calculation of the cost of the control interventions (acids, disinfectants)
- Estimation of potential benefits (i.e. improvement of growth)
- Measurement of the cost-benefit

*Salmonella* was shown to decrease the productivity of Irish pig farms and control measures, even when these cost money, can result in a cost-benefit to the farmer as demonstrated in this project. Success in controlling the infection, is the key to getting an economic response. Adding other interventions to the use of organic acids (biosecurity, control of concomitant diseases etc.) increases the control of *Salmonella* with low cost for the farmer.

4. **Impact of the Research**

*Salmonella* carriage in pigs is a significant food safety issue and low-cost control measures on farm may provide a useful element in reducing the prevalence of *Salmonella* in pigs. This project aimed to investigate several pre-harvest *Salmonella* control strategies.

The first studies aimed to identify if breeding sows played a role in the perpetuation of *Salmonella* on-farm and examine whether vertical transmission occurred. Results suggested that *Salmonella* shedding in sows is low and transmission to their progeny appears negligible. Instead, the contaminated pen environment appears to be more significant in the spread of the organism. This is an important result for Irish farmers as findings on this subject internationally are contradictory. However, these findings are in agreement with other Teagasc findings on biosecurity. Data from another study showed that while Irish pig farms are in line with their European counterparts in relation to external biosecurity, internal biosecurity on Irish pig farms is poor. Thus, it is likely that improving management and hygiene practices within farms would be beneficial for the control of *Salmonella* and other infections.

Several studies investigated the usefulness of organic acid-based feed additives in the control of *Salmonella* in weaned and finisher pigs. Findings suggested that, although some of the additives reduced faecal shedding, feed additives are unlikely to be effective as the sole measure in controlling *Salmonella* levels on commercial pig farms. Good management including effective biosecurity and control of concurrent disease is essential also.

The new protocol for experimental *Salmonella* infection developed during the course of the project is likely to be a useful research tool for researchers both in Ireland and elsewhere where mimicking of natural infection is desired.

The studies conducted in the abattoir showed that drying lairage pens after cleaning and disinfection with a chlorocresol-based disinfectant eliminated *Salmonella*. This is a useful finding for the industry as the role of contamination acquired in lairage in subsequent contamination of carcasses is well established. Additionally, findings suggested that misting with a peroxyclean disinfectant might have a role in topical antisepsis for pigs contaminated with *Salmonella* prior to slaughter and as such warrants further investigation.
Overall conclusions suggest that each herd is different and that control of Salmonella must be part of the overall health plan for the individual herd. The Salmonella problem is multifactorial but can be addressed by enhanced biosecurity, better hygiene and nutritional management, reduced use of antimicrobials and increased use of vaccines for other diseases. The project results are readily applicable to farmers, abattoirs and regulatory agencies and have added novel findings to the field of Salmonella control in pigs.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

This project was the first DAFM FIRM funded project to link researchers (pig production, veterinary and food safety) with stakeholders across the pig production chain (farmers, specialist pig advisors, pork processors and DAFM) and was thus very application driven and focused in its direction and outcomes.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

The key stakeholders in this project were the Teagasc specialist pig advisors, specialist pig veterinarians, pig producers, pig processors, DAFM and other researchers who were kept fully informed and engaged on the activities and outputs of this project through one to one meetings, small focus meetings and participation at workshops. The Teagasc Specialist Pig advisors provided a key link between the researchers and the pig producers and there was extensive one to one contact and engagement between the project team and the advisors as well as presentations and discussions at a number of their quarterly In-service training sessions. The controls for Salmonella at lairage were developed and carried out and results discussed with one of the country’s largest pig processing facilities. A full national stakeholder workshop was held on completion of the project and was attended by about 50 key stakeholders including pig producers, processors, DAFM, FSAI, and MII. The main results and findings of the project were presented and excellent discussion and feedback took place. It highlighted that the issue of Salmonella in pigs is not solved and there is no single solution though a combined multi-faceted approach may work. The project has demonstrated how complicated the issue remains. It is expected that Salmonella will be one of the problems addressed during on-going and future work with the pig industry, particularly in relation to the changes that will be required to enable expected mandatory reductions in antimicrobial use and tighter welfare regulations. The improvements in management and other necessary changes required to meet these regulations are likely to have benefits for Salmonella control also. In turn, the findings of this project will be useful to inform the use of strategies such as in-feed acid supplementation that may have other benefits apart from Salmonella control.

(iii) Outcomes with economic potential

As the agri-food and the pigmeat sector make a valuable contribution to the Irish economy. Food Harvest 2020 (DAFF, 2010) sets out targets to achieve a 50% increase in output value of the pig meat sector by 2020. Assurances about the highest standards of pork safety and maintaining the “green” image of Irish food are essential to opening up new export markets world-wide and in particular, Asian markets, which are being targeted as new markets for Irish food. The research in this project builds on knowledge and capacity in this area.
Outcomes with national/ policy/social/environmental potential

This project was directly in line with the food programme research strategies and priorities of Teagasc, UCD and WIT to produce science to underpin a risk-based approach to control pathogens along the farm to fork chain. This project fully utilised the unique cross-disciplinary skills and facilities available at Teagasc, UCD and WIT linking veterinarians, food safety and pig production specialists and advisors. This multi-disciplinary team together with DAFM and the pig industry as key collaborators in the project has fed data into the national Salmonella control programme in this area. It highlights that control can only be achieved by a total chain approach which links back to the farm level.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.


(ii) Popular non-scientific publications and abstracts including those presented at conferences


Walia, K. (2016). Targeted strategies to combat *Salmonella* in finisher pigs and in the lairage of the abattoir LoCostSalmonella stakeholder workshop, December 5th Teagasc, Ashtown


(iii) National Report

(iv) Workshops/seminars at which results were presented

Safefood Salmonella Knowledge Network Seminar Series, 22nd March 2016, Radisson Blu St. Helen's Hotel, Stillorgan Road, Blackrock, Co. Dublin, Ireland.

Tracking and management of Salmonella in Irish pigs.


25th International Committee on Food Microbiology and Hygiene (ICFMH) Conference, Food Micro 2016, 19th-22nd July 2016, University College Dublin, Ireland.

The efficacy of feeding sodium butyrate during the late finishing period on Salmonella shedding, seroprevalence and growth of finishing pigs.


25th International Committee on Food Microbiology and Hygiene (ICFMH) Conference, Food Micro 2016, 19th-22nd July 2016, University College Dublin, Ireland.

The efficacy of different cleaning and disinfection procedures to reduce Salmonella and Enterobacteriaceae in the lairage environment of a pig abattoir.


International Pig Veterinary Society Congress 2016

Investigation of in-feed organic acids as a low cost strategy to combat Salmonella in weaned pigs


International Pig Veterinary Society Congress 2016 Dublin, Ireland 7th - 10th June, 2016

Salmonella in breeding pigs: Shedding pattern and transmission of infection to progeny in farrow-to-finish herds


25th International Committee on Food Microbiology and Hygiene (ICFMH) Conference, Food Micro 2016, 19th-22nd July 2016, University College Dublin, Ireland.

Effect of Organic acids on Salmonella shedding and growth performance in weaned pigs.

The effect of in feed organic acids on Salmonella shedding and growth in weaned pigs, Belfast

LoCostSalmonella stakeholder workshop, December 5th 2016 Teagasc, Ashtown
Salmonella in sows and targeted strategies for Salmonella control in weaner pigs.
Arguello, H.

LoCostSalmonella stakeholder workshop, December 5th 2016 Teagasc, Ashtown
Targeted strategies to combat Salmonella in finisher pigs and in the lairage of the abattoir
Walia, K.

LoCostSalmonella stakeholder workshop, December 5th 2016 Teagasc, Ashtown
Risk factors for Salmonella in pig production and cost benefit analysis of on-farm controls
Arguello, H.

LoCostSalmonella stakeholder workshop, December 5th 2016 Teagasc, Ashtown
Reducing Salmonella in a pig production cycle (farm to slaughter): a case study.
Leonard, N.

(v) Intellectual Property applications/licences/patents
None

(vi) Other
None

5. Scientists trained by Project

Total Number of PhD theses: 2

Kavita Walia, Targeted low cost strategies to combat Salmonella spp. in finisher pigs and in the slaughterhouse. Thesis submitted for the Degree of Doctor of Philosophy to Waterford Institute of Technology December 2016 (conferred in October 2017)

Helen Lynch. Targeted low cost solutions for control of Salmonella in pig production. Thesis is submitted to University College Dublin in fulfilment of the requirements for the degree of Doctor of Philosophy to University College Dublin, School of Veterinary Medicine, January 2017 (Conferred in June 2017)

Total Number of Masters theses: 0
6. **Permanent Researchers**

<table>
<thead>
<tr>
<th>Institution Name</th>
<th>Number of Permanent staff contributing to project</th>
<th>Total Time contribution (person years)</th>
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<td>1.795</td>
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<td>WIT</td>
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<td>.110</td>
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<td>UCD</td>
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7. **Researchers Funded by DAFM**

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<tbody>
<tr>
<td>Post Doctorates/Contract Researchers</td>
<td>2</td>
<td>2.922</td>
</tr>
<tr>
<td>PhD students</td>
<td>2</td>
<td>6.913</td>
</tr>
<tr>
<td>Masters students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary researchers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1*</td>
<td>.053</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4</strong></td>
<td><strong>9.888</strong></td>
</tr>
</tbody>
</table>

*Other: Post Doctorate had some of his time on this project but funded by different project.

8. **Involvement in Agri Food Graduate Development Programme**

<table>
<thead>
<tr>
<th>Name of Postgraduate / contract researcher</th>
<th>Names and Dates of modules attended</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

9. **Project Expenditure**

- Total expenditure of the project: €526,552.46
- Total Award by DAFM: €599,844.50
- Other sources of funding including benefit in kind and/or cash contribution(specify): €
Leveraging

This project has built capacity and leveraged the group to obtain funding in areas related to both *Salmonella* and pigs

- A Teagasc funded Project (2015 to 2019) is under way in collaboration with Norwich Food Research Institute (recently renamed Quadram Institute Bioscience) is using whole genome sequencing to look at *Salmonella Typhimurium* (4,12:i) isolates from the Irish pork chain. This is a recently emergent serovar in the Irish pork chain.
- A DAFM-funded project (AMURAP, 2016-2020) includes a task investigating the relationship between antimicrobial use and the prevalence of *Salmonella* and resistance patterns in *Salmonella* serotypes.
- An Enterprise Ireland Commercialisation Fund project (ProSwine, 2017-2020) which is a collaboration between the Teagasc Pig Production Development Dept and WIT, is investigating the development of a probiotic feed additive for pigs. One of the workpackages will evaluate the probiotic for *Salmonella* control in finisher pigs.
- A Teagasc funded project (WF) will commence in 2018 (Teagasc Food safety in collaboration with the Teagasc pig production unit and UCD) focusing on the impact of the Zinc Oxide (ZnO) supplementation in the pig weaner diet on AMR in the pig gut microbiome.

11. Future Strategies

This research has highlighted that in relation to *Salmonella*, each herd is different, and the best strategy to control *Salmonella* is an overall health plan for individual herds. *Salmonella* on farm is a multifactorial problem which would be helped by improved biosecurity, better hygiene and management, better nutrition management, reduced use of antimicrobials and increased use of vaccines. Ongoing internal Teagasc projects on biosecurity, removal of Zinc oxide from feed, and
the AMURAP project will provide further data on the interrelationships between many of these factors and how they impact on control of Salmonella levels. The WIT-Teagasc project will investigate a probiotic Bacillus strain for Salmonella control in finisher pigs.