



An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

15F641 - Clean Broilers through Enhanced Farm Biosecurity, Processing Prerequisites and HACCP Based Interventions Final Report

This project was funded under the Department of
Agriculture, Food and the Marine Competitive Funding
Programme.

SUMMARY

The main objective was to ensure that the maximum number of birds at retail are as clean as possible thus facilitating compliance with the Process Hygiene Criterion (PHC) (Commission Regulation (EU)2017/1495). The research focused on biosecurity and anti-Campylobacter water additives on the farm, as well as bird crate decontamination, control at key processing stages and carcass decontamination in the processing stage. A baseline survey on Campylobacter carriage (caeca) and carcass contamination was undertaken, isolates were characterised and harmonised Campylobacter testing strategies, including methods, were developed for the poultry processing sector and private laboratories and delivered via a training course. Online food safety training was also provided for farmers and processors. Updated data was also published on the antibiotic resistance rates of Campylobacter spp. isolated from Irish broilers, and it was found that rates to clinically relevant drugs were generally comparable to figures reported nationally over the last two decades. The main outputs included a broiler farm biosecurity system, Campylobacter in Irish poultry/on carcasses baseline data, WGS characterisation of isolates, antimicrobial testing, information on the potential effectiveness and issues with using anti-Campylobacter water additives on broiler farms, details of the microbiota in the different sections of the broiler GIT including the effect of antimicrobial treatments, an evaluation of bird crate washing and additional data on stage in the processing plant that need a renewed focus on hygiene to prevent cross contamination of carcasses. These were transferred to specific stakeholders through participation in the Campylobacter Stakeholder Group, training courses, a training video, national and international conference presentations and peer-reviewed publication. This project contributed to reducing broiler Campylobacter contamination rates from 83.9% (flocks), 98%(carcasses) with 42% of carcasses exceeding the PHC limit of 1000 bacteria/g in 2008 to 66% (flocks), 53%(carcasses) with 13% carcasses above the PHC level in 2017/18.

KEYWORDS

Broilers, Campylobacter, Control

ACRONYM

Clean Broilers

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PUBLICATION DATE

November 2023

Section 1 - Research Approach & Results

Start Date

01 January 2017

End Date

30 September 2021

Research Programme

Food Institutional Research Measure

TRL Scale

TRL 3: Experimental Proof of Concept

NRPE Priority area

Sustainable Food Production and Processing

Total DAFM Award

€1,042,845.00

Total Project Expenditure

€898,494.39

Rationale for undertaking the Research

The 2008 EU baseline survey highlighted an issue with Irish broilers as 84% of flocks and 98% of carcasses were contaminated. This project formed part of a national initiative involving all the key stakeholders, including DAFM, FSAI, broiler farmers, processors and research institutions such as Teagasc, UCD and MTU (CIT) to improve the food safety of broilers. Previous research had identified some of the key issues on broiler farms and in processing plants that needed to be addressed but, in addition to finding solutions to these problems, other issues need to be investigated. The project focused on solutions, such as enhanced biosecurity, anti-Campylobacter water additives, carcass decontamination technologies, etc. that were most likely to be successful. Moreover, a harmonised testing strategy was developed for the Irish broiler sector to ensure progress could be accurately assessed. All activities were undertaken in consultation and with the cooperation of all the stakeholders and it was important that the knowledge, data and technologies generated were transferred to these stakeholders to ensure full impact. Thus the project partners were actively involved in initiatives such as the Campylobacter Stakeholder Group and training was provided for laboratory personnel, farmers and processors.

Methodology

Laboratory, on-farm and in-plant studies were undertaken using a range of methods including the Horizontal Method for Detection and Enumeration of Campylobacter spp. (ISO 10272: 2006) for detection and enumeration. Biochemical tests (aerobic growth, L-alanine test, Oxidase test and growth on chromogenic agar) and PCR testing (Wang et al., 2002) were used for confirmation and speciation. The isolates were characterised using phenotypic methods (eg. the E-test for antimicrobial resistance) as well as using whole genome sequencing with a range of different bioinformatics software being used to analyse the sequence data. Dissemination and technology transfer was achieved through participation in relevant stakeholder groups, training courses, a training video, presentations at national and international conferences and peer-reviewed publications.

Reference: Wang, G., Clark, C. G., Taylor, T. M., Pucknell, C., Barton, C., Price, L., Woodward, D. L., Rodgers, F. G. Colony Multiplex PCR Assay for Identification and Differentiation of *Campylobacter jejuni*, *C. coli*, *C. lari*, *C. upsaliensis* and *C. fetus* subsp. *fetus*. J Clin Microbiol 2002, 40(12), 4744–4747.

Project Results

The biosecurity infrastructure on broiler farms was further developed. Broilers reared using this system were *Campylobacter* negative and had superior performance to those in the general population facilitating increased productivity by up to 20% per annum. Research on the survival and/or growth of *C. jejuni* NCTC 11168 in broiler digestate concluded that the bacterial microbiome and the nutrients it produces play a critical role in *Campylobacter* colonisation of broilers. The results of laboratory testing of a range of potential anti-*Campylobacter* water additives was used to formulate organic acid, medium chain fatty acid and essential oil blends for in vivo trials. However, the treated birds performed poorly and by day 35 were approximately half the weight of the control broilers. Changes in the caecal microbiota may, at least in part, be responsible for the poor broiler performance. Studies on the effect of antibiotic treatment (doxycycline at 100 mg/ml per kg body on days 8-12) on the broiler gastrointestinal tract (GIT) microbiota observed major changes in the broiler microbiota which persisted throughout the rearing period. Important data relating to the impact of processing on *Campylobacter* prevalences and levels on carcasses from first & final thin broiler batches was generated. All carcasses from first thin batches complied with the EU Process Hygiene Criterion while 52% of carcasses from final thin exceeded this legal limit.

Studies on antimicrobial resistance from carcass isolates showed high levels of resistance to tetracycline (46%) and ciprofloxacin (30%) with 61% of isolates being resistant to at least one antimicrobial tested. All isolates were sensitive to erythromycin and gentamicin. Generally, it was found that rates of resistance to clinically relevant antibiotics were comparable to figures reported nationally over the last two decades. Notably, fluoroquinolone resistance appears persistent and stable in Ireland, while tetracycline resistance has increased among *Campylobacter jejuni*. A small number of multidrug-resistant *Campylobacter* isolates were detected and one isolate was resistant to the three major antibiotics used to treat severe enteric campylobacteriosis. Genetic determinants for antibiotic resistance and potential dissemination were characterised. Whole genome sequencing of *C. jejuni* isolates revealed high levels of strain diversity, with many possessing virulence genes associated with human infection. Furthermore, a high proportion of isolates recovered from carcasses following chilling possessed genes associated with survival, including the ability to form biofilms. WGS isolate characterisation also suggested that in general processed carcasses are contaminated by the same *Campylobacter* strains originating in the caeca of birds from within the same batch. Investigations assessing the performance of current live broiler transport equipment revealed that 20-30% of equipment samples remained contaminated with campylobacters following washing and disinfection, illustrating the potential risks for transmission to other farms, biosecurity, etc. as well as the need for improvement. Chemical immersion treatments of carcasses as a potential decontamination strategy with or without ultrasonication can be used to reduce bacterial populations on chicken skin. In general, acidified sodium chlorite combined with ultrasonication and an elevated temperature (54 degrees Celsius) resulted in the highest levels of reductions, including for *Campylobacter*.

Section 2 - Research Outputs

Summary of Project Findings

The Clean Broilers project has made a considerable contribution to reducing the incidence and concentration of *Campylobacter* contamination on Irish chickens. As previously stated, the contamination rate of flocks and carcasses has decreased by 18% and 45%, respectively in recent years. Although this may not be reflected in the

number of confirmed human infections, because the vast majority (over 90%) of campylobacteriosis cases go unreported and there are sources other than poultry, lower food contamination rates reduce exposure and the risk to consumers. The Clean Broilers project published an up-to-date baseline survey, the results of which reflect the work that has been done by all the stakeholders, charts progress (which is important feedback for all those involved) and shows Irish food producers in a positive light, in contrast to the 2008 EC survey. This is important for the reputation of the Irish food industry, Irish food exports and the Irish economy. In January 2018 the EC introduced a Process Hygiene Criterion (PHC) (Commission Regulation (EU)2017/1495 of 23 August 2017 amending Regulation (EC) No 2073/2005) for *Campylobacter* spp. It was very important that the private laboratories undertaking the testing for our poultry processors received proper training on the methods for *Campylobacter* detection, as this organism can be difficult to culture. The Clean Broilers project, including our colleagues in DAFM Backweston, developed and delivered the required training and provide ongoing support. Thus the data generated, which is being recorded by DAFM Backweston, is reliable and an accurate reflection of the current *Campylobacter* status of Irish broilers, essential information to validate current and future *Campylobacter* control initiatives and assure retailers and consumers of the product safety.

Summary of Staff Outputs

Research Output	Male	Female	Total Number
PhD Students	0	2	2
Post Doctorates	0	1	1
MSc Students	0	1	1

Summary of Academic Outputs

Research Outputs	Total Number	Details
Publications in Peer Reviewed Scientific Journals	11	<ol style="list-style-type: none"> G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, J. Egan, L. O'Connor and D. Bolton (2020). An in vitro investigation of the survival and/or growth of <i>Campylobacter jejuni</i> in broiler digestate from different feed types. <i>Letters in Applied Microbiology</i>, 72 (1), 36-40. G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, L. O'Connor and D. Bolton (2021). Testing barrier materials in the development of a biosecurity pen to protect broilers against <i>Campylobacter</i>. <i>Food Control</i>, 128, 108172.doi.org/10.1016/j.foodcont.2021.108172. G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, J. Egan, L. O'Connor and D. Bolton (2021). Maximising productivity and eliminating <i>Campylobacter</i> in broilers by manipulating stocking density and population structure using 'biosecurity cubes'. <i>Pathogens</i>, 10, 492.https://doi.org/10.3390/pathogens10040492. G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, J. Egan, L. O'Connor and D. Bolton (2021). The efficacy of organic acid, medium chain fatty acid, and essential oil based broiler treatments; in vitro anti-

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- Campylobacter jejuni activity and the effect of these chemical-based treatments on broiler performance, *Journal of Applied Microbiology*, 132 (1), 687-695.
5. Lynch C, Hawkins K, Lynch H, Egan J, Bolton D, Coffey A, Lucey B. (2019). Investigation of molecular mechanisms underlying tetracycline resistance in thermophilic *Campylobacter* spp. suggests that previous reports of tet(A)-mediated resistance in these bacteria are premature. *Gut Pathogens* 2019;11(1):56; doi: <http://dx.doi.org/10.1186/s13099-019-0338-1>.
 6. Caoimhe Lynch, Helen Lynch, John Egan, Paul Whyte, Declan Bolton, Aidan Coffey, Brigid Lucey (2019). Antimicrobial resistance of *Campylobacter* isolates recovered from broilers in Ireland in 2017 and 2018: an update. *British Poultry Science*, 15, 1-7.
 7. Caoimhe T Lynch, Helen Lynch, Sarah Burke, Kayleigh Hawkins, Colin Buttimer, Conor Mc Carthy, John Egan, Paul Whyte, Declan Bolton, Aidan Coffey, Brigid Lucey (2020) Antimicrobial resistance determinants circulating among thermophilic *Campylobacter* isolates recovered from broilers in Ireland over a one-year period. *Antibiotics* 2020,9, 308; doi:10.3390/antibiotics9060308.
 8. Emanowicz, M., Meade, J., Bolton, D., Golden, O., Gutierrez, M., Byrne, W., Egan, J., Lynch, H., O'Connor, L., Coffey, A., Lucey, B., Whyte, P. (2020). The impact of key processing stages and flock variables on the prevalence and levels of *Campylobacter* on broiler carcasses. *Food Microbiol.* 2021May;95:103688. doi: 10.1016/j.fm.2020.103688. Epub 2020Nov
 9. Emanowicz, M., Meade, J., Burgess, C., Bolton, D., Egan, J., Lynch, H., O'Connor, L., Coffey, A., Lucey, B., Golden, O., Gutierrez, M., Byrne, W., Whyte, P. (2021). Antimicrobial resistance and genomic diversity of *Campylobacter jejuni* isolates from broiler caeca and neck skin samples collected at key stages during processing. *Food Control*, 135 108664.doi.org/10.1016/j.foodcont.2021.108664.
 10. Lynch, C.T., Buttimer, C., Epping, L., O'Connor, J., Walsh, N., McCarthy, C., O'Brien, D., Vaughan C., Semmler, T., Bolton, D., Coffey, A., Lucey, B. (2022) Genomic comparison of two *Campylobacter fetus* isolates from a case of relapsed prosthetic valve endocarditis. *Pathogens and Disease*;79(9):ftab055. doi: 10.1093/femspd/ftab055.
 11. Lynch, H., Franklin-Hayes, P., Koolman, L., Egan, J., Bolton, D., Reid, P., Coffey, A., Lucey, B., O'Connor, L., Unger, K., Whyte, P. (2022). Prevalence and levels of *Campylobacter* in broiler batches and carcasses in Ireland in 2017-2018. *International Journal of Food Microbiology*, 372, 2022,
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Peer Reviewed
Conference Papers

6

1. Declan Bolton, Genevieve Greene, Tara Battersby and Paul Whyte (2019) Enhanced Biosecurity to Prevent Campylobacter Infection in Broilers. Poster presentation at the Campylobacter, Helicobacter and related Organisms (CHRO) international conference held at the ICC, Belfast, 8th to 11th September 2019, p1.
2. Malgorzata Emanowicz, Joseph Meade, Declan Bolton, John Egan, Helen Lynch, Lisa O'Connor, Aidan Coffey, Brigid Lucy, Paul Whyte. The impact of key processing stages on Campylobacter populations on broiler carcasses. Poster presentation at the Campylobacter, Helicobacter and related Organisms (CHRO) international conference held at the ICC, Belfast, 8th to 11th September 2019.
3. Helen Lynch, Peter Franklin-Hayes, John Egan, Declan Bolton, Pauline Reid, Aidan Coffey, Brigid Lucy, Lisa O'Connor, Killian Unger, Paul Whyte. Baseline survey on the prevalence of Campylobacter in broiler batches and carcasses in Ireland. Poster presentation at the Campylobacter, Helicobacter and related Organisms (CHRO) international conference held at the ICC, Belfast, 8th to 11th September 2019.
4. Eve Greene, Leonard Koolman, Paul Whyte and Declan Bolton (2020). Maximising productivity and eliminating Campylobacter in broilers by manipulating stocking density using biosecurity cubes. Oral presented at the 49th Annual Food Science & Technology Conference organised by the IFSTI online on 15th December 2020.
5. Malgorzata Emanowicz, Joseph Meade, Declan Bolton, John Egan, Helen Lynch, Lisa O'Connor, Aidan Coffey, Brigid Lucy, Paul Whyte. Effect of key processing stages and process variables on prevalences of Campylobacter on broiler carcasses. Oral & poster presentation at the Food Safety Authority of Ireland Conference, 'The Science of Food Safety– What's our Future?', Dublin, 21-08-19 to 22-08-19.
6. Malgorzata Emanowicz, Joseph Meade, Declan Bolton, John Egan, Helen Lynch, Lisa O'Connor, Aidan Coffey, Brigid Lucy, Paul Whyte. Antimicrobial resistance of Campylobacter isolates from broiler caeca and neck skin samples collected at key processing stages. Poster presentation at the 48th Annual Institute of Food Science & Technology of Ireland (IFSTI) conference, University of Limerick, 16-12-19.

PhD Theses

2

1. Investigation of novel strategies to control Campylobacter in commercial broiler flocks (Ph.D. Genevieve Greene, UCD, 8th March 2022).
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		2. Elucidation of novel and established <i>Campylobacter</i> species with clinical and agricultural significance through phenotypic, genotypic, and taxonomic investigation. PhD Thesis of Caoimhe Lynch, submitted the MTU in October 2021 and successfully defended in January 2022
Masters Theses	1	The impact of key processing stages on the prevalence of <i>Campylobacter</i> on broiler carcasses. (MSc Malgorzata Emanowicz, UCD, January 2021).
Training Courses	3	<ol style="list-style-type: none"> 1. Food Safety Training for Broiler Farmers (Online Training, Thursday 24th June 2021) 2. 'Clean Broilers' Food Safety Training for Broiler Processors (Online Training, Tuesday 21st September 2021). 3. Training courses provided by DAFM Backweston for Private testing laboratories on methods for the detection and enumeration of <i>Campylobacter</i> in broiler flocks and processed carcasses. (8th & 15th June 2017, 2nd August 2018).
Other	1	<p>Book chapter: Whyte, P., Bolton, D., Pedros-Garrido, S., Lynch, H., Emanowicz, M., Greene, G., Fanning, S., (2022). <i>Campylobacter</i> spp. In: McSweeney, P.L.H., McNamara, J.P. (Eds.), <i>Encyclopaedia of Dairy Sciences</i>, vol. 4. Elsevier, Academic Press, pp. 419–430. https://dx.doi.org/10.1016/B978-0-08-100596-5.00984-7. ISBN: 9780128187661.</p>

Intellectual Property

Not applicable.

Summary of other Project Outputs

Project Outputs	Details	Total Number
New Processes	Data generated in this project has been disseminated to processors and farmers and will provide important information to revise and improve food safety management systems and options for risk mitigation in the future relating to carcass and transport equipment decontamination and hygiene improvements during processing.	1

Potential Impact related to Policy, Practice and Other Impacts

Impact	Details
Industry	The Irish poultry industry currently employs 6000 people and assuming planning issues can be resolved, has potential for expansion. Future success is reliant on producing a 'safe' product and being able to demonstrate that every possible action was taken to protect consumers. The Clean Broilers project provides the scientific basis to achieve this objective.
Socio-Economic	Lower broiler contamination rates means lower risk for consumers and less campylobacteriosis in the population. Apart from the obvious health and welfare benefits for consumers, this will contribute to reducing the estimated€2.5bn costs associated with Campylobacter infection in the EU annually.

Dissemination Activities

Activity	Details
	Poster presentation: Lynch, C., O' Connor, J., O' Brien, D, Bolton, D., Vaughan, C., Coffey, A., Lucey, B. (2017) First reported detection of biofilm formation by Campylobacter fetus during investigation of a case of prosthetic valve endocarditis. CHRO2019 Campylobacter, Helicobacter and Related Organisms. Belfast, Ireland. Sept 9, 2019, https://chro2019.com/abstracts
	Poster presentation: Declan Bolton, Genevieve Greene, Tara Battersby and Paul Whyte (2019) Enhanced Biosecurity to Prevent Campylobacter Infection in Broilers. Poster presentation at the Campylobacter, Helicobacter and related Organisms (CHRO) international conference held at the ICC, Belfast, 8th to 11thSeptember 2019, p1. https://chro2019.com/abstracts
Seminars at which results were presented	Poster presentation: Helen Lynch (2019) 'Baseline survey on the prevalence of Campylobacter in broiler batches and carcasses in Ireland' was presented at the2019 CHRO conference which was held in Belfast in September. https://chro2019.com/abstracts
	Poster presentation: "Baseline survey on the prevalence of Campylobacter in broiler batches and carcasses in Ireland" was presented at the 2019 CHRO conference which was held in Belfast in September.
	Oral presentation: On 22nd September Dr. Declan Bolton presented on 'Broiler Farm Biosecurity' as part of the Teagasc webinar series 'Lets Talk Poultry' organised by Rebecca Tierney, Teagasc Poultry Advisor.
	Poster presentation: Malgorzata Emanowicz (2019) 'Effect of key processing stages and flock variables on prevalence of Campylobacter on broiler carcasses' at the FSAI Science Conference in Dublin, August 2019. https://app.oxfordabstracts.com/events/804/program-app/program
	Oral presentation: Lynch, C., Lynch, H., Burke, S., Hawkins, K., Egan, J., Whyte, P., Bolton, D., Coffey, A., and Lucey B. (2019) Antimicrobial resistance determinants circulating

among thermophilic *Campylobacter* isolates recovered from broilers in Ireland. Proceedings of the 48th Annual Food Science and Technology Conference. Limerick, Ireland. Dec 16, 2019.

Poster presentation: Lynch, C., Lynch, H., Egan, J., O' Connor, L., Whyte, P., Bolton, B., Lucey, B., & Coffey, A. (2019) Antimicrobial resistance of *Campylobacter* isolates recovered from Irish broilers in 2017 and 2018. CHRO2019 *Campylobacter*, *Helicobacter* and Related Organisms. Belfast, Ireland. Sept 9, 2019, <https://chro2019.com/abstracts>

Oral presentation: Lynch, C., Lynch, H., O' Connor, L., Egan, J., Whyte, P., Bolton, B., Lucey, B., & Coffey, A. (2019) Antimicrobial resistance of *Campylobacter* isolates recovered from Irish broilers in 2017 and 2018. One Health EJP ASM2019. Dublin, Ireland. May 22-24, 2019. https://57cb27e8-1ca7-49f9-a76c-be54e2ae60c7.filesusr.com/ugd/c416fd_ab7cf6709f424a0ca26b4f1c3cd73b22.pdf.

Oral presentation: Declan Bolton (2019) Enhanced Biosecurity to Prevent *Campylobacter* Infection in Broilers.

Oral presentation at the One Health EJP ASM, Teagasc (Ashtown) Dublin, Ireland, 22nd to 24th May 2019, Abstract Book, page 80
Poster presentation: "Effect of key processing stages and flock variables on prevalence of *Campylobacter* on broiler carcasses" at the FSAI Science Conference in Dublin, August 2019

Oral presentation: On 22nd September Dr. Declan Bolton presented on 'Broiler Farm Biosecurity' as part of the Teagasc webinar series 'Lets Talk Poultry' organised by Rebecca Tierney, Teagasc Poultry Advisor.

Knowledge Transfer Activities

Identify knowledge outputs generated during this project.

Knowledge for industry: This project generated knowledge on controlling *Campylobacter* on broiler farms through enhanced biosecurity; effective crate washing and control in the processing plant through enhanced hygiene and potential interventions.

Knowledge for regulatory: A baseline survey was undertaken which measured progress in controlling *Campylobacter* in Irish poultry which will motivate further actions.

Knowledge on testing methodologies was collated and transferred to private laboratories to ensure *Campylobacter* testing was harmonised and effective.

Academic knowledge: New insights were developed on how *Campylobacter* achieve high concentrations in the caeca while new data was generated on the broiler GIT microbiota and how this changes after antimicrobial treatments, while the genomes of 300 isolates were sequenced and analysed for genotype, virulence, and antimicrobial resistance. Updated comprehensive data was gathered and published regarding the resistance rates of clinically relevant antibiotics of *Campylobacter* spp. isolated from Irish broilers.

The knowledge generated above was transferred directly to our industry and regulatory stakeholders through the farmer, processor and laboratory training courses mentioned above, participation in the Campylobacter Stakeholder Group, and via the online project workshop on the 28th September 2021. In addition to oral presentations, there were Q&A and discussion on how this knowledge could be translated into actions to further enhance Campylobacter control.

Identify any knowledge transfer activities executed within the project.

Knowledge was shared with academia and also with food safety regulatory personnel through the peer reviewed papers and participation in the workshops, seminars and other events mentioned above. The knowledge presented in posters was discussed with interested parties at dedicated sessions while oral presentations afforded an opportunity for discussion and feedback. Knowledge transfer activities have also occurred through dissemination activities and meetings with the Minister for Agriculture appointed Campylobacter Stakeholder groups which represents Regulators, farmers, Processors, Retailers and feed manufacturers.

The provision of knowledge, collated from international publications and generated in the project, contributed to significantly reducing broiler Campylobacter contamination rates in Ireland and that has considerable impact on:

List any impacts resulting from the knowledge transferred during the project.

Public health protection: reducing the 70,000 campylobacteriosis cases annually and the associated risk of developing Guillain Barre Syndrome (GBS), a chronic debilitating and potentially fatal illness in which the body's immune system attacks the nervous system.

Food industry reputation: the agri-food sector is worth €15bn annually to the Irish economy and much of this trades on our reputation for producing clean food. The 2008 baseline survey data was a poor reflection on Irish food and updating with the 2017/18 data is a positive development for the reputation of the Irish food sector.

Increased knowledge: controlling Campylobacter in broilers has been inhibited by a lack of understanding of key scientific issues such as the role of the microbiota in their proliferation in the caeca and difficulties in transferring in vitro success to a commercial setting. Moreover our genome sequence data is providing information on virulence, antimicrobial resistance, stress response etc. which is the scientific basis for new control strategies in the future.

Section 3 - Leveraging, Future Strategies & Reference

Leveraging Metrics

Type of Funding Resource	Funding €	Summary
Exchequer National Funding	€1,234,349.00	Teagasc & UCD have received funding from DAFM (Project2021R453) to investigate pathogen prevalence and survival in a range of wastes, including <i>Campylobacter</i> in spent broiler litter along with assessing their survival in soils when land spread and the impact of a range of potential chemical and other risk mitigation treatments that could be applied to reduce pathogen loads in these matrices.
EU R&I programmes	€45,000.00	Teagasc received funding for a Marie Curie Research Leaders2025 funding for research on the influence of viral and bacterial interaction on <i>Campylobacter</i> carriage/infection in broilers. This work is being undertaken in collaboration with the Agri-Food and Bioscience Institute in Northern Ireland

Future Strategies

Teagasc, UCD and MTU scientists will continue to cooperate with other stakeholders to continuously improve the *Campylobacter* status of Irish poultry. This will be achieved through current and future research and continued participation in the *Campylobacter* Stakeholder Group, the FSAI Biological Safety Committee, the European Food Safety Authority Biohazard Panel, etc. Ongoing research includes a Marie Curie Research Leaders 2025 project that will undertake microbiome analysis to better understand the role of the bacterial population in promoting or inhibiting *Campylobacter* carriage in broilers. Interaction with broiler farmers will also be facilitated through the Teagasc Poultry Advisory function, which has a dedicated webpage on the Teagasc website with plans to develop discussion groups and possibly a demonstration farm.

Project Publications

1. G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, J. Egan, L. O'Connor and D. Bolton (2020). An in vitro investigation of the survival and/or growth of *Campylobacter jejuni* in broiler digestate from different feed types. *Letters in Applied Microbiology*, 72 (1), 36-40.
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4. G. Greene, L. Koolman, P. Whyte, H. Lynch, A. Coffey, B. Lucey, J. Egan, L. O'Connor and D. Bolton (2021). The efficacy of organic acid, medium chain fatty acid, and essential oil based broiler treatments; in vitro anti-*Campylobacter jejuni* activity and the effect of these chemical-based treatments on broiler performance, *Journal of Applied Microbiology*, 132 (1), 687-695.
5. Lynch C, Hawkins K, Lynch H, Egan J, Bolton D, Coffey A, Lucey B. (2019). Investigation of molecular mechanisms underlying tetracycline resistance in thermophilic *Campylobacter* spp. suggests that previous reports of tet(A)-mediated resistance in these bacteria are premature. *Gut Pathogens* 2019;11(1):56; doihttp://dx.doi.org/10.1186/s13099-019-0338-1.

6. Caoimhe Lynch , Helen Lynch, John Egan, Paul Whyte , Declan Bolton , Aidan Coffey, Brigid Lucey (2019).Antimicrobial resistance of *Campylobacter* isolates recovered from broilers in Ireland in 2017 and 2018: an update. *British Poultry Science*, 15, 1-7.
7. Caoimhe T Lynch, Helen Lynch, Sarah Burke, Kayleigh Hawkins, Colin Buttimer, Conor Mc Carthy, John Egan, Paul Whyte, Declan Bolton, Aidan Coffey, Brigid Lucey (2020) Antimicrobial resistance determinants circulating among thermophilic *Campylobacter* isolates recovered from broilers in Ireland over a one-year period. *Antibiotics* 2020, 9, 308; doi:10.3390/antibiotics9060308.
8. Emanowicz, M., Meade, J., Bolton, D., Golden, O., Gutierrez, M., Byrne, W., Egan, J., Lynch, H., O'Connor, L., Coffey, A., Lucey, B., Whyte, P. (2020). The impact of key processing stages and flock variables on the prevalence and levels of *Campylobacter* on broiler carcasses. *Food Microbiol.* 2021 May;95:103688. doi:10.1016/j.fm.2020.103688. Epub 2020 Nov
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