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Research

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Acoustic sensors for monitoring dairy processes

SPECIAL FEATURE: BLIGHT

SAFER DRINKING WATER

RISK-BASED BIOSECURITY

teagasc
Agriculture and Food Development Authority

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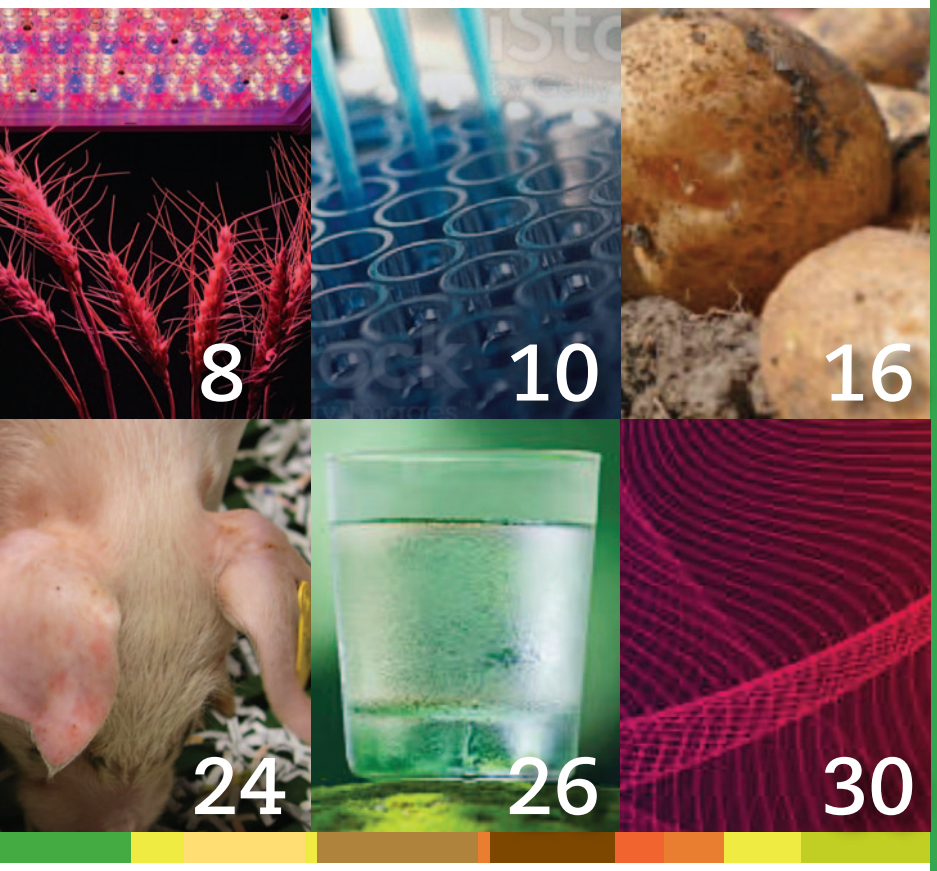

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Potato late blight: 175 years of research

The importance of *Phytophthora infestans*, the causal agent of potato late blight, and its arrival in Ireland in 1845, cannot be overemphasised. Prior to this event most of Irish society was dependent on the potato crop, which produced an abundance of nutritious food with relatively low inputs and area. Late blight co-evolved with its potato and tomato hosts in the Toluca valley of Mexico. The first introductions of potato from this region to Europe and North America were blight free, allowing the potato crop to flourish in a relatively disease-free environment. However, shipments of infected potato from South America to New York in 1844 introduced blight there, and further shipments to Belgium in 1845 introduced it to Europe. From there it rapidly spread throughout Europe, eventually making its way to Ireland by the end of the summer of 1845.

The challenge to understand the disease and methods to control it sparked a flurry of scientific developments leading to the foundation of the science of plant pathology and the initiation of plant breeding for disease resistance. Through the scientific endeavour of people like George Pethybridge and Paul Murphy, who established some of the earliest research on the pathogen at their research station in Clifden, Co. Galway in the early 20th century, Austin Bourke who devised the forecasting model used to this day, and Leslie Dowley, Eugene O'Sullivan and Harry Kehoe, who led combined research into the pathogen and potato breeding at An Foras Talúntais (later Teagasc), substantive advances in protecting Irish potato crops have been made. Yet, the next challenge is how we can protect these advances while meeting the ambitious 50% reductions in pesticide usage as set down by the EU's Farm to Fork strategy.

2020 marks the 175th anniversary of the arrival of *P. infestans* and late blight in Ireland. In this issue of *TResearch* we reflect on the progress made in combatting late blight in Ireland, highlight the impact of current research initiatives, and project how future control maybe achieved.

Denis Griffin, potato breeder
Steven Kildea, plant pathologist
Ewen Mullins, Head of Crop Science Department
Teagasc Oak Park Crops Research Centre



Dubh mall na bprátaí: Taighde 175 bliana

Ní féidir an iomarca béime a chur ar an tábhacht a bhaineann le *Phytophthora infestans*, oibreán ócáideach dhubh mall na bprátaí, agus lena theacht isteach in Éirinn sa bhliain 1845. Sular thit an teagmhas sin amach, bhíodh formhór na ndaoine i sochaí na hÉireann ag brath ar an mbarr prátaí, rud as a dtagadh neart bia chothaithigh agus nach mbíodh ach méid measartha íseal ionchuir agus talún ag teastáil ina leith. D'éabhlóidigh an dubh mall i dteannta a óstach práta agus tráta i ngleann Toluca i Meicsiceo. Ba shaor ón dubh a bhí na chéad phrátaí a tugadh ón réigiún sin chun na hEorpa agus chuig Meiriceá Thuaidh. Dá bharr sin, bhíodh an barr prátaí ag fás go rathúil i dtimpeallacht a bhí saor ó ghalar, beagnach. Bhain an dubh Nua-Eabhrac amach ar lastais phrátaí galracha a tugadh ó Mheiriceá Theas chuige sa bhliain 1844, áfach, agus bhain an dubh an Eoraip amach ina dhiaidh sin ar lastais bhreise a tugadh chun na Beilge sa bhliain 1845. Leath sé go tapa ón áit sin go háiteanna ar fud na hEorpa, agus bhain sé Éire amach faoi dheireadh shamhradh na bliana 1845.

De bharr na n-iarrachtaí teacht ar thuiscint ar an ngalar agus ar mhodhanna a d'fhéadfaí é a rialú, spreagadh lear forbairtí eolaíocha ar dá mbarr a bunaíodh eolaíocht na paiteolaíochta plandaí agus a tionscnaíodh pórú plandaí le haghaidh frithsheasmhacht in aghaidh galar. Rinneadh dul chun cinn substainteach ar bharra prátaí na hÉireann a chosaint mar thoradh ar shaothar eolaíoch na ndaoine seo: George Pethybridge agus Paul Murphy, a bhunaigh roinnt den taighde ba luaithe ar an bpataigin ina stáisiún taighde ar an gClochán, Co. na Gaillimhe, go luath san 20ú haois; Austin Bourke, a cheap an tsamhail réamhaisnéisithe a úsáidtear fós sa lá atá inniu ann; agus Leslie Dowley, Eugene O'Sullivan agus Harry Kehoe, a bhí i gceannas ar thaighde comhcheangailte san Fhoras Talúntais (Teagasc ina dhiaidh sin) ar an bpataigin agus ar phórú prátaí. Dá ainneoin sin, is é an chéad dúshlán eile ná an dul chun cinn sin a chosaint le linn dúinn cloí leis an sprioc uaillmhianach a leagtar síos sa straitéis 'Ón bhFeirm go dtí an Forc' ón Aontas Eorpach go laghdófaí úsáid lotnaidicídí faoi 50%.

Ós rud é gur comóradh 175 bliain ó theacht *P. infestans* agus an duibh mhall in Éirinn atá sa bhliain 2020, déanaimid machnamh san eagrán seo de *TResearch* ar an dul chun cinn atá déanta ar an dubh mall a chomhrac in Éirinn, leagaimid béim ann ar an tionchar a bheidh ag tionscnaimh thaighde reatha agus réamh-mheasaimid ann cén dóigh a bhféadfaí rialú a bhaint amach sa todhchaí.

Denis Griffin, póraitheoir prátaí
Steven Kildea, paiteolaí plandaí
Ewen Mullins, Ceann na Roinne Eolaíochta Barr
Lárionad Taighde Barr Pháirc na Darach de chiuid Teagasc

Science Week Festival of Farming and Food

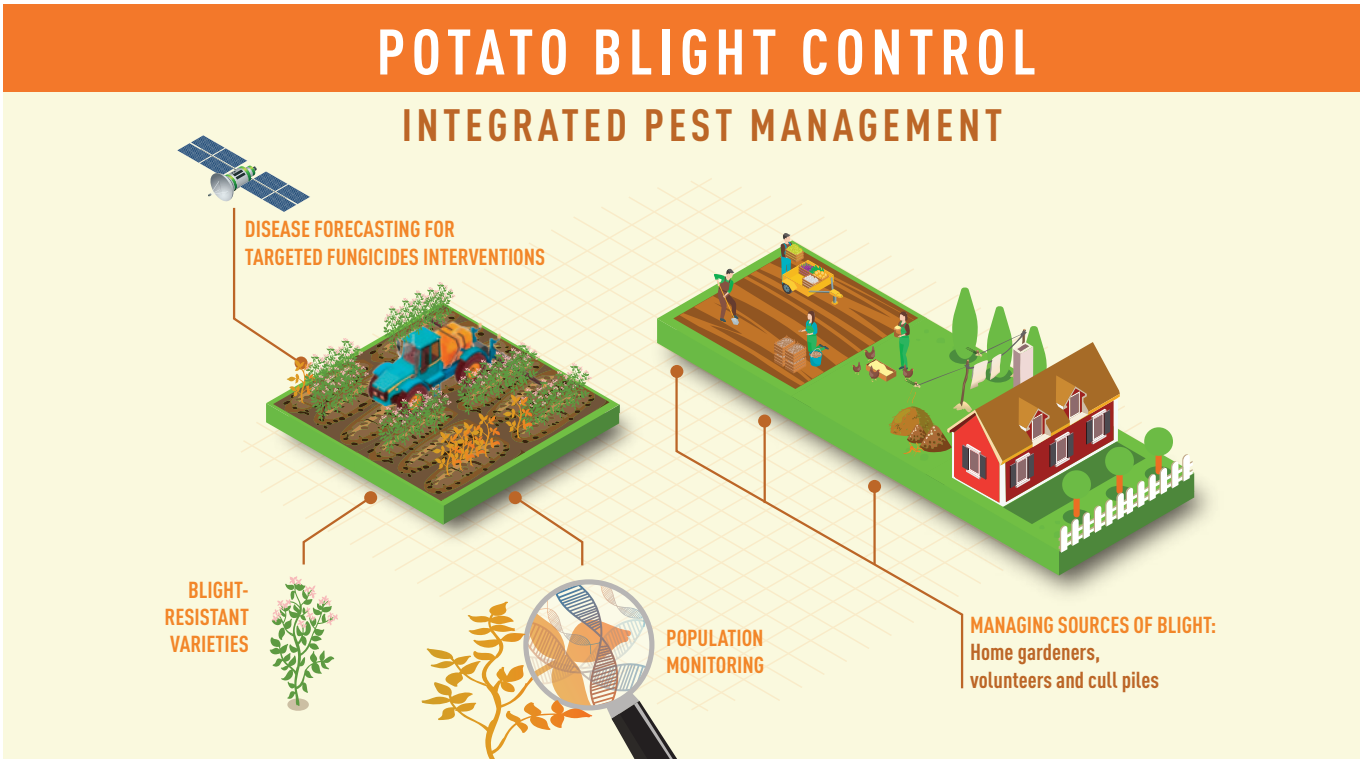
Teagasc held a series of exciting virtual events for Science Week (November 8-15) as part of 'The Festival of Farming and Food – SFI Science Week at Teagasc' (#FestFarmFood).
The core theme for Science Week 2020 was 'Choosing our Future', focusing on how science can improve our lives in the future, and in the present. This explored how science can help us to make positive choices that will impact the environment, our health, and our quality of life. Changes based in scientific evidence that we make today can hugely improve our future life, but also right now. All of the events were broadcast live on Zoom with celebrity presenters Damien O'Reilly and Jonathan McCrea. Other activities held in addition to the online events were: *Ask a Researcher* events for schools (where our scientists were teamed up with schools for Zoom meetings) and *A Day in the Life* videos (what do scientists actually work on?). In addition, there was a special Science Week episode of *The Research Field* podcast, the Research Insights seminar, the Walsh Scholars Next Generation event, and the Science Experiments at Home video series. Researchers at Oak Park also developed experiment packs for a local school.

All event videos, plus numerous other videos and accompanying documents, can be found on the Teagasc website – https://www.teagasc.ie/scienceweek/ – and on our YouTube channel under the Science Week playlist. These events were free to all thanks to funding by Science Foundation Ireland and Teagasc.

Researcher profile

Cathal Buckley

Cathal Buckley is a Research Officer in Teagasc's Department of Agricultural Economics & Farm Surveys, Rural Economy & Development Programme (REDP). Originally from a dairy and cattle farming background in Co. Kerry, he has degrees in agriculture from University College Dublin (BAgSc and MAgSc) and in economics from National University of Ireland, Galway (MEconSc and PhD). Between his studies in UCD and NUIG he took up a role as a research and policy officer within the Irish Creamery Milk Suppliers Association, where he was responsible for policy development in the areas of dairying and taxation. With the exception of a year where he lectured in Agricultural Science at the Tralee Institute of Technology, Cathal has been employed as a Research Officer with Teagasc since 2007, working across the Agricultural Catchments Programme and the Rural Economy & Development Programme. While within the Agricultural Catchments Programme, his research focused on nutrient management efficiency, adoption of nutrient management best practices and provision of environmental public goods related to agriculture. Cathal was responsible for developing nitrogen and phosphorus use indicators using farms within the Teagasc National Survey, an approach that is now being used as a template for other EU countries. Since joining the REDP his research has focused mainly on farm-level sustainability, with particular emphasis on the interface between agricultural production and the environment.
Cathal led the publication of the last three Teagasc sustainability reports, and was co-editor of the recently published Teagasc Ammonia Marginal Abatement Cost Analysis report. Cathal sits on the Teagasc gaseous emissions and water quality working groups and on the editorial board of *Land Use Policy*, and is economics subject editor for the *Irish Journal of Agricultural and Food Research*.
He has been involved in the publication of over 35 peer-reviewed journal papers, two book chapters and 11 national reports, and in successful grant applications worth over €4 million in research funding to Teagasc.
In his free time, Cathal likes swimming, the outdoors and has been known to hit the odd golf ball. He is also an avid Liverpool and Kerry football fan.



Geographical Society of Ireland Doctoral Awards

Congratulations to Shane Conway, who recently won the Geographical Society of Ireland Doctoral Awards. Two of the three finalists for this year's award, Jack McCarthy, a former Teagasc Walsh Scholar, and Shane Conway, collaborated extensively with Teagasc in the development of their research.

Shane's PhD explored collaboration and co-operation among farmers and rural policy stakeholders involved in the EIP-AGRI initiative. David Meredith of Teagasc's Rural Economy and Development Programme and Christine Bonnin of UCD's School of Geography supervised the research. Shane's doctoral research focused on generational renewal in Irish farming and was completed under the guidance of John McDonagh and Maura Farrell at the Rural Studies Unit of NUI Galway. As part of this research, Shane collaborated with Teagasc's 'Transferring the Family Farm' clinics and the Land Mobility Farm Survey.

David Meredith, Senior Research Officer with Teagasc and adjunct fellow at UCD's School of Geography, said: "These contributions to knowledge demonstrate the important role that human geography can play in expanding our understandings of the challenges and opportunities facing farmers, farm households and rural communities. Teagasc continues to work with leading geography departments to advance this line of research".

International Fertiliser Society Brian Chambers Award

Congratulations to Romain Hebert, a Teagasc Walsh Scholar who won runner-up at the International Fertiliser Society Brian Chambers Award against a very impressive line-up of research. Romain is supervised by David Wall, Teagasc; Sara Vero, Waterford Institute of Technology; and, Phil Jordan, Ulster University. Romain is working on agronomic and environmental impacts of phosphorus fertilisers with field trials across the Agricultural Catchments Programme.

Romain Hebert, presenting at an Agricultural Catchments Programme event.

WALSH SCHOLARSHIPS PROGRAMME

Walsh Scholars: The Next Generation

The Teagasc Walsh Scholars Gold Medal was awarded to Meritxell Grau Butinyac from Teagasc's Crops, Environment and Land Use Programme. The Gold Medal award was presented at the online event – Walsh Scholars: The Next Generation, which took place in Teagasc Oak Park in November, and recognises the top Walsh Scholar of the year.

The online event, hosted by Sharon Ní Bheoláin, RTÉ, was a showcase of Teagasc's leading postgraduate agri-food research. Attendees learnt about the Walsh Scholarships Programme and heard about some of the fascinating studies by final year scholars.

Teagasc Director of Research, Frank O'Mara, said: "The Programme's mission is to provide the sector with a pipeline of talent, 'the next generation' of leaders in agri-food research, advisory and education. We currently have more than 250 Scholars pursuing a PhD or Master's degree. The majority are funded by Teagasc, with others supported nationally by DAFM's FIRM, Stimulus and CoFoRD Programmes, SFI, EPA, and internationally by the EU's Horizon funding streams".

Frank continued: "Our Scholars are carrying out research projects that seek to find the knowledge and innovation needed to drive advancements across all levels of the agri-food sector. It is inspiring for us to hear from some of our final year Scholars today and I hope that this attracts others watching to apply for a Scholarship".

Frank congratulated Meritxell Grau Butinyac on being awarded the Walsh Scholars Gold Medal.

Meritxell's research project is examining the effect soil pH and phosphorus has on the microbial communities emitting nitrous oxide (N_2O), a potent greenhouse gas. To reduce N_2O emissions, she hopes that the research will highlight the most suitable soil management for microbes.

This is Teagasc's 27th time to award the Gold Medal, the Programme's highest accolade. Other Walsh Scholars recognised at today's event included:

Meritxell Grau Butinyac, Teagasc Gold Medal winner 2020.

- Paul Smith, Walsh Scholar of the Year for the Animal & Grassland Research and Innovation Programme. Paul's PhD project is investigating the link between the composition of the rumen microbiome, feed efficiency and methane output in beef cattle.
- Gemma Regan, Walsh Scholar of the Year for the Food Programme and Institute of Food Science and Technology Ireland (IFSTI) medal winner. Gemma's PhD project analysed nitrofuran residues, antibiotics that have been banned from use in food-producing animals, and shortened the analysis time from four days to 1.5 days.
- Adrienne Attorp, Walsh Scholar of the Year for the Rural Economy and Development Programme. Adrienne's PhD project considers challenges faced in the continued management of waterways shared by Ireland and Northern Ireland post Brexit.
- Kevin Maher, Walsh Scholar of the Year for the Knowledge Transfer Programme. Kevin's Master's project examined the factors influencing the adoption of nutrient management plans among Nitrates Derogation farmers.

Videos from each Walsh Scholar of the Year are available on https://teagasc.ie/about/research--innovation/postgraduate-scholarships/the-next-generation/. Articles from the winning presentations are highlighted in a special feature section in this issue of *TResearch* (starting on page 10).

Walsh Scholars Alum Award Winner for 2020

Carol Newman is the Walsh Scholars Alum Award Winner for 2020. Carol is a Professor of Economics and the Head of the School of Social Sciences and Philosophy at Trinity College Dublin.

She completed her Walsh Scholarship in 2001, having undertaken a PhD that examined the impact of income growth on food expenditure. The announcement was made by Teagasc Director, Gerry Boyle.

On receiving the award, Carol said: "I am delighted to be the Walsh Scholars Alum Award winner for 2020. My time as a Walsh Scholar provided me with a set of skills and competencies that paved the way for my research career and opened my eyes to the importance of research for policy making. I am really grateful to Teagasc for the opportunity they gave me all those years ago and am very honoured that my work is recognised through this award".

Gerry called for graduates of the Programme to reconnect with Teagasc,

Carol Newman, Walsh Scholars Alum Award winner 2020.

and one another, through the Walsh Scholars Alumni LinkedIn Group: "We now have over 1,200 alumni working in Ireland and across the globe, many in very influential positions in academia, the public sector and private industry. A priority of the Programme's future development is to connect, share and engage with alumni".

Five Teagasc researchers on Highly Cited list

Five Teagasc researchers have been named among the top 1 % in the world for highly cited papers in the Clarivate list of Highly Cited Researchers.

The highly anticipated annual list identifies researchers who demonstrated significant influence in their chosen field, or fields, through the publication of multiple highly cited papers during the last decade.

Their names are drawn from the publications that rank in the top 1 % by citations for field and publication year in the Web of Science citation index.

Declan Bolton,

Declan is a Principal Research Officer, Food Safety Department at Teagasc Food Research Centre, and Adjunct Professor in the School of Veterinary Medicine, University College Dublin. Declan's research focuses on controlling bacterial pathogens including *Campylobacter*, *Salmonella* and Shiga toxin-producing *Escherichia coli* (STEC) along the food chain, shelf-life and the prevention of food spoilage, *Clostridium* spp. (*C. estertheticum*, *C. gasigenes* and *C. difficile*), and the public and veterinary health aspects of green technologies such as anaerobic digestion.

Paul Cotter,

Paul is Head of the Department of Food Biosciences at Teagasc Food Research Centre, Principal Investigator in APC Microbiome Ireland and VistaMilk, and CTO of the Teagasc/APC spin-out, SeqBiome. Paul's research focuses on the microbiology and microbiomes of food (especially fermented and other dairy foods), food processing and production environments, and the gastrointestinal tract with a view to maintaining/establishing a healthy gut microbiota through dietary interventions, especially in athletes.

Catherine Stanton,

Catherine is Senior Principal Research Officer, Teagasc, Department Psychiatry, UCC, and APC Microbiome Ireland. Catherine's research includes nutritional aspects of dairy and functional foods, probiotic cultures, bioactive metabolite production, infant gut microbiota, and healthy proteins and fats (including conjugated linoleic acid and short chain fatty acids) that are produced by gut bacteria. She is also very interested in the microbiome during pregnancy and in infancy.

Brijesh Tiwari,

Brijesh is a Principal Research Officer, Food Chemistry and Technology Department at Teagasc Food Research Centre, and Professor (Adjunct), University College Dublin. Brijesh's research includes application of novel food processing, extraction and preservation technologies, with a strong focus on the investigation of biochemical aspects of food and food products. A particular focus of his current research relates to the investigation of green and sustainable solutions to food industry challenges.

Paul Allen

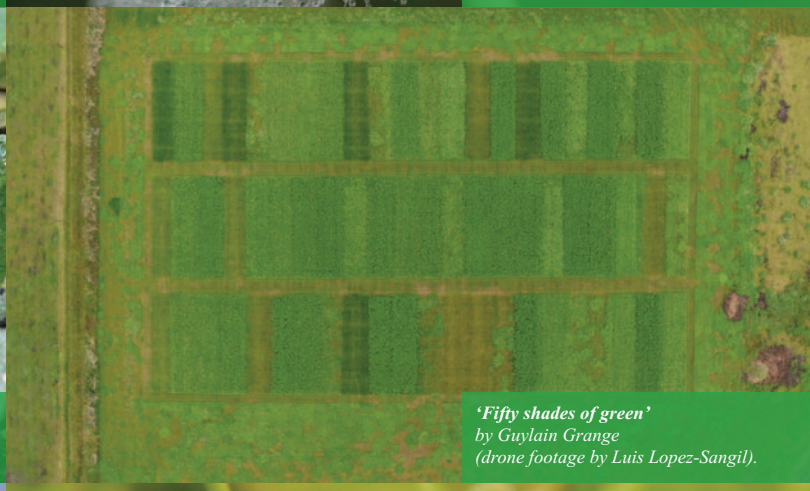
Paul is a retired Principal Research Officer from Teagasc, whose research interests covered a range of cutting-edge approaches to important meat research challenges, including assurance of meat palatability, application of imaging and spectroscopic methods to prediction of meat eating quality, optimising and controlling colour in fresh meat, packaging solutions for fresh meat, objective carcass evaluation, and innovation in healthier meat products.

The methodology that determines the who's who of researchers draws on data and analysis performed by bibliometric experts at the Institute for Scientific Information at Clarivate. It uses InCites and Essential Science Indicators, and a unique compilation of science performance metrics and trend data based on scholarly paper publication counts and citation data from the Web of Science, the world's largest publisher-neutral citation index and research intelligence platform. More than 6,000 researchers around the world (33 in Ireland), in 21 fields of the sciences and social sciences, and cross field categories, were selected based on the number of highly cited papers they produced over an 11-year period from January 2009 to December 2019.

'Speed up the generations'
by Dheeraj Singh Rathore.

'Blow me away'
by Fiona Hutton.

'Droplets'
by Brian McGuinness, Farhana Afroze.



'Fifty shades of green'
by Guylain Grange (drone footage by Luis Lopez-Sangil).

'Golden dusk'
by Peter Doyle.

'Multispecies sward biodiversity'
by Michelle Liddane and Ciaran Hearn.

Visions of research and innovation

The fifth Vision of Research and Innovation photography competition provided insight into the microscopic and macroscopic worlds of TEAGASC research.

The winners of the Vision of Research and Innovation image competition were announced in November, with Dheeraj Rathore taking first place for his image 'Speed up the generations'. The competition was open to all Teagasc staff and students, inviting them to submit digital images created in the course of their work, with the aim of finding the most innovative and compelling images showing the range of research and innovation activities taking place across Teagasc.

"The competition continues to be an excellent showcase of the fine work being performed by Teagasc's research and innovation staff. The diversity of the entries provides a fascinating window into the varied research being undertaken by Teagasc".

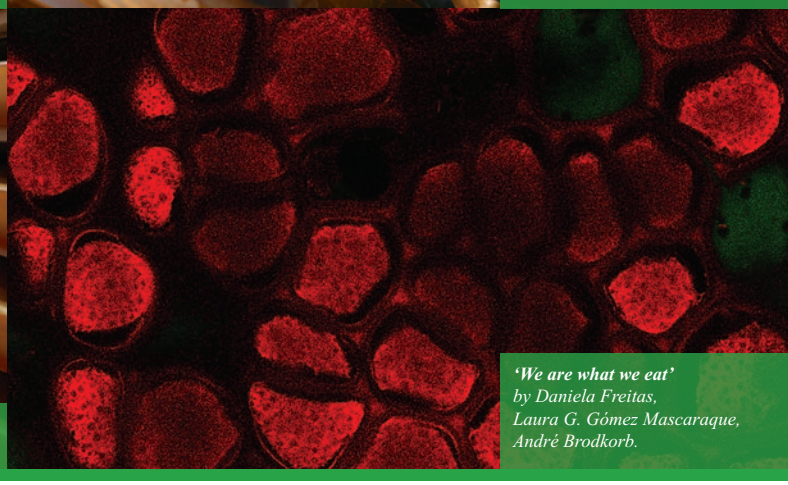
'Mushroom'
by Ankit Singh, Carloalberto Petti and Helen Grogan.

'Naptime'
by Orla Kinnane.

'Rural fabric on the horizon'
by Anne Kinsella.

'Seaweed process'
by Xianglu Zhu.

'To cheesinfinity and beyond'
by Antonio A. Lourenco.



'We are what we eat'
by Daniela Freitas, Laura G. Gómez Mascaraque, André Brodkorb.

Winners

The full list of winners is as follows:

- **'Speed up the generations'** – *Dheeraj Singh Rathore*
- **'Fifty shades of green'** – *Guylain Grange (drone footage by Luis Lopez-Sangil)*
- **'Rural fabric on the horizon'** – *Anne Kinsella*
- **'Blow me away'** – *Fiona Hutton*
- **'Multispecies sward biodiversity'** – *Michelle Liddane and Ciaran Hearn*
- **'Naptime'** – *Orla Kinnane*
- **'Mushroom'** – *Ankit Singh, Carloalberto Petti and Helen Grogan*
- **'We are what we eat'** – *Daniela Freitas, Laura G. Gómez Mascaraque, André Brodkorb*
- **'To cheesinfinity and beyond'** – *Antonio A. Lourenco*
- **'Golden dusk'** – *Peter Doyle*
- **'Droplets'** – *Brian McGuinness, Farhana Afroze*
- **'Seaweed process'** – *Xianglu Zhu*

Dheeraj's entry is from the Horizon2020-funded Marie Curie Action Fellowship GSAS-Genomic Strategies Against STB disease of wheat, which looks at faster ways of breeding new crop varieties under LED light. His image shows wheat being grown under pink LEDs.

This year's competition was judged by Jim Carroll (editor of *RTÉ Brainstorm*), Tony Byrne (Designer, Think Media), and Catriona Boyle (Teagasc, editor of *TResearch*). The winning images were selected from a total of 93 entries to the competition. Teagasc Director Gerry Boyle congratulated the winners, while noting the high quality of all entries and expressed his thanks to the judges for their care and attention to detail in selecting the winning images. Speaking about the competition, Frank O'Mara, Teagasc's Director of Research, said: "The competition continues to be an excellent showcase of the fine work being performed by Teagasc's research and innovation staff. The diversity of the entries provides a fascinating window into the varied research being undertaken by Teagasc".

A video of the winning images was produced as part of the 'Festival of Farming and Food – SFI Science Week at Teagasc'. The video can be viewed at: https://www.teagasc.ie/about/research--innovation/visions-of-research/.

The next "Vision of Research and Innovation" image competition launches in May 2021 and will close in September 2021.

Managing soil microbial communities to reduce N_2O emissions through pH management

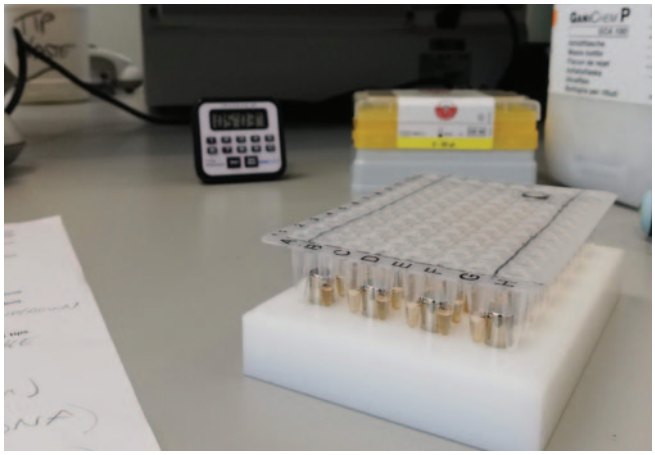
Meritxell Grau, Walsh Scholarships Programme Gold Medal Winner and Walsh Scholar of the Year for the Crops, Environment and Land Use Programme.

Nitrous oxide (N_2O) is a potent greenhouse gas with a global warming potential 298 times greater than carbon dioxide (CO_2). Agricultural soils are one of the main sources of N_2O emissions, with higher production rates of the gas induced by the application of nitrogen (N) fertiliser. The gases are primarily produced by microorganisms within soil that can transform plant-available N into gaseous forms. These emissions can be partly reduced by good agronomic practices; however, the project Mitigating Agricultural Greenhouse Gas Emissions by improved pH management (MAGGE-pH) aims to identify more efficient and specific approaches to decrease the production of N_2O. To do so, the project focuses on the microbial communities responsible for emitting and consuming N_2O in soils, and on the potential of soil pH management to control these emissions. pH has been shown in previous studies to play an important role in determining N_2O levels emitted from soils and is known to strongly affect soil microbial communities.

Impact of soil management

Microbial communities, like all living organisms, respond and adapt to their environment, and thus are strongly impacted by soil management. Microbes in the soil carry out a range of chemical transformations to obtain energy and essential nutrients. As part of the chemical transformation of N, N_2O can be produced, mainly through the denitrification process. This pathway is carried out by microbial denitrifiers when there are low levels of oxygen in the soil (anaerobic environments) and a ready supply of both available N and carbon. The application of N fertilisers leads to a supply of available N in soil that can be potentially transformed by microorganisms, leading to higher emissions of N_2O. Recent studies have shown that soil pH can dictate the N_2O losses, with acidic soils increasing the levels of N_2O emitted from soil. Laboratory studies report that increasing soil pH caused N_2O emissions to be reduced, providing a possibility of a more sustainable approach within agronomic practices.

The evidence of soil pH influencing the production of this greenhouse gas is predominantly restricted to laboratory studies. The MAGGE-pH project has brought together partners form across Europe and New Zealand to further explore the potential of soil pH management to reduce N_2O emissions under realistic field conditions. This collaboration has allowed this relationship to be tested over a wide range of soil types,



As part of the sequencing protocol, DNA samples are loaded into a 96-well plate, which is then placed on a magnetic stand. The magnet pulls the metal beads to the walls of each well allowing the sample to be cleaned.

liming strategies and geoclimatic conditions, as well as a wide pH gradient (4.1 to 7.4). This will enable us to assess how important soil pH is at regulating microbial communities involved in N_2O emissions across the globe.

PhD research

As part of the MAGGE-pH project, Meritxell's research is quantifying the abundance of microbes involved in the denitrification pathway, how their abundance changes across the international partners' experimental sites, and if their relationship with soil pH is maintained across them. This is achieved by using molecular techniques such as quantitative polymerase chain reaction (qPCR). Once DNA is extracted from soil, the samples are processed to quantify target genes known to be important in the denitrification process. These can be described as molecular labels that allow microbes capable of carrying out denitrification to be recognised. Their abundances can then be related to the pH range included in the study, allowing the identification of trends and patterns between the microbes and the soil property.

Soil pH could potentially turn into a key soil factor to manage and reduce the emissions of N_2O from soils. However, not only soil properties but also nutrient availability influence the microbial communities involved in different pathways. N availability is known to induce denitrification, but there are other nutrients that are less understood such as phosphorus (P). As part of Meritxell's PhD, the application and availability of P has been taken into consideration to establish any potential roles of the nutrient in relation to denitrification product rates. Using a long-term experimental trial with four P treatments as well as pH levels, potential N_2O production (laboratory-based experiment) and composition of microbial communities has also been studied to identify more specific approaches that can lead to the reduction of N_2O emissions from agricultural soils. Looking into the future, a target management of soil pH to benefit the microbial communities present in the soils may lead to a significant reduction of the production of N_2O from agricultural soils while improving agronomic practices and moving forward to a more sustainable management.

Molecular sampling set up in the pH x P field trial in Moorepark (Co. Cork). After soil samples are collected and mixed inside a plastic bag, a subset sample is collected inside a sterile tube and flash frozen in liquid nitrogen in the field.

Acknowledgements

This research is funded by the Department of Agriculture, Food and the Marine (DAFM) and ERA GAS.

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Professor of Microbiology, National University of Ireland Galway

Cutting GHGs from cattle

Paul Smith, Walsh Scholar of the Year, Animal & Grassland Research and Innovation Programme.

Paul's PhD project is investigating the link between the composition of the rumen microbiome, feed efficiency and methane output in beef cattle. Paul is supervised by Sinéad Waters, David Kenny and Alan Kelly (UCD).

The microbial ecosystem (microbiome) inhabiting the rumen provides ruminant livestock with the ability to convert forage into high-quality sources of dairy and meat protein for human consumption. However, one group of rumen microbes, known as methanogens, are responsible for nearly 60 % of Irish agricultural-related greenhouse gas (GHG) emissions through the production of methane. As a GHG, methane is 28 times more potent to the environment than carbon dioxide, with ruminant-derived methane originating as a natural by-product of feed degradation in the rumen. Therefore, decreasing the volume of methane produced by the Irish livestock industry will be key to adhering to the 2030 EU target of a 30 % reduction in Irish GHGs.

Understanding the links

Potential exists to breed low-methane-emitting cattle. However, the effectiveness of selecting more sustainable livestock will be dependent on an increased understanding of the microbiological mechanisms underpinning methane production. As a result, Paul's project aims to better understand the link between the composition of the rumen microbiome and feed efficiency, methane output and the host genome in beef cattle. To achieve the objectives of the project, GreenFeed systems have been installed at the Irish Cattle Breeding Federation (ICBF) progeny test centre in Tully (Kildare) to estimate methane output from cattle. These units, the first of their kind in Ireland, allow for large-scale measurements of methane output from individual animals. At the end of a three-week methane measurement period, a sample of rumen fluid is obtained from each animal to facilitate examination of the relationship between the composition of the rumen microbiome and the aforementioned phenotypes. With the use of next-generation sequencing, rumen fluid samples are currently undergoing molecular analysis in an effort to determine the relationship between the composition of the rumen microbiome, feed efficiency and methane output. An additional element of this project will be to investigate the potential genetic influence of the host (cow) on the rumen microbiome, feed efficiency and methane output.

Developing future strategies

Findings from this project will provide a greater knowledge to develop future methane mitigation strategies via breeding and dietary supplementation. In addition, this work has the potential to identify animals with a greater genetic propensity to efficiently utilise feed, while minimising their impact on the environment, assisting Ireland in achieving a 30 % reduction in national GHG emissions.

Acknowledgements

Paul's PhD forms part of the EU-funded international projects RumenPredict (funded by the Department of Agriculture, Food and the Marine (DAFM) through the FACCE ERA-GAS programme) and MASTER (EU H2020), with Teagasc researchers, along with colleagues in UCD and the ICBF, participating in both projects.

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Speeding up antibiotic measurement

Gemma Regan, Walsh Scholar of the Year, Food Programme, and Institute of Food Science and Technology Ireland (IFSTI) medal winner.

Gemma's research developed a new and improved rapid method for measuring banned nitrofuran antibiotics in meat.

Background

Nitrofurans are a class of broad-spectrum antibiotics, which were previously licensed as veterinary drugs for the prevention and control of disease, and as feed additives for growth stimulation. Upon administration, nitrofuran drugs are biochemically transformed in the muscle tissue into protein-bound metabolites, which can persist for months. It was found that these bound residues posed a potential threat to the consumer, due to concerns regarding their toxicological properties. Hence, nitrofurans are now classed as a zero-tolerance substance and are completely banned from use in food-producing animals.

Challenges in nitrofuran analysis

Due to the efficacy, availability and low cost of nitrofuran drugs, their illegal use still occurs. To ensure food safety, strict legislation exists for monitoring the levels of nitrofuran marker residues in food. Methodology for analysing these banned compounds is standard in most countries, with analysis primarily focusing on four main compounds, namely furazolidone, furaltadone, nitrofurantoin and nitrofurazone, detected as their respective marker residues: AOZ; AMOZ; AHD; and, SEM. Analysis of nitrofurans using the traditional bound-residue approach provides the most sensitive and selective detection; however, it is time consuming and leads to longer sample turnaround times.

Rapid method development

The aim of this research project was to extend the scope of analysis for nitrofurans and to develop a high-throughput liquid chromatography-tandem mass spectrometry (LC-MS/MS) method to include four additional nitrofuran compounds, namely nifursol, nifuroxazide, nifuraldezone and nitrovin, detected as their respective markers: DNSAH; HBH; OAH; and, AGN. The conventional analysis approach includes a 16-hour overnight derivatisation step, followed by a double liquid-liquid extraction. In this work, the analysis time was shortened from four days to 1.5 days, by developing an alternative rapid sample preparation approach, which incorporates a 13-minute microwave-assisted derivatisation step and a modified Quick Easy Cheap Effective Rugged and Safe (QuEChERS)-based extraction (**Figure 1**). The impact of this project is the development and application of a more efficient, reproducible and greener method for nitrofuran analysis, resulting in shortened laboratory turnaround times and higher method throughput for these substances. This improved confirmatory methodology for nitrofuran analysis in food aims to harmonise trade between the EU and China.

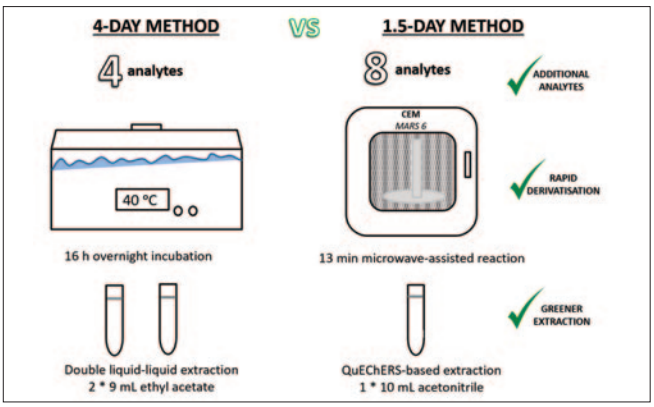

FIGURE 1: New research method used in this project, versus the older analysis approach.

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Managing Ireland's trans-boundary waterways post Brexit

Adrienne Attorp's research examines the challenges in continuing to collaboratively manage trans-boundary water catchments on the island of Ireland after Brexit.

Brexit is likely to trigger significant changes in the agri-food sector between the Republic of Ireland, Northern Ireland and Great Britain, including shifts in market conditions, industrial organisation, and policy. The island of Ireland may be disproportionately impacted due to its highly integrated agri-food sector and shared ecosystems. Resultant challenges, if not properly addressed, could negatively impact current provision of ecosystem services (ES) in agriculture and undermine the sustainability of the industry.

Trans-boundary ecosystem services post Brexit

Many ecosystem services on the island are trans-boundary in nature, meaning that changes to the provisioning of these in the north can exhibit positive or negative externalities in the south, and vice versa. New regulatory regimes may also result in different standards across a single ecosystem, such as water catchment areas. For example, while the management of shared waterways on the island of Ireland has, until now, been governed by EU regulations such as the Water Framework Directive, post Brexit there may be divergence in regulations, which could have a significant impact on agricultural practices and the environment on both sides of the border.

Adrienne's research considers challenges that farmers, practitioners and policymakers face in continuing to collaboratively manage shared, trans-boundary water catchments on the island of Ireland, post Brexit. It explores the potential impacts of diverging agri-environmental policy between north and south, including possible interactions and trade-offs between economic and environmental outcomes.

A key challenge for policymakers and farmers alike will be to determine how to weather upheavals in agriculture policy, practice and trade, so that farmers on both sides of the border can collaboratively continue to survive and thrive. Further, current efforts to support the agriculture sector's provision of ES should not only be sustained but improved.

Managing land and waterways: not just about economics

To achieve these aims, there must be greater consideration of the social and cultural factors that impact farmers' decisions around land use management.

Contrary to the prevailing neoclassical theory of land use, farmers are driven not only by market factors and economic incentives, but by a complex mix of social and political factors, household and individual profile characteristics, and concern for the natural environment. Understanding these is critical in understanding how farmers adapt to changes in agricultural policy.

Through providing a better understanding of the policymaking process and of farmers' roles in and response to it, the aim of this research is to aid in developing policy that fosters cross-border collaboration, and better supports farmers to farm in ways that are not only economically viable, but also limit agriculture's impact on the island's shared waterways.

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Farmers' views on nutrient management planning

Kevin Maher, Walsh Scholar of the Year, Knowledge Transfer Programme

Kevin's research examined the factors that influence Nitrates Derogation farmers when they use their nutrient management plans as a decision-making tool around fertiliser. Mismanagement of fertilisers leads to leaching of nutrients such as nitrogen (N) and phosphorus (P) into waterways, leading to pollution and loss of biodiversity. Nutrients (nitrates and phosphates) from diffuse agricultural sources remain a critical problem across Europe, and agriculture is the dominant source of N and P contamination in Irish waterways and coastal waters. Leached nutrients end up in rivers, lakes and estuaries, where they can cause a range of environmental problems, such as eutrophication. The objective of this study was to establish the factors that influence Nitrates Derogation farmers using their nutrient management plans (NMPs) as decision-making tools around fertiliser.

Data collection

Data from 20 beef farmers from Co. Kilkenny and 20 dairy farmers from Co. Wexford was collected through the completion of phone surveys. The questionnaire established the selected farmers' attitudes towards and use of the nutrient management planning tool and their attitudes to soil testing and a liming programme. A phone survey was the chosen method for data collection due to social distancing restrictions. Survey data was supplemented by data on each of the farmers from existing Teagasc records, including age, land area and nitrogen per hectare (NPH). All the selected farmers were participating in the Nitrates Derogation scheme, as it is a mandatory requirement for these farmers to take soil samples at least once every four years and to develop an NMP for their farms.

Study findings

The study found that there was a good understanding by farmers of why it was important to follow soil sample recommendations and use NMPs when making decisions on fertiliser application. Almost all farmers claimed to understand the purpose of following an NMP. However, there was a gap between farmers' understanding of why it was important to follow soil sample recommendations and using an NMP when making decisions on fertiliser applications, and putting these into practice. Opinions and attitudes of farmers towards NMPs were relatively positive. Almost 80 % of farmers felt that following an NMP helps to increase productivity on farms, while just over 90 % felt that following an NMP improves soil fertility. Some 80 % of farmers felt that following an NMP helps protect the environment. Age and farming enterprise type were found to be associated with the uptake of soil sampling and using NMPs as decision-making tools on fertiliser applications. Farmers under 50 years of age were more likely to use soil sample recommendations and NMPs as decision-making tools with fertiliser applications than farmers over the age of 50. Dairy farmers were also more likely to use the NMP for fertiliser decisions compared to beef farmers, as dairy farmers placed a higher reliance on soil sample recommendations and NMPs when making decisions on fertiliser applications.

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Phytophthora infestans – the plant destroyer

With the arrival of new genotypes and increasing fungicide resistance, control of *Phytophthora infestans* continues to be a challenge.

While fungal, bacterial and viral pathogens continue to shape global societies, there are few plant-specific pathogens that can be regarded as having impacted the 19th and 20th centuries in the way *Phytophthora infestans* has. Aptly named, this plant destroyer is the cause of late blight of both potato and tomato, and its arrival in Ireland over 175 years ago contributed to the Irish famine, with the ensuing consequences still felt to the present day. In Ireland, while we no longer depend as heavily on the potato, globally potato production and consumption is growing, particularly in developing countries. As such, *P. infestans* continues to pose the most serious biotic threat to global potato crops, with intensive fungicide programmes rigorously implemented for its control on an annual basis.

Global crop threat

So what is it about this pathogen that makes it such a threat to Irish potato crops? Although late blight caused by *P. infestans* is often referred to as a fungal disease, it is actually an oomycete, more closely related to brown algae than to true fungi. The differences between oomycetes and fungi may be subtle but can have enormous consequences: for potato growers this is probably most evident in the different chemicals used to control them. Most fungicides used to control cereal diseases provide no control against late blight and those used for late blight have little or no effect on cereal diseases. The arrival of late blight in Europe and its resulting devastation also led to the development of the science of plant pathology with the discovery that microbes can cause the infection and are not only a symptom of disease. These findings form the cornerstone of plant disease control programmes, with manipulation of one or more of the components of the disease triangle – pathogen, environment or host potato crop – providing control. Over the past 175 years *P. infestans* has demonstrated that it can also readily adapt to overcome any changes imposed, whether directly or indirectly, in the form of the host or environment. As production systems in Ireland and throughout Europe have changed, the economic consequences associated with even minor outbreaks of the disease have increased. This has led to increased monitoring of the pathogen for changes that may indicate potential changes in disease development and subsequent control measures.

New genotypes

The first method readily utilised to monitor potential changes in the pathogen is an assessment of the structure of the population based on its mating type. *P. infestans* can reproduce both clonally or by hybridisation between different mating types designated A1 and A2, which produces long-lived oospores, hence altering the pathogen lifecycle. For this to happen, a co-infection must occur on the same leaf or tuber. As *P. infestans* is not native to Ireland it has until now been dominated by a small number of clonal genotypes that overwinter in infected tubers and spread from volunteer plants and cull piles. Initially, population monitoring suggested that a single clonal genotype designated US-1, which was A1, dominated the *P. infestans* population in Ireland and globally from shortly after the famine until the late 1970s/early 1980s. At this time a second major migration of *P. infestans* from South America is believed to have occurred, followed by potentially another in the late 1990s/early

When weather conditions are conducive to the spread of late blight, the speed at which the disease can spread and devastate potato crops if left unprotected is astonishing, as is evident from the above pictures from the Teagasc late blight trials in 2009 (pictures taken two weeks apart).

2000s, both indicated by the increased detection of the A2 mating type in field populations. The first A2 strain was confirmed in Ireland in 1987 but had little impact on disease control or oospore formation. Analysis of the 1996 population structure suggested that the original US-1 genotype had been completely displaced but the population was still clonal with a few genotypes dominating, which were mainly A1 and sensitive to the phenylamide fungicides. The arrival of the A2 genotype Blue-13 or EU_13_A2 in the mid 2000s, which was more aggressive and resistant to the phenylamide fungicides, had a major impact on all aspects of late blight, from disease control to monitoring. Blue 13 quickly established and with other A1 genotypes present in the population, mating type determination alone was no longer useful to determine whether *P. infestans* was sexually active in Ireland. With the advent of molecular techniques, including simple sequence repeat markers (SSRs), it has been possible to monitor *P. infestans* in more detail, down to specific strains. Through continued monitoring of populations, it is believed that although both mating types can now readily be identified in the same field, and in some instances on the same plant, there is no evidence of genotypes resulting from sexual combination. For the continued management of the disease this is of importance as oospores, in addition to increasing genetic diversity in the population, are long lived and can survive in soil in the absence of the host and initiate late blight epidemics following planting.

Fungicide resistance

The arrival of Blue-13 presented an additional hurdle for the control of late blight. The genotype combined increased aggressiveness with resistance to the phenylamide fungicides and no fitness penalty, which had traditionally maintained resistant genotypes at a low level in the population. Furthermore, Blue-13 was more aggressive on previously resistant varieties, which changed variety resistance ratings. Throughout Europe strains of this genotype rapidly dominated the *P. infestans* population, resulting in increased intensity of fungicide applications. Unfortunately the emergence of Blue-13 has marked the emergence of a continual wave of increasingly aggressive genotypes, each displacing the other. Contemporary Irish populations are now composed of up to five major genotypes that we know of, each with their own unique advantage. For instance, in 2019 the genotype EU_37_A2 was first detected in the Republic of Ireland. This genotype displays resistance to the fungicide fluazinam, which until this point was heavily relied upon by Irish growers. As it remains difficult to predict what strains of *P. infestans* may be present in any given field prior to the outbreak of the disease, Irish growers have adjusted control programmes by increasing the intensity of fungicide applications to ensure control of all potential genotypes. Even with this increased vigilance, given the variability of the Irish weather, the risks posed by late blight to Irish potato production continue to be immense, highlighting the need to devise fully integrated disease control strategies, including pathogen monitoring, host resistance deployment and accurate forecasting.

Acknowledgement

Monitoring of Irish *P. infestans* populations has been supported over the past decades through Teagasc and the Department of Agriculture, Food and the Marine through their Research Stimulus Fund (Ref07:567; MonPESC: 11/s/113; EPIC: 14/s/879).

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Breeding for resistance

INTERNATIONAL YEAR OF PLANT HEALTH 2020

TEAGASC researchers are using lessons from the past to guide the future of breeding potatoes for late blight resistance.

The success of the potato in Ireland prior to the famine was due to its exceptionally high yield, low input requirement, short cropping season and high nutritional value. Potato favours a cool climate with adequate rainfall and is particularly well suited to Irish conditions. By the early 19th century, these characteristics had made it a lynchpin of the diet of a largely agrarian Irish population. In 1845, when late blight arrived in Ireland, the main variety, Lumper, which was selected for its extremely high yield, was especially susceptible, which led to complete destruction of the crop.

First organised breeding

Potato breeding is performed by sowing true seed from potato berries (derived from crosses between pairs of existing varieties) and selection of the best performing seedlings. Records show that informal selection or breeding of potato varieties was taking place around the time of the famine, as true seed was being produced and traded. These informal breeding efforts were conducted by individual farmers, botanists and gardeners on the basis of yield and taste. When the true cause of potato blight was discovered it kick-started the area of formalised potato breeding, particularly for late blight resistance. In Ireland, the first organised breeding effort was carried out in 1881 by the director of the Albert Institution, Thomas Carroll, who distributed true seed of potato varieties to national schools around the country for selection in school gardens. Although many varieties were produced from this programme, it did not yield any highly successful varieties; the national crop was dominated by the Scottish variety Champion, which exhibited some blight resistance, until Kerr's Pink became dominant in the early 20th century. The improved resistance of these varieties, although incomplete, coupled with use of early fungicides such as the Bordeaux mixture (based on copper sulphate), allowed continued potato cultivation in Europe in the face of continuing blight pressure. International breeding efforts in the 1950s and 1960s focused on introgression of major resistance (R) genes to cultivated potato from the wild Mexican potato species *Solanum demissum*. These R genes conferred near complete resistance; however, the resulting resistant varieties soon became susceptible, indicating poor durability and the ability of *Phytophthora infestans* to evolve and 'break' the resistance they confer. Further breeding efforts, both Irish and international, focused on 'field resistance', which was believed to be more durable because it was partial and did not rely on R genes, but rather on a combination of different physiological factors controlled by many genes.

Teagasc breeding programme

The potato breeding programme in Teagasc was set up in 1962 to breed varieties primarily for the domestic market and blight resistance was a major focus. During the 1970s Teagasc formed a partnership with IPM Potato Group to breed varieties for both export and domestic markets. Varieties produced by this programme, including Cara, Setanta, Orla, Galactica, Banba, Druid and Kikko, exhibited good levels of partial resistance to the pathogen, and Orla and Setanta are widely grown for organic production, at least in part because of this resistance. In the last 20 years a revolution in our understanding of plant–pathogen interactions has taken place, and the differences between field resistance and major gene resistance have become blurred. It is apparent that some varieties possess multiple R genes, the

Late blight-resistant seedling surrounded by susceptible seedlings.

Late blight resistance screening trial demonstrating effect of resistant genes from wild species in potato.

combination of which give both strength and durability in terms of blight resistance (a good example is the variety Sarpo Mira). At the same time, screening wild relatives of cultivated potato has identified numerous new R genes, from species other than *S. demissum*, which exhibit very strong levels of resistance, and seem to break down more slowly in the face of a constantly evolving pathogen. One important lesson has been that it is important to maximise the difficulty experienced by the blight pathogen in evolving to overcome R genes bred into varieties. One approach is to 'stack' multiple R genes into varieties. This contributes to the durability of resistance, as the blight pathogen has to go through multiple mutation and selection events to overcome multiple R genes. Another concept is to use R genes in the context of a wider integrated pest management (IPM) strategy, where other control methods, such as early cropping, decision-support systems and judicious use of fungicides, reduce the adaptive ability of the blight pathogen and help to protect naturally resistant varieties while reducing cost and environmental burdens.

Marker-assisted selection

In conventional breeding, the cycle of development for a single variety after its two parents are crossed is over a decade, and this limits the ability to stack multiple R genes quickly; it can take several decades to achieve multi-R-gene stacks. Genetically modified (GM) approaches for stacking have been demonstrated to be highly effective, and would greatly speed up the development of durably resistant varieties, but the technology remains unpopular in Europe, and no significant GM potato varieties have been released in the EU. In response to these time constraints, conventional breeding programmes such as the Teagasc/IPM Potato Group programme are developing technologies to augment and speed up the development of resistant varieties. At Teagasc, we are engaged in identifying novel R genes and developing genetic fingerprinting assays for these genes, to be used in a strategy called marker-assisted selection. This has contributed to the development of varieties such as Java, which combines resistance to late blight, potato virus Y, potato cyst nematode, and wart disease. In collaboration with international partners, potato breeders and geneticists at Oak Park Research Centre are also exploring novel 'rapid-cycle' breeding approaches such as diploid hybrid breeding and fixation-restitution breeding (diffugat.eu), which have the potential to cut variety development time in half.

Potato is the most important non-cereal food crop in the world, important in both the developed and developing world due to its productivity, nutritional profile and potential to build profitable value chains. While consumption is dropping in the western world, potato is expanding in the global context, and late blight remains a major constraint on production. Lessons that began with the famine continue to guide potato breeders and scientists in Ireland and across the world in combatting this challenging disease.

Acknowledgement

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INTERNATIONAL YEAR OF PLANT HEALTH 2020

Can novel breeding techniques deliver a solution to late blight?

TEAGASC researchers are evaluating the potential of novel techniques such as cisgenics to deliver durable blight resistance.

Potato late blight disease remains the primary stressor of commercial potato production across the EU, responsible for ~€1bn in annual damage to the EU potato sector alone. In the absence of resistant varieties that meet consumer demands on taste and appearance, growers are wholly dependent on fungicide applications to preserve yields. In Ireland alone, this equates to >10 sprays per crop, to offset losses.

The recently published Farm to Fork (F2F) strategy of the European Commission outlines the need to reduce chemical inputs by up to 50 % by 2030. To achieve this ambitious goal, multiple strategies need to be considered to assist farmers in reducing current reliance on inputs while maintaining the economic sustainability of Irish potato production.

Sources of genetic resistance to late blight disease do exist in wild potato species but the transfer of this resistance into commercial varieties through conventional breeding practices is time consuming due to the complexity of the potato genome. It typically takes ~12 years to breed a new potato variety, but introducing traits from wild germplasm can extend this even further, as seen with varieties Sarpo Mira, Bionica and Toluca.

A previous article in this series on breeding potatoes highlights the gains that exist with the use of molecular techniques to increase the efficiency of breeding in the delivery of more stress-resilient varieties. More recently, novel breeding techniques have illustrated the potential to enhance existing varieties further through the addition of a single trait via a process termed 'cisgenics'.

Cisgenics

Cisgenic refers to the transfer of genes within a genus (e.g., from a wild potato to a commercial potato), but because of the method used to transfer the genes they are still covered by genetic modification (GM) legislation. This contrasts with the traditional understanding of GM, which is transgenic. In this case, genes are taken from one genus and transferred into any other (e.g., transferring a gene from a fish into a plant).

Significantly, a 2010 Eurobarometer survey on the theoretical marketing of a cisgenic variety to Irish consumers reported that while only 36 % of Irish people surveyed would accept a transgenic variety, 61 % would accept a cisgenic variety.

Through cisgenics, novel potato lines can be engineered in a matter of weeks, highlighting the potential of the technique to accelerate the potato breeding process and address a trait deficit (e.g., late blight susceptibility), without compromising the processing/quality traits the variety already possesses.

The EU-funded 'AMIGA' project was established to assess and monitor the impact of specific GM crops on agro-ecosystems. As partners in this project, we undertook field evaluations, at a licensed site in Oak Park Carlow, of a potato line, which possessed a late blight resistance gene (Rpi-vnt1.1) taken from

the wild potato species *Solanum venturii* (**Figure 1**). Through three consecutive field seasons the impact of the cisgenic potato line (A15-031) on specific parameters of soil biodiversity was investigated. In addition, the potential of integrated pest management (IPM) strategies to support the durability of this source of late blight resistance against Irish late blight strains was also determined.

Significantly, the IPM control strategy adopted in the study, and based on the use of the cisgenic potato line, reduced the average fungicide input by 80-90 %, without compromising late blight control or yield.

Results

Significantly, the IPM control strategy adopted in the study, and based on the use of the cisgenic potato line, reduced the average fungicide input by 80-90 % across the three years, without compromising late blight control or yield. This was made as a direct comparison with the experimental control variety, cv. Desiree. Of interest, the work was also completed at a site in The Netherlands, and delivered equivalent fungicide reductions, in spite of the higher level of late blight pressure experienced there compared to what was recorded at Oak Park. Separately, the environmental side-effects of late blight control were reduced significantly. For this, in-depth studies looked at the impact of growing the cisgenic potato line on soil bio-indicators, including nematodes, which play a key role in soil processes, with alterations in the nematode community structure having the potential to considerably influence ecosystem functioning. As a result, fluctuations in nematode diversity and/or community structure can be gauged as a 'barometer' of a soil's functional biodiversity. Based on the metrics studied, the cultivation of the cisgenic potato line exerted no significant effect on nematode community diversity. In fact, greater disturbance of nematode diversity was recorded from the yearly weather patterns, as opposed to from the material grown. Similarly, investigations also concluded that there were no tangible effects associated with the cultivation of the field-grown cisgenic potatoes on soil microbial communities either.

Impact

The results from the AMIGA project have been fully published with a significant proportion of the work focussed on monitoring the impact of the cisgenic potato line on biodiversity. Based on the three-year study, the environmental and agronomic impact of the cisgenic line was positive and indicates the potential of certain breeding techniques to rapidly deliver novel potato lines with enhanced field performance while reducing fungicide reliance.

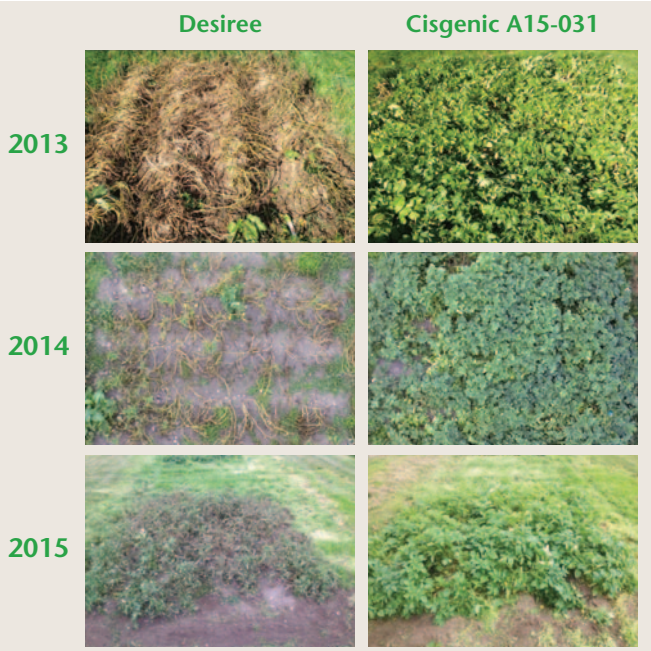

FIGURE 1. Resistance of cisgneic potato line A15-031 (right) relative to its equivalent comparator non-GM variety Desiree (left) against natural late blight at a licensed field location in Carlow, Ireland. Field assessments were conducted in 2013, 2014, and 2015. A15-031 was cisgenically engineered at Wageningen University through the DuRPh programme.

As with all disease control strategies, the durability of the therapeutic is dependent on the presence/absence of supporting measures. Late blight has a fantastic ability to rapidly evolve new strains and this constant 'arms race' between plant and disease is continuous. However, while the cisgenic line used in the AMIGA study contained a single R gene, it is technically straightforward to include a series of R genes in the modification step. If deployed as part of an IPM-based strategy, this material has the potential to negate the high level of current fungicide inputs while attaining the processing quality required.

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Overview of the Teagasc late blight trials conducted at Oak Park Carlow on an annual basis. Photo courtesy of Colum Kennedy, CELUP.

INTERNATIONAL YEAR OF PLANT HEALTH 2020

Keeping a weather eye for blight

TEAGASC researchers are collaborating on the evaluation and improvement of late blight forecasting models.

The phrase "blighty weather" is often used during the summer months to describe mild damp weather conditions. In the broadest sense the phrase is correct as these are the weather conditions that favour the spread and development of potato late blight. It was this apparent association between weather conditions and subsequent outbreaks of late blight that led researchers in the earlier part of the 20th century to devise late blight forecasting models to aid farmers in making decisions on whether to apply fungicides for its control. One such model was devised by Austin Bourke of Met Éireann in the mid 1950s and, later referred to as 'the Irish Rules', was fundamental to the control of late blight in Ireland in the following decades. Since the inception of these models, potato production systems have dramatically changed, with production more centralised and on a much larger scale. Associated with these changes has been a continual change of *Phythophthora infestans* populations, the pathogen causing the late blight disease, with more aggressive and/or fungicide-resistant strains regularly emerging and dominating local populations. As the original model devised by Bourke was reflective of both the production system and *P. infestans* population present in Ireland over 50 years ago, an evaluation of whether improvements in the predictive power of the Irish Rules model to reflect current production and *P. infestans* populations could be made was long overdue. As part of a collaborative effort between Teagasc, Maynooth University and Met Éireann as part of the Department of Agriculture, Food and the Marine- (DAFM) funded EPIC project (2015-2020), a critical evaluation of the current model was undertaken. Utilising late blight outbreak data from the Teagasc potato breeding trials conducted annually at the Teagasc Crops Research Centre at Oak Park Carlow and the detailed weather data collected by Met Éireann's automated synoptic weather station located on site, the relationships between weather conditions during the summer months and the first occurrences of late blight in the trials was analysed. Initially, the current model was used as a baseline and its ability to accurately predict outbreaks was determined. As anticipated the model was overly conservative, completely missing the onset of outbreaks on numerous occasions and only reaching the threshold to trigger a warning in four of the ten years. Model parameters were evaluated and recalibrated to better reflect the current pathosystem, with thresholds for pathogen activity being reduced mainly with regard to relative humidity requirements. Based on these revisions alone the conditions favouring disease development were identified in all ten seasons, with a high level of sensitivity identified in eight of these seasons.

Implications for fungicide application

The implications of these changes on the frequency of fungicide applications was also evaluated. The typical prophylactic seven-day fungicide programmes currently utilised by growers were compared to a control programme with targeted fungicide applications with regard to the timing of application and dosage applied based on the current model (Default IR), the most efficient based on the above (Optimised IR) and a slightly modified version reducing risk of early

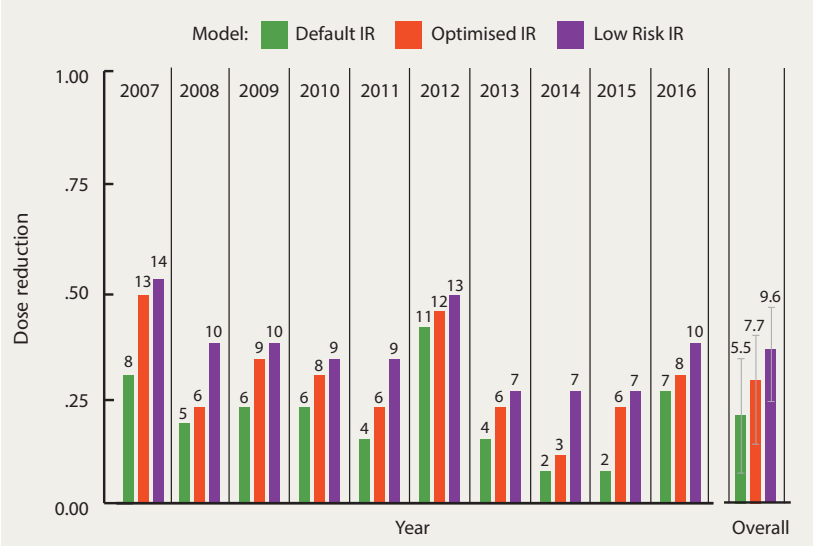

FIGURE 1: Theoretical reductions in fungicide usage based on the use of forecasting models. While the current model (IR) provides significant reductions in fungicide use, it fails to adequately provide protection from the development of late blight. Both the Optimised and Low Risk models provide significant reductions in fungicide use but are also able to accurately predict the onset of the disease.

outbreaks of blight (Low Risk IR). In theory, both the Optimised and Low Risk models could reduce the number of applications on average across the season and total quantities of fungicides applied by more than 50 % (**Figure 1**).

The next step of the validation was undertaken under field conditions. Field trials were conducted during 2016-2019 at Oak Park (main image). To facilitate the research a software application was devised whereby the observed and 10-day forecasted weather provided by Met Éireann were used to calculate risk according to several models. Risk outputs were converted into spray recommendations, whether to apply fungicide or not and at which dose, and provided to the field trials team. In the trials these were compared to an untreated control, a typical seven-day full-dose programme routinely utilised by Irish growers, a half-dose fungicide programme, a programme based on the current model and, finally, a comparison to a Danish late blight prediction system. To further advance the principles of integrated pest management, the trials included a range of potato cultivars varying in their susceptibility to late blight, including the market standards such as Rooster and British Queens. Comparable to the theoretical exercise, the currently used version of the Irish Rules, while significantly reducing fungicide usage, was unable to prevent the development of late blight. In contrast, the control programme based on the Low Risk IR model provided comparable control of late blight to the full fungicide programme, but significantly reduced both the number of applications and total dose of fungicides applied by >50 %. In the context of the EU's Farm to Fork strategy, which is focused on reducing chemical inputs by 50 % by 2030, this is a highly significant result and underlines the importance of accurate forecasting as a disease control measure. The value of cultivar resistance was also apparent in these trials, with minimal late blight detected on either of the resistant control cultivars included in the trials.

Implications

As the availability of pesticides continues to decrease across Europe due to the development of resistance and increased regulation of the sector, it will become increasingly important to devise control programmes that reduce the need for chemical inputs. Through this research, significant reductions in fungicide usage on Irish potatoes can be achieved with minimal impacts to production. However, as production systems continue to change and the pathogen adapts as highlighted, continual evaluations and revisions to disease forecasting systems will be required.

Acknowledgements

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For further information relating to this project, including the details relating to the data analysis used for the model evaluation and field trials, please see https://mladencucak.github.io/AnalysisPLBIreland/ and https://mladencucak.github.io/PLBFieldTrial/index.html.

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Implementing biosecurity practices in intensive animal productions systems

TEAGASC researchers are using risk-based scoring indexes to quantify biosecurity measures on pig and poultry farms.

Background

Biosecurity can be defined as the implementation of measures that reduce the risk of introducing infectious disease agents (i.e., external biosecurity) and minimise the spread of those already present in the farm (i.e., internal biosecurity).

Infectious agents cause significant health problems and contribute substantially to the use of antimicrobials, compromising sustainability of animal production. Implementation of biosecurity practices ensures healthier animals, high standards of food safety and food security, and reduces the environmental impact of animal production.

Although some biosecurity principles apply to all farming systems and infectious diseases, biosecurity plans tailored for specific farming systems are important to target particular diseases. While factors such as perceived costs and labour requirements could influence the decision to implement certain biosecurity practices, producers are more inclined to implement those that can be expected to improve animal performance and increase profit. Risk-based scoring indexes (e.g., Biocheck.UGent) have been developed to provide an objective way to quantify biosecurity status and harmonise recommendations. Such scoring systems are good for benchmarking, and to provide useful information to farmers, veterinarians and pig advisors on which areas of biosecurity could be improved.

The Department of Agriculture, Food and the Marine- (DAFM) funded project Surveillance Welfare and Biosecurity of Farmed Animals (SWAB) is investigating biosecurity practices implemented in Irish pig and poultry farms, and their associations with animal performance and antimicrobial use.

To date, we have analysed biosecurity practices in 56 farrow-to-finish pig farms, and we are getting ready to start the biosecurity assessment of 50 broiler farms.

Biosecurity in pig farms

Pigs are raised mostly indoors in buildings that are specialised for each age (i.e., sows, piglets, growing pigs). Implementation of biosecurity in pig farms is associated with better growth, improved health, and reductions in the use of antimicrobials. This is particularly important since pigs are the main farm species to which antibiotics are administered, especially in-feed antibiotics for preventive purposes. Results from the Biocheck.UGent questionnaire in Ireland showed that in pig farms, external biosecurity practices are implemented more often and internal biosecurity practices seem to be regarded as less important (Rodrigues da Costa *et al.*, 2019). Implementing biosecurity practices related to feed, water and equipment supply, and practices related to disease management and hygiene between buildings, was associated with lower growing pig mortality.

When examining associations with antimicrobial usage, our results highlight the usefulness of cleaning, disinfection, and farm compartmentalisation to reduce the use of antimicrobials in pig farms. We observed lower antimicrobial use in farms where farm staff wore farm-specific clothing and shoes, washed their hands before entering the stables, and in farms where footbaths were installed at the entrance to each building. Antimicrobial usage was also lower in farms where pigs were kept with higher space allowance during the growing stage.

Regularly cleaning the storage bin for casualty pigs (i.e., dead and euthanised pigs), and wearing gloves when manipulating casualty pigs, were associated with lower antimicrobial usage. The good news is that many of these practices could be easily implemented on farms with relatively low costs.

Biosecurity in poultry farms

Poultry production is a highly organised and intensive operation where large numbers of birds are kept in proximity. It differs from pig farms because different ages are located in different locations and so the main risk is bringing disease into the farm (external biosecurity). The importance of specific biosecurity measures in the control of particular diseases such as *Campylobacter* spp. in poultry farms has long been recognised, including those with implications for public health. Outbreaks of endemic diseases result in decreased animal performance and economic loses for producers, while epidemic diseases could affect the entire poultry production sector by necessitating the implementation of mandatory preventive measures such as quarantine or mass culling of poultry. This is particularly important in the wake of the avian influenza H6N1 outbreak we are experiencing this year in Ireland, where culling of birds has occurred in all affected flocks as per the decision of flock owners.

Nowadays, broiler chickens are produced in short production cycles (approximately 42 days) with limited treatment options and leaving little recovery time in the aftermath of a disease outbreak. In this situation biosecurity becomes key. Flock owners need to be vigilant, implement strict biosecurity practices, and review their biosecurity plans with their veterinary practitioners regularly, especially during periods of heightened risk. Thus, we are aiming to identify easily implemented and cost-effective biosecurity practices associated with improved animal performance and reduced antimicrobial usage in broiler farms. We plan to survey at least 50 farms using the Biocheck.UGent questionnaire in the coming months, once the avian influenza H6N1 outbreak is under control.

Benefits to the industry

Biosecurity is a public good; it can benefit everybody involved in the food production chain from animals and producers to consumers of animal products. Characterisation of farm-level biosecurity practices in pig and poultry farms will result in disease prevention and reduction in antimicrobial usage, thereby improving farm sustainability.

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Mapping Irish stakeholder engagement for safe drinking water

Researchers from TEAGASC and Ulster University are investigating stakeholder engagement as part of the EU Horizon 2020 project WaterProtect.

Drinking water governance requires a large stakeholder collaboration of industries, agencies, pressure groups and individual users to ensure high source quality and reduced treatment costs. However, it is important to know how this collaboration operates in practice and if there are bottlenecks that need to be overcome. WaterProtect aimed to create an integrated multi-actor participatory framework including innovative instruments that enable monitoring, financing and implementation of effective management practices and measures for the protection of water sources.

A global question

Drinking water governance is challenging, with different perceptions and priorities among stakeholders in different countries. Before methods and strategies can be developed to ensure drinking water is protected in leaky agricultural areas, country-specific governance systems first need to be assessed. This assessment or 'mapping' has not been completed in Ireland and there is currently no method to complete such a task across the EU. Our project demonstrated how the use of fuzzy cognitive mapping (FCM) addressed this challenge. The method enables direct engagement with representative stakeholder groups. By pooling all the data from different stakeholder groups, factors of importance and their connectivity to one another were explored. This enabled bottlenecks in the existing system to become obvious. Once bottlenecks are identified, strategies to overcome such problems can be tested using a modelling approach.

What is fuzzy cognitive mapping?

FCM is a flexible tool that has been successfully applied in environmental and water policy-related studies. The tool is particularly useful in obtaining stakeholders' perceptions while undertaking face-to-face interviews. The method gathers information from designed group exercises and converts these data into a form that can be analysed.

To build FCMs for this research, face-to-face interview sessions with stakeholder representatives were organised. In total, 11 interviews were undertaken with six representative stakeholder groups, i.e., catchments scientists, Water Initiative Officers, environmental researchers, policymakers, local authorities, and water service providers. During the sessions, each representative group was asked to draw causal interconnections among the stakeholders provided on a water governance map and the factors of importance for the provision of good drinking water quality. Participants were also encouraged to add additional stakeholders and factors of importance to the maps. The resulting interconnections represent either the interactions among stakeholders or the influence that each drinking water quality factor has on the others. The groups were then asked to assign a weight to each connection to specify its strength. The data collation allowed us to: visualise the maps using computer software; develop a more thorough analysis of outcomes individually and as a group; and, rank the views of group representatives. Next a graph theory hierarchy index (h) approach examined if stakeholder groups preferred top-down hierarchical

governance or a more inclusive democratic governance approach. Finally, a sophisticated auto-associative neural network method was deployed on group maps for examination of three scenarios, i.e., changing "Farmers' knowledge", "best management practice (BMP) uptake" and "Farmers' behaviour and belief", and seeing how the system reacted. An example of a constructed FCM is illustrated in **Figure 1**.

Current strengths and bottlenecks

The results of the FCM exercise highlighted the strengths and weaknesses (or bottlenecks) within the current system (Shahvi *et al.*, 2021). Strengths were that most stakeholder representative groups showed similar opinions concerning the ranking importance of the involved stakeholders in the drinking water governance of Ireland. The most important stakeholders identified within the system were "farmers" and "the Department of Agriculture". In addition, all representative stakeholder groups ranked the factors of importance regarding the supply of good drinking water quality in a similar way. The most important indicators that could be used to ensure that water quality targets within agricultural catchments could be met were: "the nutrient concentrations found in water"; and, knowledge pertaining to the "total amount of applied pesticides". The analysis showed a weakness in the structure in that all stakeholder representative groups had a different perception of the water governance framework. This means that certain stakeholders may be unsure of who does what within the framework and who to contact for a particular reason or piece of information.

Most stakeholder groups had a democratic point of view (bottom-up or inclusive approach) regarding water governance structures, and the ranking and importance of the stakeholders within the framework. Other results showed that most of the groups had similar opinions regarding the highest ranked factors affecting drinking water quality and the possible environmental policy options. In this part of the analysis only one representative group showed a democratic outlook, whereas all others had a hierarchal (top down or non-inclusive approach) outlook. Results also showed that boosting "Farmers' behaviour and belief" to the highest possible level on the analysis could result in a large increase in other factors, i.e., a scenario where farmers could benefit from the outcome. This would be achieved by enhancing farmers' willingness and intention to participate in and implement best management practices (BMPs). Discussion group results showed that better results would be achieved where farmers believed in the method being implemented on the ground and could benefit from the outcome. In addition, the analysis showed that keeping "Farmers' knowledge" at the highest point had a positive influence on the other factors. This supports continuation or enhancement of farmer training and knowledge transfer by local and national actors.

Conclusion

The presented method of using FCMs and graph theory analysis was suitable for comparing different actors' and stakeholders' perceptions on both water governance and the indicators affecting water quality, and should be repeated over time in Ireland and rolled out across the EU.

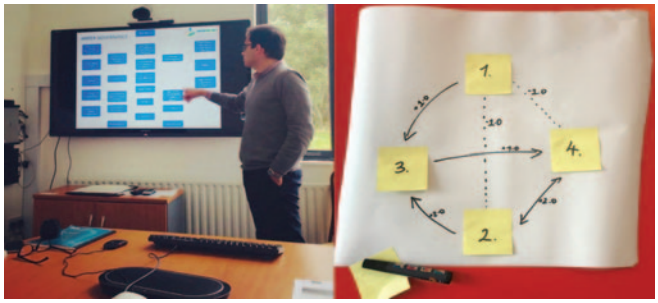

FIGURE 1: Left: presentation of the FCM process to representative stakeholder groups. Right: FCM enables linkages (arrows) between various stakeholders or organisations (e.g., 1, 2, 3 and 4) to be mapped (values on arrows represent their assigned weight).

Acknowledgements

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Molecular signatures of beef tenderness

Ground-breaking integromics analysis co-ordinated by TEAGASC has led to the publication of the world's first and most robust set of beef tenderness biomarkers and major molecular signatures.

Background

Meeting consumer demands for consistency and high quality is an important challenge for the meat sector. Currently, there is no rapid, objective method available for estimating the eating quality of beef, either in the live animal or in the carcass. Addressing this gap in knowledge and technology would not only assist in generating higher-quality product but would also contribute to improved efficiency for the beef industry in Ireland and ultimately worldwide. To accomplish this, the underlying mechanisms responsible for creating the most important meat quality traits must be defined. A number of attempts have been made to achieve this immense challenge over the past decades, specifically the study of meat quality variation using high-throughput protein analytical platforms, also known as proteomics. One research area where proteomics has been of particular interest is in the discovery of meat quality biomarkers. Considering the vastness of the data collected thus far, and the need to establish a biologically meaningful and comprehensive list of biomarkers for tenderness, the aim of our study was to apply an integrative 'omics' ('integromics') approach to integrate worldwide proteomics datasets (Gagaoua *et al.*, 2021). The final aim was to identify the major molecular signatures of beef meat tenderness, which in turn will lead to the optimisation of management systems for guaranteed quality.

Integromics meta-analysis to gather putative protein biomarkers

Many large omics datasets, especially proteomics, have been generated in the quest to identify molecular signatures for meat tenderness. To broaden our understanding about the biological mechanisms underpinning meat tenderisation across a large number of proteomics studies, a systematic computerised literature search was performed, followed by an integromics and holistic meta-analysis to determine the current status of protein biomarker discovery targeting beef tenderness. This study is the first of its kind to provide clarity on the most consistently and robustly identified biomarkers of beef tenderness. It gathers data from 28 independent proteomics-based experiments (888 animals including bulls, cows, heifers and steers) from which a comprehensive list of 124 proteins was initially identified to create the first worldwide repertoire of beef tenderness biomarkers.

Multistep bioinformatics analyses including Gene Ontology annotations, pathway and process enrichment, and literature mining were applied to the database to reveal the major pathways and mechanisms underlying the conversion of muscle into tender meat.

Interconnectedness of the molecular signatures underpinning beef tenderness

Protein network analysis delivered a functional annotation of the 124 proteins from striploin and provided key insights into the interconnectedness among various pathways and processes in the muscle that are pivotal in producing high-quality beef. Six interconnected pathways were identified: (i) muscle contraction and structure development; (ii) energy metabolism; (iii) cellular responses to stress; (iv) response to oxidative stress; (v) proteolysis; and, (vi) regulation of cellular processes, binding, apoptosis and transport.

This analysis revealed the importance of the changing integrity of muscle contractile and structure proteins, energy metabolism enzymes, heat stress proteins and oxidative stress proteins in the determination of beef tenderness, in that order of importance. Interestingly, our analyses revealed that these major pathways and proteins directly or indirectly impinge on apoptosis (programmed cell death) onset in post-mortem muscle, which may be initiated by mitochondrial degradation signals.

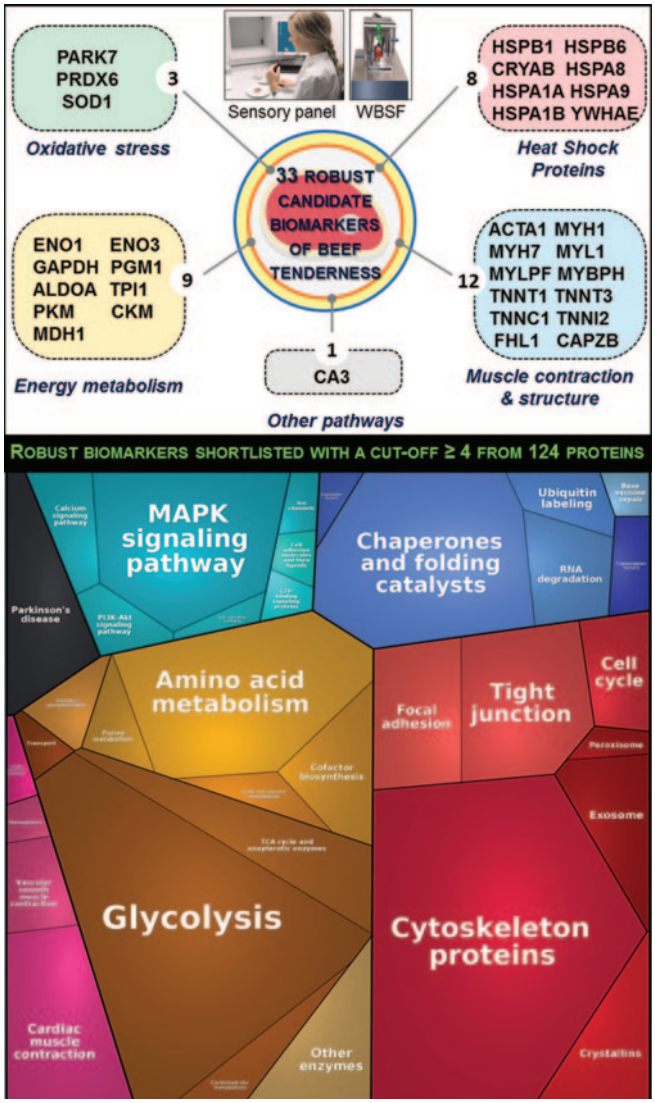

FIGURE 1: Major pathways and list of the 33 robust biomarkers of beef tenderness, from five main biological pathways, shortlisted with a cut-off ≥ 4 from 124 proteins (Gagaoua et al., 2021*).*

A robust list of putative biomarkers of beef tenderness released

From the list of 124 putative protein biomarkers, a cut-off of two or more datasets (≥ 2) was applied to identify common proteins across studies regardless of the animal category, leading to a panel of 64 proteins that were reported in at least two independent proteomic experiments. From these, we shortlisted a panel of 33 robust candidates (**Figure 1**) worthy of evaluation using targeted or untargeted data-independent acquisition proteomic methods to develop future predictive tools. Among the putative list of biomarkers, we further searched for potential quantitative trait loci (QTL) by interrogating the public library of the Animal QTL Database, which contains cattle QTL and associated data curated from published scientific articles. As a result, 18 QTLs among the candidate biomarkers were identified for tenderness score and shear force at different chromosomes.

Benefits to the beef industry

Our integromics study revealed the importance of omics tools and the power provided by data integration approaches such as this. The data gathered demonstrated how protein dynamics across the different metabolic pathways are associated with the development of tenderness early post mortem and during the ageing process. Anticipated downstream applications for the beef industry will see shortlisted protein biomarkers informing carcass management systems for delivering consistency in beef tenderness while at the same time leading to the development of prediction equations enabling rapid evaluation of beef tenderness potential.

Acknowledgements

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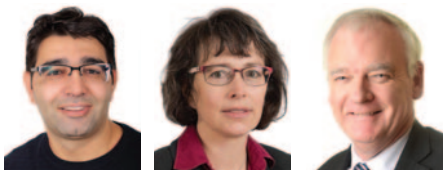

Acoustic sensors for monitoring dairy processes

Researchers from TEAGASC are investigating the application of acoustic sensors as potential new process analytical technology tools in food production.

Process analytical technology (PAT) was first defined by the US Food and Drug Administration as a mechanism for manufacturing via design, analysis and control of processes. PAT systems can provide more information about a process in real time compared to traditional process laboratory methodologies (**Figure 1**). Current testing protocols can be time consuming and include taking a sample from the process, analysing the sample in a laboratory using instrumental/chemical analysis, and recording the results in an information management system. Low-cost sensors designed as PAT tools can contribute to an optimised and consistent process. Novel sensors (i.e., optical sensors and acoustic sensors) with robust measuring capabilities for monitoring critical control parameters in a process are now available. Advantages of using such PAT sensors in dairy processes include rapid, non-destructive and non-invasive measurements taken of the process media, which can highlight if corrective action is required during production.

Potential applications in dairy processes

Researchers from Teagasc are now investigating the application of acoustic sensors as potential new PAT tools for monitoring major dairy processes, i.e., gel formation stage during cheese and yoghurt manufacture. Our current studies focus on using acoustic sensors to provide in-line process monitoring, especially for intermediate products. Such products include acid-induced milk gels, fermented milk, and heat-induced whey protein gels.

During processing, these products undergo a physical change from a liquid state to a semi-solid/solid state. Researchers are investigating if these changes can be detected using acoustic sensors. In particular, physicochemical parameters, i.e., density, viscosity and acoustic velocity, are measured using an inline acoustic sensor and correlated with traditional offline reference methods (e.g., rheometry and particle size distribution).

FIGURE 1: Dairy processing environment.

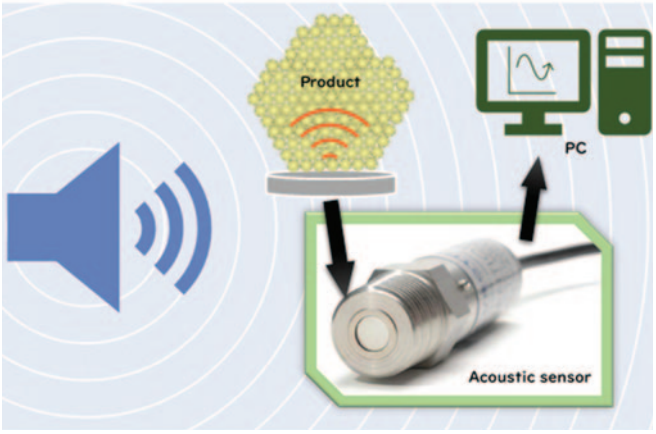

FIGURE 2: Bulk acoustic wave (BAW) sensor.

How does an acoustic sensor operate?

Acoustic sensors have been used for more than 80 years, especially in the telecommunications industry. These sensors measure the properties of a substrate via changes in an acoustic wave generated by a piezoelectric disk. When these waves propagate through the substrate being measured, they are influenced by the physiochemical properties (i.e., density, viscosity) of the substrate (e.g., milk), and are then converted back into an electrical signal to complete the measurement. The physicochemical properties of the substrate affect the travelling path of the acoustic waves, which causes changes in wave velocity and amplitude. These acoustic parameters can be used to measure and monitor the desired attributes of a product (i.e., rheological properties). Examples of acoustic sensors include bulk acoustic wave (BAW) and surface acoustic wave (SAW) sensors.

The BAW sensor used in the current study (**Figure 2**) was originally designed for measuring the viscosity of lubricating oil. This is one of the first food applications where this sensor has been utilised, and our work demonstrates that the BAW sensor has potential for monitoring acid-induced (glucono-delta-lactone) milk coagulation and yoghurt fermentation processes. In particular, it is more sensitive for detecting the onset of gelation compared to traditional gelation rheological methodologies. During the fermentation process, the BAW sensor successfully detected differences in viscosity of yoghurt made from low viscosity- and high viscosity-producing cultures. The sensor was capable of determining the viscosity and gelation time of samples measured using reference rheometry. The sensor has potential to be included as part of a suite of analysis, i.e., pH, texture, colour and syneresis for characterising yoghurt formation and final product quality.

A major benefit of using this sensor is for obtaining additional information on the gelation process.

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Actifensin – a novel antimicrobial from sheep

TEAGASC researchers have discovered a novel bacteriocin from sheep faeces with activity against a broad range of food and gut pathogens.

The World Health Organisation (WHO) considers antibiotic resistance to be one of the foremost challenges to global public health, food security and development (WHO, 2020). Antibiotic resistance occurs naturally but is accelerated by overuse and misuse in both humans and animals. In response to this growing crisis, other potential biocontrol agents such as bacteriocins, bacteriophages and other microbial metabolites have been put forward as an alternative to antibiotics.

Bacteriocins are small, antimicrobial, post-translationally modified peptides that are produced by bacteria. They are typically defined as "narrow spectrum", in which they target members of the same species, or "broad spectrum", whereby they are active against bacteria of other species or genera (O'Connor *et al.*, 2020). This potential for target specificity is another advantage over traditional antibiotics, which can have deleterious effects on the entire microbiota (Dethlefsen, *et al.*, 2011).

In silico genome mining methods have shown that the gut microbiome is a rich source of bacteriocin-producing bacteria (Walsh *et al.*, 2015). *Actinomyces* are Gram-positive non-spore forming anaerobes commonly isolated from the gastrointestinal tract of humans and other animals. In humans they are also found in the oral cavity where they play a role in plaque formation. On the Longlife project, we have isolated a strain of *Actinomyces ruminicola* that produces a novel, broad-spectrum bacteriocin called actifensin (Sugrue *et al.*, 2020).

Structure of actifensin

A. ruminicola DPC 7226 was isolated from sheep faeces. The antimicrobial activity of the strain was first identified by screening against the acid-tolerant indicator strain, *Lactobacillus delbrueckii* subsp. *bulgaricus* LMG 6901. Further analysis of the bacterial cells and the cell-free supernatant by high-performance liquid chromatography (HPLC) and matrix-assisted laser desorption ionisation-time of flight mass spectrometry (MALDI-TOF MS) revealed a mass of approximately 4 kDa responsible for this activity. Treatment with proteinase K resulted in a loss of activity, indicating that the antimicrobial was proteinaceous in nature.

A combination of N-terminal sequencing of the purified peptide and genome analysis of *A. ruminicola* DPC 7726 identified a small (69 amino acid) open reading frame, which encodes the antimicrobial peptide, designated *afnA*. Encoded homologues of the AfnA peptide were identified in 14 other strains of *Actinomyces*, as well as in a number of eukaryote genomes, including fungi and arthropods. These homologues of *afnA* encode defensins, ubiquitous and ancient

antimicrobial peptides in eukaryotes that play a key role in innate immunity. *AfnA* therefore represents a new family of defensin-like bacteriocins and was thereafter named actifensin.

Antimicrobial activity of actifensin

Actifensin was classified as having a broad spectrum of inhibition, demonstrating antimicrobial activity against Gram-positive bacteria such as *Lactococcus*, *Lactobacillus*, *Streptococcus*, *Pediococcus*, *Bacillus*, other *Actinomyces* spp., and *Clostridium* spp. Notably, actifensin inhibited pathogens such as *Clostridioides difficile*, vancomycin-resistant *Enterococcus* and methicillin-resistant *Staphylococcus*, bacteria that represent a significant challenge to the medical field due to their antibiotic resistance. Weak inhibition was also demonstrated against the common food-borne pathogens *Listeria monocytogenes* and *Listeria innocua*.

Future prospects for actifensin and other defensin-like bacteriocins

Actifensin demonstrated a number of traits that would be advantageous from a food industry perspective. Notably, the peptide is heat stable, retaining its antimicrobial activity after 30 minutes at 100°C. It is also quite potent, with a minimum inhibitory concentration of 0.76 µM against *Streptococcus agalactiae* and *C. difficile*. It is also notable that the homologues of *afnA* identified in other species and strains of *Actinomyces* had a low level of similarity. This diversity in the amino acid sequence (52 % on average) suggests that this family of defensin-like bacteriocins may provide a broad structural basis on which to deliver and design new broad-spectrum antimicrobials for treatment of animal and human infections.

Conclusion

The discovery of actifensin and other defensin-like bacteriocins represents new possibilities in the field of biocontrol and an opportunity to reduce our reliance on antibiotics. Actifensin's broad spectrum of activity and physical properties may have widespread applications in both food and health.
This work and the image in **Figure 1** featured on the cover of the *Journal of Bacteriology* in May 2020.

Funding information and acknowledgements

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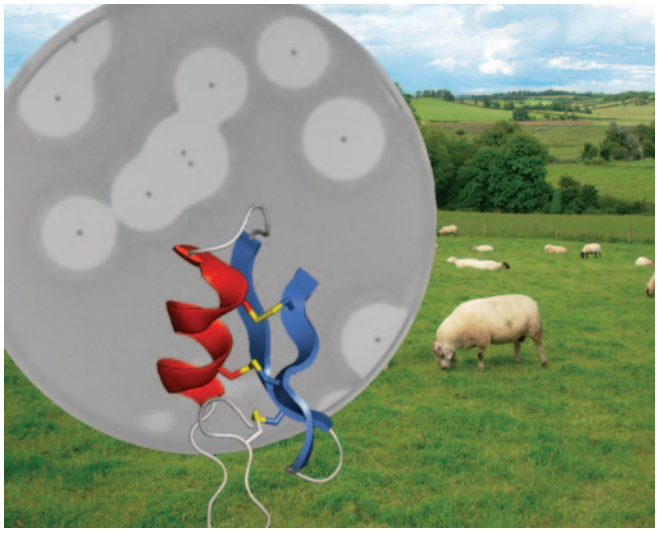

FIGURE 1: This research featured on the cover of the Journal of Bacteriology in May 2020.

Sugrue, I., O'Connor, P.M., Hill, C., Stanton, C. and Ross, R.P. (2020). '*Actinomyces* produces defensin-like bacteriocins (actifensins) with a highly degenerate structure and broad antimicrobial activity'. *Journal of Bacteriology*, 202 (4): e00529-19.
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Consumer perceptions of OneHealth

Accelerated by the Covid-19 pandemic, awareness of AMR and OneHealth is increasing among consumers and there are early signs that consumer behaviours may also be changing. Research in the DAFM SWAB project is exploring what this means for the agri-food sector.

Background

Covid-19 is the latest of many examples emphasising the interconnectedness of human and animal health. In November 2020, the Food and Agriculture Organisation (FAO)/World Health Organisation (WHO)/World Organisation for Animal Health (OIE) Tripartite Collaboration on AMR organised World Antimicrobial Awareness Week under the slogan 'Handle with Care'.

The aim was to increase awareness of antimicrobial resistance (AMR) – a OneHealth emergency that is exacerbated by the overuse and misuse of antimicrobials (including antibiotics) in both human and animal health practices. The farming sector is taking action to reduce the use of antibiotics (iNAP; Department of Health/Department of Agriculture, Food and the Marine, 2017). However, engaging with the public on this issue involves communicating a complex message: agriculture needs to reduce its use of antimicrobials, but to eliminate them completely could lead to unintended impacts on farm animal welfare.

Communication of this message is made difficult by "antibiotic-free" labelling initiatives and suspected low awareness among consumers about the purpose and use of antibiotics in farming. In Ireland specifically, there has been limited research exploring what consumers know about antibiotic use in farming, whether they are concerned by these practices, and whether they link agricultural antibiotic use to OneHealth and AMR.

Consumer research

During October/November 2019, eight focus groups were carried out on the island of Ireland with key informant groups (n = 36): urban seniors; rural seniors; young urban females; young rural males; low socio-economic status (SES) urban parents; rural parents; urban vegetarians; and, rural 'foodies'. The focus groups were followed up in September 2020 with a large-scale representative survey of consumers (n = 972) on the island of Ireland. The first findings from this research indicate the extent of consumer knowledge of antibiotic use in farming, and the level of their awareness of AMR and OneHealth.

Low public knowledge of antibiotic use in farming

Some 62 % of survey respondents felt that they did not have enough information on the use of antibiotics in agriculture. Focus group insights identify the nature of these knowledge gaps in areas including antibiotic use farm practices, regulation of the sector, and impacts on human health (**Figure 1**). Within the focus groups, awareness of the link between antibiotic use on farms and AMR was relatively low.

Increased awareness of AMR and OneHealth due to Covid-19

The focus groups indicated relatively high awareness of AMR as a public health threat; this was mirrored in the survey, with 71 % of respondents indicating that they were aware of AMR as an issue. The survey

FIGURE 1: Example questions asked by consumers about the use of antibiotics in farming.

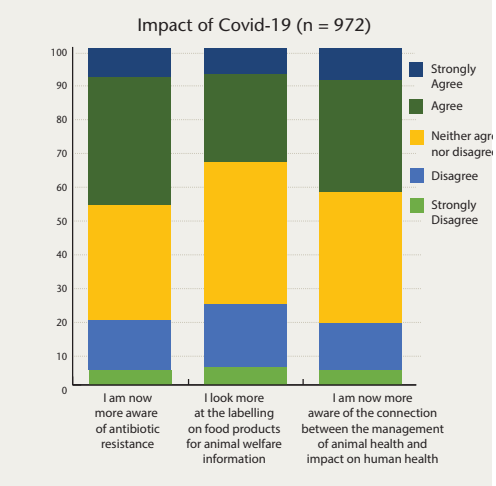

FIGURE 2. Impact of Covid-19 on consumers' awareness and behaviour.

revealed that almost half of the participants (47 %) believed that Covid-19 had made them more aware of AMR, and of particular interest, 43 % indicated that Covid-19 had also made them more aware of the connection between animal health management and human health. For one in three (34 %), this awareness translated into behaviour change in the form of increased use of animal welfare food labels (**Figure 2**).

Implications for the agri-food sector

Covid-19 has been a catalyst for awareness raising and behaviour change in many different areas of life – this effect has extended to changing consumers' perceptions of AMR and OneHealth. We also see early evidence of an impact on some consumers' behaviour in the form of increased use of animal welfare food labelling. Despite increased awareness, the findings suggest that a sizable proportion of consumers are likely to have low baseline knowledge levels around the purpose and use of antibiotics in agriculture. In this environment, communicating with these consumers solely in a top-down manner (for example, through the use of labels and logos) is likely to be ineffective, and potentially could have unintended negative impacts.

A proactive approach is needed to communicate to consumers the commitments and actions that are required and undertaken by farmers to reduce antibiotic use. This includes significant actions taken to improve animal husbandry and undertake disease prevention measures, and continued responsible use of antibiotics where needed. Such complex messages cannot be communicated solely through labels. Greater engagement with the public by a range of actors (including farmers, veterinary bodies and scientists) is also required, meeting consumers on the channels and platforms they currently use to receive information on farm animal welfare, as well as creating new opportunities for engagement and public participation. Understanding consumer perceptions, and how they are formed, is a required first step in developing future initiatives seeking to engage and communicate with consumers on the topic of antibiotic use in agriculture.

Acknowledgements

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JANUARY

January 6 to 8

TEAGASC AT THE BT YOUNG SCIENTIST AND TECHNOLOGY EXHIBITION (BTYSTE 2021)

Visit the Teagasc virtual stand in the 'World of Science and Technology'. The exhibition will feature 550 finalists from 213 schools spanning 29 counties. The Teagasc prize will be awarded to the student project that best demonstrates a thorough understanding of the science of agricultural or food production, or the use of science to improve technologies available to agricultural or food production.
Contact: catriona.boyle@teagasc.ie
https://portal.btyoungscientist.com/

January 6 (9.30am-10.30am)

TEAGASC RESEARCH INSIGHTS WEBINAR: UNDERSTANDING AND MAPPING LAND USE

This is the fourth of five Teagasc Research Insights Webinars focusing on 'Land Use – Making the Most of our Land'. Land-use mapping is an important tool to account for changes in land use over time allowing the human-environmental interactions associated with land use change to be accounted for. Join Teagasc researchers on this webinar to learn about the latest techniques being used that allow us to better understand land use in Ireland.
Contact: jane.kavanagh@teagasc.ie
https://www.teagasc.ie/about/research--innovation/teagasc-research-insights-webinars/

January 6 (2.00pm) and the first Wednesday of the month thereafter

INFOGEST WEBINAR SERIES ON FOOD DIGESTION

Understanding the effect of food on human health is a current research priority in Europe. INFOGEST is an international network with the aim of sharing information on food digestion, consisting of scientists from academia and industry from over 45 countries. This webinar series is hosted by André Brodkorb of Teagasc and features two speakers each month from the INFOGEST network.
Contact: andre.brodkorb@teagasc.ie or muireann.egan@teagasc.ie
Visit https://www.teagasc.ie/news--events/ for Zoom registration link.

January 20 (9.30am-10.30am)

TEAGASC RESEARCH INSIGHTS WEBINAR: BALANCING DEMANDS FROM LAND

Agricultural sustainability is a core element of Teagasc's research programme. Farmers and policy makers face a challenge in balancing society's demand for food with its concurrent demands for improvements in the environmental performance of Irish farming. In this webinar Teagasc economists use microeconomic data from Teagasc's National Farm Survey to examine different aspects of this complex multidimensional sustainability challenge.
Contact: jane.kavanagh@teagasc.ie
https://www.teagasc.ie/about/research--innovation/teagasc-research-insights-webinars/

FEBRUARY

February 3 and 17

THE 2021 NATIONAL TILLAGE CONFERENCE

The first session will provide an insight into the strategic research Teagasc is completing in oats agronomy, barley yellow dwarf virus (BYDV) diagnostics, generating high-value breeding material, the potential of rye, and beans agronomy. The second session will deal with more immediate issues, detailing the continuous need for integrated pest management approaches to mitigate against the problem of grassweeds and *Septoria tritici* blotch of winter wheat, while also discussing the impact of results from the ongoing Teagasc systems trial.
Contact: ewen.mullins@teagasc.ie
www.teagasc.ie/tillagecon21

JUNE

BOVINE PAN-EUROPEAN GENERAL ASSEMBLY (FIRST ANNOUNCEMENT)

The French Livestock Institute, IDELE, will host the project's fourth pan-European General Assembly meeting in June (date to be announced). Farmers and researchers will hear of the latest research innovations and on-farm good practices from various members of the BovINE team. BovINE is an EU-wide network, led by Teagasc, focused on knowledge exchange through its online platform – the BovINE Knowledge Hub – our Network Managers based in nine EU countries, and our online and face-to-face meetings (when travel returns). Keep up to date with forthcoming events and opportunities that BovINE offers to all involved in cattle farming via our website and social media accounts.
Contact: richard.lynch@teagasc.ie or maeve.henchion@teagasc.ie
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For a full list of Teagasc food industry training events, see https://www.teagasc.ie/food/research-and-innovation/research-areas/food-industry-development/.
For presentations from previous Teagasc events see: www.teagasc.ie/publications