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

17RDSUSFOOD2ERANET3 Improving sustainability in food processing using Moderate Electric Fields (MEF) for process intensification and smart processing

Final Report

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

SUMMARY

MEEFPROC aimed to bridge the gap in scientific and technical knowledge that is currently preventing the uptake of moderate electric fields (MEF) and ultrasound (US) applications for the food industry. In addition, it also aimed to investigate the impacts of MEF and US (where relevant) on yield and energy consumption compared to existing conventional food processing systems.

The innovation hub concept which served as a key to creating awareness and encouraging the uptake of MEF technology brought together MEFPROC RPOs, food and equipment manufacturers to build strong working relationships through consultations and workshops. It was also used to identify key potential areas for collaboration to implement MEF and US applications in various food processes. In addition, the support from the equipment manufacturers was crucial in designing, constructing and testing various MEF prototypes with advanced control systems. The implementation of science-based digital tools to model heat/mass transfer during MEF treatment of homogenous and heterogenous products in batch and continuous demonstrated that model-based advanced control systems can produce better control performance, reduce processing time and improve efficiency.

Project results revealed that MEF significantly reduced the processing time and energy consumption during pasteurization of meat products and freshly squeezed juice compared to conventional systems while also ensuring the quality and microbiological safety of the product. In addition, MEF was shown to be suitable for protein coagulation which can be applied in waste treatments to reduce chemical oxygen demand (COD) of wastes from the food industry.

The contribution of three potential drivers for the slow uptake of electro-heating processed food has been identified: (a) consumer concerns about the electro-heating processed products, (b) hesitation of senior managers to take up new food processing technologies, and (c) on the basis of anti-cartel law, competition authorities might block industry agreement about processing products using electro-heating technology.

KEYWORDS

Food Processing, Intensification, Sustainable

ACRONYM	MEFPROC
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Section 1 - Research Approach & Results

Start Date

01 May 2018

End Date

30 December 2021

Research Programme

Food Institutional Research Measure

TRL Scale

TRL 6: Technology demonstrated in relevant environment

NRPE Priority area

Sustainable Food Production and Processing

Total DAFM Award

€350,000.00

Total Project Expenditure

€330,996.01

Rationale for undertaking the Research

The adoption of novel sustainable, innovative processing solutions capable of producing microbiologically safe and high-quality products is essential for the food industry. However, the uptake of some innovative technologies in the food industry is not always simple as challenges from consumers and manufacturers can negatively impact on uptake. Moderate electric fields (MEF) are one of the 'greenest' ways electrical energy can be used in food processing which arises from the direct application of electrical current and the volumetric nature of the heating. It reduces heating time and energy loss providing an outstanding alternative to conventional heating methods thereby reducing the environmental impact of food manufacture. Furthermore, MEF is considered to improve sustainability and product quality when used for process intensification and valorisation compared to conventional processing methods. This is due to MEFs effectiveness, energy efficiency and flexible control. However, the uptake of this technology in the food processing industry is not widely explored. Therefore, quantification and demonstration of yield gain and reduced energy consumption with MEF (and assisted by US where relevant) compared to existing conventional systems required further investigation on various food processing operations. Furthermore, the challenges of sustainable processing of foods and utilization of food by-products need to be considered to ensure that sustainable food production systems are applicable from a safety, heathy-diet, consumer choice, and economic growth perspective. In addition, dissemination and information generation to counteract non-technical barriers to assist the commercial uptake of MEF technology is required.

Methodology

The research involved key work packages which deal with industry consultation, experimental study, behavioural economics, and implementation of MEF technology in food processing. Initial consultation meetings attended by

the RPOs, food, and equipment manufacturers were organized to identify and prioritize key areas of MEF (and US where relevant) application relevant to each food manufacturer followed by a series of innovative hub workshops which included hands-on working sessions. These workshops allowed a greater interaction between all stakeholders which also encourage innovation that led to productive collaboration. With the support of equipment manufacturers, existing MEF systems have been upgraded and new prototypes were built incorporating new control mechanisms with the aim to deliver the required energy to achieve a target temperature during processing. Science-based digital tools were also employed to model and simulate MEF processes to design and optimize processes and process parameters. MEF pasteurization of different meat products (beef muscle and pork sausages) was investigated in relation to the energy delivered and time to target temperature to capitalize the volumetric heating nature of MEF to treatment time and energy consumption thereby optimizing yield and product quality. The impact of product parameters (conductivity, mass) and process parameters (applied voltage/power) on energy delivered to elevate the product to a target temperature and product quality were investigated. The behavioural economics work package identified the contribution of potential drivers for the slow uptake of MEF technology by the food industry. Finally, the implementation and economics of MEF systems were analysed and quantified.

Project Results

The innovation hub workshops (IHW) were a cross-sectoral interaction between complementary stakeholders with a goal to eliminate barriers that prevent the uptake of moderate electric field (MEF) or ultrasound (US) by the food industry. The interaction brought together MEFPROC RPOs, food manufacturers, and the food industry to encourage innovation and help realize MEF/US commercial potential in the food industry. The innovation hubs approach was also used to explore the potential application of MEF/US in replacing or intensifying existing unit operations. The face-to-face workshop was very productive in exploring and identifying the most promising applications for the uptake of MEF/US and for a great knowledge transfer. The project results demonstrated that the innovation hub approach applied in this project was a key to creating awareness and encouraging the food manufacturers to consider the uptake of MEF (and US) in food processing. In the pasteurization of food products, MEF significantly reduced the processing time and the specific energy usage compared to conventional systems while also ensuring the quality and microbiological safety of the product by delivering appropriate F0 values for the inactivation of a target pathogen at an optimum holding time that is used to develop the desired changes to the product. As various physical process conditions and compositions of the food product affects the MEF heating process, it is possible to implement physics based digital tools to determine the optimum process conditions used for the design and manufacture of MEF. In addition, MEF is also suitable for protein coagulation which can be applied in waste treatments to reduce the chemical oxygen demand (COD) of wastes from the food industry. Overall, MEF (and occasionally MEF with US) has shown great potential to provide alternative, innovative, sustainable food processing solutions with great potential thereby playing a significant role in the future of a circular bioeconomy.

MEF assisted by US showed high potential to improve extraction of fruit polyphenols and thereby increase yield or decrease extraction/mash incubation time. MEF processing was also a promising way to extract oleuropein from olive leaves. The combined application of MEF and US was able to increase MEF effectiveness in the extraction processes even at low intensities. In addition, MEF is also suitable for reversibly permeabilizing rucola leaves enabling the infusion of cryoprotectants. No difference in the survival percentage after freezing and thawing was detected between leaves treated with MEF and leaves treated with pulsed electric fields (PEF).

The contribution of three potential drivers for the slow uptake of electro-heating processed food has been identified: (a) consumer concerns are a potential barrier to commercial update of electro-heating processed products, (b) senior managers may be hesitant to take up new food processing technologies and (c) on the basis of anti-cartel law, competition authorities might block industry agreement about processing products using

electro-heating technology. Finally, factors that need to be considered for the implementation of MEF systems into existing or new production lines have been identified including the capital and operational costs of a MEF system.

Section 2 - Research Outputs

Summary of Project Findings

Industry:

The innovation hub approach used in this project helped not only to bridge the knowledge gap that prevented the uptake of MEF technology by the food industry but also helped to establish a strong link between RPOs, the food industry and equipment manufacturers which will function beyond the project has been established. The project has provided more sustainable processing techniques to improve efficiency and reduce energy consumption and environmental impact.

Consumers:

MEF technology produces safe, high-quality food products, and consumers should have absolutely no concern about its use. As the global food systems come under pressure due to the highly increasing demand for high-quality and nutritious food products, innovative technologies such as MEF can increase competitiveness and improve yield which may reduce the purchase price and give more affordable foods. Behavioural economic studies suggest that consumers are positive about MEF technology.

Regulatory authorities and policymakers:

The coordinator has delivered a number of presentations and publications/reviews on regulatory aspects of electrical field application to foods in the context of the novel food regulations and has also been involved in an adhoc working group on novel processing technologies in the Food Safety Authority of Ireland. It would appear as though there are few if any regulatory hurdles to the uptake of MEF, particularly with the correct electrode design (e.g., platinised titanium) which is stable in terms of electrolysis.

The scientific community:

- MEF technology is simple, sustainable and energy-efficient technology that is capable of rapid volumetric thermal heating and non-thermal applications to enhance mass transfer across a broad range of foodstuffs.
- MEF technology is scalable which can be applied at any scale, and can be smartly controlled to accelerate, and intensify processes.
- The volumetric nature of heating allows uniform processing which avoids nutrient and quality degradation.

Summary of Staff Outputs

Research Output	Male	Female	Total Number
Post Doctorates	1	1	2
Research Technicians/ Assistants	0	1	1

Summary of Academic Outputs

Research Outputs	Total Number	Details
Publications in Peer Reviewed Scientific Journals	3	1. Bedane, T.F., Pedrós-Garrido, S., Quinn, G., Lyng, J.G., The impact of emerging domestic and commercial electro-heating technologies on energy consumption and quality parameters of cooked beef. Meat Science, 2021, 179: p. 108550 DOI: https://doi.org/10.1016/j.meatsci.2021.108550. 2. Lyng, J. G., Lalor, F., Pedrós-Garrido, S., Legislative Considerations Relating to the Uptake of Emerging Food Processing Technologies Within the European Union, in Innovative Food Processing Technologies, Editor, 2021, p. 318-328. DOI: https://doi.org/10.1016/B978-0-12-815781-7.00021-4 3. Lyng, J. G., Lalor, F., Quinn, G., Pedrós-Garrido, S., Regulation of Foods Processed by Pulsed or Moderate Electric Fields (PEF or MEF), in Pulsed Electric Fields Technology for the Food Industry: Fundamentals and Applications, Raso, Javier, Heinz, Volker, Alvarez, Ignacio, Toepfl, Stefan, Editor, 2022, Springer International Publishing: Cham. p. 541-561. DOI: https://doi.org/10.1007/978-3-030-70586-2_20
Training Courses	11	1. Lyng, J.G. Green Cooking - The potential for moderate electric field (MEF) processing for milder heat processing of meats. All Ireland Meat Science Conference in AFBI 2019 Agri-Food and Biosciences Institute, 28th February to 1st March 2019, Belfast, Northern Ireland. 2. Lyng, J.G. Green Processing of Foods using Moderate Electric fields – Present Status and Future Prospects. Innova 2019,2nd October 2019, Montevideo, Uruguay. 3. Lyng, J.G, Legislative Considerations in Emerging Food Process Technologies.2018 EFFoST / IFT-NPD International Non-thermal Processing Short Course. 4. Lyng J.G. Legislative Considerations & Consumer Acceptance of MEF and PEF technology. 3rd to 7th June 2019, 6th PEF School, Bologna, Italy. 5. Lyng, J.G, Processing of Foods using moderate electric fields – present status and future prospects. 7th Jinshan Food Physical Processing Conference, 20th September 2020. Jiangsu University, China. 6. Lyng, J.G, Electro-processing of Food, UCD Institute of Food and Health, Research Day, 15th October 2020, UCD. 7. Bedane, T.F. The impact of domestic and commercial electro-heating on quality parameters of cooked beef. UCD Institute of Food and Health, Research Day, 15th October 2020, UCD. 8. Lyng, J, G. The role of emerging technologies in the sustainable processing of quality foods for the future, Food Processing: Its

role in a sustainable healthy diet. UCD Institute of Food and Health, March 5th, 2021, Dublin.

9. Lyng, J.G, Food Processing - What are the Benefits? UCD Institute of Food and Health, Nutrition & Health Public Health Lecture Series, 10th May 2021, UCD 10. Lyng J.G. The use of moderate electric fields in sustainable processing of foods, 11th March 2022, International Society of Food Engineering.
10. Lyng J.G. Regulation of foods processed by electro processing technology. 30th May to 3rd June 2022, 8th PEF School, Compiegne, France.
11. Lyng J.G. Legislative Considerations on electro processing technology. 31stmMay to 2nd June 2021, 7th PEF School, Zaragoza, Spain.

Intellectual Property

Two aspects associated with the application of MEF have been described in invention disclosure forms (IDFs), registered with the UCD Technology Transfer Office:

1. The first IDF (EI Identifier number 2021-UCD-019-I) describes a smart means to control MEF for application in both AD plants and wider fields. The system monitors various data streams with the data used as feedback to accurately control, regulate and automate the MEF process in an efficient manner. A patent attorney has reviewed the technology and believes there may be scope to patent a system based on its ability to log energy consumption and control the amount of energy delivered to a non-variable substrate.
2. The second IDF (EI Identifier number 2018-UCD-031-I) describes the use of a frequency inverter which applies specific wave features using heating to prevent the electrolysis of electrodes used in MEF. This may also be patentable with further work to demonstrate its unique components.

Summary of other Project Outputs

Project Outputs	Details	Total No.
New Processes	In this project, new MEF control mechanisms have been developed to ensure that a specific amount of energy is delivered to a food product and desired microbiological inactivation of a microorganism is achieved through delivering an appropriate F0 value.	1
New Industry Collaborations Developed	This project has developed a good collaboration with food manufacturers (Kerry, The Apple Farm, Nutrafur, Platos Tradicionales, Feger, and Diesdorfer) and equipment manufacturers (OHM-Technology and PUSONICS). Another new collaboration has been established with IXLNetherlands, a company that developed Nutri-Pulse® e-Cooker during this project time. IXL-Netherlands provided a laboratory-scale domestic e-cooker to UCD.	8

Potential Impact related to Policy, Practice and Other Impacts

Impact	Details
Environmental Sustainability	Food processing techniques based on MEF technology have shown economic viability in terms of reducing energy and environmental impact. Integrating MEF technology in existing unit operations that are mainly dependent on conventional heating systems, will increase energy efficiency while also reducing water consumption and environmental impact. MEF has shown a potential to reduce environmental impact and to contribute innovative solutions for the food industry to deal with the highly increasing pressure for environmental sustainability and the health and safety of the consumers. This project revealed that the food industries have the potential to reduce their environmental burden by adopting alternative, innovative and sustainable energy solutions.
Socio-Economic	The industrial uptake of MEF technology contributes to economic growth through product and/or process innovation in an environmentally friendly sustainable manner to increase domestic and global market area. The collaborative nature of the project via its innovation hubs improved linkages between RPOs, food (Kerry and The Apple Farm), and equipment manufacturers (OHM-E Technology and PUSONICS).
Industry	The innovation hub approach implemented in this project enabled industries to look into alternative processing approaches to minimize their energy consumption and enhance the quality and safety of their products by replacing conventional methods. Integrating alternative processing technologies with existing conventional systems was indicated to improve production and increase the time for a food product to reach the market. In addition, MEF has a definite role to play in the circular economy and biorefineries of the future which will be constructed from green field sites with sustainability on the agenda. The food industry partners involved in this project have shown a strong interest to further exploring the application of MEF technology in their existing production lines. Kerry showed an interest in the application of MEF for fermentation, and extrusion of plant-based products while The Apple Farm showed interest to implement MEF technology for pasteurization of the apple juice to minimize the high energy consumption.

Dissemination Activities

Activity	Details
Workshops at which results were presented	MEFPROC Initial consultations and Innovation Hub Workshops: 1. Initial consultation meetings with Kerry, The Apple Farm, Nutrafur, Platos Tradicionales and Feger,along with each RPOs and equipment manufacturers (OHM-E Technology and PUSONICS). 2. Innovation Hub Workshop with The Apple Farm, OHM-E Technology and UCD, March 25, 2021 3. Innovation Hub Workshop with Nutrafur IFF, PUSONICS, OHM-E Technology, Universitat Politècnica deValència (UPV) and UCD, June 30, 2021. 4. Innovation Hub Workshop with Platos Tradicionales, PUSONICS, OHM-E Technology, UniversitatPolitècnica de València (UPV) and UCD, September 30, 2021. 5. Innovation Hub Workshop with Kerry, OHM-E Technology and UCD, November 15, 2021. 6. Innovation Hub Workshop with Kerry, OHM-E Technology and UCD, December 9, 2021. 7. Innovation Hub Workshop with Feger, University of Salerno, OHM-E Technology and UCD, December17, 2021. SUSFOOD2 Workshops: 1. MEFPROC Interim meeting 1 in Toulouse, France, September 2, 2019. 2. MEFPROC Interim meeting 1 at Amsterdam, The Netherlands, November 7-8, 2019. 3. SUSFOOD2 communication and Dissemination training meeting, in Stockholm, Sweden, October 23–26, 2018. 4. Midterm seminar of SUSFOOD2, Ghent, Belgium, November 28-29, 2019. 5. SUSFOOD2 Policy workshop, webinar, July 2, 2021 6. SUSFOOD2 Final seminar and stakeholder workshop, Istanbul, Turkey, October 26-27, 2021.
Seminars at which results were presented	1. ERA-NET SUSFOOD2 Session on the 3rd World Congress of Electroporation, 3rd to 6th September 2019, in Toulouse, France. a) Lyng, J.G, Bedane, T.F and Pedros-Garrido, S. Improving sustainability in food processing through process intensification and smarter processing using moderate electric field - An introduction to the MEFPROC project (UCD). b) Christiana, I., Gomez, F. Galindo. Comparison between the effect of pulsed electric field (PEF) and moderate electric field (MEF) on the improving of freezing intolerance of rucola leaves (UL). c) Martens, N, Baier, A.K. and Rauh, C. Impact of moderate electric fields on mass transfer processes and product quality in fruit processing (TUB). d) Garcia, L.G, Garcia-Perez, J.V, Raso, J, Carcel, J.A. Enhancement of betanin extraction from red beetroot by ultrasounds and pulsed electric field (UPV).

e) Zhang, H, Meng, Q, Howarth, M. Modelling and Control of Moderate Electric Field (MEF) Heating Processes (SHU).
f) Casaburi, O, Marra, F. Analysis of Moderate Electric Field processing in a heterogeneous system. (UNISAL).

2. Lyng, J.G. Green Cooking - The potential for moderate electric field (MEF) processing for milder heat processing of meats. All Ireland Meat Science Conference in AFBI 2019 Agri-Food and Biosciences Institute, 28th February to 1st March 2019, Belfast, Northern Ireland.
3. Lyng, J.G. Green Processing of Foods using Moderate Electric fields – Present Status and Future Prospects. Innova 2019,2nd October 2019, Montevideo, Uruguay.
4. Lyng, J.G, Legislative Considerations in Emerging Food Process Technologies. 2018 International Nonthermal Processing Short Course.
5. Lyng J.G. Legislative Considerations & Consumer Acceptance of MEF and PEF technology. 3rd to 7thJune 2019, 6th PEF School, Bologna, Italy.
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8. Bedane, T.F. The impact of domestic and commercial electro-heating on quality parameters of cooked beef. UCD Institute of Food and Health, Research Day, 15th October 2020, UCD.
9. Lyng, J, G. The role of emerging technologies in the sustainable processing of quality foods for the future, Food Processing: Its role in a sustainable healthy diet. UCD Institute of Food and Health, March 5th, 2021, Dublin.
10. Lyng, J.G, Food Processing - What are the Benefits? UCD Institute of Food and Health, Nutrition &Health Public Health Lecture Series, 10th May 2021, UCD.

Knowledge Transfer Activities

Identify knowledge outputs generated during this project.	The knowledge outputs generated from this project provide a further experience to industries by addressing knowledge gaps currently preventing the MEF technology to achieve its true potential in sustainable food processing thereby reducing environmental impact. The industry engagement and industry-oriented nature of the project filled the gaps through robust research coupled with effective knowledge exchange through initial consultations and innovation hub workshops. The application of MEF as an alternative method in existing food processing operations was implemented on the food products and processes relevant to the industries participating in the project. In addition, a series of MEF application videos were produced and used during innovation hub workshops to help the industry partners to understand the application of MEF in various processes and its potential in reducing energy consumption and environmental impact compared to conventional systems. Enterprise Ireland funded a Commercial feasibility study to explore aspects of MEF application for the processing of waste streams and Anaerobic digestion slurries. The findings of this study were very positive. EI then invited us to submit a commercialization fund application which is in mid preparation and will be submitted by mid-July. The proposal is for the development of MEF systems for food processing.
Identify any knowledge transfer activities executed within the project.	• The workshops occurred between RPOs, food and equipment manufacturers throughout the project time through Initial consultations, and innovation hub workshops provided a strong platform to communicate with relevant stakeholders. • Presentations delivered at international conferences and summer schools highlighting the results of the project to the scientific community and industry. • A series of videos produced to support the online innovation hub workshops, and videos produced for consumers and industry. • A standalone app to simulate heat and mass transfer operation during MEF heating was developed in COMSOL Multiphysics and used for knowledge transfer.
List any impacts resulting from the knowledge transferred during the project.	The knowledge gained and lab/pilot scale MEF systems developed in this project have enabled the group to apply for funding for an EI Feasibility study and follow on EI Commercialization fund. We would be hopeful that the latter will be funded. If that is the case and we are successful in the lifetime of the fund, we will need to be at a point at the end of 2 years where we will have spin out company with a turnover of 1 million and employing 10 people in the construction and deployment of MEF systems in the Anaerobic Digestion Industry, an area which much experience significant growth in the years ahead if Ireland and the EU are to meet the GHG emission targets and improve sustainability in food processing. The stimulus for this work was MEFPROC and the systems it allowed UCD to develop in the project lifetime.

Section 3 – Leveraging, Future Strategies & Reference

Leveraging Metrics

Type of Funding	Funding €	Summary
Exchequer National Funding	€15,000.00	An Enterprise Ireland Feasibility fund application was awarded to support the exploration of MEF in food and food waste pasteurisation for application in an anaerobic digestion environment. Currently a follow-on invited Commercialization fund application is in preparation (final budget will be circa €500K) for the development of MEF systems for use in such environments.
Exchequer National Funding	€110,000.00	In addition, an SFI funded Food Innovator Challenge (WAVA) was successfully funded through the seed and concept phases (circa €110K) which had MEF as a key technology. MEF and the systems developed in this project will also be central to a number of the key flagship projects which are central to the Food Waste Challenge Component of Biorbic2 (currently under review).

Future Strategies

From innovation hub workshops with industry and equipment manufacturers, we have identified different opportunities where MEF can be applied on an industrial scale. Further collaboration work with the industry is important to test the technology in the area where it is relevant.

In future work, identifying non-invasive online measures for advanced process control methods for MEF based on energy delivered to the product is required to optimize smart processing capabilities. Furthermore, the integration of technologies based on the direct use of electrical energy could potentially bring the food industry to zero emissions. In addition, MEF can also be implemented to produce sustainable food systems to minimize waste and recover all possible nutrients from the food matrix. So, further research on electric-based technologies for food processing will significantly contribute to more sustainable food.

Project Publications

1. Bedane, T.F., Pedrós-Garrido, S., Quinn, G., Lyng, J.G., The impact of emerging domestic and commercial electro-heating technologies on energy consumption and quality parameters of cooked beef. Meat Science, 2021, 179: p. 108550 DOI: https://doi.org/10.1016/j.meatsci.2021.108550.
2. Lyng, J. G., Lalor, F., Pedrós-Garrido, S., Legislative Considerations Relating to the Uptake of Emerging Food Processing Technologies Within the European Union, in Innovative Food Processing Technologies, , Editor, 2021, p. 318-328.DOI: https://doi.org/10.1016/B978-0-12-815781-7.00021-4
3. Lyng, J. G., Lalor, F., Quinn, G., Pedrós-Garrido, S., Regulation of Foods Processed by Pulsed or Moderate Electric Fields (PEF or MEF), in Pulsed Electric Fields Technology for the Food Industry: Fundamentals and Applications, Raso, Javier, Heinz, Volker, Alvarez, Ignacio, Toepfl, Stefan, Editor, 2022, Springer International Publishing: Cham. p. 541-561. DOI: https://doi.org/10.1007/978-3-030-70586-2_20