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

# 17F260 – Extraction and exploitation of bioactive fish components for health enhancement (MaraBioActive)

## Final Report

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

## SUMMARY

Overall objectives: (i) generation of blue whiting soluble protein hydrolysates (BWSPH) at larger-scale and detailed characterisation of the resulting hydrolysates; (ii) screening of the hydrolysates using in vitro bioassay protocols relevant to metabolic health; (iii) performance of acute and chronic mice studies to validate the potential beneficial effects of the selected hydrolysate(s); (iv) identify peptide sequences within the selected lead functional hydrolysate(s) which may contribute to their health enhancement effects; (v) performance of market/consumer studies to assess consumer perception, incorporation of selected hydrolysates into different food formats and characterisation of their technofunctional and sensory properties; (vi) dissemination of the results.

Key results: Six prototype BWSPHs generated at industrial scale. In vitro bioactivity screening identified the most potent samples. Hydrolysates were characterised in vivo during acute and chronic mouse ingestion studies. Histological analysis of pancreatic tissue showed impacts of hydrolysate ingestion on islet properties. Eighteen synthetic peptides were identified for further study following targeted fractionation of the lead hydrolysate. Four of the peptides showed improvements in the sensitivity of molecules associated with glucose and lipid metabolism in an acute setting. Selected BWSPHs were incorporated into protein-fortified bars and into pasta. Based on the results, it was concluded that the incorporation of BWFPH at levels not exceeding 5% (w/w) in pasta yielded minimal adverse effects on its overall acceptability including its sensory attributes. Project results were widely disseminated in the peer-reviewed literature, via scientific conferences and to key stakeholders.

Overall impact: A new understanding around the utilisation of marine protein-derived peptides for health enhancement has been obtained which is of relevance to industry, policy makers and practitioners in the development of new approaches to exploit and add value to low value food protein ingredients by targeting their application in a science-based approach to health enhancement.

## KEYWORDS

Marine, Bioactive, Hydrolysates, Peptide, Seafood, Health, Food Processing

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|---|---|
| **ACRONYM** | MaraBioActive |
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| **COLLABORATORS, INSTITUTION** | Prof Nora O'Brien, University College Cork<br>Prof Finbarr O'Harte, University of Ulster<br>Dr Lisa Ryan, Atlantic Technological University<br>Dr Francesco Noci, Atlantic Technological University |
| **PUBLICATION DATE** | February 2024. |

## Section 1 - Research Approach & Results

**Start Date**

01 December 2018

**End Date**

30 June 2023

**Research Programme**

Food Institutional Research Measure

**TRL Scale**

TRL 3: Experimental Proof of Concept

**NRPE Priority area**

Sustainable Food Production and Processing

**Total DAFM Award**

€844,779.00

**Total Project Expenditure**

€726,358.70

**Rationale for undertaking the Research**

Ireland has a significant quota for blue whiting, a high protein content underutilised fish species, which must now be landed given EU Regulations in relation to all caught fish species. This research project contributed to validation of the health beneficial effects of blue whiting. Due to its small size and bony structure, blue whiting is not readily amenable for direct consumption. However, it is possible to extract protein from blue whiting in the form of protein hydrolysates. Therefore, the objectives were to identify the health beneficial impacts and the food product utilisation potential of blue whiting protein hydrolysates. The seafood sector is a significant contributor to the Irish economy worth over €800 and £67.3 million, respectively, and employing approximately 11,000 and 2,000 people in the Republic of Ireland and in Northern Ireland, respectively (in 2010). Food-Harvest-2020 and FoodWise2025 highlighted "the growth opportunities for Ireland's marine bioresources sector in food as a source of food and food ingredients". FoodWise2025 recognised seafood as a 'protein source with specific and recognised health properties which resonate with the modern consumer'. The project aligned with the National Marine Research & Innovation Strategy (2017-2021) and with Harnessing our Ocean Wealth. 'Food and Health' and 'Sustainable Food Production and Processing' are key components of the National Research Prioritisation Exercise (NPRE) Report. The project aligns with the EU Bioeconomy Strategy, the EU's Blue Growth Strategy and EUFood2030 which recommends that 'all citizens and consumers adopt sustainable and healthy diets for good health and wellbeing'.

**Methodology**

The project consisted of five research and one dissemination tasks:

Task 1: Generation and characterisation of marine peptide ingredients (identification of enzyme combinations/conditions for generation of protein hydrolysates from minced blue whiting meat, scale up to semi-

pilot scale; detailed physicochemical characterisation of hydrolysates (molecular mass, peptide profile) for use in food fortification studies.

Task 2: Bioactivity screening to identify functional marine hydrolysates for the development of functional food ingredients (application of in vitro (measurement of DPP-IV inhibition and antioxidant activity (ORAC, FRAP)) and in situ assays, i.e., release of GLP-1, CCK and peptide YY from STC-1 enteroendocrine cells. Investigate the stability of hydrolysates, i.e., retention of bioactivity following simulated gastrointestinal digestion).

Task 3: Investigation of the in vivo effects of marine protein hydrolysates and their associated synthetic peptides on appetite control and food intake in mice (assessment of cytotoxicity, assessment of the acute effects in normal mice (blood glucose, plasma PYY, ghrelin, active GLP-1, CCK-8, glucagon and insulin, and DPP-IV activity), chronic studies in a diet induced obese mouse model (PYY, ghrelin, active GLP-1, CCK-8, glucagon, insulin and DPP-4 activity assessment).

Task 4: Strategy for the enrichment and identification of bioactive peptides (bioassay-guided fractionation (semi-preparative RP-HPLC) of lead hydrolysate for individual peptide ID using in vitro and in situ bioactivity assays, confirmation studies with synthetically produced peptides).

Task 5: Formulation of new products with selected blue whiting protein hydrolysates and determination of consumer requirements (assessment of market and regulatory requirements, incorporation of hydrolysate(s) into different food formats, assessment of product stability and consumer acceptance of blue whiting supplemented food products).

Task 6: Dissemination (peer reviewed publications, seminar conference presentations, stakeholder updates, along with IP assessment and protection, where relevant).

**Project Results**

Task 1: Laboratory scale processes (UL) for the generation of blue whiting protein hydrolysates (BWPH) were transferred to industry scale (BII). Six high-quality prototype BWPHs were subsequently generated under GMP conditions. The in vitro bioactivity and physicochemical properties of the BWPHs was characterised. Blue whiting, is a rich source of high-quality protein. This protein resource not only has potential applications as an alternative dietary protein source to meet global demand for high quality protein but it also has the potential to act as a substrate for the generation of health enhancing biofunctional peptides.

Task 2: Specific BWPHs, their simulated gastrointestinal digests, specific BWSPH derived peptide fractions, BWSPH ingredient fortified foods and specific peptides present in BWSPHs were shown to display dipeptidyl peptidase-IV inhibitory (potential anti-diabetic) and antioxidant (potential for alleviation of metabolic syndrome) activities. BWPHs with satiety hormone releasing and with anti-obesity/anti-adipogenic potential were assessed using cell-based bioassays. The protective potential of specific BWSHHs on adverse obesity related conditions was assessed. The results demonstrated the potential to add value to a low value underutilised fish species.

Task 3: Data was generated on hydrolysate safety using cultured cells. Data generated on the efficacy of acute orally ingested hydrolysates on food intake in mice. Data generated on efficacy of acute orally ingested hydrolysates in mice. Data generated on efficacy of chronic orally ingested slab-scale hydrolysates and selected semi-pilot scale hydrolysates in mice. Data generated on efficacy of synthetic peptide in Diet Induced Obese mouse model. Identification of candidate BWSHP-derived peptides for future development. Overall, the results indicate that the oral administration of the identified lead peptides result in improvements in the sensitivity of molecules associated with glucose and lipid metabolism in the acute setting. This is the first time that such results have been obtained for BWSPS-derived peptides.

Task 4: A strategy based on semi-preparative reverse-phase HPLC was developed for the fractionation of peptides in a specific BWSPH (as identified in the bioactivity screening Task). Bioassay driven fractionation, using in vitro,

in situ and in vivo assays, allowed identification of the most potent BWSPH derived peptide fraction. Mass-spectral analysis allowed identification of the peptides sequences therein. A selection of these peptides (18) were characterised for their glucose management and antioxidative properties using in vitro and cell-based assays. The results from these studies adds new information on the structure-activity relationship between specific BWSPH derived peptides and their metabolic health enhancement potential.

Task 5: Selected BWPHs were utilised for incorporation into protein bars and into pasta. The technofunctional and the sensory properties of the BWSPH supplemented foods was assessed. In general low level (< 5%) incorporation had minimal negative impacts on the technofunctional properties of the model foods. The incorporation of BWSPHs at all levels had a negative sensory impact on the supplemented protein bar products. However, incorporation of BWSPH up to 5 % gave pasta products which had overall acceptability to consumers during a large sensory analysis trial.

Task 6: The results from the project have been published/submitted for publication (see publications list).

## Section 2 - Research Outputs

**Summary of Project Findings**

Many benefits have accrued from this project as follows:

Industry: lab-scale enzymatic hydrolysis processes have been successfully transferred from small to pilot scale.

Consumers: an underutilised fish protein-derived hydrolysate ingredient has been successfully supplemented into pasta (and protein bars) and new information in terms of the overall acceptability (technofunctional and sensory) has been developed. The results show that the hydrolysate(s) can be successfully utilised for protein supplementation at low levels of incorporation.

Regulatory authorities: the project has shown that BW-SPH ingredients can be generated at large scale under GMP conditions and that these ingredients display various potentially beneficial effects during the course of small animal in vivo studies. The BW-SPHs have also been extensively characterised which is a critical factor in pursuing any future health claims.

Policymakers: the project has demonstrated that BW-SPH ingredients can be developed which may act as alternative sustainable sources of high quality protein for human nutrition. It therefore has potential in addressing the ‘protein deficit’.

Scientific: New scientific information has been generated in relation to the ability of different blue whiting-derived protein hydrolysates to modulate biomarkers relevant to different metabolic disease states, e.g., obesity (via their anti-adipogenic and adipolytic activities, and their impacts on the expression of various satiety hormones (in cells grown in culture) and diabetes (via their ability to promote insulin secretion in pancreatic cells and to reduce serum glucose concentrations in vivo (mice)). Specific peptide sequences have been identified in two protein hydrolysates which have been shown to have beneficial effects in relation to oxidative status and glycaemic management (from cell-based assays). Advanced scientific training has been provided to MSc and PhD students as well as post-doctoral fellows. Six peer reviewed publications have been generated to date outlining the new scientific developments.

**Summary of Staff Outputs**

| Research Output | Male | Female | Total Number |
|---|---|---|---|
| PhD Students | 0 | 1 | 1 |
| Post Doctorates | 3 | 1 | 4 |
| Research Technicians/Assistants | 0 | 2 | 2 |

**Summary of Academic Outputs**

| Research Outputs | Total Number | Details |
|---|---|---|
| PhD Thesis | 1 | 1. Heffernan, S. 2022. Assessment of blue whiting protein hydrolysate bioactivities using cell culture models. PhD Thesis, University College Cork. |
| Publications in Peer Reviewed Scientific Journals | 7 | 1. Heffernan, S., Giblin, L., & O'Brien, N. (2021). Assessment of the biological activity of fish muscle protein hydrolysates using in vitro model systems. Food Chemistry, 359, 129852. DOI:10.1016/j.foodchem.2021.129852<br>2. Sharkey, S.J., Harnedy-Rothwell, P.A., Allsopp, P.J., Hollywood, L.E., FitzGerald, R.J. & O'Harte, F.P.M. (2021). A narrative review of the anti-hyperglycaemic and satiating effects of fish protein hydrolysates and their bioactive peptides. Molecular Nutrition & Food Research. 64: 2000403. https://doi.org/10.1002 /mnfr.202000403<br>3. Harnedy-Rothwell, P.A.; Khatib, N.; Sharkey, S.; Lafferty, R.A.; Gite, S.; Whooley, J.; O'Harte, F.P.; FitzGerald, R.J. (2021) Physicochemical, Nutritional and In Vitro Antidiabetic Characterisation of Blue Whiting (Micromesistius poutassou) Protein Hydrolysates. Mar. Drugs, 19:383. https://doi.org/10.3390/md19070383<br>4. Heffernan, S., Harnedy-Rothwell, P. A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., & O'Brien, N. M. (2021). Blue Whiting Protein Hydrolysates Exhibit Antioxidant and Immunomodulatory Activities in Stimulated Murine RAW264.7 Cells. Applied Sciences, 11(20), 9762. https://doi.org /10.3390/app11209762<br>5. Parthsarathy, V., McLaughlin, C. M., Sharkey, S. J., Harnedy-Rothwell, P. A., Lafferty, R. A., Allsopp, P. J., McSorley, E. M., FitzGerald, R. J., & O'Harte, F. P. (2021). Protein hydrolysates from boarfish (Capros aper) and Atlantic salmon (Salmo salar) skin gelatin improve metabolic control in genetically obese diabetic (ob/ob) mice. Journal of Food Bioactives, 16. https://doi.org/10.31665/JFB.2021.16292<br>6. Heffernan, S., Nunn, L., Harnedy Rothwell, P. A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., O'Brien, N. M. (2022). Blue Whiting (Micromesistius poutassou) Protein |

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| | | Hydrolysates Increase GLP-1 Secretion and Proglucagon Production in STC-1 Cells Whilst Maintaining Caco-2/HT29-MTX Co-Culture Integrity. Marine Drugs, 20(2), 112. https://doi.org/10.3390 /md20020112.<br>7. Khodaei, D., Forde, A., Noci, F. and Ryan, L. (2023), Physicochemical and sensory characteristics of pasta enriched with blue whiting (Micromesistius poutassou) fish protein hydrolysate. Int J Food Sci Technol. 58, 2782–2789. doi:10.1111/ijfs.16278 |
| Peer Reviewed Conference Papers | 4 | 1. Heffernan, S., Harnedy-Rothwell, P.A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., & O'Brien, N. M. (2021). Blue whiting protein hydrolysates stimulate GLP-1 secretion from STC-1 cells. Presented at The Nutrition Society Conference. December 7th, 2021. Proceedings of the Nutrition Society , Volume 81 , Issue OCE1: Winter Conference 2021, 7–8 December 2021, Obesity and the brain , 2022 , E6 DOI: https://doi.org/10.1017/S0029665122000064.<br>2. Heffernan, S., Harnedy-Rothwell, P. A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., & O'Brien, N. M. (2021). Investigation of the antioxidant potential of blue whiting protein hydrolysates in oxidatively-stressed 3T3-L1 adipocytes. Proceedings of the Nutrition Society, 80(OCE3). https://www.cambridge.org/core/journals/proceedings-of-the-nutrition society/article/investigation-of-the antioxidant-potential-of-blue-whiting-protein hydrolysates-in-oxidativelystressed-3t3l1-adipocytes/298E5327BB701D682826ABA05E703C41<br>3. Heffernan, S., Harnedy-Rothwell, P., Gite, S.,Whooley, J., FitzGerald, R., & O'Brien, N. (2021). Antioxidant activity of blue whiting protein hydrolysates – an in vitro study. Proceedings of the Nutrition Society, 80(OCE2) https://www.cambridge.org/core/journals/proceedings-of-the-nutrition-society/article/antioxidant-activity-of-blue-whiting-protein hydrolysates-an-in-vitro study/1B41F3A225373139BF91B87A3388D5D9<br>4. R.A. Lafferty, S. Sharkey, P.A. Harnedy-Rothwell, S. Gite, J. Whooley, R.J. FitzGerald, F.P.M. O'Harte. "Blue Whiting protein hydrolysate administration reverses pancreatic distortion at islet level in streptozotocin-induced, diabetic-obese mice" Special Issue: Diabetes UK Professional Conference 2022, Hybrid 28 March, QEII Centre, London, Online 29 March-1 April 2022 Volume39, IssueS1, P59. Diabetic Medicine. 2022;39:e14810 (P59). DOI: 10.1111/dme.14810. |
| Training Courses | 9 | Shauna Heffernan: |

1. Health and Safety Authority online course “Managing Health and Safety in Healthcare: Biological Agent Hazard”. April 12th 2021.

Dick FitzGerald:

1. Epigeum Research Integrity online course "Research Integrity: Specialist" Jan 20th 2022

Pádraigín Harnedy-Rothwell:

1. Epigeum Research Integrity online course "Research Integrity: Core" Feb 24th 2022
2. Dignity and Respect Course – UL: Online – 10/03/2022
3. Interviewee Skills workshop: UL: 07/07/2022
4. Unconscious Bias Course-UL: online- 24/08/2022
5. Interviewer skills training course UL-online - 01/09/2022
6. Conflict of Interest course – UL-online-06/09/2022
7. Freedom of Information course – UL online- 07/09/2022

**Intellectual Property**

Following assessment, it was decided that the IP developed within the project would be very difficult to protect. Therefore, the decision was to publish as much of the information as possible in the peer reviewed literature in keeping with the public good remit of the funding agency.

**Summary of other Project Outputs**

| Project Outputs | Details | Total No. |
|---|---|---|
| New Processes | Six new processes were elucidated at lab level for the enzymatic generation of blue whiting soluble protein hydrolysates (BWSPH), these processes were transferred in confidence to Biomarine Ingredients Ireland. This company successfully employed the lab-scale protocols to generate BWSPHs at industrial scale. This led to the ability to characterise 'real world' samples during the course of this project. | 6 |
| New Products | Prototype BWSPHs were generated successfully at industrial scale. These hydrolysates were shown to have different physicochemical, technofunctional and bioactive properties. These hydrolysates may have potential in finding utilisation in different applications.<br><br>A selected BWSPH was incorporated into protein bar and into pasta model food products. While the BWSPH supplemented protein bar had some unacceptable overall properties, it was shown that the pasta supplemented product had an acceptable overall profile in terms of sensory and colour properties. This indicated that supplementation of pasta at low levels (approx 5 %) was a potential strategy for the utilisation of this high quality protein ingredient. Furthermore, it was demonstrated that the in vitro bioactive properties of the BWSPH were retained when incorporated into the pasta format. | 2 |

**Potential Impact related to Policy, Practice and Other Impacts**

| Impact | Details |
|---|---|
| Environmental Sustainability | It has been demonstrated that a low value underutilised fish species, a fishing discard, may be utilised to generate soluble proteinaceous ingredients which can be successfully incorporated into pasta, thus enhancing the environmental sustainability of blue whiting (rather than discarding it to landfill or using it as a low value animal feed) while generating protein supplemented foods. |
| Socio-Economic | Addition of value to a fishing industry discard may help stabilise rural economies by the provision of new manufacturing jobs in the generation of higher value proteinaceous ingredients in a world where there is a need to meet a projected protein deficit. |
| Industry | A new process validated for the development of blue whiting soluble protein hydrolysates which can be successfully scaled to industrial scale manufacture. |

**Dissemination Activities**

| Activity | Details |
|---|---|
| Seminars at which results were presented | Harnedy-Rothwell PA, et al. The Institute of Food Science and Technology of Ireland Conference, Dublin, 15/12/2020 (online).<br><br>Khatib N, et al. The Institute of Food Science and Technology of Ireland Conference, Dublin, 15/12/2020 (online).<br><br>Harnedy-Rothwell, P.A., et al. BIOPROSP-21, Norway, 9th-11th/3/2021 (online). Khatib, N., et al. BIOPROSP-21, Norway, 9th 11th/3/2021 (online).<br><br>Harnedy-Rothwell, P.A., et al. International Society of Nutraceuticals and Functional Foods Conference, China, 7th-20th/10/2021 (online).<br><br>Heffernan, S., et al. Nutrition Society-Irish Section Conference, Limerick, 22–24/06/2021 (online).<br><br>Heffernan, S., et al. Nutrition Society-Spring Conference, Scotland, 29–30 March 2021 (online).<br><br>Lafferty, R.A., et al. Endocrine Society Annual Conference, Dublin, 20/11/21 (online).<br><br>Heffernan et al (2021). The Nutrition Society Conference, London, December 7th, 2021.<br><br>Harnedy-Rothwell et al. 7th International Conference on Food Digestion (ICFD2022) Cork, 3-5th May 2022.<br><br>Lafferty et al. Diabetes UK Professional Conference 2022, London, 29 March to 1 April 2022 (online)<br><br>Lafferty et al. Irish Endocrine Society, Annual Conference 11-12th Nov. 2022. Mater Misericordiae University Hospital Dublin.<br><br>Khodaei et al., 5th Food Structure and Functionality Symposium 2022, Cork, 18-21 September 2022. |

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| Other | Harnedy-Rothwell PA, Extraction and exploitation of bioactive fish components for health enhancement (MaraBioActive). Department of Biological Science's (UL) newsletter no 2-June 2020. https://biologicalsciencesul.blogspot.com /2020/06/newsletter-no-2-june-2020.html<br><br>Heffernan, S. Marine Hydrolysates for Health. UCC Food Research e-compilation magazine April 2020 https://www.ucc.ie/en/media/research /fitu/foodinstitute /LinkingtheFoodChain_Final.pdf<br><br>Harnedy-Rothwell PA, The Minister of State at the Department of Agriculture, Food and the Marine with responsibility for Research and Development, Martin Heydon, T.D meets Department of Biological Sciences researchers. Department of Biological Science's (UL) newsletter no 6-June 2022. Biol_Sci_UL: Newsletter No 6, June 2022 (biologicalsciencesul.blogspot.com)<br><br>Kondrashina, A.; Heffernan, S.; O'Brien, N.; Giblin, L. Chapter 26—Application in medicine: Obesity and satiety control. In Biologically Active Peptides; Toldrá, F., Wu, J., Eds.; Academic Press: Cambridge, MA, USA, 2021; pp. 629–664.<br><br>Advisory Board Meeting<br>Date: 9th November 2021<br>Time: 13.00-14.00<br>Virtual Meeting: Microsoft Teams<br>In attendance: UL: Dick FitzGerald (DF), Pádraigín Harnedy-Rothwell (PHR), UCC: Shauna Heffernan (SH), UU: Finbarr O'Harte (FOH), Ryan Lafferty (RL), GMIT: Lisa Ryan (LR), and Diako Khodaei (DK), BII: Snehal Gite (SG), KI: Cal Flynn (CF). Advisory Board Members: EI: Martin Fleming (MF) and Ellen NiCleirigh (ENC), BIM: Michael Gallaher (MG), MI: Majbritt Bolton-Warberg (MBW).<br>The aim of this meeting was to provide an overview and disseminate the project outcomes to date to interested stakeholders and to receive strategic feedback for future direction of the project. A detailed draft of the meeting minutes was subsequently circulated to all project partners |

**Knowledge Transfer Activities**

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| **Identify knowledge outputs generated during this project.** | A process has been developed to generate a protein rich ingredient from a fishery discard.<br><br>Lab scale enzymatic hydrolysis processes have been successfully transferred to pilot scale.<br><br>The ability to incorporate blue whiting proteinaceous ingredients into model food systems has been evaluated with particularly favourable results being obtained in terms of the incorporation of this ingredient into pasta.<br><br>New scientific information has been generated on the potential of marine derived high quality proteinaceous ingredients to beneficially modulate biomarkers of health in relation to conditions associated with metabolic diseases. This can help add value to low value underutilised components in the marine processing industry. |

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| **Identify any knowledge transfer activities executed within the project.** | The lab-scale processes for the generation of blue whiting derived soluble protein ingredients has been confidentially transferred to BioMarine Ingredients Ireland (BII), a partner within the project.<br><br>All the results generated during the project have been shared, e.g., during project meetings, with project partner personnel from BII and Kerry Ingredients.<br><br>The scientific findings arising from the project have and are being disseminated in the peer reviewed scientific literature.<br><br>Research students pursuing MSc and PhD programmes along with post-doctoral fellows have benefited from exposure to the knowledge generated during the project while themselves generating new scientific knowledge during the course of their work within the project. |
| **List any impacts resulting from the knowledge transferred during the project.** | New processes developed and successfully transferred to industry for the development of BWE-SPH ingredients which may, e.g., be used for protein supplementation of pasta, and which enhance the ingredient portfolio of Irish industry.<br>New scientific knowledge generated concerning the biofunctional properties of blue whiting soluble protein hydrolysates which helps in marketing the benefits of consuming such ingredients (and is supported by peer reviewed scientific publications).<br>Open scientific knowledge sharing took place during the course of the project leading to fruitful collaborative interactions and joint peer reviewed publications. |

## Section 3 – Research, Future Strategies & Reference

**Leveraging Metrics**

| Type of Funding | Funding € | Summary Resource |
|---|---|---|
| Other | €30,000.00 | Ulster University obtained support for a PhD student, Shaun Sharkey, from the NI Department of Education (approx €30k). |

**Future Strategies**

Research proposals were submitted in conjunction with the UL research team to the recent DAFM FIRM call which aimed to leverage the capability, facilities and expertise generated during the course of the MaraBioActive project to valorise other sustainable alternative sources of high quality food proteins. While highly ranked, the proposal was not prioritised for funding.

Opportunities for submission of proposals for EU funding will be investigated to perform basic studies on the mechanism of action of the BW-SPH peptides in the modulation of pathways associated with metabolic health enhancement.

The Enterprise Ireland Commercialisation Fund may be assessed for the further development/commercialisation of the technology and added-value ingredients developed within the present project.

The Enterprise Ireland Commercialisation Fund will be assessed for the further development/commercialisation of the technology and added value ingredients developed within the present project.

Opportunities for the submission of proposals for EU funding will be investigated to perform basic studies on the mechanism of action of the BW-SPH peptides in stimulation of anabolic pathways associated with muscle protein synthesis.

**Project Publications**

The following peer reviewed scientific publications have arisen from the project, DOI details are provided for all publications in order to allow ease of direct online access:


1. 1. Heffernan, S., Giblin, L., & O'Brien, N. (2021). Assessment of the biological activity of fish muscle protein hydrolysates using in vitro model systems. Food Chemistry, 359, 129852. DOI:10.1016/j.foodchem.2021.129852
2. 2. Sharkey, S.J., Harnedy-Rothwell, P.A., Allsopp, P.J., Hollywood, L.E., FitzGerald, R.J. & O'Harte, F.P.M. (2021). A narrative review of the anti-hyperglycaemic and satiating effects of fish protein hydrolysates and their bioactive peptides. Molecular Nutrition & Food Research. 64: 2000403. https://doi.org/10.1002 /mnfr.202000403
3. 3. Harnedy-Rothwell, P.A.; Khatib, N.; Sharkey, S.; Lafferty, R.A.; Gite, S.; Whooley, J.; O'Harte, F.P.; FitzGerald, R.J. (2021) Physicochemical, Nutritional and In Vitro Antidiabetic Characterisation of Blue Whiting (Micromesistius poutassou) Protein Hydrolysates. Mar. Drugs, 19:383. https://doi.org/10.3390/md19070383
4. 4. Heffernan, S., Harnedy-Rothwell, P. A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., & O'Brien, N. M. (2021). Blue Whiting Protein Hydrolysates Exhibit Antioxidant and Immunomodulatory Activities in Stimulated Murine RAW264.7 Cells. Applied Sciences, 11(20), 9762. https://doi.org /10.3390/app11209762
5. 5. Parthsarathy, V., McLaughlin, C. M., Sharkey, S. J., Harnedy-Rothwell, P. A., Lafferty, R. A., Allsopp, P. J., McSorley, E. M., FitzGerald, R. J., & O'Harte, F. P. (2021). Protein hydrolysates from boarfish (Capros aper) and Atlantic salmon (Salmo salar) skin gelatin improve metabolic control in genetically obese diabetic (ob/ob) mice. Journal of Food Bioactives, 16. https://doi.org/10.31665/JFB.2021.16292
6. 6. Heffernan, S., Nunn, L., Harnedy Rothwell, P. A., Gite, S., Whooley, J., Giblin, L., FitzGerald, R. J., O'Brien, N. M. (2022). Blue Whiting (Micromesistius poutassou) Protein Hydrolysates Increase GLP-1 Secretion and Proglucagon Production in STC-1 Cells Whilst Maintaining Caco-2/HT29-MTX Co-Culture Integrity. Marine Drugs, 20(2), 112. https://doi.org/10.3390 /md20020112.
7. 7. Khodaei, D., Forde, A., Noci, F. and Ryan, L. (2023), Physicochemical and sensory characteristics of pasta enriched with blue whiting (Micromesistius poutassou) fish protein hydrolysate. Int J Food Sci Technol. 58, 2782–2789. doi:10.1111/ijfs.16278