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Technologies to recover high-value ingredients from food processing wastes

Key external stakeholders:

Brewers, Potato processors, Mushroom processors, functional food manufacturers, pharmaceuticals, government authorities/legislators, consumers, food research scientists.

Practical implications for stakeholders:

Every one-third of primary processing of cereals and vegetables is discarded as waste or fetch low value. These uniform wastes contain substances with high market value in the food ingredient and pharmaceutical industries. This project optimised novel methodologies to recover these molecules in enriched forms.

Main results:

- A set of optimized methods for the extraction of β-glucans from brewer's spent grains. Conventional solid-liquid extraction method resulted in a β-glucan extraction yield of 57.98%. Ultrasound assisted extraction gave a higher β-glucan extraction yield (66.9%) at a shorter extraction time, however the β-glucan extracted had a lower molecular weight than the conventional method. The fermentation method using *Lactobacillus plantarum* increased the β-glucan yield by 3-fold than the conventional extraction method.
- Amongst the different optimized methods for the extraction of glycoalkaloids from potato peels, the best yield (247mg/kg of dried peels) was from the conventional solid-liquid extraction at 80° in 30 min. While the ultrasound and pulsed electric field could extract between 154 and 159 mg/kg total glycoalkaloids dry weight.
- An industrially relevant extracting protocol for the isolation of chitin from mushroom stipes was developed and optimized. The optimized chemical method involving deproteination and demineralization can extract up to 33% chitin, of which less than 1% was chitosan. Through the application of proteases, the chitin yield increased up to 44%, which was slightly higher than the fermentation process (~40%).
- A validated rapid quantification method of specific glycoalkaloids was developed. A rapid colourimetric method for quantification of chitin (glucosamine equivalent) was also set up. A high-throughput quantification method for beta-glucan, which can quantify as low as 3 ng/mL glucose (monomeric units of beta-glucan) was also developed.

Opportunity / Benefit:

Outcomes of the project will especially be of use to the breweries, mushroom and potato processors as the development of above methodologies for the recovery of high value compounds from their waste stream will allow them to exploit a potentially valuable resource. For example, most commercial β-glucan is extracted

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from the cell wall of *Saccharomyces cerevisiae*, also known as Brewer's yeast. Its commercial value is relatively high (~12 euro/100g), therefore its extraction from BSG could offer high economic rewards as β-glucan is expected to play an increasing role in future global food and medical sectors. This strategy therefore seeks to harness new technologies for use in plant sciences, food innovation and pharmaceutical applications. In addition, levels of toxic glycoalkaloids in the various Irish potato cultivars can be assessed for the safety of the consumers.

Collaborating Institutions: University College Dublin; Dublin Institute of Technology; Diageo Ireland, Dublin; Largo Foods, Ashbourne, Co. Meath; Monaghan Mushrooms, Tyholland, Co. Monaghan.

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1. Project background:

Several plant food processors produce high levels of uniform by-products (waste) in Europe and globally. Brewing industries in Ireland in 2016 generated approximately 160,000 tonnes of spent grains, and annual production worldwide is estimated at 30 million tonnes. Similarly, about 14,000 tonnes of potato peels and mushroom discards are generated annually in Ireland. These by-products contain high value compounds such as β-glucans in spent grains, chitins in mushrooms and cytotoxic glycoalkaloids in potato peels. Both β-glucans and chitins have recently gained approval from the European Food Safety Authority as ingredients in functional foods to reduce/lower blood cholesterol. The project will seek to exploit waste streams of the major Irish agri-food and drink industries, with a view to provide a low cost source for chitins, glycoalkaloids and β-glucans as well as other bioactives using various green and clean extraction technologies.

2. Questions addressed by the project:

The project addresses the following specific questions:

- Can 'green' extraction methodologies be developed and optimise to recover higher yield of β-glucans, chitins and glycoalkaloids compared to conventional extraction methods from the uniform waste-streams?
- What are the levels of co-extracted compounds within the extracts that are rich in β-glucans, chitins and glycoalkaloids?
- Are there added advantages for sequential extraction processes in the recovery of high value compounds?

3. The experimental studies:

A number of extraction technologies from conventional solid-liquid, novel physical (ultrasonication and pulsed electric field) and biological (enzymes, fermentation) extraction techniques were employed. Response surface methodology assisted the optimisation of various parameters for the conventional and novel extraction methods to get the high yield of targeted biomolecules. Identification and quantification of the target compounds and other co-extracted bioactives were performed on LC-MS/MS systems.

4. Main results:

- Conventional solid-liquid extraction method resulted in a β-glucan extraction yield of 57.98%. Ultrasound assisted extraction gave a higher β-glucan extraction yield (66.9%) at a shorter extraction time, however the β-glucan extracted had a lower molecular weight than the conventional method. The fermentation method using *Lactobacillus plantarum* increased the β-glucan yield by 3-fold than the conventional extraction method.
- Amongst the different optimized methods for the extraction of glycoalkaloids from potato peels, the best yield (247mg/kg of dried peels) was from the conventional solid-liquid extraction at 80° in 30 min. On contrast, the ultrasound and pulsed electric field could extract between 154 and 159 mg/kg total glycoalkaloids of dried peels.
- An industrially relevant extracting protocol for the isolation of chitin from mushroom stipes was

developed and optimized. The optimized chemical method involving deproteination and demineralization extracted up to 33% chitin, of which less than 1% was chitosan. Through the application of proteases, the chitin yield increased up to 44%, which was slightly higher than the fermentation process (~40%).

- A validated rapid quantification method of specific glycoalkaloids was developed. A rapid colourimetric method for quantification of chitin (glucosamine equivalent) was also set up. A high-throughput quantification method for beta-glucan, which can quantify as low as 3 ng/mL glucose (monomeric units of β-glucan) was also developed.
- Ultrasound enhanced the extraction rate of phenolic compounds from potato peels, carbohydrates, phenolics and amino acids from mushroom stalks than traditional solid liquid extraction. Ultrasound alone gave better yield than in its combination with pulsed electric field for recovery of biomolecules from mushroom stalks.

5. Opportunity/Benefit:

The results of this study have revealed opportunities for application of novel extraction technologies for maximum recovery of high value molecules that have established health claims, i.e. β-glucans and chitins from spent grains and mushroom-discards that lower blood cholesterols, or the cytotoxic glycoalkaloids for phyto-pharmaceutical applications. Such an approach also provides the opportunity to develop efficient greener technology that also contributes to reducing the waste disposal to landfills.

- **Dissemination:**

The technology has been transferred in a number of ways, primarily through two doctoral thesis, book chapters, scientific A1 publications, conferences and an industry workshop as outlined below:

Main publications:

- Frontutu D. 2019. An evaluation of the effectiveness of conventional and novel technologies for the enrichment and recovery of novel bioactive ingredients from plant food processing wastes. PhD Thesis (in preparation).
- Kumari, B. 2018. Novel extraction techniques to enhance nutritional and bioactive qualities in agro-food processing by-products mainly potato peels, brewers spent grains and mushroom stalks. PhD Thesis.
- Kumari B., Tiwari, B.K., Walsh D., Griffin P.G., Islam N., Lyng J.G., Brunton, N.P. and Rai, D.K. (2019). 'Impact of pulsed electric field pre-treatment on nutritional and polyphenolic contents and bioactivities of light and dark brewer's spent grains' *Innovative Food Science & Emerging Technologies* 54: 200-219.
- Kumari B., Tiwari, B.K., Hossain M.B., Brunton, N.P. and Rai, D.K. (2018). 'Recent Advances on Application of Ultrasound and Pulsed Electric Field Technologies in the Extraction of Bioactives from Agro-Industrial By-products (A Review)' *Food and Bioprocess Technology* 11(2): 223-241.
- Kumari B., Tiwari, B.K., Hossain M.B., Rai, D.K. and Brunton, N.P. (2017). 'Ultrasound-assisted extraction of polyphenols from potato peels: profiling and kinetic modelling' *International Journal of Food Science and Technology* 52(6): 1432-1439.
- Dellarosa, N., Frontuto, D., Laghi, L., Dalla Rosa, M., Lyng, J.G. (2017). The impact of pulsed electric fields and ultrasound on water distribution and loss in mushrooms stalks. Food Chemistry, 236, 94-100.
- Hossain, M. B., Brunton, N. P.and Rai, D. K. (2016). 'Effect of Drying Methods on the Steroidal Alkaloid Content of Potato Peels, Shoots and Berries' *Molecules* 21(4): 403.
- Hossain M.B., Rai, D.K. and Brunton, N.P. (2015). 'Optimisation and validation of ultra-high performance liquid chromatographic-tandem mass spectrometry methods for qualitative and quantitative analysis of potato steroidal alkaloids' *Journal of Chromatography B* 997: 110-115.

Popular publications:

- Brunton, N.P. (2019). 'Extraction of anthocyanins from food processing waste – potential and issues' In *Anthocyanins from natural sources: Exploiting targeted delivery for improved health*, The Royal Society of Chemistry: 2019; pp 106-120.
- Abu-Ghannam N. and Balboa E. (2018). 'Biotechnological, food, and health care applications' In *Sustainable recovery and reutilization of cereal processing by-products*, Galanakis, C.M., Ed. Woodhead Publishing: pp 253-278.
- Lyng J.G., Arroyo C., Alberti O.C., Frontuto D., Apel C., Brunton N., O'Sullivan M. and Whyte, P. (2016). 'Harnessing the structure modifying potential of pulsed electric fields (PEF) – food

processing examples in product stabilization, process acceleration and compound extraction' In JARM, T. & KRAMAR, P. (eds.) 1st World Congress on Electroporation and Pulsed Electric Fields in Biology, Medicine and Food & Environmental Technologies: Portorož, Slovenia, September 6 –10, 2015..Springer Singapore: Singapore, pp 7-10.

Conference abstracts

- Kumari B, Brunton N.P., Rai D.K. and Tiwari B. K. (2017). "Ultrasound assisted extraction of bioactive enriched fractions from button mushroom stalks by-product" 17th International Conference on Food & Nutrition (ICFN), 22nd to 24th May, Nevada, USA.(Oral)
- Kumari B, Hossain M., Brunton, N and Rai, D.K. (2017). "Analysis of β-glucan from brewers' spent grain by UHPLC-MS/MS method" 2nd International Summer School on Natural Products (ISSNP), 3rd to 7th July, Naples, Italy.(Oral)
- Kumari B., Hossain M., Tiwari B.K., Rai, D.K., Lyng J.G. and Brunton, N. (2016). Novel approaches for effective valorisation of agro industrial by-products: Extraction of polyphenols from potato peel and brewer's spent grain assisted by ultrasound and pulsed electric fields" 18th World Congress of Food Science and Technology Annual Food Research Conference, IUFoST, 21st to 25th August, Dublin, Ireland.(Oral)
- Kumari, B., Hossain, M.B., Tiwari, B.K., Rai, D.K., Brunton, N.P. (2014). Ultrasound Assisted Extraction of Bioactive Polyphenols from Potato Processing By-products. 43rd Annual Food Research Conference, UCD, Dublin, IRELAND, 10-11 December 2014.
- Kumari B., Islam N., Walsh D., Rai, D.K. and Brunton N. (2016). "Pulse electric field (PEF) assisted extraction of novel bioactive preparations from brewer's spent grain (BSG): 1st International Conference on Food Bioactives and Health (FBHC), 13 - 15 September 2016, Norwich, United Kingdom.
- Kumari, B., Hossain, M.B., Brunton, N.P. and Rai, D.K. (2015). "Effect of novel extraction technology on phenolics of commercially processed potato-peel". 7th International Conference on Polyphenols, Tours, FRANCE, 27-30 October 2015.
- Frontuto, D., Apel, C., Brunton, N., Arroyo, &andC. Lyng, J. (2015). An Evaluation of Potential for the Pulsed Electric Fields to Assist Extraction of Compounds from Food Processing Waste. School on Applications of Pulsed Electric Fields for Food Processing, February 7-12 2015, Salerno, ITALY.
- Frontuto, D., Arroyo, C., Lyng, J., and Brunton, N. (2015). An Assessment of the Potential to Valorise Brewers Spent Grain, Barley and Potato Peels Using Pulsed Electric Fields. IFT15 Institute of Food Technology, July 11-14 2015, Chicago, USA.
- Frontuto, D., Arroyo, C., Lyng, J., and Brunton, N. (2015). Pulsed Electric Field (PEF) Assisted Extraction of β-glucans From Brewers Spent Grains. 1st World Congress on Electroporation and Pulsed Electric Fields in Biology, Medicine and Food & Environmental Technologies September 6 - 10 2015, Slovenia.(Oral)
- Jaiswal, A. and Abu-Ghannam, N. (2014). Optimization of Enzymatic Hydrolysis of Cellulose and Hemicellulose from Brewers' Spent Grain. 7th International conference and Exhibition on Nutraceuticals and functional foods, Istanbul, TURKEY, 14-17 October 2014.

Industry Blueprints

Lyng J. and Brunton N. (2018). Valorisation of mushrooms by-products by isolating chitin from mushroom stipes: optimization of extraction parameters.

Abu-Ghannam N. (2018). β-glucan extraction from brewers' spent grain, the main brewery by-product.

Rai, D.K. (2018). Glycoalkaloids in potatoes: a validated quantification method.

Industry Workshops

Jaiswal, A.K. & Abu-Ghannam, N. 'Enzymatic Extraction of High-value Ingredients from Food Waste'. Waste not Want not - Recovering value from food waste, Teagasc Food Conference Centre Ashtown, Dublin, 7th February 2014.

6. **Compiled by:** Dilip Rai