BIOSYSTEMS AND FOOD ENGINEERING

RESEARCH REVIEW 25

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FOREWORD

The Twenty Fifth Annual **Research Review** describes the ongoing research programme in the School of Biosystems and Food Engineering at University College Dublin from over 124 researchers (15 academic staff, 1 technician, 10 postdoctoral researchers and 98 postgraduates). The research programme covers three focal areas: Food and Process Engineering; Bioresource Systems; and Bioenvironmental Engineering. Each area is divided into sub-areas as outlined in the Table of Contents which also includes the name of the research scholar (in bold); the research supervisor(s); the title of the research; the nature of the research programme; and the research sponsors. It also includes the noting of four awards for presentational excellence at the Twenty Fourth Annual **Biosystems and Food Engineering Research Seminar** held in University College Dublin on **Thursday 11th March 2020**.

The Appendices in the Review provide:

- a listing of research projects in progress which were not included in the Review;
- profiles of Postdoctoral Research Scholars;

The Editors gratefully acknowledge the dedicated work of the individual research scholars, their research supervisors and the financial support of research sponsors. Suggestions as to how future editions might be improved in presentation, style or content would be greatly appreciated. A copy of this book is available to download from the UCD Research Repository at: **http://researchrepository.ucd.ie**

The review also includes papers from the School's Taught Masters Programmes as follows:

ME - Biosystems and Food Engineering
https://www.ucd.ie/engineer/engineering/biosystemsfood/index.html

MEngSc – Food Engineering
https://www.ucd.ie/engineer/engineering/biosystemsfood/food.html

MSc – Environmental Technology
https://www.ucd.ie/engineer/engineering/biosystemsfood/environmental.html

MSc – Sustainable Energy and Green Technologies
https://www.ucd.ie/engineer/engineering/biosystemsfood/sustainable.html

ENDA CUMMINS and TOM CURRAN 31st May 2020

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APPENDICES

ANALYSIS OF SENSORY PROPERTIES IN FOODS BY HYPERSPECTRAL IMAGING: A REVIEW

Gozde Ozdogan, Xiaohui Lin, Da-Wen Sun
UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

There is an ever-growing and innovative race in the food industry for new products, quality improvements, extended shelf-life which changes with consumer demands. In order to be successful in this race, it is necessary to understand consumer demands and make changes according to these requests. Sensory evaluation is a critical component for that purpose. Hyperspectral imaging technology has gained great attention in recent years for sensory analysis since it is an objective, rapid and non-destructive method. This paper reviews the application of hyperspectral imaging in the sensory evaluation of food. First, a summary of sensory analysis and hyperspectral systems are presented, then, important applications of hyperspectral imaging for sensory evaluation are reviewed. The accomplished application of hyperspectral imaging in sensory evaluation demonstrate the feasibility to carry out sensory analysis without trained panelists.

Introduction

Food quality is defined as "*the combination of characteristics that play a role in the consumer's choice, each can be measured and controlled individually, and that distinguishes the food unit in question from others*". In addition to chemical, microbiological, physical and instrumental methods, sensory evaluation methods have an important place among the quality control measurement techniques used in establishing standards and specifications in food establishments, preparation for production, inspection, determination of conformity and planning for development. Quantitative characteristics (economically), hidden characteristics (health) and sensory characteristics (consumer senses) constitute important quality criteria (Grunert 2005).

Sensory evaluation is a theoretical discipline used to investigate receptions to stimuli perceived through senses – sight, smell, touch, taste, and sound. Sensory food quality monitoring is traditionally implemented by human panels (Lawless and Heymann 2013). In these analyzes, since the measuring instrument is a human, there are sources of variability to be controlled. Human senses can vary with time and even between each other and are prone to deviations. Perceptions may be affected by many factors such as ambient conditions, and thus there is a need for sensory assessment process which is objective and non-time-consuming (Murray *et al.* 2001).

Hyperspectral imaging (HSI) as a promising imaging technique with successful study results has recently appeared for fast and non-destructive quality, safety, and sensory analysis of foods on a very large scale. HSI also is known as "imaging spectroscopy" has thus been integrated both spectroscopic and photographic techniques into one system to cope with spectroscopic and photographic information. The output of the system is a three dimensional (3-D) form (spatial- spectral) and named as a spectral cube or data cube (Sun 2010).

The current study aims to review the applications of hyperspectral imaging techniques in sensory quality determination for numerous food products.

Hyperspectral Imaging System

Hyperspectral imaging system consists of five main components: camera with 2-D light detector, spectrograph, translation stage, illumination units and a computer (Figure 1).

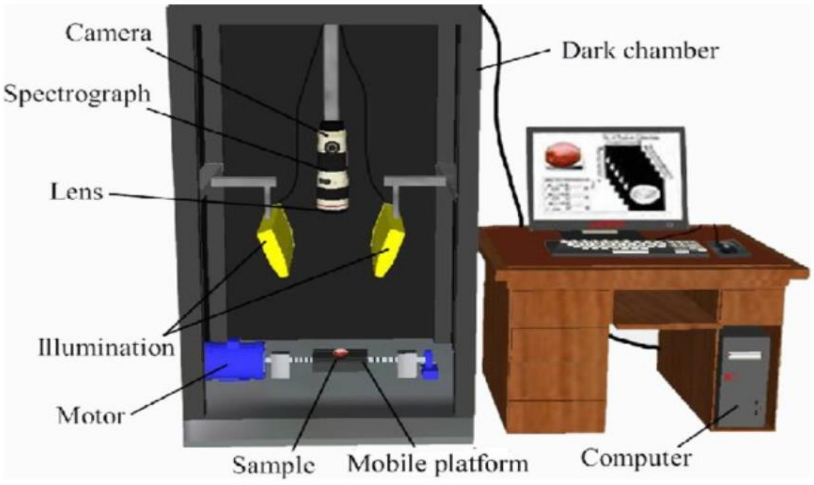

Figure 1. The illustration of hyperspectral imaging equipment (Yu *et al.* 2014).

A hyperspectral image can be created in three traditional ways based on related move between sample and the detection unit: point-to-point scanning (known as whisk-broom imaging), line-by-line scanning (known as push-broom), area scanning (known as staring imaging) (Basantia *et al.* 2018).

Spectral Analysis

The common steps of HIS operation processing and data analyzing include (I) image acquisition, and image pre-processing, (II) data extraction, and data treatment, (III) data modelling, and image post-processing. The image acquisition, and pre-processing includes some calibrations such as wavelength calibration, and radiometric calibration for getting more obvious images. Data extraction, or data treatment step consists of removing the noises to get rid of instrumental errors or determining the region of interests. For data modelling or image post-processing there are many useful mathematical applications depending on the purpose of the study such as; principal component analysis (PCA), partial least square regression (PLS), Fisher's discriminant analysis (FDA), multilinear regression (MLR), maximum likelihood classification (MLC), independent component analysis (ICA) (Lin and Sun 2020).

The Application of HSI in Sensory Analysis

Sensory analysis is very important to check that the product supplies the demands of the customer. In this sense, adequate monitoring of sensory evaluation can be a useful and cost-effective approach for mapping of sensory quality of products, for instance, by using hyperspectral imaging. In Table 1, a summary of studies related to spectral imaging for sensory evaluation is presented.

The most important factor that determines the purchase of the product, especially in the meat industry, is the sensory properties of the product. Measurement methods available for the sensory properties of meat are time consuming, destructive and cost effective than hyperspectral imaging technology. Some features, such as exudation, still do not have a standard measurement method. Therefore, sensory studies using hyperspectral imaging are mostly concentrated on meat products. Recent studies have shown that difficult analysed features of meat such as firmness, colour, and sensory quality index can be predicted by using hyperspectral imaging technology with the coefficients of determination of about 90%.

Table 1. Spectral imaging applications for sensory evaluation in different types of foods.

Approach	Application	Product	Coefficients of Determination	References
PCA	Tenderness Prediction	Beef	96.4%	Naganathan *et al.* (2008)
PLS	Color Features Prediction	Pork	93%	Barbin *et al.* (2012)
LS- SWM	Prediction of Sensory Quality Index	Fish	94.4%	Cheng and Sun (2015)
PLS	Prediction of Color and Tenderness	Fresh Beef	88% / 83%	ElMasry *et al.* (2012)
PLS	Firmness Prediction	Blueberry	87%	Leiva-Valenzuela *et al.* (2013)
PLS	Color Prediction	Soybeans	83.9%	Huang *et al.* (2014)
F- Value	Detection of Physical Damages	Pear	92%	Lee *et al.* (2014)
PLS	Firmness / Color Prediction	Nectarine	87%	Munera *et al.* (2017)
PLS	Firmness Prediction	Pear	86.7%	Fan *et al.* (2015)
PLS /LS-SWM	Color Prediction	Beef, Lamb, Pork	88%, 91%, 92%	Kamruzzaman *et al.* (2016)
PLS-DA	Tenderness Prediction	Chicken	92%	Jiang *et al.* (2018)

(PCA: Principal component analysis, PLS: Partial least square regression, LS-SWM: Least squares-Support vector machine, DA: Discriminant analysis)

Since cereals are grained products, it is very difficult to perform sensory analysis and estimate the total product. Studies have proved that the hyperspectral imaging is a rapid methos to predict the sensory properties of cereals with coefficients od determination of about 85%.

Conclusion

Sensory analysis is necessary to make detailed estimates about the quality of the product. HSI is an encouraging, non-damaging technology for the evaluation of sensory characteristics or physical defects, as it has several advantages, such as speed, precision, and reliability over other methods. Furthermore, there is no need to prepare any chemicals or samples. Studies have shown that it is possible to use HSI for predicting sensory properties.

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Shane Browne, B.Agri.Sc, (MSc student)

Project Title: Rapid prediction of moisture and ash content in biomass through near infrared spectral imaging.

Project Leader: Professor Aoife Gowen

Abstract

The generation of energy from biomass or bioenergy has grown in popularity as an alternative to fossil fuel combustion. The value of waste forestry residues and manufacturing byproduct has led to an increase in feedstock. Biomass fuels are heterogeneous in their shape, size and chemical constituents. Combustion of biomass requires a knowledge of these fuel attributes, in order to avoid system failures such as slagging or fouling. Slow laboratory analysis inhibits quality control systems that aim to identify problematic fuels. The moisture and ash content are a vital quality parameter, which often change across feedstocks (Mancini et al., 2018, Posom et al., 2016). The objective of this research is to determine if near infrared spectral imaging can predict moisture and ash content in biomass samples collected from a biomass burning plant. A biofuel feedstock was sampled over six months generating samples weighing approximately 350 – 550g. Vacuum sealing of samples was chosen to minimize decomposition. Bagged materials were refrigerated at approximately 5 - 8°C. Moisture and ash contents were determined using conventional laboratory methods. Moisture content was determined by drying overnight in moisture ovens. The ash contents were determined through loss on ignition in a furnace. Initial reference results range in moisture content of 6 – 64 % total moisture and ash content of 0.5 – 8.3%. A push-broom spectral imaging system will be used to generate spectra that represent the chemical and physical make-up of the material. Spectral pre-processing via MATLAB will be used to remove noise from the data. Training or calibration models will be created to predict total moisture and ash values. Partial Least Squares regression will be used as it has been used before to good effect. A full K-Fold Cross Validation will be used to validate predictions as used in similar studies. Model accuracy will be deemed sufficient depending on the coefficient of determination of predictions (R^2). The Ratio of Performance to Deviation (RPD) will provide a further estimation of accuracy (Fagan et al., 2011).

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Jiani Luo, BE, M.EngSc.

Project Title: Application of PAT tools to monitor milk coagulation in cheese manufacture.

Project Leader: Prof. Colm O'Donnell, C. Esquerre

Abstract

Milk coagulation is an important step in cheese making processing which can affect final product's nutritional and sensory quality (Fox 2004). It is necessary to explore an effective tool for monitoring milk coagulation in cheese processing. The objective of this study was to monitor milk coagulation in real-time by NIR, fluorescence spectroscopy and rheometer. Rheological analytical methods can determine physical cheese gel characteristics, e.g. storage modulus G' (Lucey et al., 2003), that cutting time is directly dependent on. NIR, fluorescence data can be used for predicting cutting time in cheese producing. For this purpose, data was collected in cheese plants. The milk samples were obtained from multiple cheese vats after rennet addition. This study involving 739 coagulation trials carried out at four cheese plants, variations were observed and quantified in milk gel firmness at fixed cutting times. Factors which contributed to the observed and quantified coagulation variability for fixed cutting times included milk protein concentration, cheese recipe and process parameters (coagulation temperature, milk volume in the vat). Coagulation time prediction models developed using randomly selected data collected and validated using the remaining (non-selected) data (Model 1: RMSEc = 1.51 min, R2 = 0.99, RMSEv = 2.17 min, R2 =0.97; Model 2: RMSEc = 1.23 min, R2 = 0.99, RMSEv = 1.48 min, R2 =0.97). Therefore, this study demonstrated a PAT tool for real-time modelling of milk coagulation in the real industry environment which could potentially applied for better control and optimization of cutting point in cheese production.

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Anastasia Falkovskaya, B.Sc., M.Sc.

Project Title: Monitoring poultry using spectral imaging

Project Leader: Prof. Aoife Gowen

Abstract

Consumption of poultry products is increasing worldwide, leading to an increased demand for safe, fresh, high quality products. To ensure consumer safety while meeting quality standards, poultry products must be routinely checked for safety and quality. Novel techniques, such as spectral imaging, are being developed to acquire real-time chemical and spatial information about products in non-destructive way to ensure safety and quality of products while preventing economic losses. The overall aim of this research is to utilize spectral imaging techniques to monitor poultry products. This research has utilized both laboratory based and handheld spectral imaging techniques in the Vis-NIR (400 – 1,000 nm) and NIR (900 – 1000 nm) spectral ranges. To date, research has been focused on monitoring poultry quality by determining if it is possible to discriminate between fresh and thawed from frozen poultry. In a comparison between the Vis-NIR (400-1000 nm) and NIR (978 – 1,678 nm) regions to discriminate between fresh and previously frozen poultry with and without skin, partial least squares discriminant analysis (PLS-DA) models were built at the pixel and object level. Successful discrimination between fresh and previously frozen poultry could be accomplished using pixel level models built on Vis-NIR data. The best PLS-DA results were achieved by using samples with skin present, resulting in a correct classification of 88.2% in the independent test set. Wavelengths determined to be important for discrimination are associated with myoglobin and its derivatives, which are mainly responsible for the colour of meat. Discrimination of the two classes in the NIR range was poor in samples with and without skin. No object level classification models were successful. In a following experiment using a handheld visible spectral imaging system (443-726 nm) and white LED illumination, it was possible to discriminate between fresh and thawed chicken thighs with a 96.3% correct classification rate on an independent test set using a PLS-DA model on the object level using sample means for training and testing.

Selected Recent Publications

Falkovskaya, A. and A. Gowen. (2020). ‘Literature review: spectral imaging applied to poultry products’, *Poultry Science*.

Falkovskaya, A., Herrero-Langreo, A., and A. Gowen. (2019) ‘Comparison of Vis-Nir (400-1,000 Nm) And Nir (978-1,678 Nm) Hyperspectral Imaging For Discrimination Between Fresh And Previously Frozen Poultry.’ In *2019 10th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS)*, IEEE, 1-5.

Falkovskaya, A., and A. Gowen. (2019) ‘Discrimination between fresh and previously frozen poultry during and after thawing using hyperspectral imaging’ *Biosystems and Food Engineering Research Review*, 24, 1-4.

Tong Lei, BAgrSc, MEng,

Project Title: Intelligent Analytical Methods on Food and Agricultural Products

Project Leader: Prof. Da-Wen Sun

Abstract

A growing world population is increasing our demand for food safety. For this reason, developing rapid, nondestructive and accurate methods for quality evaluation of food products has a great value. To achieve this objective, near infrared hyperspectral imaging system and time-domain terahertz spectroscopic and imaging system combined with novel chemometrics are employed in this project. These novel tools are applied to dairy products (cheese and milk) and transgenic crops (*Arabidopsis thaliana* seeds), both of which have high value economic in food industry. Currently, a rapid classification method of Cheddar cheeses from different brands and a novel NIR spectral calibration method have been proposed. In conclusion, intelligent analytical tools are developed by combining novel hardware and software, which have great potential in food quality evaluation.

Selected Recent Publications

Lei, T., Sun, D. W. (2020). 'A Novel NIR Spectral Calibration Method: Sparse Coefficients Wavelength Selection and Regression (SCWR)', *Analytica Chimica Acta*, 1110, 169-80.

Lei, T., Sun, D. W. (2019). 'Developments of nondestructive techniques for evaluating quality attributes of cheeses: A review', *Trends in Food Science & Technology*, 88, 527-542.

Lei, T., Lin, X. H., & Sun, D. W. (2019). 'Rapid classification of commercial Cheddar cheeses from different brands using PLSDA, LDA and SPA–LDA models built by hyperspectral data', *Journal of Food Measurement and Characterization*, 13, 3119-3129.

Vicky Caponigro, BSChem, MSChem

Project Title: Detection of whole milk residues on food processing surfaces

Project Leader: Prof. Aoife A. Gowen

Abstract

The goal of this study is to detect dried whole milk foodborne residues and estimate the detection limit on stainless steel 316-2B, stainless steel 304-2B and aluminium comparing macro NIR HSI, micro Raman and FT-IR.

In a previous study the characterisation of dried whole milk, skimmed milk, protein milk, butter milk and butter on stainless steel 316-2B, stainless steel 304-2B and aluminium using Raman and FTIR HSI was investigated.1 This research is focused on the investigation of the spectroscopic signal variation due to the initial milk volume, from 0.5 mL to post water washed residues. All the samples were dried at room temperature (about 20°C), for 48 h prior to analysis.

In order to identify milk residue presence, a PLS-DA model was built for each modality: macro NIR, Raman and FT-IR (NIR, MIR and total FT-IR). Two independent repetitions were used as calibration set and one repetition as validation set. Both calibration and validation sets included mean spectra of empty surfaces. The number of latent variables (LVs) were chosen based on the minimum misclassification value. To evaluate the built models, both pixel and object interpretation were applied.

For pixel interpretation, the percentage of correctly classified pixels (%CC) were calculated as the ratio between the sum of the correctly classified pixels and the total number of pixels of the validation set. Object interpretation was carried out by considering the values of each predicted image that occurred most often (the mode). All the models presented %CC > 80%. Each model was applied to E samples (9 samples in total = 3 repetitions x 3 surfaces) to evaluate the models' ability to discriminate between the surfaces with milk residues after washing (sample E) and empty surfaces. For each image the number of predicted milk pixels divided by the total pixel per image was calculated and the mean of three replicates was calculated.

Among all the techniques studied, macro NIR seems to discriminate correctly between the two groups. The third repetition of cleaned stainless steel 304 can be considered as outlier. Considering the validation set alone, FT-IR has a more efficient model. However, it does not recognise the difference between empty surfaces and sample E, while the model developed for Macroscopic NIR imaging did.

Acknowledgement: Funding for this research was provided by Science Foundation Ireland (SFI) under the investigators programme Proposal ID 15/IA/2984—HyperMicroMacro.

Selected Recent Publications

Caponigro, V. *et al.* (2019) Raman and Fourier transform infrared hyperspectral imaging to study dairy residues on different surfaces. *J. Spectr. Imaging* **8,** 1–20.

Xiaohui Lin, BE, M.Sc., PhD

Project Title: Non-destructive investigation on moisture content uniformity and shrinkage rate of peach slices during microwave-vacuum drying

Project Leader: Prof. Da-Wen Sun

Abstract

Microwave-vacuum drying (MVD) are relatively time saving and efficient drying methods. However, its major issue is local heating and uneven moisture distribution, which could reduce the product quality. It is important to evaluate the moisture distribution pattern to optimize the product quality. In recent few decades, hyperspectral imaging (HSI) has emerged as an attractive non-contact process analytical tool, which integrates both spectroscopic and imaging techniques. Therefore, this study applied the hyperspectral imaging and computer vision to investigate the shrinkage and moisture distribution of peach slices during MVD processes. The microwave-vacuum dryer used in the experiment was designed by Food Refrigeration and Computerized Food Technology (FRCRT, Dublin, Ireland). A laboratory hyperspectral imaging system was used to acquire the hyperspectral images of peach slices in the reflectance model. A computer vision system was applied to acquire the images of samples during MVD. The values of shrinkage and total color difference were acquired from the images. All the data analysis was carried out by Matlab R2019a (The MathWorks, Inc., Natick, Massachusetts, USA). The partial least squares regression (PLSR) models based on standard normal variate (SNV) preprocessing spectra obtained good results for predicting moisture contents (MC) with the coefficient of determination in prediction of 0.921. The moisture evaporated faster in the center part than that in the edges. The shrinkage rate of peach slices increased gradually during the drying procedures and reached 55% in the final products. Total color difference of peach slices kept constant after drying for 9 min. The current study showed the non-uniform moisture distribution maps of peach slices, which could inspire the optimization of drying procedure to avoid such uneven moisture distribution.

Selected Recent Publications

Lin, X., Xu, J.-L., & Sun, D.-W. (2020) 'Evaluating drying feature differences between ginger slices and splits during microwave-vacuum drying by hyperspectral imaging technique', *Food Chemistry*, 332, 127407.

Lin, X., & Sun, D.-W. (2020) 'Recent developments in vibrational spectroscopic techniques for tea quality and safety analyses', Trends in Food Science & Technology, doi: https://www.sciencedirect.com/science/article/pii/S0924224420305100.

Lin, X., Xu, J.-L., & Sun, D.-W. (2020) 'Comparison of moisture uniformity between microwave-vacuum and hot-air dried ginger slices using hyperspectral information combined with semivariogram', Drying Technology, 1-15.

EXPOSURE ASSESSMENT FOR BIOTOXINS AND VIRUSES ARISING FROM CONSUMPTION OF IRISH PRODUCED SHELLFISH

Xiyao Wang, Francis Butler
UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Marine biotoxins are naturally occurring chemicals generated by harmful algae blooms (HABs). They are easily accumulated in shellfish, leading to human intoxication after the ingestion of contaminated seafood products. Snave is one of the shellfish productions sites in Bantry Bay, Ireland. It has been suffering from diarrheic shellfish poisoning (DSP) toxins contamination for years, presenting a sea temperature-driven seasonal trend. This project used the Netica to develop a Bayesian Network model that predict the biotoxin level in Snave so that it could give relatively reasonable suggestions to both fishery farmers and customers. The result showed that the accuracy of the prediction model is relatively low with a 0.77 AUC value.

Introduction

Marine biotoxins are considered growing concerns worldwide. Their prevalence not only poses a threat to fishery industries but also to humans. These biotoxins are produced by phytoplankton, especially those harmful algal blooms (HABs). In recent years, due to global warming and therefore changes in weather conditions, specific HAB taxa tend to occur more often and at unexpected places, leading to higher biotoxin level can be detected from water samples (Alexander *et al.* 2009).

Shellfish is regarded as the primary food vectors due to their filter-feeding pattern. When HAB happens, there could be millions of algal per litre of water, making high concentrations of toxin accumulate in the shellfish tissues (Paredes *et al.* 2011). Consumption of contaminated shellfish could result in human intoxication. Reported cases are up to 6000 worldwide during the 21st century. Based on poisoning symptoms, marine biotoxins are grouped into paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), diarrheic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), and ciguatera fish poisoning (CFP) (Gao *et al.* 2015).

Several marine biotoxins are prevalent in Irish waters. The Irish Marine Institute routinely monitors for several HABs that are responsible for different toxin groups, including the *Pseudo-nitzshia* species responsible for Amnesic shellfish poisoning (ASP); the *Protoperidinium* species (most likely) responsible for Azaspiracid Poisoning (AZP); *Dinophysis* species (and others) responsible for Diarrhetic Shellfish Poisoning (DSP); *Alexandrium* species responsible for Paralytic Shellfish Poisoning (PSP). Among these toxin groups, DSP attracts the most attention from the Marine Institute as it causes the most bay closures in Ireland, resulting in a severe impact on shellfish industries. In addition, there have been many outbreaks associated with the ingestion of DSP toxins (Valdiglesias *et al.* 2013).

The objective of this project is to develop a Bayesian model that predicts biotoxin contamination in Snave in the southwestern production region in Ireland, initially concentrating on DSP toxins in mussels.

Methods

Model development

The Netica was used as the tool to develop a Bayesian Network for Snave diarrhetic shellfish poisoning toxin prediction. Snave is a shellfish production site located in Bantry Bay (Figure 1.). The prediction model was developed based on the hypothesis that biotoxin contamination in Snave was influenced by those surrounding production sites, and changes in sea temperature as well.

According to previous observations, there is clockwise circulation constantly that could transport biotoxins from outer to the inner part, and thus accumulated(Raine *et al.* 2010). Therefore, DSP concentration from surrounding production sits potentially affects Snave DSP level.

Meanwhile, a seasonal trend was identified within biotoxin occurrence data (Figure 2.). It peaked from early September to late October corresponded with higher sea temperature in the whole year.

Thus, it is assumed that sea temperature and its surrounding DSP level are the main factors for Snave prediction.

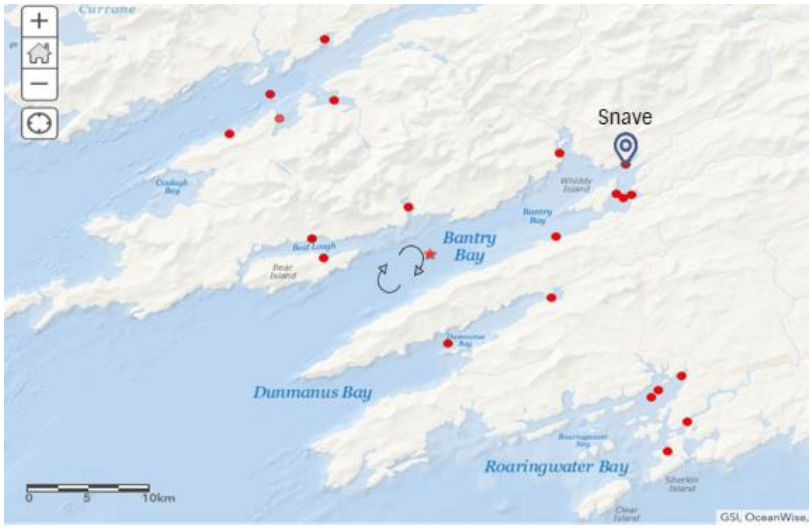

Figure 1. The shellfish production site Snave in Bantry Bay.

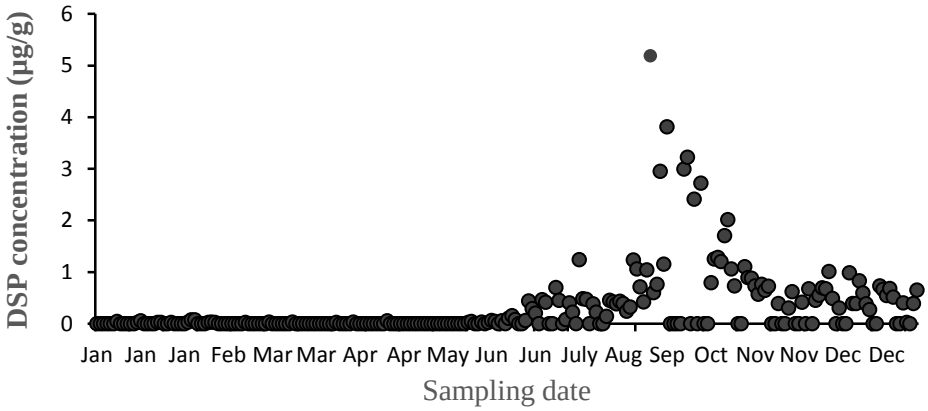

Figure 2. DSP concentration in Bantry Bay in the year of 2014

Data collection

Biotoxin data were provided by the Marine Institute from its online publicly accessible data center, available at: http://webapps.marine.ie/HABs/. The sea temperature data are obtained from Irish Weather Buoy Network Observations.

Table 1. Hazard occurrence data and sea temperature used as parameter for prediction model

Parameters	Unit	Description
Sea temperature	℃	Provided by Irish Weather Buoy Network Observations, M3 station
Biotoxins	μg/g	Diarrheic shellfish poisoning toxins
Phytoplankton	cells/liter	Species generate DSP toxins, including Dinophysis and Prorocentrum

Results and Discussions

The basic concept of the model is to calculate the possible DSP value based on the hazard occurrence data from the last seven days, including sea temperature, phytoplankton and DSP concentration from other production sites.

After construction, the model was trained with data set from the year 2014 to build the connection between each node. And then it is tested with data from 2015 to evaluate its accuracy.

The case test result shows that the accuracy is relatively low with an AUC value of 0.77. For a better result, the AUC should between 0.85 to 1.

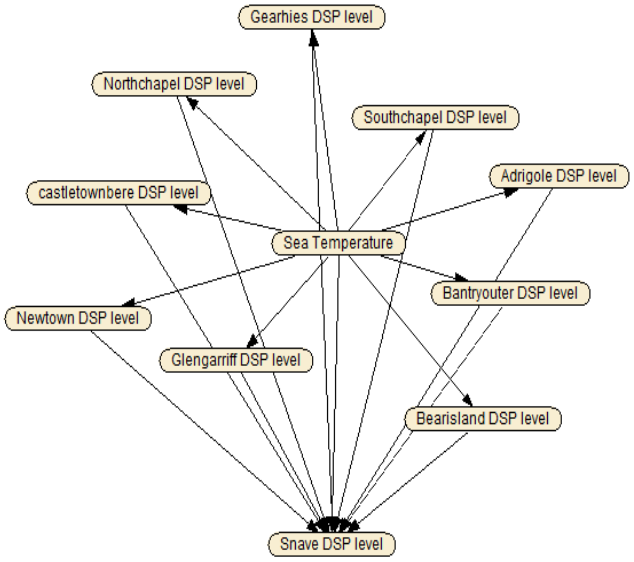

Figure 3. The Bayesian Network for Snave DSP prediction.

There are many potential reasons resulting in a relatively low accuracy. One of the possible reasons could be the missing data in the dataset. For some production sits in the Bantry Bay,

biotoxin or phytoplankton value were not fully recorded within the whole sampling year. With this situation, when input a new data beyond the calculating range of the model, an error value would be presented as the outcome. Thus, to perfect the model, the data gap needs to be compensated.

Acknowledgments

This project is undertaken with the instruction of Joe Silk from the Marine Institute, and also the cooperation with the RIKILT, Wageningen University & Research, Netherlands.

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Qicheng Hao

Project Title: Monitoring and control of *Cronobacter spp*. In Dairy powder processing facilities

Project Leader: Prof. Francis Butler

Abstract

Cronobacter Sakazakii can be commonly found in the environment of dairy processing facilities and is potentially of concern due to its ability to cause illness in neonates. While *Cronobacter sakazakii* has commonly been associated with powder infant formula manufacture, attention has recently been focused on other dairy powders which potentially can be used in infant formula manufacture.

This research is to analysis the source and heat resistance of *Cronobacter* contamination in powder manufacture. A detailed surveillance study was carried out in a dairy powder production facility and 20 environmental sampling locations were selected and were sampled monthly for 12 months. Detection for *Cronobacter spp* was carried out according to ISO22964. All positive samples were whole genome sequenced on an Illumina Hiseq. The sequencing data were analyzed by using various bioinformatics technique.

There were 88 positive environmental samples detected over the total surveillance period. The occurrence of *Cronobacter* was at its lowest in summer compared to the other times of the year. MLST profiling of positive samples indicated 4 sequence types. Phylogenetic analysis indicated 8 separate genotypes. Within each genotype, the SNP differences was very small, indicating that the isolates were essentially clonal and most likely came from the one original contamination source. Combining the phylogenetic data with the other meta data including location and sample date allowed the identification of a location within the process environment that was highly likely to have been the location of the contamination. Phylogenetic analysis also demonstrated the persistence of some strains over the year long period of the surveillance.

NGS allows very precise ‘fingerprinting’ of pathogens isolated in food process facilities and allows advance root cause analysis to be carried out to control and manage pathogens in the process facility environment. The sequence can also underpin the risk assessment of *Cronobacter* in dairy ingredients.

Viruja Ummat

Project title: Application of novel technologies for estimation of biomolecules from seaweeds

Project leaders: Prof. Colm P. O'Donnell, Prof. Brijesh Kumar Tiwari and Dr. Gaurav Rajauria

Abstract

Seaweeds are rich in a range of high value bioactive compounds and phlorotannins being one of them has gained attention of several researchers, nutra-, cosme- and pharmaceuticals, owing to their antioxidant, antimicrobial, anti-inflammatory and antiviral properties. Since the bioactive compounds are embedded deeply in the complex seaweed matrices, it becomes important to develop such technologies which not only facilitate the extraction of these compounds, but are also energy efficient, less time consuming and do not compromise on the quality of the target compound. This has led to emergence of ultrasound assisted extraction (UAE) as an effective green and clean extraction method, which not only enhances the extraction yield, but also helps in combatting the drawbacks of the conventional methods.

Eleven Irish seaweeds; *Fucus serratus(FSe)*, *Fucus vesiculosus(FV)*, *Fucus spiralis(FSp)*, *Himanthalia elongate(HE)*, *Halidrys siliquosa(HS)*, *Laminaria digitate(LD)*, Laminaria *saccharina(LS)*, *Laminaria hyperborean(LH)*, *Ascophylum nodosum(AN)*, *Alaria esculenta* (AE) and *Pelvetia caniculata*(PC), were dried in an air circulating oven (50°C, 9 days) and milled to 1 mm particle size. Extraction was carried out using the optimum conditions for extraction using ultrasound (35 kHz, 30 min and 50% ethanol) and conventional extraction (50% ethanol for 30 min without ultrasound). The yield (%) obtained and TPhC (total phlorotannin content) were determined.

The optimised ultrasound conditions (35 kHz for 30 mins with 50% ethanol) compared to conventional method showed higher extract yields in all the seaweeds. The yields obtained by UAE were in the range of 20.4 – 36.9%, while with conventional method 10.5 – 19.3% yields were obtained. Ultrasound enhanced the extraction yield from 1.5-fold to 2.2-fold in all seaweeds. The highest yield obtained using UAE was 36.9% from LH, while with conventional method a highest of 31.225% was obtained in LD. It was observed that the extraction yield varied with the seaweed species. Also, UAE, was found to be beneficial in enhancing the recovery of TPhC (1.2 – 3.8-fold) in all the seaweeds compared to conventional method. With the ultrasound, the highest recovery of TPhC (476.3±2.19 mg PGE/g) was obtained from *Fucus vesiculosus* while the lowest (TPhC: 50.3±2.01 mg PGE/g) was obtained from *Laminaria digitata*. While, with the conventional method, a range of 19.0 – 292.0 mg PGE/g, was reported.

Ultrasound assisted extraction improved the extraction yield in all the seaweeds. Also, the recovery of target bioactive compound i.e. total phlorotannins in overall extract was higher with UAE treatment compared to conventional method.

Selected Recent Publications

Viruja Ummat, Brijesh K Tiwari, Amit K Jaiswal, Kevin Condon, Marco Garcia-Vaquero, John O'Doherty, Colm O'Donnell, Gaurav Rajauria Optimisation of ultrasound frequency, extraction time and solvent for the recovery of polyphenols, phlorotannins and associated antioxidant activity from brown seaweeds. Marine Drugs **2020**, *18*, 250; **doi:10.3390/md18050250**

Kexin Zhang, PhD student

Project Title: Modification on rheological properties of milk protein concentrate using DBD plasma

Project Leader: Prof. Da-Wen Sun and Prof. Brijesh Tiwari

Abstract

As the fourth state of matter, plasma has been employed as a novel processing technique and applied on various products in the food and pharmaceutical industry. Besides the initial antimicrobial effect, it shows a great potential in biomolecule modification without employing any chemical reagent. Milk protein concentrate (MPC) is a high-quality protein ingredient which is obtained from skim milk *via* ultrafiltration, evaporation and spray drying. For its outstanding functional and nutritional properties, MPC has been commonly used in dairy applications. The objective of this study is to investigate plasma induced modification on rheological properties of milk protein concentrate.

The viscosity and dynamic viscoelastic properties of MPC dispersion were determined using a rheometer (Anton Paar MCR 92, Austria) coupled with a con-plate CP50-1 measuring system (50mm diameter, 1^{o} cone angle) and a concentric cylinder system, respectively. The shear stress and viscosity of 20 % (w/w) MPC dispersion was monitored over a shear rate of 10-1000 s^{-1}. For the measurement of dynamic viscoelastic properties of MPC dispersion, 20 µl of CHY-MAX® Extra (650 IMCU/ml, Chr. Hanssen, Denmark) was added into 60ml MPC dispersions (10% w/w). Constant shear strain of 0.05%, frequency of 1 Hz and temperature of 30^{o}C was used to measure storage modulus(G') and lose modulus(G'') during milk coagulation within 60 min.

The viscosity of MPC was reduced after plasma treatment. However, the rennet induced coagulation process of plasma-treated MPC dispersion was accelerated. All in all, DBD plasma treatments showed the capacity in green modification on rheological properties of MPC.

Selected Recent Publications

Zhang, K., Perussello, C.A., Milosavljević, V., Cullen, P.J., Sun, D.W. and Tiwari, B.K., (2019) 'Diagnostics of plasma reactive species and induced chemistry of plasma treated foods'. *Critical reviews in food science and nutrition*, 59(5):812-825.

Renxi Kang, BE, M.EngSc.

Project Title: Monitoring of cheese maturation using near infrared hyperspectral imaging (NIR-HSI)

Project Leader: Prof. Colm P. O'Donnell

Abstract

This study investigated the feasibility of NIR-HSI combined with chemometrics to monitor cheese maturation during the ripening process. Two batches of Camembert-style cheese samples (n=16) were obtained from Cooleeney Farm (Cooleeney, Moyne, Thurles, Co. Tipperary, Ireland). The cheese was ripened for 7 days at 13 °C. Subsequently, the cheese was packaged and half of each batch was stored at 4 °C and 8 °C respectively for further ripening for up to 37 days. Samples were scanned using a line scanning NIR-HSI system after 14, 21 30, and 37 days of ripening. For each sample, spectral data were acquired from 950-1664 nm at 7 nm increments. Principal component analysis (PCA), k-means and partial least squares discriminant analysis (PLS-DA) were used to monitor Camembert-style cheese maturation. This study demonstrated the potential of NIR-HSI to monitor cheese ripening process for the quality control purpose.

APPLICATION OF ULTRAVIOLET-VISIBLE (UV) AND NEAR INFRARED (NIR) SPECTROSCOPY FOR ADULTERATION DETECTION OF VODKA

Arul Ashok, Colm O'Donnell
UCD School of Biosystems and Food Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Vodka is a popular alcoholic beverage which is made from ethyl alcohol produced from fermentation of potatoes and grains. The minimum strength of vodka is 37.5% by volume. In this study, near-infrared (NIR) and ultraviolet-visible (UV-Vis) spectroscopy is applied along with chemometrics to detect adulteration in vodka. Vodka samples adulterated with water, ethanol, methanol and a mixture of cheap and expensive vodka are analysed using NIR and UV-Vis spectroscopy and chemometric models. This methodology is inexpensive, less time consuming, efficient and uses small test samples. Therefore, NIR and UV-Vis spectroscopy can be applied for identification of adulterants in vodka.

Introduction

Vodka is a popular alcoholic beverage in Poland, Russia and other Eastern European countries. It is made from ethyl alcohol of agricultural origin that has been produced via fermentation of potatoes, grains or other agricultural products. The derived ethanol containing solution is distilled or rectified to selectively reduce the intensity of taste and smell of the raw materials and by-products of fermentation. The minimum strength of vodka is 37.5% by volume and can exist either in the pure or flavoured form. These flavoured vodkas are characterized by a dominant flavour which is different than the taste of raw materials used in its production (Wiśniewska *et al.* 2015).

Vodka, similar to other alcoholic beverages like whiskey and wine, has faced issues of adulteration. Since it has a low commercial value, the consumption rate is high. One of the principal risks for the consumers of adulterated alcoholic beverages is the ingestion of drinks elaborated with not qualified raw materials, mainly those containing high methanol levels. Methanol is a constituent naturally present in alcoholic beverages in small amounts. Ingestion of large quantities of methanol can lead to headache, nausea, vomiting and in extreme cases, blindness and death (Pontes *et al.* 2006). In addition, adulteration of alcoholic beverages damages the credibility of the companies that produce the legalized drinks (Pontes *et al.* 2006). Common adulteration of vodka may include diluting it with water, addition of methanol or mixing of cheap vodka with expensive ones. These malpractices are usually carried out to stretch out the supply and to increase the forgers' profit margin. Therefore, it is important to develop a strategy and analytical tool to detect adulteration of alcoholic beverages to ensure consumer safety and fair competition (Markechová *et al.* 2014).

In this study, near-infrared (wavelength range: 750-2500nm) and ultraviolet-visible (wavelength range: 190-750nm) spectroscopy and chemometric methods are used for identifying, classifying and verifying adulteration of vodka samples. Spectroscopic techniques can be used to analyse composition and structure of the functional groups or substance present in the sample through an absorption spectrum (Li *et al.* 2014). Traditional chromatographic methods are relatively expensive, time-consuming and require skilled operators. Hence, there is a demand for rapid, inexpensive and efficient techniques like spectroscopy and chemometrics for discriminating between alcoholic beverages (Jakubíková *et al.* 2018).

The objective of this study is to identify adulteration of vodka using ultraviolet-visible (UV-Vis) and near -infrared (NIR) spectroscopy along with chemometrics.

Materials and Methods

Samples
Different adulterated vodka samples will be analysed in this study. The vodka will be purchased from a trusted source. Adulteration will be carried out using deionized water, ethanol or methanol in rising levels of 5% v/v, 10% v/v and so on in pure vodka with each sample numbered properly.

UV-Visible and NIR Spectroscopy
The study will use the UV-Vis (Figure 1) and NIR Spectroscopy equipment in the UCD School of Biosystems and Food Engineering laboratory to identify the adulterant in the samples. The different materials that will be used during the experiment include: deionized water, ethanol or methanol, vodka, pipette, cuvette and beakers. In the first phase of the experiment, deionized water will be used as an adulterant to dilute the vodka sample. The second phase of the experiment will involve using ethanol or methanol as the adulterant for the vodka samples. Third phase will consist of analysing the effect of mixing cheap and expensive vodka. In all the three phases, adulterated vodka samples will have a varying adulterant to pure vodka ratio (v/v). The analyses will be carried out twice to verify results and efficiency. Once the tests are carried out, the spectral data obtained will be analysed using chemometric models and MATLAB.

Figure 1. UV-Vis Spectrophotometer

Results and Discussion

A study by Jakubíková *et al.* (2018) focused on differentiating plum brandies of different varietal origins using UV-Visible, NIR and fluorescence spectroscopy. The spectral diagrams aided in identifying the OH overtone of water, ethanol and methanol. The peaks and bands created due to stretching and angular bending of water OH helped analyse the adulterants.

Vodka, being an alcoholic beverage, will depict a similar NIR and UV-Visible spectral diagram. The sensitivity of the data will not be the same as the samples, equipment used and methodology may differ, ultimately leading to varying results.

The score plots developed using chemometric models for NIR and UV-Visible spectroscopy will help differentiate adulterated and non-adulterated samples of vodka.

Conclusions

The study will represent the application of spectroscopy and chemometrics to identify adulteration of vodka to be inexpensive, safe and effective. This is achieved by classifying and verify adulteration of vodka samples using NIR and UV-Vis spectroscopy along with chemometric methods and

programming software like MATLAB. The study will help determine whether the given vodka sample is authentic and safe for human consumption.

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CHANGES IN FOOD SHELF LIFE UNDER CLIMATE CHANGE SCENARIOS

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Abstract

Any increase in ambient temperature resulting from climatic change may have a substantial effect on the current and developing food cold-chain. A rise in temperature may increase the risk of food contamination and food spoilage. The changes in human pathogenic and spoilage micro-organisms on three lightly processed and packaged products (milk, a dairy product; beef, a meat product and lettuce, a ready to eat product) were investigated using a predictive modelling approach. The logistic model was run for the bacterial growth prediction responsible for spoilage and/or causing a reduction in the shelf life of the three products under consideration. The effect of changing climatic conditions was studied by monitoring the predicted influence of temperature change on microbial growth and shelf life. The model describes the reduction of lag time of the spoilage micro-organism and enhancement of the exponential increase in the growth at dynamic temperature conditions. The study revealed that due to temperature fluctuation the shelf life of a food product may be affected.

Introduction

The shelf life of food is the period during which the food retains an acceptable quality and can be kept under stated storage conditions. Shelf life depends on four main factors, namely: formulation, processing, packaging and storage conditions. Foods are perishable and there are many intrinsic and extrinsic factors that can deteriorate the quality during storage and distribution and make it unfit for consumption. Intrinsic factors are the properties of the final product, which includes pH, level of nutrients, natural microflora and surviving microbiological counts and available oxygen. Extrinsic factors are those factors that the final product encounters as it moves through the food chain and includes relative humidity, exposure to light, environmental microbial counts during the food processing, temperature and composition of atmosphere within packaging (Gallagher *et al*. 2011).

The present global scenario explains convincingly that climate is changing. Global temperature has increased by 0.5˚C in the past century and the Intergovernmental Panel on Climate Change envisages an increase in global mean temperatures of 1.1–5.4˚C by 2100 (IPCC, 2018). Generally, food may be frozen or generally maintained at a temperature below 18˚C throughout storage, transport, retail and domestic storage. The shelf-life, in particular, is based upon sensory and microbiological properties of the packaged product (Nicoli *et al.* 2012). Climate change may disrupt food availability, reduces access to food, and affect food quality and also accelerate the growth of pathogens/ bacteria in the stored food. Spoilage micro-organisms may proliferate during storage and may ultimately increase the rate of food spoilage and reduce the shelf life of the stored product.

This study was established to evaluate the effect of different refrigerating temperatures (2, 4 and 7 °C) and temperature abuse (10 °C) conditions on the shelf-life (based on the evaluation of the microbiological proliferation of spoilage and pathogenic micro-organisms and sensory quality) of a number of packaged food products (Milk, Beef and Lettuce).
The objective of the present study was to study the potential change in shelf life of selected food products under a range of climate change scenario.

Materials and Methods

Materials

The three food products that are chosen for this study are Milk (dairy product), Beef (meat product) and Lettuce (ready to eat food). The pathogen/bacteria potentially responsible for the spoilage of the food and the reduction of food shelf life is given in the following table.

Table 1. Pathogen/Bacteria responsible for food product spoilage

Food Product	Pathogen/Bacteria	Storage Temperature/ ºC
Milk	*Listeria monocytogenes*	2 to 4
Beef	*Yersinia enterocolitica*	0 to 4
Lettuce	*Pseudomonads*	4

Modelling

A logistic model is established. During the initial period of incubation, bacterial cells need physiological adaptation to the new environment. The growth in this period is lowered. This is considered by a factor related to the minimum cell concentration, N_{min} which is almost equal to the initial cell concentration observed.

A graphical model is developed to study the effect of the change in temperature by 5°C at domestic refrigeration (Figure 1).

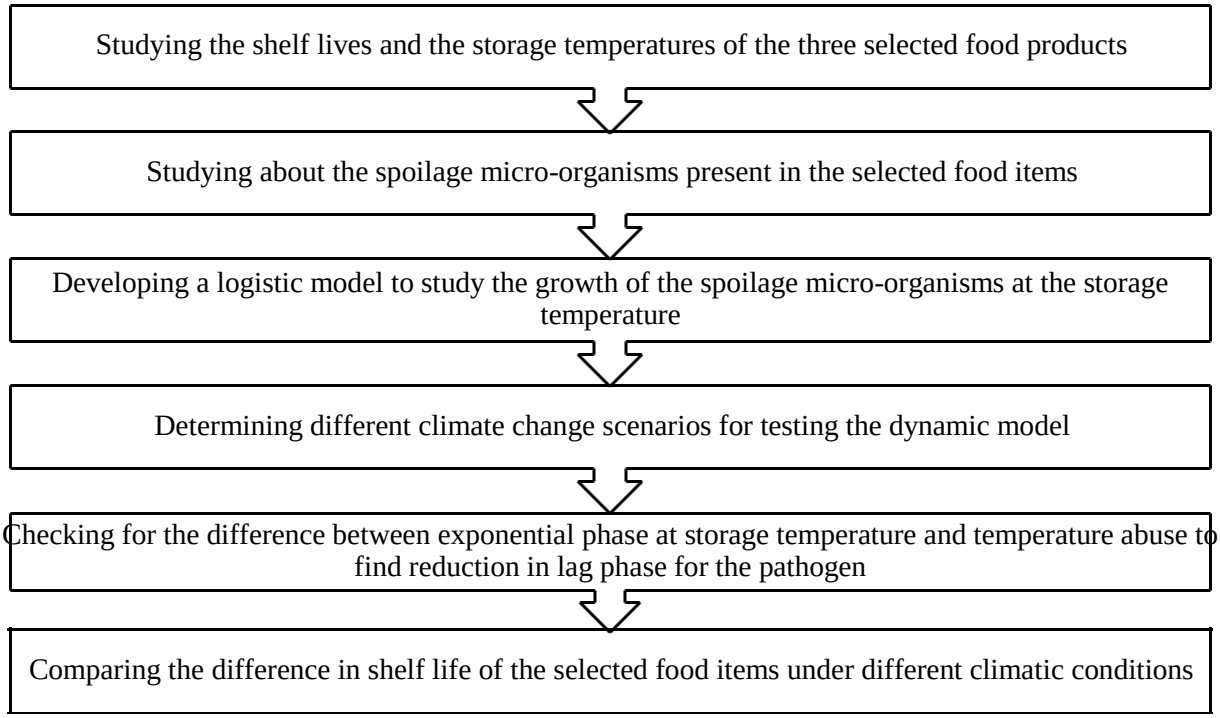

Figure 1. Framework model for studying the changes in food shelf life with changing climatic conditions

The rate of growth of the logistic model is described as in equation 1 (Fujikawa *et al.,* 2004).

$$dN / dt = r\ N\ (1-N/N_{max})\ (1-N_{min}/N)_c \quad (1)$$

where, N = cell population
t = incubation time
r = the rate constant of growth
N_{max} = the maximum population (at the stationary phase)
N_{min} = the minimum population
c = adjustment factor

Here, $c \geq 0$ is an adjustment factor and the rate constant, r is a function of temperature, T. In this model, N increases between the two asymptotes of N_{min} and N_{max} with time.

The rate of growth of the model is strongly suppressed by the term $1-N_{min}/N$ during the lag phase and by the term $1-N/N_{max}$ during the stationary phase. The growth model was setup within a spreadsheet using Microsoft Excel.

Data Analysis
The increase in the pathogen level for the product shelf life was graphically studied. The colony forming unit (*cfu)* count for the pathogen on temperature abuse was compared.

Results and Discussion

The programming was performed in Microsoft Excel to obtain the growth curves for the three bacteria, namely *Listeria monocytogenes, Yersinia enterocolitica* and *Pseudomonads* responsible for reducing the shelf life of Milk, Beef and Lettuce under specific storage conditions over time. The effect of changing climatic conditions on the growth of these bacteria was also studied by considering a temperature abuse of 5ºC. The ComBase Predictor and Food Models were referred to get the data values for Initial population count (N_0) and lag time (in hours) for each bacteria at the specific temperature as mentioned. The programming was run for a certain period of time and the cell count values (Log N) versus time graph were plotted.

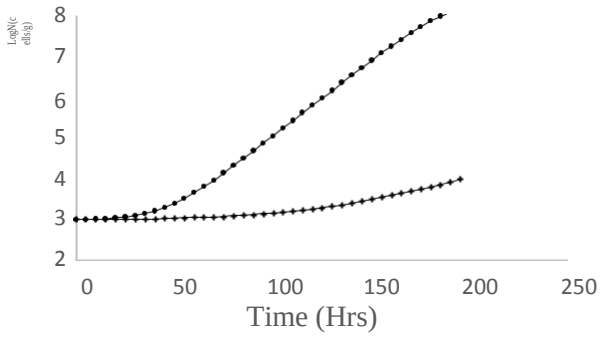

Figure 2. Growth curve for *L. monocytogenes* at storage temperature i.e. 3ºC (depicted by ▪) and at 8ºC Temperature abuse (depicted by +)

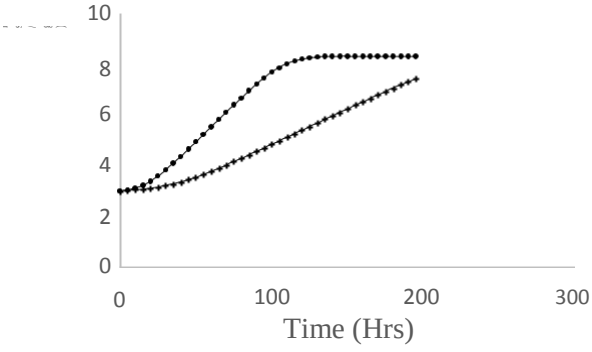

Figure 3. Growth curve for *Y. enterocolitica* at storage temperature i.e. 2ºC (depicted by ▪) and at 7ºC Temperature abuse (depicted by +)

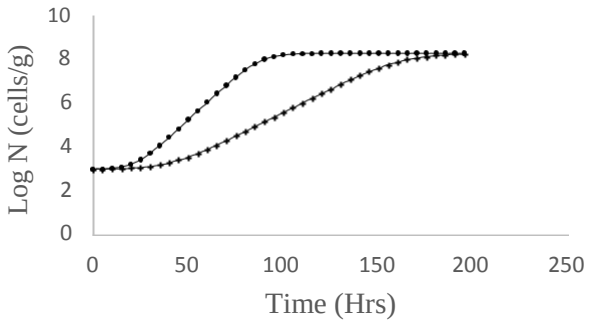

Figure 4. Growth curve for *Pseudomonads* at storage temperature i.e. 4ºC (depicted by ▪) and at 9ºC Temperature abuse (depicted by +)

Conclusion

The microbiological properties is affecting the overall shelf-life of the food product. Spoilage micro-organisms proliferated during storage. The effect of temperature on microbial counts became very clear with the graphical study of the logistic model. As the temperature increased, the lag-phase decreased and the exponential increase in the population density of the spoilage micro-organisms is reached faster. With temperature abuse of 5 ºC at the storage temperature, the lag phase is reduced by 35 hrs. , 5 hrs. and 10 hrs. for the three spoilage micro-organisms *L. monocytogenes, Y. enterocolitica* and *Pseudomonads* respectively. This reduces the shelf life of the stored food products.

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EMBEDDED SYMBIOLOGY TO ENHANCE FOOD TRACEABILITY

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Abstract-

Food traceability can be generally considered as one of the most important requirements in order to provide the most efficient and complete details of the food journey from farm to fork and vice versa. The potential and applications of a range of traceability systems are discussed, including various novel methods such as laser etching of bar codes and 2D QR codes directly onto the food product thus eliminating the need to carry the product details on the individual packaging of the food product while also contributing towards enhanced system efficiency. The use of Braille in food marking and its social acceptance in society is also reviewed.

Introduction-

Food traceability addresses the provenance of the food and should be easily available to customers, producers, and distributors alike. The contemporary and prevalent food supply chain also known as (FSC) must provide detailed and fool-proof information including a variety of food attributes, country of origin of the product and should adhere to local and regional legislation. Any genetic modification and alterations should be properly notified as it can be a source of concern to some consumers and customers (Bosona and Gebresenbet 2013). There are various driving forces for food traceability which include: quality and safety concerns of the food product, economic specific concerns, social concerns, regulatory and technological concerns, etc. (Zhang and Zou 2017). Some of the state-of-the-art technologies that are being implemented/experimented in the food traceability domain are- Batched based traceability for pork which uses modern 2D barcode technology (Chen *et al.* 2020). Using IoT sensors and machine learning-based systems to improve the efficiency of RFID based traceability systems (Alfian *et al.* 2020). Utilization of blockchain and food quality data index for efficient food traceability (prototype) in restaurants and its respective supply chains(George *et al.* 2019). DNA based approaches are being used for olive oil authentication, traceability, and adulteration. They are also used for authenticating the origin of meat species(Kalaitzis and ElZein 2016), (Ahmed *et al.* 2018). One of the most successful implementations of sustainable food traceability measures can be seen in some south-east Asian countries where GIS (Global Information Systems) and Remote Sensing is used for fisheries management including efficient feeding, breeding, and mobilization of fishes as per requirement. These research developments aim to provide better traceability options that are both economically viable and highly efficient.

Shelf-healing of fruits and vegetables is one of the main hurdles of laser etching technology. Fruits and vegetable consider the laser-etched symbology as a mechanical injury and tends to There are various factors that determine the shelf-healing abilities, one of them being the overall A_w of the fruit/vegetable(Knee and Miller 2002). Higher the $A_{w,}$ faster shelf-healing is observed and sooner the etched pattern is deformed. Shelf healing of mechanical injury also depends on the composition and structure of the outer shell depending on the smoothness/ruggedness of respective fruits and vegetables.

The objective of the study was to evaluate the application of laser marking using laser etching to directly imprint smartphone-readable symbology (e.g. QR codes) onto food products, thus removing the reliance on packaging as the carrier of the product information and contributing to a more environmentally friendly approach towards traceability.

Materials and Methods

To successfully undertake the experiment, the products need to be efficiently and correctly laser etched. A pasting agent is also considered to provide additional contrast. The pasting agent must be food grade and comply with the EU regulations.

Fruits and Vegetables- Various fruits and vegetables were considered for the experiment. Organic products were preferred as pesticides might lead to altered readings of the final output. The fruits and vegetables have been individually experimented upon, and analysis was done based on retention of the laser-etched symbology and its overall ability of self-healing. Broccoli, Potatoes, Carrots, Apples, Watermelon and Swedes were tested in the experiment.

Pasting Agent- A food-grade pasting agent was considered which had E171 Titanium Di Oxide as its main component. The product also contained E 55 Silicon Di Oxide which provided the required stability and retention of the paste. Pasting agents help to provide a stark contrast on the product surface which further enhances the readability on the end-user smartphone device.

Laser Engraving System- The laser engraving system (courtesy of UCD School of Civil Engineering) is manufactured by Trotec and had the following specifications.

Table 1: Laser Engraver Specifications (this study)

Serial No.	Product Type	Manufacturer Name	Product Name	Work Area	Maximum workpiece height	Laser Power- CO_2	Laser Power - Fibre
1	Laser Engraver	Trotec	Speedy 300	736×432 mm	165 mm	12-120 W	10-50 W

A specific proprietary software Job Control® was used for the purpose of managing and designing the specific bar/QR/braille code over the food product.

Methodology The methodology included a selection of desired raw material. AutoCAD software was used to design the desired shape/QR code. The software allowed the imprinting of variations in the size and shape as required. Various options and variations were considered in undertaking the same. The file was transferred to the Job Control® software which could read the AutoCAD files. A typical android/apple compatible app that has the capability to read and understand QR/Braille/Barcodes will be used to analyse the samples.

The food product selected for the purpose was observed for major physical injury and placed with proper support in the designated space of the etching unit. The laser is automatically calibrated, and a measuring device used to measure the distance between the food product and the lens. The intensity, frequency, and power are adjusted virtually as per the software directions. The etching process is then initiated, and the desired results obtained. The graphic created by the Job Control® software is then successfully etched on the surface of the food product same (Alfian *et al.* 2020). The steps are given in chronological order (Figure- 1,2,3).

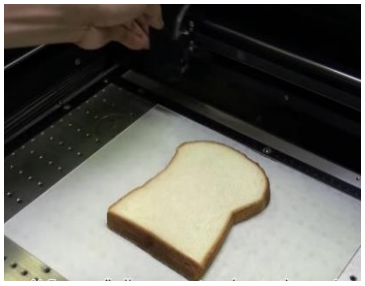

Figure 1- Placement of the product

Figure 2- Calibration of the laser and power

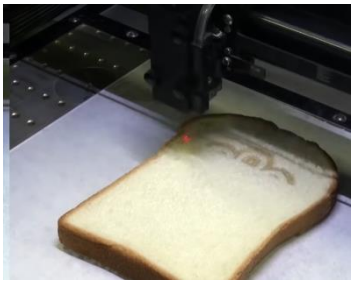

Figure 3- Etching of the desired shape

Results and Discussions

The results and observations obtained from this study provided us with various observations which are shown below-

Figure 4- Laser Etched Potato (this study)

Figure 5- Laser Etched Watermelon (this study)

Figure 6- Laser etched Swedes (this study)

Figure 7- Braille etched Broccoli (this study)

Table -2 Some experimental results from this study are depicted in the table below

Food Product	Power	Size dimensions	Storage Conditions	Obtained Shelf Life (Readability)
Potato	25	15 x 15 mm	Room Temp.	1 day
	30	15 x 15 mm	Refrigerated (0 ±1^{0}C)	2 days (with add. Contrast)
Broccoli	30	15 x 15 mm	Room Temp.	2 days (with add. Contrast)
	35	20 x 20 mm	Refrigerated (0 ±1^{0}C)	2 days (with add. Contrast)
Swedes	30	15 x 15 mm	Room Temp.	0.5 Day
	30	15 x 15 mm	Refrigerated (0 ±1^{0}C)	0.5 Day
Watermelon	30	20 x 20 mm	Room Temp	4 days (with add. Contrast)
	35	25 x 25 mm	Refrigerated (0 ±1^{0}C)	5 days (with add. Contrast)

The experiments are still in progress and must be undertaken with more repetitive samples and the efficient utilisation of a food colouring options is still being extensively considered. A trend analysis can be seen that food with higher water activity, for example, apples and swedes tend to self-heal. Apples were tested and it was seen that healing began very rapidly and the sharpness of the imprint was reduced within minutes. Swedes showed the same characteristics.

The use of braille imprints was also assessed. The main aim of imparting the braille code onto the food product is to provide opportunities for the visually challenged individuals to be self-sufficient and provide them the necessary information about the product including the expiry date.

Conclusion

Inclusion of laser marking, and food printing has a lot of potential and scope. Further research will help in the development and analyses of the possibilities for laser imprinting on other food products. The most immediate research would be able to find proper contrast with regards to coloured laser or a food paste. Food traceability, waste reduction and reduced packaging requirements are the most important benefits of this system and has the potential to contribute towards more sustainable food systems and reduced carbon footprint.

Acknowledgments

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A RISK ASSESSMENT OF SALMONELLA IN POULTRY PRODUCED IN CHINA

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Abstract

Salmonella is a common pathogen, which causes serious damage to human health by food poisoning. The pathogen causing the infection is mainly transmitted by animal food, especially poultry. China is a big producer of poultry and poultry consumption is quite large. The objective of this study was to conduct a risk assessment of *Salmonella* in poultry produced in China and provide human exposure estimates to *Salmonella* by consumers including susceptible populations.

Introduction

Salmonella is a gram-negative bacterium belonging to the *Enterobacteriaceae* family and it can be spread throughout the food chain, from animal feed and primary production all the way to homes or food service establishments (Vandeplas *et al.* 2010). Most cases of salmonellosis are mild but sometimes life-threatening. The severity of the disease depends on a host of factors and the serotype (Li *et al.* 2019). Food producers and consumers pay more and more attention to food safety problems caused by microorganisms through the improvement of food safety supervision.

China's production and export of poultry has increased in recent years, with 22.39 million tons of poultry produced in 2019, according to the food and agriculture organization of China (Sun *et al.*). Poultry processing involves preliminary processing, storage and transportation. In addition, the product is nutrient-rich and easily contaminated with foodborne bacteria, so it is important to control the bacteria during processing and storage. Although *Salmonella* will be killed by heating and other means during subsequent cooking, the improper operation of the kitchen stage may cause secondary contamination by *Salmonella* (Foley *et al.* 2013). As early as 2002, the WHO developed a risk assessment document for *Salmonella*, which provides expert advice to member countries. There are various factors which should be considered in the assessment process, including the frequency and duration of *Salmonella* contamination of poultry, the characteristics and biological morphology of *Salmonella* (Hungaro *et al.* 2013). Most of the studies on *Salmonella* risk assessment in China remain at the level of qualitative risk assessment, while few are conducted on quantitative risk assessment (Li *et al.* 2019).

The objective of this study was to conduct a risk assessment of *Salmonella* in poultry produced in China and provide human exposure estimates to *Salmonella* by consumers including susceptible populations.

Materials and Methods

Data collection

The concentration of *Salmonella* on poultry carcass in poultry slaughterhouse had been found from published literature (Zhang *et al.* 2015). Using the data of the special monitoring of *Salmonella* broiler in Jinan City in 2012 and the process parameters obtained from the survey, the depilation as the starting point for evaluation, and the removal of offal and cleaning and pre-cooling as the following processing in slaughterhouse. The positive rate of *Salmonella* in whole poultry after depilation was 42%.

The data required for the FAO model (http://tools.fstools.org/poultryRMTool/) includes the Initial Contamination (IC), Processes Flow Contamination, Consumer Practices (CP) and Dose Response (DR). These data are collected from the published literatures of relevant papers. The model of the contamination of *Salmonella* in poultry will be made by PoultryRMTool which is contributed by FAO and WHO (C/F Figure 1).

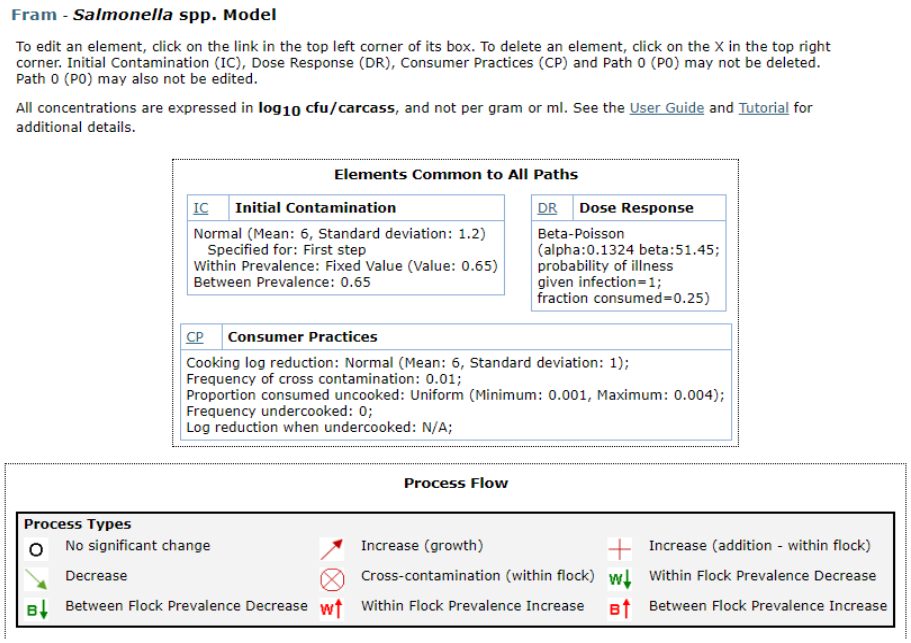

Figure 1: the primary element of *Salmonella* spp. model by PoultryRMTool

Data analysis

Data analysis will include the *Salmonella* detected in poultry and the risk assessment. The method to analyse the risk assessment should be follow the standard human health risk assessment method:

(1) Hazard identification: the identification of biological, chemical and physical compounds of causing adverse health effects. (2) Hazard characterisation: the dose response assessment relates the amount consumed to a clinical outcome. (3) Exposure assessment: the qualitative or quantitative evaluation of likely intake of biological, chemical and physical compounds from food. (4) Risk assessment: the qualitative or quantitative estimation of the probability of occurrence and severity of known or potential adverse health effects in a given population.

Result and Discussion

The result indicates the positive rate of *Salmonella* in poultry after pre-cooling was 18% and the concentration of *Salmonella* on the carcass of broilers after the pre-cooling tank was 1.96 MPN / g. The contamination concentration of positive samples is shown at Table 1(Zhang *et al.* 2015).

Table 1: The quantitative data of *Salmonella* on positive carcass after pre-cooling

Salmonella concentration/(MPN/g)	Sample/carcass	Cumulative frequency
0	0	0
<0.3	17	0.77
2.3	2	0.86
4.3	2	0.95
9.3	1	1

It is expected that the model which indicates the change of *Salmonella* over the pathway. Figure 2 includes the values of carcass concentration, between flock prevalence and within flock prevalence. All results are shown for the end of each stage and the weighted residual risk of the path will be shown below the model.

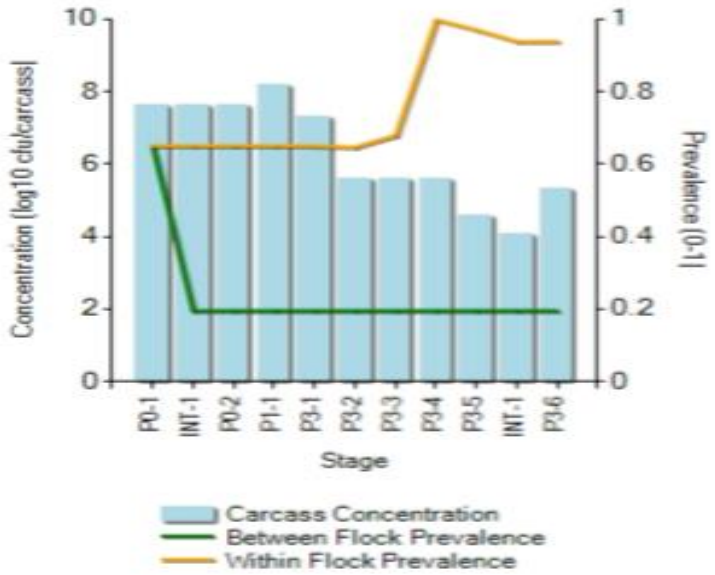

Figure 2: Illustrative change in the concentration of *Salmonella* over the farm to fork production chain of poultry

Figure 2 shows illustrative changes in *Salmonella* concentration over the complete pathway from farm to fork. The Figure clearly indicates the most *Salmonella* concentration in P1-1 which is the stage of receiving chicken at the slaughterhouse. The value of between flock prevalence is 0.2 after P0-1 step. It has an increasing trend in value within flock prevalence

from P3-2 to P3-4, to the top of 1. Poultry from production to consumption are susceptible to *Salmonella* infection during the pre-treatment and consumption. The relevant department should design stronger intervention and controlling the concentration of *Salmonella* for these stages.

Conclusion

In this study, the increase in the level of *Salmonella* was affected by different processing stages. The greatest probability of *Salmonella* contamination occurred in the pre-treatment process, like at the slaughterhouse. The cooking stage is also a big issue for *Salmonella* contamination. The research will continue to work on the collection of data for the model development.

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HYPERSPECTRAL IMAGING OF BANANA MOISTURE CHANGES DURING HOT AIR DRYING

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Abstract

After being harvested, banana will rot and deteriorate due to the growth of microorganisms during storage, transportation, and selling, making it challenging to ensure the quality and shelf life. Drying is the oldest preservation method for fruits and vegetables, which reduces the water activity to enhance the storage stability. Hot-air drying (HAD) technology is the most common fruit and vegetable drying technology, the main principle is to use hot air convection to dehydrate and dry food. During HAD process, due to poor heat transfer and low mobility of moisture through the material, the moisture content inside the product is often higher than the moisture content on the surface. Therefore, Increasing hot air temperature or flow rate could ensure the product achieving a specific average moisture content. This article uses hyperspectral imaging technology, combined with multivariate data analysis and image processing, the moisture content distribution on banana slices subjected to HAD method was visualised. Hyperspectral imaging technology can be used to detect the moisture change of banana slice samples during hot-air drying, to determine the optimal drying time.

Introduction

Drying is one of the most common thermal techniques for preserving food and agricultural products. Standard drying technologies are generally divided into hot-air drying (HAD), microwave-vacuum drying (MVD) and vacuum freeze-drying (FD). Hot air drying (HAD) is a typical convection drying method. In the process of hot air drying, the water inside the material first diffuses to the surface through the capillaries and then evaporates to the outside air medium under the effect of convection (Liu, Y., Pu, & Sun, 2017). The main feature of hot-air drying (HAD) is that it can control the temperature and wind speed of hot air to adjust the rate of moisture diffusion of material. Generally, HAD regulates the rate of water diffusion of material by controlling the temperature and wind speed of hot air, the internal moisture content is higher than the surface due to poor heat transfer and low mobility of moisture through the material, especially for low-porosity materials. As a result, the total drying time is

extended to ensure that the entire product reaches a specific average moisture content. However, in the later stage of HAD, when the moisture content of the material drops to a relatively low level, the moisture is concentrated inside the material, and the surface of the material is hardened due to excessive drying. At this time, the surface temperature of material is usually higher than the internal temperature, and the temperature gradient is opposite to the water gradient, which further limits the diffusion of water from the inside to the surface. Therefore, Hyperspectral imaging technology can be applied to detect the moisture change of banana slice samples during hot-air drying to determine the optimal drying time.

Materials and Methods

Sample preparation

The bananas were purchased from a local supermarket (Tesco). After the pre-treatment of the banana slices, cut out 2×2 cm slices with a knife.

Drying procedures

Hot-air drying of banana slices was carried out in a convective drying-oven. 66 banana slices were used for the investigation of colour changes during hot-air drying. The oven was first preheated to the required temperature of 60℃. Three samples were taken out each time for moisture content measurement and returned to the oven to continue the drying (from 1 to 11 h), another three banana slices were taken for the measurement of colour changes each hour (from 1 to 11 h).

Hyperspectral imaging (HSI)

Hyperspectral imaging (HSI) is a spectral imaging acquisition where each pixel of the image was employed to acquire a set of images within certain spectral bands (Pu, Y.-Y, & Sun, 2015). A laboratory HSI system was used to acquire the hyperspectral images of banana samples in the reflectance model.

Colour measurement

The color parameters of banana slices were measured by Chroma meter, and three samples were measured simultaneously and the average value was calculated. The CIELAB colour space of L* (lightness, values ranging from 0 to 100 with

corresponding dark and white), a*(red (+) to green (-)) and b* (yellow (+) to blue (-)) were directly read from the meter. Chroma (C*), total colour difference (DE), and yellowness index (YI) (Pathare, Opara, & Al-Said, 2012) indicating the degree of yellow colour were calculated as follows:

$$C^{*}=\sqrt{(a_t^{*2})+(b_t^{*2})} \quad (1)$$

$$\Delta E=\sqrt{(L_t^{*}-L_0^{*})^2+(a_t^{*}-a_0^{*})^2+(b_t^{*}-b_0^{*})^2} \quad (2)$$

$$\mathrm{YI}=\frac{142.86\times b_t^{*}}{L_t^{*}} \quad (3)$$

where L*t , a*t and b*t are the colour parameters of samples dried at a certain time t, and L*0, a*0, b*0 are the colour parameters of the original samples.

Shrinkages of dried bananas

Applied computer vision system to acquire a color image and convert it to a grayscale image.

Results and discussion

Moisture content variations in hot-air drying

The moisture content of banana slices was gradually decreased with the increase of hot-air drying time. When the drying time reaches a certain value, the value of moisture content changed minimal with the increased of drying time.

Colour changes during hot-air drying

During the hot air drying, the banana slices samples with an average moisture content have higher moisture content in the center and lower moisture content in the edges.

Shrinkages of surface area

Banana samples dried after HAD had a crumpled and contractive property with a distortion of shape.

Conclusions

Moisture distribution maps generated from hyperspectral imaging can be used to visualize the drying uniformity of banana slices. After HAD drying, the moisture

content of the edge is lower than that of the center, and the pores are very dense.

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PREDICTIVE MICROBIOLOGY：SURVIVAL OF SALMONELLA IN MILK POWDER

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Abstract

Salmonella in milk powder can cause human diseases, food poisoning and diarrhoea, so it is essential to ensure food safety by understanding the growth and survival of Salmonella in milk powder. This study developed a survival model of Salmonella in milk powder based on the survival curve of Salmonella measured in experiment conditions and used Combase to predict the growth of Salmonella in formula milk powder. During the process of preparation, the temperature has a significant effect on the content of Salmonella in the formula, and refrigeration can significantly reduce the final content of Salmonella.

Introduction

According to the statistics of 26 EU / EEA countries, there are 400-581 cases of Salmonella in milk powder every year (Santillana Farakos *et al.* 2013). Disease outbreaks caused by Salmonella in milk powder have always been an urgent food safety issue. Milk powder is one typical kind of low-moisture food with the water activity (aw) of about 0.2 and is recommended to be stored at room temperature. While Salmonella cannot grow at a_w below 0.9, it can survive for a long time in that dry environment and has an observed growth range between 7°C and 40°C. These growth characteristics provide the opportunity for growth of any contaminating populations during the subsequent preparation of milk powder, resulting in potentially high levels of Salmonella concentration at feeding (Paoli and Hartnett 2006). Therefore, it is very important for the food safety of milk powder to predict the growth of Salmonella in the products.

Predictive microbiology is a recent area within food microbiology, which studies the responses of microorganisms in foods to environmental factors through mathematical functions (Pérez-Rodríguez *et al.* 2013). A limited number of environmental parameters in foods determine the kinetic responses of microorganisms, such as temperature, water activity, pH, preservatives and atmosphere. Growth, survival, and inactivation of microorganisms are reproducible responses (Baranyi and Roberts 1995). These functions enable scientists to develop different models to predict the behavior of pathogens and spoilage microorganisms in food under different combinations of factors. The main goal of predictive models in food science is to assure both food safety and food quality.

So far, Farakos has developed a secondary model based on the Weibull model to evaluate the influence of a_w on the survival of Salmonella in whey protein powder (Santillana Farakos *et al.* 2013). Based on that research, Lian et al. from Jiangnan University has created a survival curve of Salmonella in skimmed milk powder (Lian *et al.* 2015). This study will create a primary survival model of Salmonella in milk powder based on the research data of Lian et al., and use Combase to predict the growth of Salmonella in formula milk in different preparation methods.

The objective of this study was to predict the survival of Salmonella in infant formula from storage to consumption and to assess the impact of different preparation and holding methods.

Materials and Methods

Data collection

This study collected data on the survival of Salmonella in low-moisture environments from the Combase database. For the storage period, the survival curve of Salmonella in skim milk powder determined by the experiment (Lian et al. 2015) has been collected. For the preparation and holding period, four scenarios have been collected from FAO and WHO reports (Santillana Farakos et al. 2013). More data are expected to be collected in further research.

Data analysis and modeling

Firstly, the number of Salmonella in skim milk powder at different times were extracted from the Salmonella survival curve by Web Plot Digitizer, and then formulas and models were established to predict the survival of Salmonella in milk powder at different storage periods. Secondly, according to the data in these four scenarios for preparation and holding, the growth of Salmonella was simulated in the Salmonella growth model in Combase.

Results and Discussion

Survival model of Salmonella

It can be judged that the concentration of Salmonella in milk powder decreases with time, and has a similar trend to the logarithmic model. Another research (Santillana Farakos et al. 2013) on whey protein powder has determined similar results, and the results demonstrated that a_w significantly influenced the survival of Salmonella at all temperatures, survival increasing with decreasing aw. This may be related to extra-ribosomal regulation of cellular response influenced by ribosomal proteins.

Growth of Salmonella during preparation and holding

There are four main stages during preparation, holding and feeding of the powdered formula (Paoli and Hartnett 2006): a) Liquid hydration of the powder b) Cooling or holding of formula prior to feeding c) Warming of formula in preparation for feeding d) Feeding of the infant. Four scenarios have been defined in terms of the differences in the duration, the ambient temperature, and the rate at which the formula is heated or cooled:

(a) Premixing of powdered infant formula in a 1-liter container, cooled briefly and then poured into servings with an extended time to consumption.
(b) Mixing of powdered infant formula occurs in the feeding bottle, followed by refrigeration with a short time to consumption.
(c) Mixing of powdered infant formula occurs in the feeding bottle, cooled briefly and then poured into servings with an extended time to consumption.
(d) Mixing of powdered infant formula occurs in the feeding bottle, but there is no refrigeration of the product, and there is an extended time to consumption at very warm room temperature.

Table 2 shows the heating time, speed and temperature in different scenarios.

Table 2. Description of the four preparation scenarios (Paoli and Hartnett 2006)

Preparation Scenario	Stage duration (hours)			Stage temperature (°C)			Cooling rate (u per second)		
	Prep	Cool	Feed	Prep	Cool	Feed	Prep	Cool	Feed
a	0.25	1	6	20	7	27	100	200	200
b	0.25	6	2	20	7	27	200	200	200
c	0.25	1	6	20	7	27	200	200	200
d	0.25	1	6	35	35	35	200	200	200

The growth of Salmonella in the powdered formula will be mainly subject to temperatures. An example of a temperature profile for the preparation, cooling, warming, and feeding stages is

shown. In this research, it is assumed that regardless of the scenario specified that the formula is cooled/warmed to specified feeding temperature and that this process takes 30 minutes.

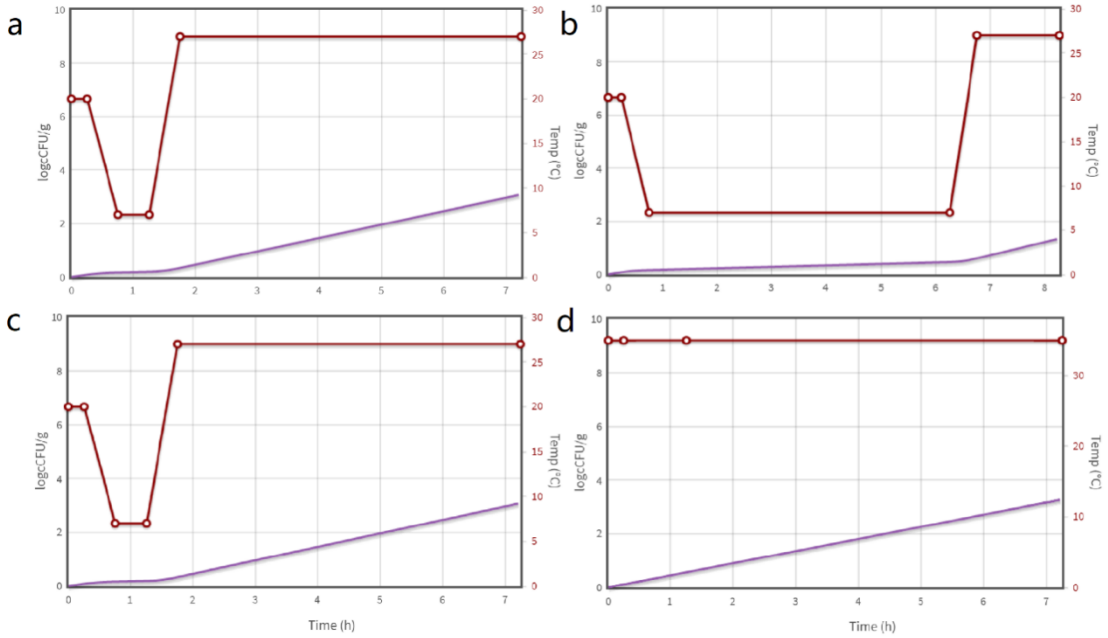

Figure 1. Temperature change and growth curve of Salmonella in four scenarios

Figure 1 shows the change in the concentration of Salmonella in the powdered formula predicted by Combase. In this simulation, we set the initial level of Salmonella in milk powder to Log (0), PH to 6.7, and water activity to 1. The upper red line in the figure shows the temperature change, and the lower blue line shows the change in the number of Salmonella. Figure a, b, c, and d correspond to the four scenarios explained above separately. After 7 hours, the contents of Salmonella in these four scenarios are 2.75 log CFU / g, 0.39 log CFU / g, 2.75 log CFU / g, and 5.09 log CFU / g. With the longest refrigeration time, the final content of Salmonella in scenario b is the lowest, while in scenario d, the final concentration is the highest because of being kept in the environment of 35 degrees Celsius, which is more suitable for the growth of Salmonella. It can be speculated that refrigeration storage can significantly reduce the risk of salmonella infections in the formula. In scenario a and c, although the container of formula milk is different, the growth curve of Salmonella is the same because of the same temperature change in the process, which means that during the preparation of formula milk, the temperature has the greatest influence on the growth of Salmonella.

However, the recommended drinking temperature for the formula is to be around 36 °C, so these four scenarios may deviate from the real situation. In further research, more realistic scenarios will be considered and the reasons and affections of Salmonella survive in low-moisture food will be analysed from more point of views.

Conclusions

This study predicted the survival and growth of Salmonella in milk powder by calculating and using the Combase Salmonella growth prediction model. The results show that the decline in the content of Salmonella in milk powder may follow a logarithmic model, and during the preparation of formula milk powder, the temperature has a great influence on the content of Salmonella in milk powder, refrigeration can significantly reduce the final content of Salmonella in milk powder.

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IMPACT OF STORAGE CONDITIONS OF BARLEY QUALITY

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Abstract

Barley grain is an essential crop in the brewing industry, the harvested crop is dried and stored in a storage facility and fitted with sensors to measure quality parameters such as temperature and relative humidity. The data of storage conditions are collected from these sensors and are collected and compared to establish a relationship between parameters and depth of grain storage. At regular intervals of time samples were taken from the storage bin and its quality parameters measured. A relationship between the quality parameters with respect to the location is derived. A correlation between outdoor weather conditions and stated storage conditions is noted. During this long period of storage time grain undergoes maturation and enters a dormancy state where germination energy breakdowns. This study looks at barley quality deteriorating during the storage period and proffering of quality improvement methods.

Introduction

Barley is the major selected common ingredient in the production of alcoholic beverages e.g. beer and spirits. For the production of these beverages the quality of barley plays a vital role in influencing the desired quality of the end product (Novoa-Muñoz 2019), to obtain that quality after post-harvesting the barley undergoes dormancy where after a certain period of time they can germinate when stored under specific storage conditions, pre-germination or pre-harvest spraying is undesirable and unacceptable in the malting process (Hogy, 2013). Understanding the controlled storage conditions required for keeping the barley to maintain quality parameters the quality of barley in due process initial care at the time of storage is critical (Woonton *et al.* 2005b).

The problems associated with post-harvest grains in a storage facility is pest or insect infestation, the rate of dormancy breakdown and grain quality maintenance during the storage depends mainly on temperature and moisture content, where high moisture content attracts pest problems, respiration, and germination which decrease the storage quality (Zegzulka *et al.* 2019). Efficient aeration is important to prevent improper control of temperature causing moisture to migrate from one grain to another grain due to temperature gradient where the accumulation of moisture could result in spoilage in the grain (Krajcovic *et al.* 2016). Thus, physical, and biochemical changes occur in grain.

Efficient storage quality is obtained by maintaining the temperature and moisture content in the storage facility by varying the depth of storage of grains and daily monitoring to record the change in temperature and moisture where pest and insect infestation can be reduced. Hot air blowing into the storage facility will reduce the spoilage occurring in grains due to external weather conditions with respect to the locations (Woonton *et al.* 2005a; Hogy, 2013)

The main objective of this study is to understand the impacts of storage on barley quality by considering the location within the storage facility and outdoor weather conditions with respect to temperature and moisture content and derive a relationship between storage parameters (temperature, moisture content and storage time) and quality parameters (germination potential, protein content) of the grain.

Material and Methods

Data collection

The sensors which are fitted horizontally and vertically in the storage facility were 6m apart and 1m respectively and the colour coding which helps to easily understand the temperature and relative humidity measured using these sensors is shown in figure 1 below. Relative humidity is used to measure the moisture content of grains. Irish barley, which is grown and harvested in region Ballycullane, Athy, Ireland in the year 2018-2019 was used as source of data.

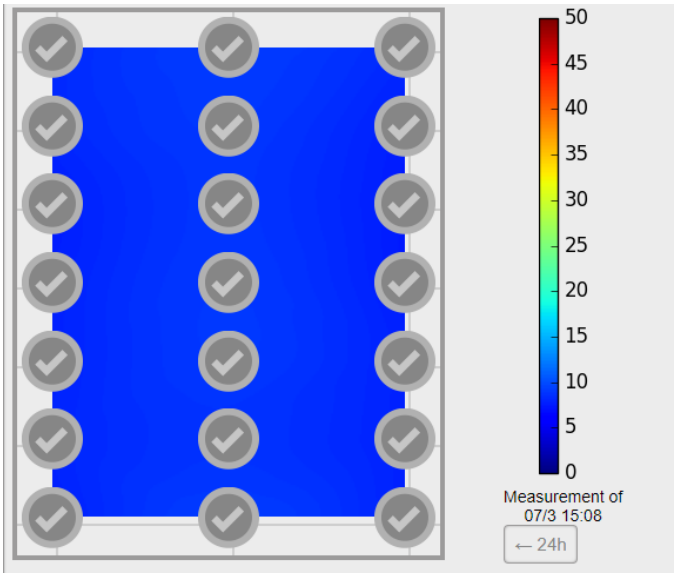

Figure 1. The Horizontal placements of sensors

The storage facility is in rectangular shape, each sensor is placed parallel to one another and the colour code represent the temperature of the storage facility, where the figure 1 shows the temperature value between 5^{o}C-10^{o}C. In the same way humidity of the storage facility can be obtained by sensors and is colour coded.

Germination potential test

Every three months once the barley samples were collected from different depths and levels of the storage facility to check the germination potential was tested. The germination test is carried out with 4ml and 8ml by using a modification methods specified by the European Brewery Convention methods 3.6.2 and 3.7 as in(Krajcovic *et al.* 2016).

Data analysis

Microsoft Excel is used to carry out the analysis of drawing a relationship and correlation between the storage parameters such as temperature, moisture content and storage time and the quality parameters such as germination potential, protein content and nitrogen content.

Results, Expected Results and Discussion

Influence of location on temperature and moisture content of stored barley

When barley is stored in a rectangular storage facility where sensors are fitted by the observation of individual obtained data we can say that the barley grains present at the centre of storage facility are warmer than those close to the walls of that bin. The cooler temperature of barley grains is observed at the edges and walls of storage facility this is due to the influence of the outside weather temperature on storage bin.

If we investigate the relative humidity data collected, we can observe that the moisture content is low in the grains which are close to bin walls. In warmer regions there is an increase and decrease in partial pressure of water vapour with respect to the temperature change and water vapours migrate from warm region to cold region to sustain the equilibrium. The relationship between the location influence on temperature and moisture content is to be drawn.

Relationship between Germination potential and Moisture content with respect to storage parameters
Germination data of 2 sets of data of 4ml and 8ml is been collected at a laboratory scale where the data shows good germination results for barley grains at 4ml test than the 8ml test where barley grains tends to be water sensitivity at the time of test. Whereas from the available literatures we can obtain the best germination results by maintaining the barley grains at or below 14% and 15^{o}C of temperature and moisture content, respectively.

Table 1. Germination test of one batch with 4ml and 8ml in laboratory scale

	4ml (%)			8ml (%)		
Sample	24 hrs	48 hrs	72hrs	24 hrs	48 hrs	72hrs
Store2 Lot 1	43	100	100	22	39	52
Store 2 Lot 2	45	100	100	21	45	61
Store 3 Lot 3	47	100	100	25	47	56
Store 4 Lot 4	54	100	100	19	42	51
Store 5 Lot 5	39	100	100	21	40	59
Store 6 Lot 6	41	100	100	26	53	71
Store 7 Lot 7	46	100	100	25	49	64

The table 1 is the test data conducted at the laboratory scale where 4ml test shows the 100% germination rate after 48 and 72 hours where as 8ml showed less as compared to 4ml due to water sensitivity of barley grains.
The correlation of temperature and moisture content and quality parameter is to be established and the recent data of storage facility is to be analysed.

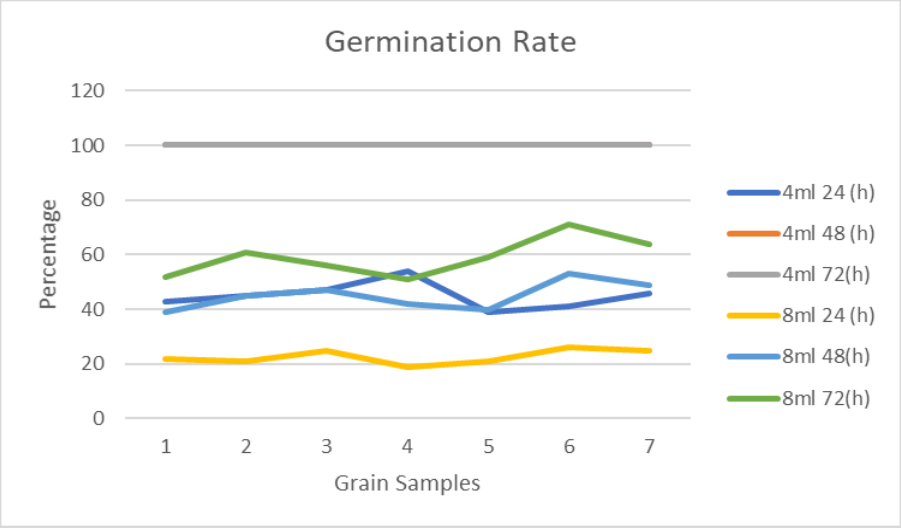

Figure 2. 4ml and 8ml laboratory germination test

Conclusion

Barley grains storage in the bin will always be impacted by temperature and moisture content. By adopting the technology of wireless sensors to monitor temperature and moisture content, specific measures can be adopted to stabilize and maintain the constant temperature and moisture content, so the barley quality does not deteriorate. At the initial stage of storage where the grains have warmer temperature and the external temperature influences the storage bin temperature causing temperature difference at different sides of the storage bin and the centre of the bin. The malting process requires the best quality barley grain in this process the maltsters and grain storage personnel seek to understand what happens during grain storage and try to prevent the barley from deterioration with a decrease in grain quality.

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EVALUATION OF A FLUORESCENCE AND INFRARED BACKSCATTER SENSOR TO MONITOR COAGULATION OF SKIM MILK

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Abstract

This study investigates whether fluorescence and infrared backscatter sensors have the potential to be used for online monitoring of rennet induced skim milk coagulation. Storage modulus (G') measurement of milk gel is used as a rheological reference measurement. A predictive model was developed using responses recorded from fluorescence and infrared backscatter sensors to predict the time required for the coagulum to reach a selected G' value.

Introduction

Rennet induced coagulation is an important processing step in dairy product manufacture. The rennet coagulation process can be briefly described as: the k-casein in milk is affected by the action of chymosin (proteolytic enzyme), which specifically cleaves the protein at the Phe_{105}-Met_{106} peptide bond, making the stable caseinomacropeptide (CMP, k-casein peptides 106-169) diffuse out from casein micelles. When the decomposition level of k-casein reaches a certain level (80%-90%), the casein micelles begin to aggregate and form a gel(Sandra *et al.* 2007). Milk coagulation rate is affected by factors such as milk pre-treatment, pH, composition, temperature, rennet type and rennet concentration(Panikuttira *et al.* 2019a).

Process analysis technology (PAT) is a system that measures the key quality and performance attributes of materials and end products in raw materials and processes in real time for design, analysis, and manufacturing, with the aim of ensuring the quality of the final product. PAT technology is used to continuously monitor and control the parameters in dairy processing, which can minimise the production of poor products and increase productivity and profitability. The PAT technology can be used for the online control of milk standardisation by detecting the fat and protein content as well as monitoring and predicting milk coagulation and syneresis(Panikuttira *et al.* 2018).

Fluorescence spectroscopy detects the fluorescence changes of tryptophan residues due to the changes in micellar structure and protein interactions caused by coagulation in milk to monitor the structural modification of proteins during the agglomeration process and their physicochemical environment(Herbert *et al.* 1999). By analysing the coagulation time measured by the fluorescence spectroscopy and the coagulation time measured by the rheology, $R^2 = 0.9$ was obtained which means the fluorescence spectroscopy technique can be used to determine the coagulation time of rennet-induced milk coagulation(Blecker *et al.* 2012).

Infrared technology has been successfully employed in the dairy industry. An infrared backscatter sensor using 880nm infrared light can be applied to monitor the coagulation time of milk. A near-infrared sensor (CoAguLite) can be used to monitor milk coagulation and predict cutting time online during cheese production(Abdelgawad *et al.* 2016). Infrared optical sensors also help detect the degree of cheese dehydration and estimate related parameters, such as whey yield, curd moisture, and fat, protein, and solid content in whey (Arango *et al.* 2015).

The objective of this study was to evaluate fluorescence and infrared backscatter sensors to monitor the rennet induced coagulation kinetics of skim milk and develop a rheological prediction model to determine the time required to reach selected G' values.

Materials and Methods

Skim milk

Skim milk was stored at 4 ± 0.2 °C. The milk protein content of 3.5% (w/w) and fat content of 0.3% (w/w) were measured using a Dairy Spec FT.

Rennet induced coagulation

30 g of diluted rennet (200 IMCU mL^{-1}) was added to 10 L of skim milk. The estimated rennet activity was 0.054 IMCU g^{-1} of skim milk. The skim milk was stirred at 31 rpm for 3 minutes to ensure good mixing of the added rennet. A 20 mL sample was obtained for rheological characterization. A fluorescence and infrared backscatter sensor was installed on the side wall of the container to monitor changes in milk during the coagulation of rennet induced skim milk. Rennet coagulation monitoring was carried out until the coagulum reached the selected G' value.

Rheological measurement

The change in storage modulus (G') during rennet induced coagulation of skim milk was monitored using a controlled stress rheometer. Experiments were conducted using a concentric cylindrical geometry in oscillation mode at a constant shear strain of 0.02% and a frequency of 1 Hz. The measurements were carried out at 10s intervals until the coagulum over a selected G' value. The times required to reach G' values were recorded and rheological prediction models were developed to determine the time required for rennet induced skim milk gels to reach selected G' values(Panikuttira *et al.* 2019b).

Fluorescence and infrared backscatter sensor

Fluorescence and infrared backscatter sensors were evaluated in this study. The UV light source in the sensor excites tryptophan in milk at 280 nm. The emitted fluorescence was measured at 350 nm. Backscatter of infrared light was recorded at 880 nm. A data acquisition (DAQ) system was used to collect the fluorescence and infrared backscatter responses F and R (V) at 10 s intervals during the coagulation process. The first derivatives of the fluorescence and infrared light backscatter (F' and R') are obtained by calculating the driving gradient using 5 minutes of data (30 points). The second derivatives (F″ and R″) were calculated in a similar manner. The following time parameters were obtained from the derivatives of F and R:

- F'_{tmin} and F'_{tmax}: time parameters corresponding to the minimum and maximum values of the first derivative of F
- F''_{tmin} and F''_{tmax}: time parameters corresponding to the minimum and maximum values of the second derivative of F
- R'_{tmin} and R'_{tmax}: time parameters corresponding to the minimum and maximum values of the first derivative of R
- R''_{tmin} and R''_{tmax}: time parameters corresponding to the minimum and maximum values of the second derivative of R

These time parameters are used to develop a rheological prediction model to predict the time at which the rennet induced skim milk coagulum reaches the selected G' value.

Statistical analysis

The experiment was performed in two batches, each batch consisted of three treatments (level of rennet), each treatment being performed in triplicate (n=18). Statistical analysis of reference rheological data and optical response from prototype sensors was performed using SAS (version 9.1; SAS Institute Inc., Cary, NC). Pearson correlation coefficient is determined by the CORR program. A non-linear regression (NLIN) procedure in SAS was used to develop a rheological prediction model to predict the time at which rennet-induced skim milk gel reaches a selected G' value using time parameters extracted from the measured optical profiles(Panikuttira *et al.* 2019b)

Results and Discussion

Rheological measurement

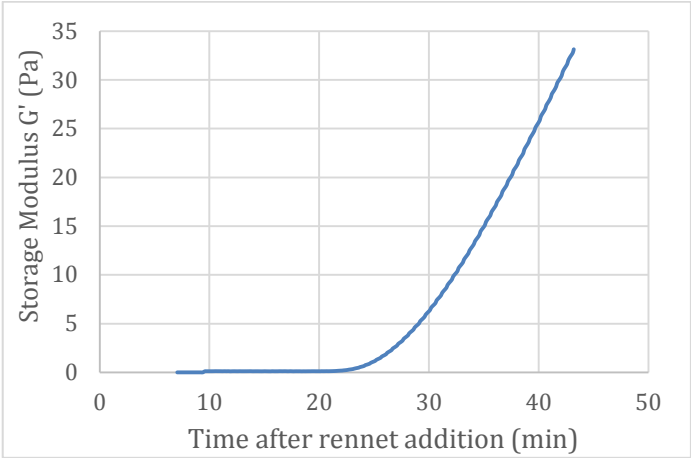

Figure 1. Changes in storage modulus G' of skim milk over time (min).

Storage modulus (G') of the milk gel is an indication of its ability to store deformation energy in an elastic manner. G' is directly related to the extent of cross-linking, the higher the degree of cross-linking the greater the storage modulus. From Figure 1 which shows the storage modulus (G') over time, it can be seen that the G' was about 0 in the first 20 minutes. After 20 minutes, G' began to rise and the upward trend was basically linear. The reason why there is no significant change in G' immediately after the addition of rennet is that only k-casein hydrolysis occurs during this period. When G' starts to rise in the figure, it indicates that the hydrolysis of k-casein has reached a certain level, so that micelle aggregation can occur(Blecker *et al.* 2012).

Fluorescence and infrared backscatter response

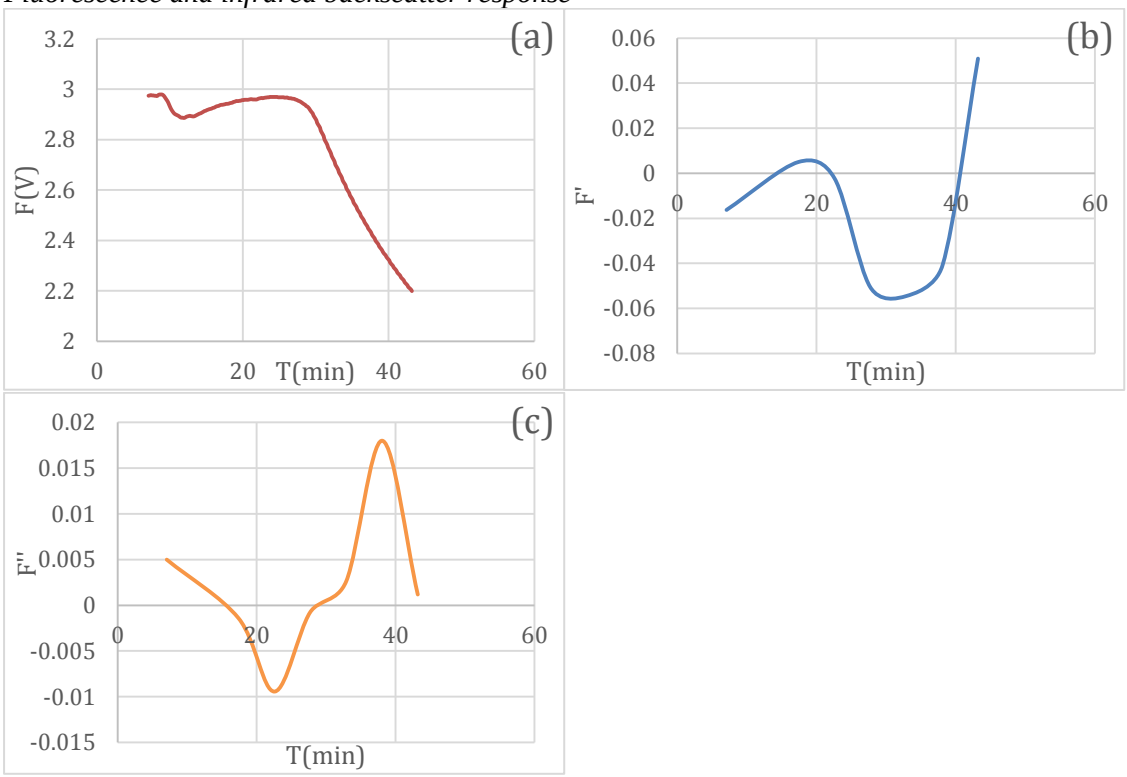

Figure 2. (a) Response from the fluorescence sensor recorded at 350nm for renneted skim milk, (b) First derivative of the fluorescence response versus coagulation time, (c) Second derivative of the fluorescence response versus coagulation time.

From Figure 2(a), we can see that in the early stage after adding rennet, the value of the fluorescence response (F) is relatively stable, and F begins to decrease after the gel begins to form. The reason for this fluorescence response result is that the aggregation and rearrangement

of casein micelles make tryptophan which emits fluorescence emitted at 350 nm reposition. This change blocks the fluorescent signal emitted by tryptophan, resulting in a decrease in the signal received by the fluorescence sensor and a decrease in F(Mains 2017). From the data obtained and Figure 2(b) and (c): F'_{tmin}= -0.06399, F'_{tmax}= 0.005005， F''_{tmin}= -0.01022, F''_{tmax}= 0.023079, which will be used in rheological prediction model.

In future experiments, infrared backscatter sensor response and its first and second derivative will be obtained as well.

Conclusions

The measured spectral data was used to develop a rheological prediction model to predict the time for the coagulum to reach a selected G' value. The accuracy of the prediction model will be determined by calculating the standard error, range standard error and R^2. These statistical vales will determine whether the model has the potential to achieve online determination of time at which the coagulum reaches a selected G' value during the rennet induced coagulation process.

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PREDICTIVE MICROBIOLOGY: FITTING A NONLINEAR MODEL TO GROWTH CURVES FOR LISTERIA MONOCYTOGENES

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Abstract

The aim of this study was to predict the growth of *Listeria* depending on the presence of food hurdles like pH and water activity (a_w). Experimental data was supplied by a collaborating research institute, where it was recorded in the laboratory. Microbial growth was observed through mathematical modelling, by using Baranyi model and simulation software i.e. ComBase (DMfit). Model outputs were promising with high R^2 values. Impact of pH and a_w were encouraging i.e. with decreasing pH and a_w the growth rate declined. This study considered two of the hurdles for food preservation, while it provides an opportunity to explore the impact of acids in addition to these hurdles.

Introduction

Predictive microbiology in is a research area which provides mathematical models to predict microbial behaviour in food environments. Although the first predictive models date back to the 20th century, the majority of the advancements in this field occurred with the development of readily available computer software (Perez-Rodriguez and Valero 2013). Globally, microbial food safety is a great challenge for the food industry (Tenenhaus-Aziza and Ellouze 2015). Therefore, the scientific community and the concerned industries have invested a great amount in the field of predictive modelling and quantitative risk assessment. This led to the development of new technologies for acquiring and processing experimental data, open databases to collect and share data, new mathematical models, and software tools efficient to generate and apply these models (Tenenhaus-Aziza and Ellouze 2015) (McMeekin *et al.* 2006).

While solving predictive microbiology problems, we try to understand the influence of environmental conditions (i.e., temperature, pH, salt concentration, etc.) on the kinetics of microorganisms. This results in producing many sets of microbial growth curves under various experimental conditions, which is statistically not optimal as it does not consider the nested structure of the data. Instead, we can develop a model which brings multiple growth curves under all conditions together. This is possible through mixed-effects modelling, which uses mixed-effects nonlinear regression, and a full data set comprising the results from all the experimental conditions can be modelled at once. This type of modelling that fits the primary (level one) and secondary (level two) model at the same time using all the experimental curves is known as omnibus or global modelling (Juneja *et al.* 2015)

Listeria monocytogenes is a well-known as a foodborne pathogen which is highly influenced by its ability to survive even under stringent environmental conditions. Thus, its presence may cause serious health problems to consumers. This psychotropic bacterium is abundant in nature and has been associated to several number of epidemics of foodborne illnesses. This bacterium can cause severe illnesses, especially during pregnancy and people with damaged immune system (Farber & Peterkin, 1991;2000).

The objective of this study was to apply predictive modelling to the growth of Listeria monocytogenes and observe its behaviour by using hurdle techniques.

Materials and Methods

Primary Model
The growth rate and lag time of Listeria Monocytogenes were calculated based on the Baranyi model (Baranyi et al. 1999):

$$log_{10}N(t) = log_{10}N_{max} + log_{10}\left(\frac{-1 + e^{c_{max}\cdot\lambda} + e^{\mu_{max}\cdot t}}{e^{\mu_{max}\cdot t} - 1 + e^{\mu_{max}\cdot\lambda} \times 10^{log_{10}N_{max} - log_{10}N_0}}\right)$$

Where $\log_{10}N(t)$ is the log of the cell concentration in time t (h) (CFU/ml), $\log_{10}N_0$ is log of the initial number of microorganisms (CFU/mL), $\log_{10}N_{max}$ is the log of the maximum number of cells (CFU/mL), μmax is the maximum specific growth rate within the conditions of the experiments (h^{-1}) and λ is the lag time (h).

Data Collection
Data under study was kindly supplied by a collaborating research institute, which recorded the growth in Listeria monocytogenes in various laboratory medium. All the readings were taken at 30°C. Environmental conditions were distributed with respect to the availability of **acid** (propionic and acetic), while various **pH** (4.7 -5.3) and water content $\mathbf{a_w}$ (0.96-0.98) was also observed respectively. In all growth data for 23 different environmental conditions were studied.

Data analysis
For each sample growth curves were obtained for *L. monocytogenes* using COMBASE, from where sample points were taken, and curves were drawn using DMfit. Growth data from COMBASE for each condition was used for curve fitting. Multiple points were taken, out of which an average of 20 points were used to fit the curve using DMfit. A few criteria were used to determine the accuracy of each condition like standard error (SE) and R square (R^2) values. Early conditions of the food material can also have an impact on the duration of the lag time. It is commonly observed that the temperature history had a considerable effect on the lag phase duration (Membré et al. 1999).

Results and Discussion

Growth rate prediction using DMfit (ComBase)
A typical sigmoidal growth curve was observed after putting in the values of growth rate using DMfit provided by ComBase. Lag-time and stationary phases along with growth phase were also considered for the modelling which is depicted in **Figure 1 & Figure 2**, which are a sample out of the given conditions. With this approach, the behaviour of *L. monocytogenes* on food, in the presence of organic acids, varying pH and a_w was explained. It allows comparison between experimental data and prediction software. The curve fitting worked out to be pretty much close to actual, with R^2 values ranging from 0.8 to 1. Samples with acids tends to have lower growth rate than the ones without any acid, which shows the inhibition of microbial growth in the presence of acids. Strain to strain variation with respect to acid type and quantity was also considered during the modelling of various conditions of the samples.

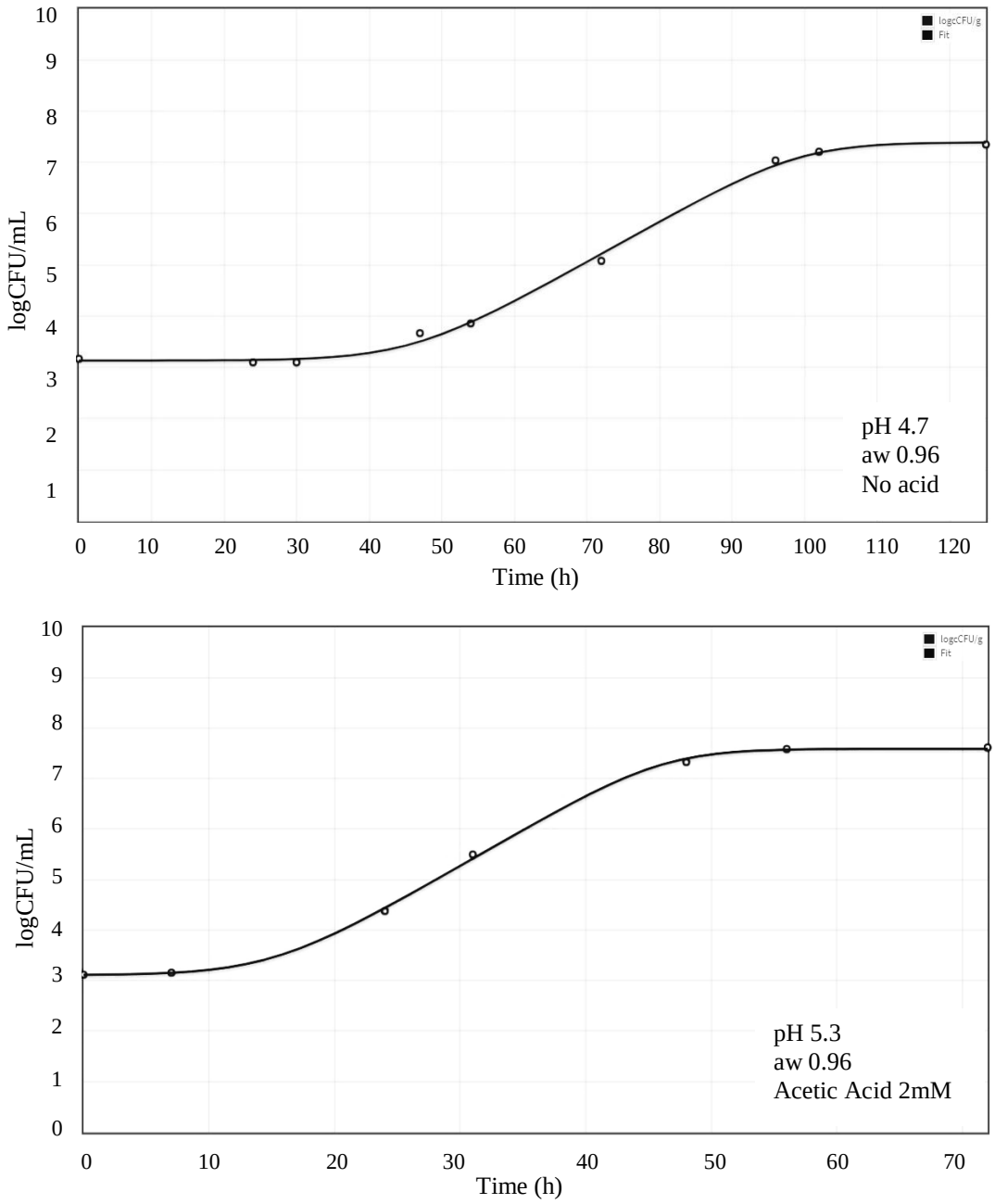

Figure 1. Growth rate prediction of *L. monocytogenes* using DMfit (Combase) curves at 30°C.

Impact of a_w on growth

Firstly, the flexibility was studied through various factors such as a_w and pH by varying them respectively. Secondly, growth rates obtained from ComBase were plotted against **a_w** and **pH**, which illustrated the behaviour of the bacteria under circumstances. As expected, the bacterial growth depicted a decline with decreasing a_w in the samples as shown in **Figure 2**, which means that by lowering the water content in the product microbial activity can be controlled. Decreasing a_w also indicates the increasing hurdle for the growth of *L. monocytogenes* in our samples. Various data points in **Figure 2** depicts the varying **a_w** in the samples under consideration.

Impact of pH on growth

Furthermore, bacteria showed some changes with the varying pH. Microbial activity tends to show somewhat similar trend as changing a_w, it decreases with the decreasing pH as shown in

Figure 2. Thus, stating that increasing acidic nature of the product also works as a hurdle for the bacterial growth. Data points shown in the **Figure 2** show varying pH in the samples.

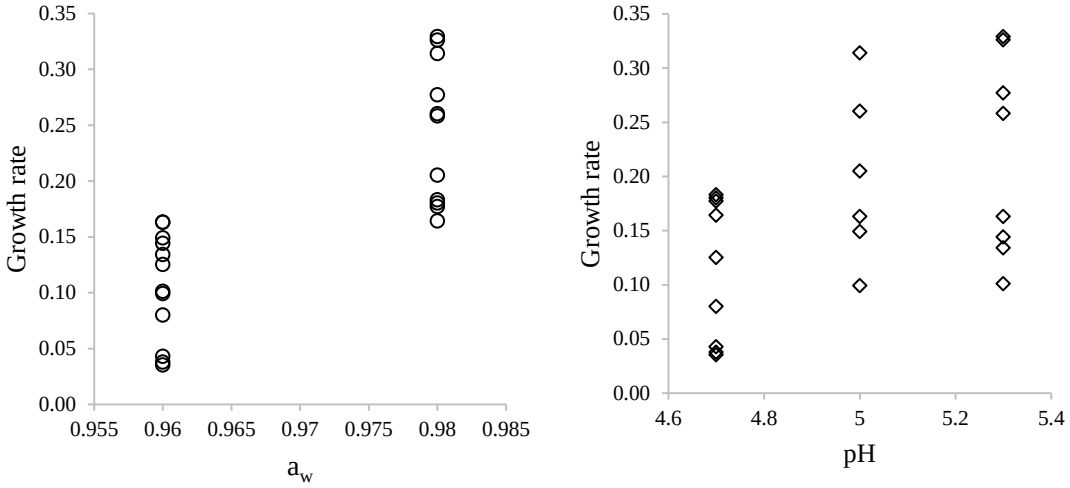

Figure 2. Variation in growth rate with a_w (o) and pH (◊) of *L. monocytogenes* at 30^{o}C.

Conclusion

The results highlight the importance of predictive microbiology in food safety and preservation techniques. Moreover, use of hurdle technology to restrict the microbial growth plays a vital role. The impact of varying a_w and pH has been studied so far, but it can be expanded to learn about the action of acids on the behaviour of *L. monocytogenes.* Use of organic acids as a hurdle in food preservation techniques is of great importance. Therefore, predictive modelling can help the food industry in providing safer products, but it is highly dependent on the experimental data.

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GREEN BIOREFINERY: A PROTOCOL FOR THE CHEMICAL ANALYSIS OF AMINO ACIDS IN GRASS SILAGE JUICE

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Abstract

With increasing climate and environmental issues such as global warming and extreme natural disasters, human demand for sustainable technologies to produce biobased products is increasing. Green biorefinery represents the capacity to satisfy the ecological and economic requirements by converting green biomasses such as grass silage into a spectrum of valuable products and energy. In grass silage juice, amino acids are produced by enzymatic hydrolysis and fermentation of proteins while lactic acid is formed from sugars by fast-growing lactic acid bacteria. The overall target of this project is to explore a protocol for the chemical analysis of amino acids in grass silage juice. HPLC and GC-MS can provide both high accuracy and efficiency and are proposed within this project as being the mechanism by which amino acids present in grass silage juice can be identified.

Introduction

Permanent and arable grasslands account for about a third of Europe's agricultural land (Kamm *et al* 2016). Hence, the large acreage of grassland can provide the abundant raw material for green biorefinery. From an environmental perspective, the use of grass silage for animal feed can represent a mitigation option by reducing greenhouse gas (GHG) emissions as opposed to feeding livestock directly with grass. Feed production and processing contributes 45% to the total livestock GHGs emissions (Gerber *et al* 2013). High-quality grass silage can significantly reduce GHGs emissions intensity by reducing the enteric methane production while maintaining the constant milk yield of cows and has greater potential to reduce emissions intensity in beef production (Åby *et al* 2019).

Green Biorefinery is a novel refinery technology which fractionates green biomass to a fiber-based cake and a nutrient-rich liquid phase (Schaffenberger, 2013).To establish a multi-product system that distinguishes and makes full use of each component of the biomass, an important measure is to use grass silage instead of fresh grass for feeding to ruminant animals to facilitate the sustainable agricultural transition (Ecker *et al* 2012). During the grass ensiling process, the sugars are hydrolyzed into lactic acid by fast-growing lactic acid bacteria and the proteins are converted into amino acids by enzymatic hydrolysis and fermentation. (Santamaria-Fernandez *et al* 2019; Thomsen *et al* 2004). Lactic acid and amino acids are the main valuable products in the grass silage juice after such a green biorefinery process.

Organic molecules that contain an acidic carboxyl group (-COOH) and at least one basic amino group ($-NH_2$) are called amino acids. Currently, amino acid analysis (AAA) in biological samples is commonly carried out by high-performance liquid chromatography (HPLC), ion exchange chromatography (IEC) and gas chromatography-mass spectrometry (GC-MS). HPLC (Thang *et al* 2008) and IEC (Ecker *et al* 2012; Santamaria - Fernandez *et al* 2019) have been successfully used in the AAA of grass silage juice. GC-MS has been used to separate, identify and quantify the amino acids in fermented potato juices within a green biorefinery (Starke *et al* (2001). These methods will be further explored for the AAA of Irish grass silage juice.

The objective of this study was to develop a protocol for the chemical analysis of amino acids in grass silage juice within a green biorefinery.

Materials and Methods

High-performance liquid chromatography (HPLC)
High-performance liquid chromatography (HPLC) is considered as the best analytical method for the AAA in the grass silage juice due to the short time for separating different amino acids together with the high accuracy and specificity (Madrid *et al* 1999; Thang *et al* 2008). Components in the mixture are separated by the different affinities of the organic molecule for the mobile phase and stational phase and the different amino acid molecules are distinguished by the retention times on the spectrum. Herbert *et al* (2000) reported that 21 amino acids in musts and port wine are successfully identified by HPLC within 20 minutes.

Gas chromatography- mass spectrometry (GC-MS)
With the advantages of the simple sample preparation, short runtime and high precision of quantification, GC-MS is an attractive alternative of AAA to HPLC. GC-MS has been used to separate, identify and quantify the amino acids in fermented potato juices within a green biorefinery (Starke *et al* 2001). The amino acids are derivatized by *N*-Methyl-*N*-tert(butyldimethylsilyl)trifluoroacetamide (MTBSTFA) to generate *t*-butyldimethylsilyl derivatives for the identification by EI and CI mass spectra (Starke *et al* 2001). The method is planned to be utilized in the AAA in grass silage juice in this project.

Ion exchange chromatography (IEC)
Ion exchange chromatography (IEC) coupled with post-column derivatization by ninhydrin is regarded as the most conservative method for amino acid detection in this project (Ecker *et al* 2012). While accurate, IEC testing requires a special analyzer and usually takes several hours for detection, which is less efficient than HPLC and GC-MS (Schwarz *et al* 2005).

Sample preparation
The raw material analyzed within this project will be grass silage juice, taken and pressed by the silage from local grassland in Ireland. After pressing, the sample preparation method refers to the method reported by Ecker *et al* (2012). Firstly, the pressed liquid phase will be left to settle for 1 day to remove sand grains and insoluble sediment, and then the feed solution for subsequent instrumental analysis will be obtained through membrane filtration and bag filtration (mesh size 50 μm).

Chemical-analytical instrument set up:
The best two of the three methods list above, HPLC and GC-MS will be assessed and discussed.

In this project, a HPLC Dionex Summit with RF 2000 Fluorescence Detector will be used. Referring to the detection parameters reported by Thang *et al* (2008), the samples will undergo the precolumn derivatization with OPA through a GROM-SIL OPA-1 column (Alltech GROM GmnH, Germany) and then gradient elution will be performed. The flow rate will be kept at 1 mL min^{-1}. The column temperature will be set at 25 ℃. Eluent A will be 25 mM sodium phosphate, pH=7.2/tetrahydrofuran (995/5); Eluent B will be 25 mM sodium phosphate, pH = 7.2/MeOH/ acetonitrile (50/35/15).

GC-MS detection will be conducted as per the method reported by Starke *et al* (2001). The juice will be derivatized by MTBSTFA. Varian (series 3400) gas chromatography coupled to an SSQ 710 quadrupole MS (Finnigan) willed be used. The carrier gas is Helium at a flow rate of 1 mL min^{-1}. The oven will be first kept at 120 ℃ for 4 minutes and measured by the temperature-programmed method. In the MS system, 70 eV of the electron energy and 200 μA of the filament current will be applied. The temperatures of the interface and the ion source will be 320 ℃ and 150 ℃, respectively. The scan rate is 1.0 s $scan^{-1}$ over the m/z range 50–700.

Expected Results and Discussion

Prediction of the amino acid concentrations in the grass silage juice
Based on previous AAA conducted, it has been estimated that the following AAA can be achieved. It is expected that HPLC and GC-MS can complete the AAA of 20 amino acids in grass silage juice. To achieve this goal, the optimal HPLC and GC-MS instrumental setups, operational-parameters and any influencing factors will be identified.

Analysis of potential problems and the influencing factors
In the HPLC analysis, the instability of OPA derivatives of several kinds of amino acids such as glycine, GABA and lysine may affect the accuracy of the determination results. Mengerink *et al* (2002) demonstrate that more than one OPA derivative of selected amino acids can be found from the transformation from the initial OPA derivative under the influence of hydrogen atoms on $-CH_2-$, which is attached to the primary amino group.

In terms of the errors of GC-MS, different additional peaks of "Maillard reaction products", which are generated by the reactions of the glucose or other reducing carbonates with amino groups, are proved to exist in the GC-MS spectra (Starke *et al* 2001). Different Maillard reactions are expected because of the existence of carbohydrates and a variety of amino acids in the grass silage juice.

IEC has been proven to accurately perform qualitative and quantitative analysis of amino acids in grass silage juice using an analyzer specially designed for AAA (Ecker *et al* 2012; Schaffenberger, 2013). It may present better specificity than HPLC and GC-MS, but due to the requirement for additional instruments and the long analysis time caused by post column derivation technology, it is not considered as the best AAA in grass silage juice but more used as reference and comparison of HPLC and GC-MS results in this subject.

Conclusions

Overall, the green biorefinery is a promising approach to exploit the value of unused biomass in a lucrative market context. A protocol for the chemical analysis of amino acids in grass silage juice within a green biorefinery is proposed in this project. As a consequence of the simplicity of the sample preparation step, rapid detection procedure and high precision, HPLC and GC-MS are recommended for routine measurement of amino acids in grass silage juice while the commonly used IEC amino acid analysis is more for reference and comparison. 20 amino acids are expected to be qualified and quantified by the retention time and peak area in the high-performance liquid chromatogram as well as the combination of the gas chromatogram and mass spectra in the GC-MS method. Further study of the influencing factors and the average limit for the detection of amino acids in grass silage juice will be carried out.

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NONDETRUCTIVE DETECTION OF MOISTURE AND CALORIE CONTENT IN ROASTED NUTS BY USING TERAHERTZ IMAING TECHNIQUES

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Abstract

Nuts are popular as a healthy food with high nutritional value and flavour. Due to the increasing demand for food, it has become an important concern of public safety to control the quality and safety of food. Conventional technologies generally have the limitations of being time-consuming with high labour requirements, and are destructive to food. Terahertz imaging technology is an emerging non-destructive method for detecting food quality. The Fourier transform converts the time-domain terahertz wave into a frequency-domain spectrum, and the stoichiometry is combined with Matlab to calculate the quality parameters in the qualified nut sample. The results show that terahertz imaging technique can be used to determine the moisture and calorie content in nuts.

Introduction

Nuts are known to be rich in biologically active substances such as large and micronutrients, phytochemicals, tocopherols and phenolic compounds that promote good health (Shakerardekani *et al.*, 2013). Therefore, the consumption of roasted nut products has always been considered as one of the components of consumer organisms to achieve a healthy diet (Chandrasekara & Shahidi, 2011). In the food processing industry, the measurement of moisture and calorie content is critical to the quality of food. The water content of products can directly affect its quality characteristics, such as bacterial growth, texture, and taste (Parasoglou *et al.*, 2009). Epidemiological evidence suggests that edible nuts may have a variety of cardioprotective effects, presumably due to their lipid composition, so efficient and accurate detection of calorie content has an important role in reducing the impact of oil on the body (Chandrasekara & Shahidi, 2011).

Common safety analysis and methods for detecting the content of substances in food have their own advantages, but they are destructive and limited. In addition, most of them are time-consuming, labor-intensive and requiring amount of laboratory and reagent resources (Afsah-Hejri *et al.*, 2019). Terahertz imaging technology is a new type of safe and reliable non-destructive testing technology that uses spectroscopy and imaging technology. Terahertz wave refers to a small area between the microwave and infrared waves in the electromagnetic spectrum (Wang *et al.*, 2017). Due to its unique frequency range, 0.1 to 10 terahertz (3.3 cm - 1 to 333.6 cm -1), terahertz waves have more characteristics and can provide information that cannot be obtained by conventional methods (Afsah-Hejri *et al.*, 2019).

Terahertz detection technology can provide qualitative and quantitative information about food samples (Afsah-Hejri *et al* 2019). Compared with commonly used spectral imaging technology, terahertz imaging can provide more accurate spectral information, higher image contrast and non-ionization characteristics.The main applications of terahertz in the agricultural food industry include moisture detection, foreign body detection, inspection and quality control, and detection of harmful compounds (Afsah-Hejri *et al* 2019).

The objective of this study is to use non-destructive testing of terahertz imaging technology to detect the moisture and calorie content of roasted nuts.

Materials and Methods

Raw material selection

According to the basic principle of the experiment, the samples of sunflower seeds, cashews and pistachios that meet the size requirements were selected. All samples were purchased from the local market and screened for size and texture. The thickness of the prepared sample slice is between 0.4 mm and 0.5 mm, and the average number of each sample reaches more than ten, and the weight is recorded separately for experimental analysis. Before analysis, store samples in the same environment at room temperature.

Determination of quality indices

The experiment requires more than 30 times separately, three samples were placed on the sample holder in sequence, each sample measured more than 10 times, and recording and saving the spectrum.

Terahertz Spectral Imaging System

The working principle of the terahertz imaging system is shown in the figure below.

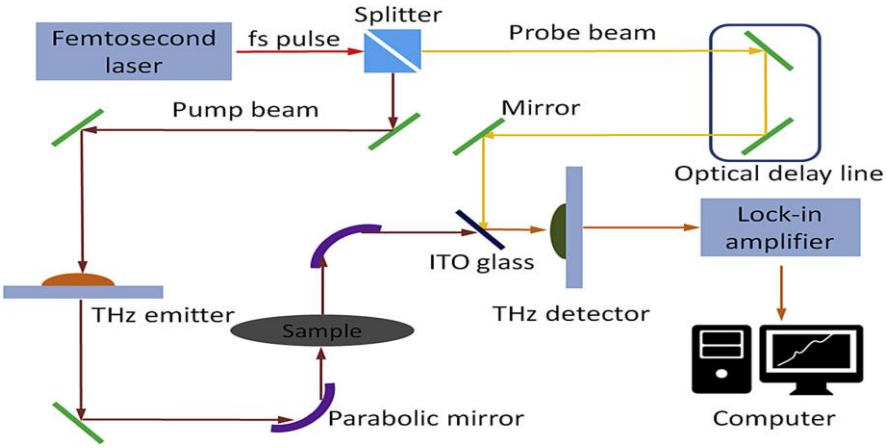

Figure 1. Schematic diagram of time-domain terahertz spectrometer (Wang *et al.*, 2017)

Data analysis

In this study, THz time-domain spectroscopy (THz-TDS) is a very effective measurement tool. It is mainly composed of femtosecond laser, 210 Ghz transmitter, collimator, Si beam splitter, focusing lens, schottky diode, petri dish, 3-axis translation stage. The laser generates an optical pulse at 800 nm with a pulse duration of less than 100 fs and a power of about 10 to several hundred milliwatts (Wang *et al.*, 2017). The laser pulse passes through the collimator and beam splitter and is divided into a transmitted wave and a reflected wave. The transmitted wave excites the THz transmitter through the objective and reaches Schottky diode -2, thereby emitting a broadband pulse of THz radiation. The effective bandwidth of the terahertz system is up to 1.5 THz, and the signal-to-noise ratio is 1100: 1. The bandwidth corresponds to a frequency of 10% of the maximum amplitude in the frequency domain (Chua *et al.*, 2005). The THz-TDS system generates a function of the time-domain signal and is converted into the frequency domain by a simple Fourier transform. The effective frequency range for analysis is 0.1-5Thz. For each sample, perform more than ten spectral scans, and use Scancontrol of Mentosystems software to record the scan time and frequency spectrum. Multiple averages will be recorded after the data stabilizes. Terahertz imaging is performed on the scanned infrared spectrum by Teralmage software to obtain a stable average spectrum of more than 10 times for each sample. Design Matlab software program to calculate the moisture and calorie content of the sample in the spectrogram. In order to evaluate the performance of the prediction model, the model needs to be corrected. The model should have

a high correlation coefficient (R), a low correction value (RMSE), and a small difference between calibration (RMSEC) and cross-validation (RMSECV) or prediction (RMSEP).

Results and Discussion

Prediction of moisture content

Select the average of ten measurements for each sample separately to generate THz-TDS images. In the frequency range of 0.1-2Thz, the higher the moisture content of the sample, the greater the absorption of terahertz radiation, resulting in a decrease in the spectrum amplitude, especially in the range below about 0.6THz. Import the image into Teralmage software to generate the spectrogram, and then use the linear regression method of PLS to linearize the latent variables in the terahertz spectrum data. Later, using Matlab software for data analysis,.

Prediction of calorie content

The food matrices (flour, milk powder and chocolate powder) were prepared with different concentrations of melamine. The moisture content of the three food base materials was less than 14%. It was found that the absorption peaks of melamine appeared at 2, 2.26 and 2.6 THz, corresponding to 66.6, 75.3 and 86.6 cm-1, respectively. It can be predicted that the terahertz spectrum scanned by the calorie content of three different nuts mainly shows in the range of 0.1-3Thz.

Conclusions

Both the moisture and calorie content of roasted nuts (sunflower seeds, cashews and pistachios) are successfully predicted using terahertz imaging technique. The combination of terahertz technology and chemometric methods can achieve qualitative analysis of food quality parameters. Because the terahertz image technology has limited sensitivity, low LOD, and depends on the thickness, increasing the scanning speed and sensitivity of this method makes it a safe and reliable non-destructive testing method in the food industry.

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USING GENOMICS TO PREDICT THE THERMAL TOLERANCE OF PATHOGENS – *Bacillus Licheniformis*

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Abstract

Bacillus Licheniformis, a food borne pathogen is responsible for food spoilage and poisoning when consumed. This pathogen forms spores which makes it resistant to thermal processes and may to survive in a commercial product. Skim milk powder is known to have the presence of this pathogen and the current study helps in investigating this. The current study evaluates the presence of Tn*1546* transposon, encapsulated in SPOVA operon that is responsible for thermal resistance in different strains of *B. Licheniformis* obtained from the industrial samples of various skim milk powders. The tool BLAST was used to compare established genomic sequences that are responsible for this trait and the query cover percentage is observed to confirm the presence of this genome in the given isolate.

Introduction

Bacillus Licheniformis is a predominant pathogenic bacteria which belongs to "Bacillus" species and is mostly found in soil, in the farm environment (feed, manure), in raw milk and at all stages of dairy processing also in unprocessed foods, food ingredients and products including: cocoa, herbs, spices, bread, milk powder *(te Giffel et al., 1996)*. This is a foodborne pathogen which poses a health hazard and is also involved in food poisoning incidents when consumed in the form of contaminated food products such as skim milk power and powdered infant formula. These spore-forming bacteria can survive in adverse environments (*Eugénie Baril et al., 2012).* Despite undergoing various stresses known as 'hurdle technologies' to get rid of pathogens, *Bacillus Licheniformis* are known to survive by developing a tolerance to the stresses that they go through *(Nidhi Gopal et al., 2015).* Amongst the different traits developed by *Bacillus Licheniformis,* the most important factor for survival is thermal tolerance. The thermal inactivation of these strains can be obtained using decimal reduction time, also known as D-value (used to explain thermal tolerance), which is defined as the time taken to kill the 90% of microorganisms at a given temperature.

The thermal tolerance of this pathogen is due to the formation of spores when subjected to harsh environment or high temperatures and these spores with high-level heat resistance contain a Tn1546 transposon, encompassing a SPOVA operon that is directly responsible for this phenotype *(Berendsen et al., 2016)*. This heat resistance is displayed as a reference decimal reduction time of spores per strain at the reference temperature of 110°C (D110°C-values) in relation to the presence or absence of the Tn1546 transposon *(Erwin M. Berendsen 2016)*. Strains *B. licheniformis* B4090, B4092, and B4094 contained the Tn1546 transposon, and the spores of these strains all required longer heating times (unpaired t-test $p < 0.001$) (2.5 times) to reach a decimal reduction than the spores of the six *B. licheniformis* strains that did not possess the Tn1546 transposon *(Erwin M. Berendsen 2016).*

The objective of this study is to identify the presence of a genomic sequence responsible for thermal tolerance in the different strains of *Bacillus Licheniformis* using the BLAST tool and to identify the presence of these strains in the isolates of various Irish skim milk powder samples.

Methodology

Isolates from various skim milk powder samples were collected from industry. With the help of public databases, the genomic sequence of SPOVA operon was downloaded and stored. To determine the presence or absence of strains which are responsible for the thermal tolerance in the skim milk powder samples, the BLAST (Figure 1) tool was used to compare the isolates extracted with the genomic sequence of SPOVA operon. In response to this comparison on the tool, a query cover percentage is resulted to influence the level of comparison and this tool also helps in identifying the alignments of the genomic regions.

BLAST tool

BLAST stands for Basic Local Alignment Search Tool; a product of National Center for Biotechnology Information helps to find regions of similarity between biological sequences. A search in this tool allows to infer the function of a sequence from similar sequences. The program compares nucleotide sequences to sequence databases and calculates the statistical significance. Besides, this also calculates an "expected value" that estimates how many matches would have occurred at a given score, which can aid a user in judging how much confidence there is in an alignment.

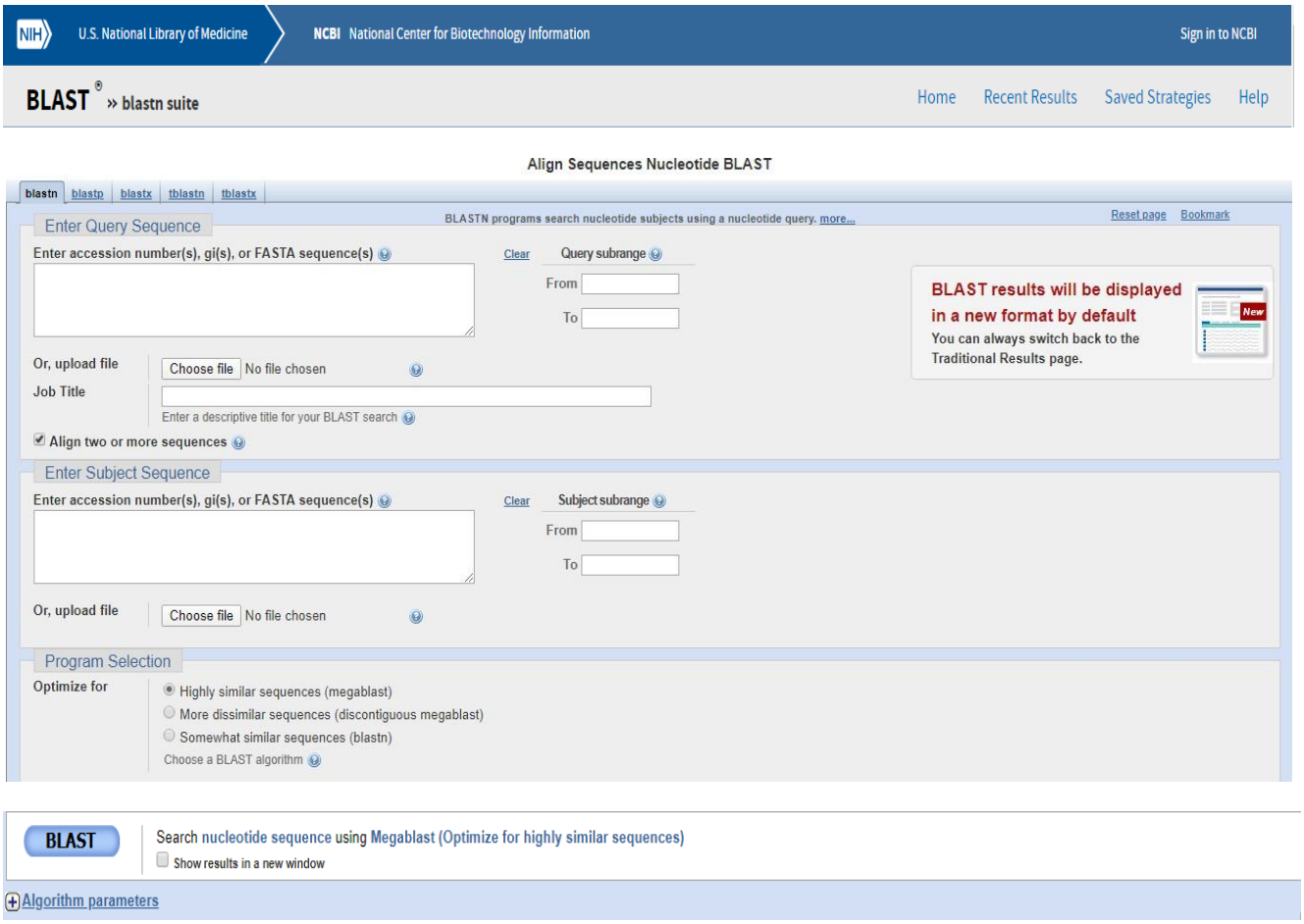

Figure 1. BLAST Tool Layout (NCBI- BLASTn)

Results and Discussion

Isolates obtained from six different industrial skim milk powder samples were compared with SPOVA operon in order to check the presence of genomic sequences responsible for thermal tolerance and it is found that almost all the processed samples have proven the presence of heat resistant spores.

Table 1. List of processed samples with the presence of SPOVA .

Isolate	Presence of SPOVA	Query Cover Percentage (%)
3127	Yes	100
3146	Yes	100
3148	Yes	100
3149	Yes	100
3168	Yes	100
3169	Yes	96

Conclusion

The presence of the SPOVA operon (with *Tn1546* transposon) in the extracted isolates of processed Irish skim milk powder samples explains the presence of heat resistant strains of *B. Licheniformis* in them, however, this does not give the complete information about the thermal properties of each individual strain. The results of this study help to take the necessary steps or techniques to eliminate the pathogen in the product for it to be safe to consume.

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EFFECT OF ULTRASOUND PROCESSING ON THE SELECTED ORANGE SMOOTHIES QUALITY PARAMETERS

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Abstract

Novel food processing, such as ultrasound treatment, is a promising method that can maintain the nutritional values of the product more than the traditional thermal processing and is commonly used to process fruits and vegetable juice/smoothies product. The effect of the ultrasound processing on the quality parameters of formulated orange smoothies was investigated in this study. The smoothie sample would be subjected to an ultrasound treatment with the amplitude level at 25%, 50%, 75%. And 100% and the exposure time of 2, 6, and 10 min. The main parameters that would be determined were the rheological property (apparent viscosity and shear rate), bioactive compounds content (ascorbic acid, phenolic compounds, and anthocyanin), and colour parameters. It was expected that the application of ultrasound on the smoothie would result in a decrease in apparent viscosity and shear rate as the amplitude level and exposure time increased. There would be slight decreases in all bioactive compounds content. Lastly, the rises in amplitude level and exposure time would induce the changes in the overall colour of the smoothie samples.

Introduction

With the global food consumption trend moving toward health and wellness, people become more concern with their health and seek healthier dietary intake. According to UN Food and Agricultural Organization statistic database, the consumption of fruit and vegetables within the European countries has been increased in the past decades as more countries have the consumption that meets the recommended dietary guideline from the World Health Organization. Thus, many manufacturers produce many varieties of healthy food products. Fruit and vegetable smoothies are becoming more popular among EU consumers within the past few years as shown in the market report conducted by AIJN European Fruit Juice Association (2019). Smoothies is made from combining fruit (as well as vegetable) blended purée and its juice with the addition of dairy ingredients, such as yogurt, and/or some functional ingredients, such as bioactive extract or microalgal biomass. As the demand of the fruit and vegetable smoothies are currently high, consumers are concerned with the quality of the product as they want products with more higher health benefits as well as its fresh-like visual appearances, tastes, and flavours. Thus, many manufacturers and researchers are seeking to find an innovative way, replacing the conventional thermal processing, to process the smoothie product that can maintain the amount of bioactive compounds and vitamins as much as possible.

One of the promising methods is the ultrasound processing. It's a treatment method that applies the ultrasonic waves into the treated liquid. The ultrasonic waves generate gas or vapor micro-bubbles within the liquid sample and as the micro-bubbles collapse, it creates high localised temperature and high localised pressure. This phenomenon is called cavitation (Villamiel *et al.* 2017). The phenomenon of cavitation is mainly contributed to the ultrasound processing potential in preserving the quality of the fruit and vegetable smoothies as it can inhibit spoilage microorganisms through cell disruption and some sonochemical reactions. Many studies have shown that the application of ultrasound treatment in fruit and vegetable fluid has capabilities in inhibiting microbial growth and improving some sensory attributes of the treated product (Irkilmez *et al.* 2017; Ordóñez-Santos *et al.* 2017; Sulaiman *et al.* 2017; Türken and Erge 2017; Ribeiro *et al.* 2019).

The objective of this study is to investigate the effect of ultrasound processing on the selected quality parameters of formulated orange smoothies and to determine the optimal conditions for the ultrasound treatment in the orange smoothies.

Materials and Methods

Orange smoothies formulation
Fruits and vegetable that were used as the main compositions included orange, banana, carrot, and mango with the addition of microalgae extract. The ingredients were then blended with the homogenizer for 3 min or until fully homogenized. The fresh control sample was immediately chilled, while other portions of the sample were subjected to the ultrasound processing.

Ultrasound treatment
The ultrasound treatments of the sample were modified from the method proposed by Keenan and co-researchers (2012). The orange smoothies samples were subjected to the twin-probe sonicator at TEAGASC Ashtown Food Research Centre, Ireland. Samples were treated with the ultrasound at the constant frequency with varied extrinsic parameters of amplitude output at 25%, 50%, 75%, and 100% and exposure time of 2, 6, and 10 min. The ultrasound machine would be set to emit a constant pulse with 5 s on and 5 s off duration.

Determination of the rheological property
The rheological property of the treated samples was measured according to Keenan *et al.* (2012).

Determination of ascorbic acid content, phenolic content, and anthocyanin content
The ascorbic content of the sample was determined using the method described by Tiwari *et al.* (2009). For the anthocyanin content, the method used was described by Keenan *et al.* (2012)

Determination of colour parameters
The colour parameters were measured according to Keenan *et al.* (2012).

Data analysis
The data obtained from the determination of ascorbic acid, phenolic content, and anthocyanin content were analysed using the response surface methodology as described by Keenan *et al.* (2012).

Expected Results and Discussions

Expected results on the rheological property
The rheological property of the smoothies sample would be expressed in a graph derived from the power law model (Keenan *et al.* 2012). The predicted results would be that all samples would show shear thinning behaviour. Moreover, the apparent viscosity of the samples showed decreasing trends as a function of applying the ultrasound treatment to the sample. Particularly, among the samples treated with the sonication, there was a decrease in the consistency index as the amplitude and the exposure time increased. If comparing with the fresh control, the treated samples should have lower consistency index than the control. This was because the ultrasonic waves have the ability to break down the particle sizes of the solids within the smoothie via mechanical energy. Thus, as the particle size reduced, the apparent viscosity and consistency index decreased.

Expected results on the ascorbic acid, phenolic, and anthocyanin content
The total content of ascorbic acid, phenolic, and anthocyanin of the smoothies sample could be predicted following the findings of Keenan *et al.* (2012) shown in Figure 2. In general, the amount of these bioactive compounds could significantly decline as the amplitude increased. The higher amplitude of the ultrasound applied onto the sample, the higher degradation of the bioactive compounds in the sample would occur. Similarly with the exposure time, as the sample was exposed to the longer sonication treatment, the higher the loss of these compounds would occur. Such degradation could be caused by the formation of free radicals due to the cavitation by the ultrasonic waves.

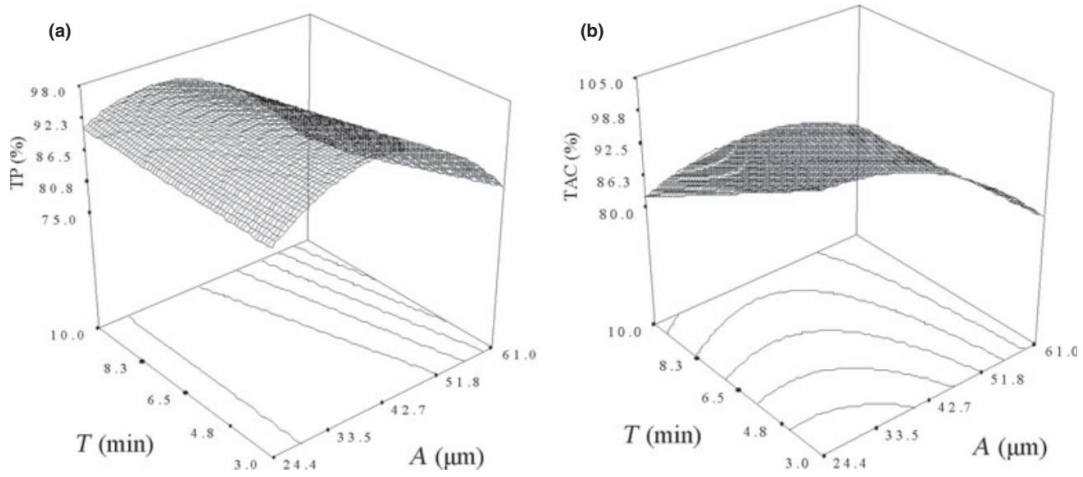

Figure 2 The response surface diagram showing the changes in total phenolic content (a) and total anthocyanin content (b) with the respect to the amplitude level and exposure time.

Expected results on the colour parameters

The colour parameters of the smoothie sample could be expressed in the response surface diagram as shown in Figure 3 (Keenan *et al.* 2012). There was a possibility that the total colour change would increase as the amplitude level and the exposure time increased. This was due to the formation of the free radicals within the smoothie due to the cavitation phenomenon. The generated free radicals could facilitate oxidation of the colour compounds in the smoothies leading to the degradation of its colour.

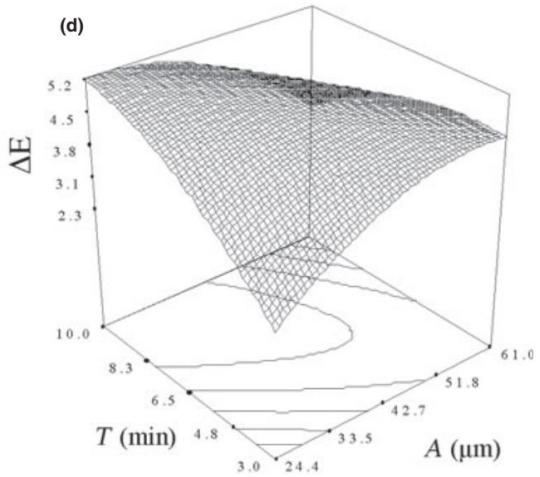

Figure 3 A preferred model for the total colour change of the smoothie samples with the respect to amplitude level and exposure time

Conclusions

Certain quality parameters of the formulated orange smoothies treated with ultrasound processing would be measured in this study, which included the rheological property, bioactive compounds contents, colour parameters, and the sensory evaluation. It was expected that the application of ultrasound treatment would cause a decrease in overall apparent viscosity, a decrease in overall bioactive compounds, slight changes in colour parameters, and have acceptable sensory scores.

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SPECTRAL IMAGING OF CABBAGE SEEDS DURING GERMINATION: EXPERIMENTAL PLAN AND EXPECTED RESULTS

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Abstract

This work will investigate the ability to accurately and non-destructively determine the germination of cabbage seeds (*Brassica oleracea capitate L.*) based on spectral imaging data. Samples will be imaged using a visible-short wave infrared (Vis-SWIR) push-broom spectral imaging system. The spectral profiles of seeds will be compared through Principal Component Analysis (PCA). Partial Least Squares Discriminant Analysis (PLS-DA) will be used to classify germinating and non-germinating seeds based on their period of imbibition and ageing pre-treatments. Individual seeds will be subjected to accelerated ageing, and standard germination tests will be performed. Based on existing literature, the results are expected to suggest that seed germination may be successfully tracked based on the reflectance spectra.

Introduction

Seeds are an essential source of raw materials which can be used as a direct or indirect source of food for animals and humans. Seed germination is initiated by the uptake of water by the seed embryo (McGoverin *et al.* 2011). This rapid water absorption, called 'imbibition', induces disruption in the cell membrane structures. Imbibition helps to trigger the events that initiate the biochemical process of germination (Lancelot *et al.* 2017). Seed viability and vigor are the two critical parameters directly related to seed germination performance. Consequently, this has become a significant focus of seed banks tasked with maintaining seed viability during long term storage. (Nansen *et al.* 2015)

Considering the time required to carry out seed viability tests, development of non-destructive analytical methods to assess germination is a pressing need (Nansen *et al.* 2015) (Ahn *et al.* 2012). The application of spectral imaging technology, which combines the non-destructive nature of NIR technology coupled with image analysis, thus enabling rapid analysis and screening of multiple seeds at a time (Caporaso *et al.* 2018), in non-destructive testing of agricultural products has become extensive (Ahn *et al.* 2012). Spectral imaging facilitates the measurement of both physical features and chemical composition of seeds (Caporaso *et al.* 2018). The HSI system generates three dimensional (3D) "hypercube" datasets composed of two spatial dimensions and one spectral dimension (Xia *et al.* 2019). It can be used to gather the spectral information of every pixel on the collected image, which can be used to examine the chemical composition of each part of the seed (Zhang *et al.* 2019).

The seeds with preferable viability are profitable to seed industries by obtaining a considerable yield for cultivators and reducing crop variability (Xia *et al.* 2019). In the past decade, spectral imaging has been successfully used to estimate seed viability in a plethora of seeds viz. barley/wheat (McGoverin *et al.* 2011), corn (Ambrose *et al.* 2016; Zhang *et al.* 2019), muskmelon (Kandpal *et al.* 2016) etc. This spectroscopic study is based on previous research that indicates that the reflectance data acquired from the seed coat can provide indicative information about the germination and quality of the seed (Nansen *et al.* 2015).

The objective of this study is to investigate the potential of spectral imaging of cabbage seeds to monitor changes during pre-treatment and germination.

Materials and Methods

The research will be conducted as follows, based on a review of the literature and development of germination of seeds using NIR-Hyperspectral Imaging.

Materials
Cabbage seeds var Spring Hero F1 (*Brassica oleracea capitata L.*) were acquired from a local store (www.thegardenshop.ie, Ireland). Petri-plates necessary for germination tests (Disposable Sarstedt Petri Dish, 92mm x 16mm) were purchased from VWR Dublin, Ireland.

Instrumentation
The spectral imaging instrument used is a HySpex Vis – SWIR system (www.hyspex.com) operating in diffuse reflectance in the wavelength region of 400-2500 nm.

Pretreatments of cabbage seeds
The cabbage seeds in this study will be subjected to two accelerated ageing treatments and scanned with their respective untreated control. The Untreated (UTT) Control samples without any accelerated ageing treatments will be kept at room temperature under constant relative humidity (~ 40%) at room temperature (~ 20ºC) to equilibrate conditions. The cabbage seeds will be subjected to treatment 1 as described in Wakholi et al., (2018) with slight modification. For treatment one (TT1), the cabbage seeds will be given microwave treatment for 40 sec at 1100W. For Treatment two (TT2), the cabbage seeds will be treated for accelerated ageing at 45ºC for 72h as described in Bittencourt & Vieira, (2006).

Germination Testing
Two sets of germination experiments will be carried out for cabbage seeds. The germination testing will be carried out as described by LeVan et al., (2008) with slight modifications. Individual seeds will be placed on Whatman Grade 1 filter paper moistened with around 1.5-2 ml of water. The moistened filter paper will be folded and arranged in Petri plates (Disposable Sarstedt Petri Dish, 92mm x 16mm) for germination. The preliminary experiment will include seeds of each treatment and their respective control (n = 20 x 3 = 60 seeds) and will be scanned in a SWIR hyperspectral imaging before the start of germination, at 24h germination and at 48h germination.

Data Analysis
For white correction, reflectance images will be obtained by dividing raw by the average spectra of a white reference tile. Principal component analysis (PCA) and Partial least squares discriminant analysis (PLS-DA) will be carried out using MATLAB (Version R2019b, Mathworks, USA).

Expected Results and Discussion

As the experimentation has not yet commenced, the following expected results are described based on the references to the literature and the preliminary results by E. Achata and A. Gowen (2019).

Germination of seeds
According to the literature, the effect of experimental ageing is expected to show around 90% germination within 0-10 days. Nansen et al., (2015) reported that the germination of Acacia and Corymbia seeds was above 90% when they were subjected to ageing at 60% relative humidity in an oven at 60°C. From the germination tests, we will obtain the number of germinating and non-germinating seeds after 3 days.

Spectral Imaging

It is expected that the reflectance profiles of dried and treated seeds post-germination would help us to classify the viability of seeds on the basis of the water uptake during imbibition (LeVan *et al.* 2008). The average reflectance profiles acquired after standardized experimental ageing pretreatments will be used to illustrate the difference in reflectance between the germinating and non-germinating seeds. A preliminary study conducted by E. Achata and A. Gowen (2019) shows the second derivative spectra of seeds that did and did not germinate and the difference between them. The difference gets more significant as the imbibition time increases. At the end of this study, we will obtain a reflectance-spectra for cabbage seeds similar to Figure 1. The second derivative spectra for dry seeds and seeds after 24h imbibition appears identical, but the difference between the germinating and non-germinating spectra can be observed. The seeds after a 24h imbibition period have not germinated, but the difference in water uptake and how it affects germination can be seen.

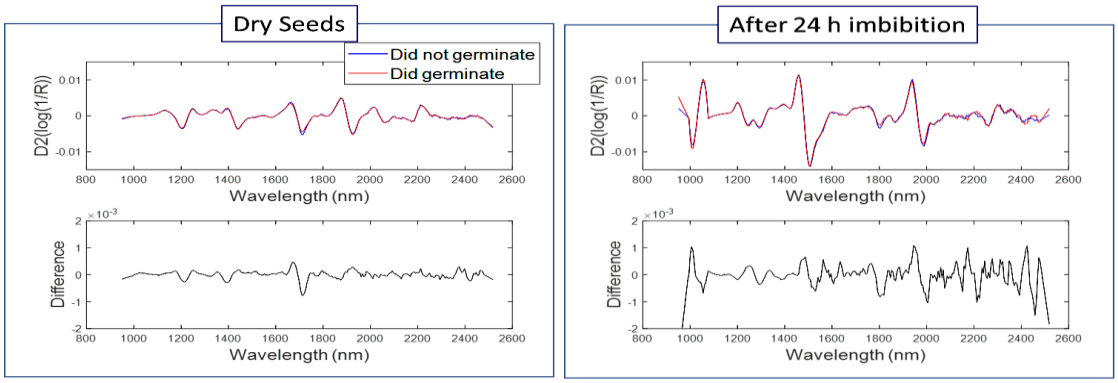

Figure 1. Mean second derivative pseudo-absorbance spectra (D2(log(1/R)) for seeds that normally germinated (in red) compared with that for seeds that failed to germinate (in blue). Spectra and their difference is shown for dry seeds (left panel), hydrated seeds 24 h (right panel)

From the literature, it can be reported that, based on PLS-DA classifications, the germination of seeds can be classified with high accuracy. The germination of barley/wheat (McGoverin *et al.* 2011), corn (Ambrose *et al.* 2016; Zhang *et al.* 2019), muskmelon (Kandpal *et al.* 2016) etc. as a measure of seed viability estimation is classified with an accuracy in the range of 60-100%. This study is expected to report the germination of cabbage seeds with high accuracy, and the relationship between the ageing treatments and the classification accuracies from the reflectance profiles are to be determined.

Conclusion

The germination of cabbage seeds will be characterized in this study through spectral imaging. Exploratory analysis (PCA) will allow the characterization of spectral differences between the germinating and non-germinating seeds on the basis of ageing pretreatments and water uptake. A multivariate classification model (PLS-DA) will allow to successfully identify the difference between the dried and imbibed seeds imaged during germination. Future work will aim at improving the robustness of the model by including data from several replicates and different varieties of seeds during their varying periods of germination. This study is part of a broader approach, carried out to provide a robust and early-stage analysis of seed germination using spectral imaging.

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ANALYSIS OF INTERNAL STRUCTURE OF DRY SEEDS BY USING TERAHERTZ IMAGING TECHNIQUE

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Abstract

This research studies whether terahertz time domain spectroscopy imaging technique is a useful tool to detect the inner structure of three kind of seeds, and whether defect seeds in the samples can be discriminated by analyzing their inner structure. The inner structure of three kinds of seeds will be detected by THz-TDS. Then THz signal will be processed by Fourier transform and novel chemometric methods, and the imagine of the inner structure can be obtained by using certain software. The THz imagine of inner structure of seeds will be obtained and defect seeds are expected to be discriminated based on the inner structure of seeds. It is possible to detect the inner structure and analysis defect seeds using terahertz THz-TDS imaging technique.

Introduction

As an important category of daily food, dry seeds have huge consumption not only as nutritious food but also as important material for further processing in the food industry. Most edible dry seeds are rich in protein, fat, fiber, sugar, calcium, phosphorus and iron elements, which make them as ideal raw material for protein beverage industry and oil extraction. However, plant diseases and insect pests or insufficient growth results in some defects in seeds, such as dried, worm-eaten, empty and broken seeds. In order to guarantee the quality for further process products, like protein beverages and edible oil, the inner structure of seeds needs to be detected and defective seeds need to be discriminated by analysis of the inner structure.

Most seeds are coated by a shell, so it is difficult to evaluate kernels without damaging their shells. The hundred-grain weight is a traditional method to measure quality by measuring the weight of 100 seeds, but the result is influenced by seed shells' weight(Sun and Liu 2020). Besides, methods like the tetrazolium and standard germination tests, pure kernel rate and electrophoresis are destructive, time-consuming and labor-intensive (Zeng et al. 2019; Sun and Liu 2020). Most enterprises rely on manual observation, and computer vision techniques with algorithms based on seeds' shape to discriminate defect products. The former method is susceptible to subjective psychology and visual fatigue, while the latter methods accuracy is not high enough (Cuiling et al. 2019a). Therefore, it is urgent to find a reliable, fast and noninvasive method to detect the inner structure of seeds and discriminate defective seeds.

Terahertz (THz) wave usually refers to the wave whose frequency is located between 0.1 and 10 THz. This small gap, once known as terahertz gap, is almost the last unexplored band in the electromagnetic spectrum due to the lack of high-efficiency sources and sensitive detectors, with both the through feature of submillimetre waves and the fingerprint spectral characteristics of infrared spectra(Spring 1993; Afsah-Hejri *et al.* 2019). Compared with X-rays whose photon energy is more than 5 keV, terahertz radiation is a non-ionizing radiation with a photon energy about 1 to 10 meV (Löffler *et al.* 2001). Therefore, the terahertz wave has high safety and could become an ideal alternative of X-ray and can be used to engage in vivo inspection (Yang *et al.* 2016). All those unique features make terahertz imaging have huge potential to be applied to detect the inner structure of seeds for non-destructive testing.

The objective of this study is to detect the inner structure of three kinds of seeds and analysis the structure to discriminate the defective seeds by using THz imaging technique.

Materials and Methods

Sample preparation
Sunflower seeds, peanuts and almonds collected from a local market will be chosen to use in the experiment and all the seeds should be coated by the shells. The thickness of the sunflower seeds sample should between 3 and 5.5 mm, and variety, size and color of the same type of seeds needs to be uniform in order to reduce the experiment error (Cuiling et al. 2019b). The moisture content of samples used in this experiment should less than 8%, because high moisture content could reduce interference for water absorbing THz wave (Sun and Liu 2020).

Data acquisition
The Terahertz-Time domain spectrometer named TeraSmart Compact Industry-Proven Terahertz Spectrometer, with a TERA Image Automated XY Translation Stage for THz Imaging, manufactured by Menlo Systems GmhH (Munich, Germany), will be adopted to carry out the research. In a typically Terahertz Time-Domain system, femtosecond laser will generate femtosecond pulses with a wavelength of 1560 nm and a pulse width of less than 90 fs. In a beam splitter, the femtosecond pulses can be divided into pump light and probe light. The former will be guided into the THz emitter where THz could be generated. After passing through a series of metal parabolic mirrors, the THz pulses which emitted from the emitter will be focused on samples and then passing through it. After penetrating the sample, there will be sample information carried in the THz wavelenght which will be shone on the detection crystal with the probe light(Sun and Liu 2020). Due to the THz-TDS device, the THz spectral frequency range used in the experiment could large than 5 THz (5.5 THz typically) and the dynamic range could higher than 90 dB (95 dB typically).

The inner structure of each sample will be detected by THz-TDS imaging spectroscope and after THz image collection, the shell and kernel of each sample will be separated carefully by manual operation and photographed respectively. In order to reduce the experiment error of the THz-TDs device, the laboratory environment should be constant. The interference of temperature and moisture in the air can led to a small jitter in some waveform of the sample signal, and also can accelerate oxidation of oils in sample and improve system errors in the experiment (Liu et al. 2016; Liu et al. 2018).According to the datasheet of the device, operating temperature should between 15 and 35 °C, while relative humidity have to be controlled at 80%.

Data processing
The THz-TDS signals, absorption coefficients will be extracted by TeraLyzer, a first-of-its-kind software for material parameter extraction from terahertz time domain spectroscopy data in transmission geometry (MenloSystems 2017a) and images of inner structure of seeds can be obtained from the softeware TeraImage 2.0.1. The absorption coefficients can represent samples' absorption capacity of THz wave per unit thickness(Sun and Liu 2020). The extraction of THz spectra of PE material, kernels and shells' spectral characteristics can pave the way for extracting characteristic images, and their frequency spectra can be obtained by adopting Fourier transformation (Can *et al*. 2018). By using software like Matlab, the THz images can be extracted and judged by artificial threshold to realize the image segmentation of complete seed and background as well as seed shells and kernels.By calculating the number of pixel points under and upon the threshold value obtained by Otsu method—an adaptive threshold judgment method proposed by a Japanese scholar Nobuyuki Otsu, the plumpness of each seeds can be obtained (Otsu 1979).

Expected Result and Discussion

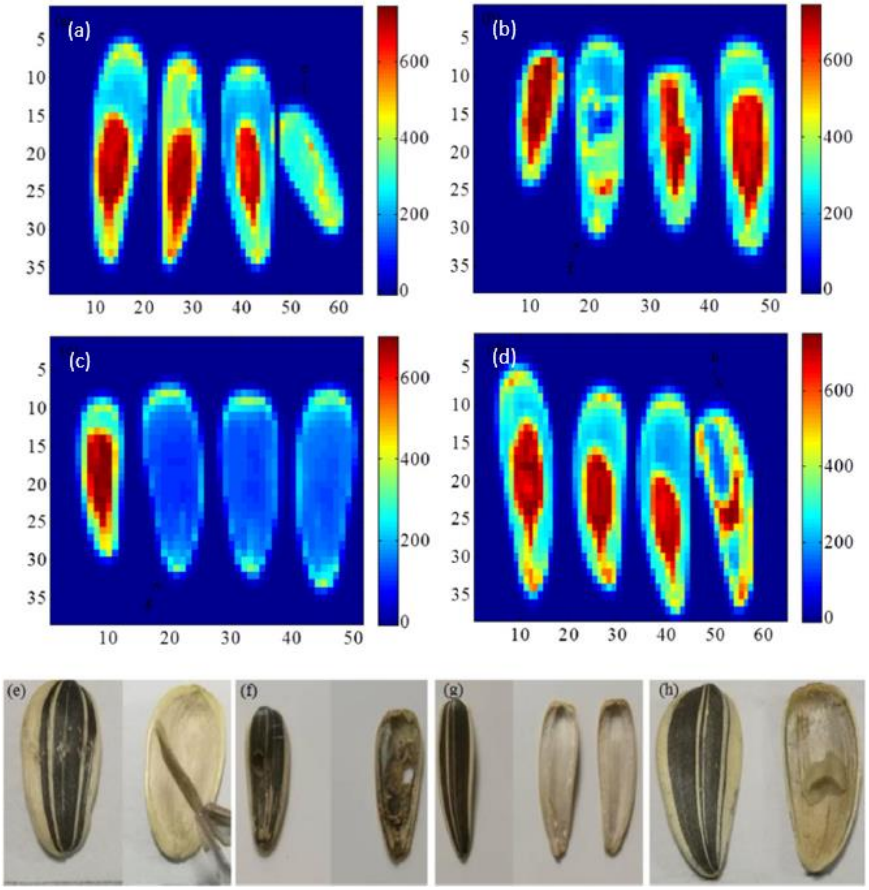

Fig 1. THz(a,b,c,d) and RGB (e,f,g,h) images of sunflowers, the RGB images (e, f, g, h) are corresponding to the fourth, second, second, and fourth images in a, b, c and d images respectively(Sun and Liu 2020).

The expected THz images of sample in the research should be similar to Figure 1. The inner structure of seeds will be detected by THz-TDS imaging and defective seeds are expected to be discriminated from healthy seeds based on the analyzation of seeds structure. Because of the different composition and content of cellulose, protein, grease and other components in seeds' shells and kernels, it will show significant different absorption intensity to THz radiation with shells and kernels. As for defects in seeds, like dried, worm-eaten, empty and broken seed samples, they contain almost no protein, grease and other components. Thus, they will show weak absorption of THz waves, which could be seen from Fig.1. In the research, kinds of seeds will be detected by using the methods mentioned above.

Conclusions

By using THz-TDS, the inner structure of three kind of seeds, sunflower seeds, peanuts and almonds are expected to be detected and defect seeds are anticipated to be discriminated based on their inner structure.

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THERMAL INACTIVATION OF *SALMONELLA SPP.* USING FRYING AND GRILLING FOR DIFFERENT MEAT PRODUCTS

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Abstract

The problem of food-borne diseases still shows a risk to public health. Apart from cross-contamination, inadequate cooking procedures is considered as one of the most vital factors contributing to foodborne illness. Few research studies which have evaluated the effect of domestic cooking on the presence of pathogens in different types of meat and have shown that consumer-style cooking methods can allow bacteria to survive and that the possibility of eating home-cooked poultry meat which still contains surviving bacteria after heating is higher than previously assumed. Hence, the main purpose of this study is to replicate and assess the effect of several types of meat products on the presence and numbers of *Salmonella* and two different cooking techniques (frying and grilling) will be applied.

Introduction

Salmonella spp. is a common and widely distributed zoonotic food-borne pathogens in the European Union (EU) (Roccato *et al.* 2015). Despite preventive measures during slaughter and good hygiene and good manufacturing practices during further processing, raw meat and meat preparations are still occasionally contaminated with pathogenic bacteria such as *Listeria monocytogenes, Salmonella spp., Campylobacter spp.* (Lahou *et al.* 2015). Meat is usually consumed after cooking. Among different food handling practices (cooling, separate raw and cooked food, cleaning and cooking), cooking is an important factor in controlling food-borne diseases (Kennedy *et al*., 2011; Juneja 2007) but approximately 30% of consumers undercook meat (Phang and Bruhn, 2011; Juneja 2007).

The recommended time/temperature combination of 70 °C for 2 minutes produces an N6 logarithm reduction of the most heat resistant bacteria and is effective in terms of minimizing the risks posed by food-borne pathogens (Lahou *et al.* 2015). Also, it is a critical control point for the food industry. The effectiveness of heat treatment on Salmonella is also affected by product composition (fat content, NaCl, pH and water activity) and geometry (volume and size) (Juneja 2007)

The objective of this study was to replicate and assess the effect of domestic-style cooking (frying and grilling) since they are considered as variable cooking processes on the presence and numbers of *Salmonella spp.* in variety of meat products available that are likely to be contaminated by *Salmonella spp.* due to the raw material being of animal origin.

Materials and Method

Various meat preparations will be studied from the literature: pork sausages, chicken breasts, meat burger patties, kababs. Where available, data will be accessed for time-temperature profiles for grilling/frying of these product types. Using the temperature profiles, thermal inactivation kinetics will be used to establish the safety of the cooking processes.

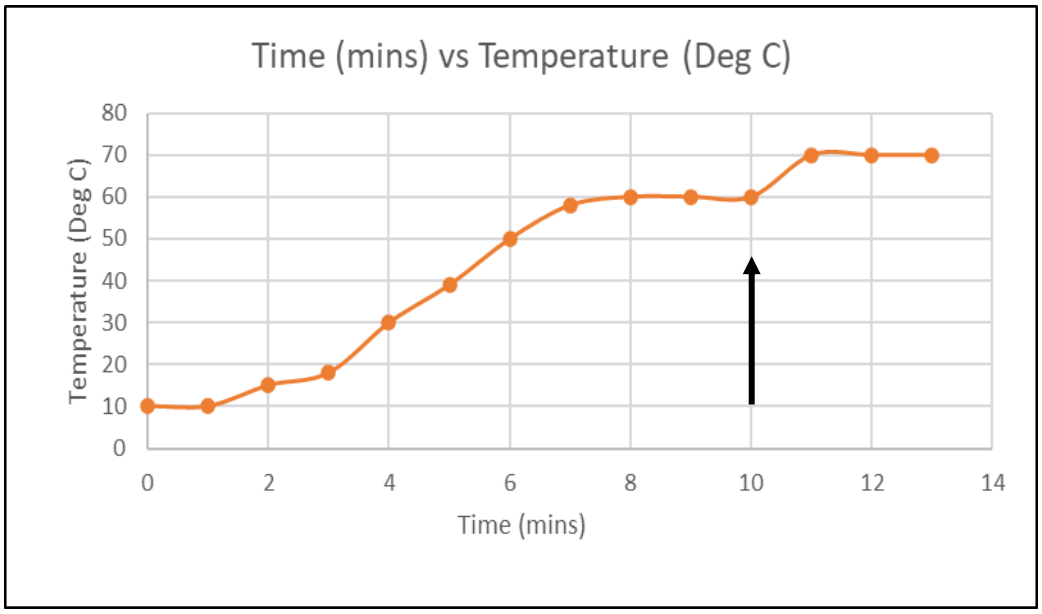
Determination of D- & Z- values

D-values (time to inactivate 90% of the viable cells), expressed in minutes, were determined for *Salmonella spp*. by plotting the log10 number of survivors against time for each heating temperature using Microsoft excel software (Juneja 2007) where the data is available. D-values were determined by using (a) linear regression from the straight-line portion of the survival curves; that is, first-order kinetics, and (b) by a linear model that was fitted to the nonlinear survival curves to account for the

lag period (Buchanan *et al*.,1993; Juneja 2007). Corresponding Z- values will also be calculated. The Z-value is the increase in the temperature to achieve a tenfold (one log) reduction in the D – value for a particular organism.

Result and Discussion

Several meat samples and their graphs of temperature vs time were taken into consideration from the literature. The graphs had three lines of repetitions of the frying process. Our focus was more on the data on meat preparation based on minced meat. The data of beef hamburger was taken into consideration from (Lahou *et al.* 2015) as it showed very less difference between the three readings that were plotted on the graph. Since the objective of this study is to replicate and assess the data given in the literature, approximate data of the same beef hamburger graph from (Lahou *et al.* 2015) was plotted using MS Excel as shown in Figure 1.



Note: The readings plotted in the above graph are approximate since the precise data is unavailable in the literature. The arrow illustrates the time that the meat was taken out of the frying pan.

Figure1. Time (mins) vs Temperature (°C) of beef hamburger

Temperature profile during pan-frying of meat preparations shows the core temperature profiles of the simulated home cooking practices (2- sided pan-frying or stir-frying) for various meat products (Lahou *et al.* 2015) in most of the results it can be noted that core temperature of 70.0 °C were only achieved in 24 out of 36 occasions. In another 3 experiments, core temperatures of 70.0 °C were only achieved after the meat was taken out of the pan and allowed to rest for 3–5 min on the serving plate (Lahou *et al.* 2015)

It was indeed noted that the core temperature of the meat still slightly increased after taking the meat out of the pan and putting it on the serving plate at room temperature. On a few occasions, i.e. in pan-frying of pork filet, chicken filet, beefsteak and beef and lamb hamburgers, the heat process of 70 °C for 2 min was not achieved throughout the experiments' time duration (thus including 3–5 min resting time).

In Figure 2, the readings were entered in ComBase and dynamic Thermal Inactivation was performed. ComBase only allows us to enter the temperature range between 54.5 to 65 ^{o}C for *Salmonella spp.*

The temperature between 54.5 – 65 ^{o}C from Figure.1 was entered into ComBase. The readings from ComBase were taken and the graph (Fig.2) was plotted using MS Excel.

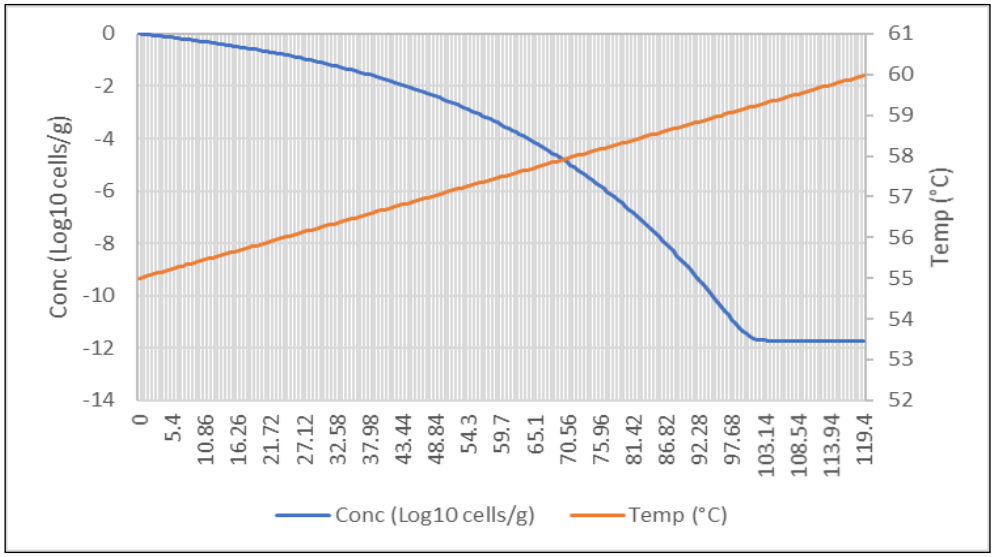


Figure 2. Time (minutes) vs Logc CFU/g vs Temperature (Deg C) of beef hamburger

It can be seen that the number of *Salmonella spp*. becomes stable at approximately -12 logc CFU/g. The time (hours) in ComBase was converted into Time (mins) in MS Excel. As seen in the graph, -12 logc CFU/g should be considered to be sufficient cooking.

The study is focused on the heat inactivation of pathogenic bacteria *Salmonella spp.* The meat preparations of different animal species, such as pork, beef, chicken and lamb, that were pan-fried according to a uniform procedure to simulate commonly used home-cooking practices. It is generally believed that when meat is heat-treated to achieve the "safe harbour" process criterion of 70 °C for 2 min (or equivalent time/ temperature combination), a 6 log reduction of *E. coli O157: H7, Salmonella spp. and L. monocytogenes* in meat products is obtained and that the meat will be free of pathogens and thus safe to eat (ACMSF, 2007; Bunning *et al*., 1990; Lahou *et al.* 2015). However, the simulation of home-cooking practices shows the occasional presence of low numbers of *Salmonella spp*. in heat-treated meat. According to Lahou *et al.* 2015, the core temperatures measured in filet, steak and hamburgers upon pan-frying did not necessarily achieve 70 °C and a time/temperature combination equivalent to 2 min at 70 °C was not always obtained during the simulated home cooking practices although the meat was visually judged as being cooked thoroughly (Lahou *et al.* 2015). Hence, the future work of this research is based on evaluating the results by taking the Time vs Temperature and *Salmonella* count data of various meat products from the literature and validating it using ComBase (publicly available database).

Conclusion

Cooking remains a primary means of removing pathogens from animal origin foods and therefore serves to protect against foodborne disease. During cooking or thermal processing, the rate of destruction of a microbial population is generally considered to follow a given temperature, the reduction in the log number of survivors occurs in a linear manner over time.

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HYBRID ANAEROBIC FERMENTATION/ENZYMATIC TREATMENT FOR ENERGY-EFFICIENT PROCESSING OF MICROALGAL BIOMASS

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Abstract

Microalgae is a promising source of sustainable biofuel and high-value bioproducts. Due to its mechanically rigid cell wall, the cell rupture for releasing intracellular products could lead to huge energy consumption and unnecessary economic loss. Therefore, finding effective cell rupture methods is essential. Previous studies have shown that dark incubation could thin the microalgae cell wall effectively. In addition, enzymes could hydrolyze the cell wall in a moderate way. This study focuses on developing a novel and energy-efficient cell disruption technology by combining dark incubation and enzymatic treatment, and measuring the extracted lipid content to prove the novel method is useful.

Introduction

Finding sustainable energy to replace conventional fossil fuel is an emerging resercah area currently, since energy shortage and global warming issue has become increasingly severe. Microalage have proven an outstanding feedstock for sustainable biofuel and also high-value bioproducts, such as ω-3 fatty acids and protein. Microalage have a high growth rate, high areal productivity, and contamination resistance; in addition, the cultivation of microalgae do not take up agricultural resources, like arable land and fresh water (Halim *et al.*, 2019; Zuorro *et al.*, 2016). While the main barrier for the large scale production of lipids from microalgae is that rupturing cell with conventional mechanical methods would consume large amount of energy.

Nannochloropsis sp. is chosen for the experiment because of its high lipid content (a total lipid content of up to 60 wt% of biomass) and high ω-3 EPA fatty acid content (Zuorro *et al.*, 2016). Microalgae cells all have strong defense against external forces, which is provided by its thick cell walls. Among them, *Nannochloropsis* cells are some of the most difficult to be ruptured; due to the complex two-layer cell wall structure, containing an outer algaenan layer and an inner layer made of cellulose and protein. Therefore, finding an energy effective method to disrupt *Nannochloropsis* sp. cell wall is essential for extract lipid economically.

Mechanical, chemical, and enzymatic methods are main methods for cell rupture. Conventional mechanical methods (i.e. high-pressure homogenization, ultrasonication, bead milling) consume much energy; while chemical methods (i.e. adding acids or bases) would cause pollution and potential risk, and may also damage the desired product. Compared with these, the use of enzymes is an outstanding alternative, because of lower energy requirements, a higher selectivity against the cell wall, and a lower chance of decomposing the desired product. In addition, in the previous studies of Halim, their group has proven dark incubation could effectively reduce the defence of *Nannochloropsis* cells by inducting cell self-ingestion (Halim *et al.*, 2019). This study will use a combination of these two methods for a comple cell wall rupture.

The objective of this study will be to couple dark incubation with an enzymatic treatment to rupture *Nannochloropsis* cells, and prove the effect of the combined treatment on protein leakage, and measure lipid yield.

Materials and Methods

Materials

Nannochloropsis gaditana stock culture (SAG 2.99) was acquired from the Culture Collection Centre at Georg-August-Universität Göttingen (SAG, Germany).

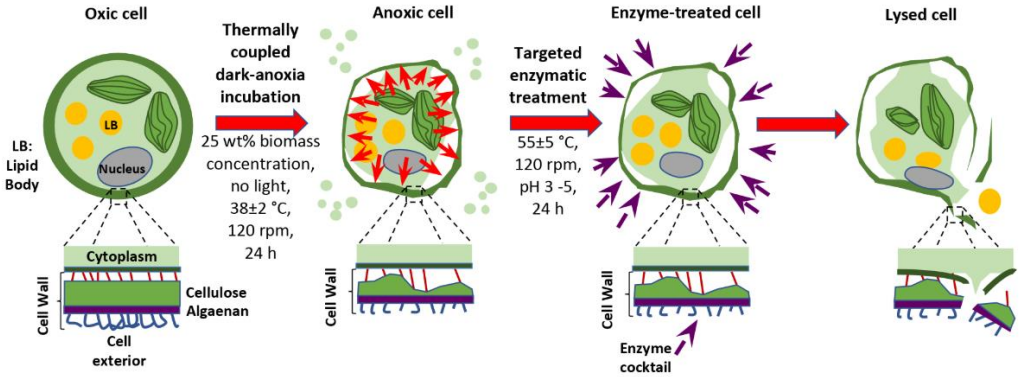

Figure 1. Schematics of the experiment

Microalgae cultivation

Nannochloropsis sp. strain will be cultivated with a modified f medium (MF) in synthetic seawater. The microalgae will be grown indoors at room temperature under a 14:10 h light:dark cycle. Then a centrifuge will be used for concentrating microalgae to get microalgae paste. After that, using MF medium to re-dilute microalgae paste to an appropriate concentration for following incubation.

The modified f nutrient composition is as follows: 0.2 g/L $NaNO_3$, 0.02 g/L $NaH_2PO_4.2H_2O$, 0.009 g/L $FeC_6H_5O_7$, 0.009 g/L $C_6H_8O_7$, 0.005 mg/L $CuSO_4.5H_2O$, 0.023 mg/L $ZnSO_4.7H_2O$, 0.011 mg/L $CoCl_2.6H_2O$, 0.2 mg/L $MnCl_2.4H_2O$, 0.0084 mg/L $Na_2MoO_4.2H_2O$ and 0.00065 mg/L H_2SeO_3, 0.00005 mg/L vitamin B_{12}, 0.00005 mg/L biotin, 0.1 mg/L thiamin.

Dark incubation

50g microalgal slurry (25 wt%) will be incubated in a 55 ml glass reactor covered with aluminium foil for a dark environment and submerged in a water bath set at 38±2 °C and 120 rpm for 24 hours. Continuous agitating (0, 60, or 120 rpm) will be needed using a turbine-shaped impeller connected to an above stirrer. Collecting three samples at 0, 24 and 72 h.

Dark incubation could activate the anaerobical fermentative pathways of *Nannochloropsis* cells, which means the intracellular sugar (including cellulose in cell walls) will be catabolised, and lead to a thinning cell wall. The previous study of Halim *et al.* (2019) has proved a significant cell wall thickness reduction happened after 24 h treatment, as shown in the figure below.

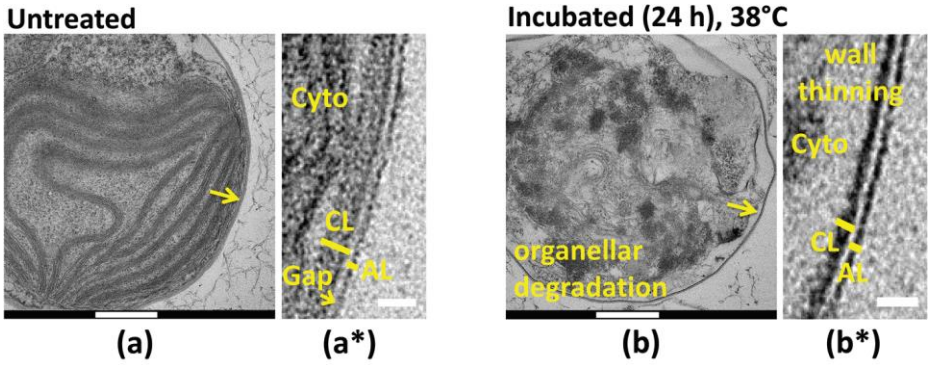

Figure 2. Representative TEM images of untreated and incubated *Nannochloropsis* sp. cells with cross-sections of the cell wall (Halim *et al.*, 2019)

Enzyme treatment

Three kinds of enzymes (cellulase, lysozyme, chitinase) would be used to hydrolyze microalage cells separately to find the most effective enzyme for the further rupture. The treated microalgae slurry collected from last step would be cultivated at 55±5 °C and 120 rpm under a pH of 3-5 for 24 h. These enzymes are chosen because of their specificity to certain content in cell wall, for example, chitinase is specific to chitin agar in outer cell wall and cellulase is specific to microfibrillar cellulose in innner cell wall (Demuez *et al.*, 2015). The principle of enzyme treatment method is by inducing autolysis process of *Nannochloropsis* cells (Demuez *et al.*, 2015).

Lipid extraction

Taking 10 g prepared microalgae paste and adding 4 g of hexane to extract lipid from the microalgae paste. A rotary suspension mixer will be used to agitate the extraction mixture at half speed at room temperature (20-30°C) for 2 h. Then the extraction mixture will be centrifuged at 8800 G and 40 °C for 15 min, as a result, two layers will be get. Hexane and extracted lipid will be in the top layer, which will be filtered through a 0.22 μm nylon membrane to avoid possible biomass pollution during the decanting process. The extracted lipid will be yielded by evaporating the solution under a N_2 stream at 40 °C for hexane remove. The yield of lipid could be calculated by a comparison of the mass of lipid extracted from the CIDES process (cultivation, incubation, disruption, extraction, separation) and the mass of lipid extracted by the modified Bligh and Dyer method; the CIDES process is also the method used in this experiment.

Total lipid determination

Using a four-stage monophasic Bligh and Dyer extraction method for the determination of the lipid content of microalgal cells.

In the first stage, mixing 400 mg microalgal slurry, 4 ml chloroform, 8 ml methanol and appropriate DI water together to form a solution with a ratio of 1:2:0.8 v/v/v. The solution will be rotated at room temperature for 2 h. After that, adding 4 ml chloroform and 4 ml DI water to perform a biphasic separation. Then centrifuging the solution at 7028 G and 20°C for 10 min and two phases will be obtained. The top phase will contain DI water and methanol, and the bottom phase will contain chloroform with lipid; in addition a thin cell debris layer will between them.

The top and bottom phases both will be removed with glass pipettes; while the cell debris layer will be resuspended in DI water to a required concentration in order to prepare for the further three stages of chloroform/methanol extraction, the step of which has been clarified before. After

finishing all stages, the cell debris will be completely bleached for the determination of total lipid recovery. In addition, all chloroform phases removed in the four stages will be put together, filtered by a 0.2 μm nylon syringe filter, and dried under N_2 gas to measure the weight.

Protein analysis of supernatant

The supernatant, which is got after the centrifugation of microalgae slurry, will be removed by glass pipettes, weighed, filtered by a 0.22 μm nylon syringe filter to avoid the residual of biomass. Then the protein content will be analyzed with Lowry assay according to the reagent's instruction manual (DC Protein Assay, Biorad Laboratories, USA). Measure the absorption of all sample solutions at 750 nm.

Total protein content will be measured against a linear bovine serum albumin (BSA) calibration curve and will be corrected with an appropriate dilution factor.

Results and Discussion

No results have been obtained in current stage. The following is the expected results. A combination method of dark incubation and enzyme treatment would be used for microalgae cell rupture; this is a novel and economic method. To prove that this method is economic, first, an enhanced lipid yield and a more significant protein leakage is expected. Second, successfully developing an enzymatic cocktail for effectively hydrolyzing microalgae cell wall. Third, finding the optimal enzymatic condition for hydrolysis; since some enzymes are more aggressive at attacking cell wall compared with others, finding the optimal one could make the cell rupture more effective.

Conclusions

In conclusion, the combination method of dark incubation and enzymatic treatment could effectively disrupt *Nannochloropsis* cells for the release of intracellular products (lipid in this study). As expected result, the measurement of lipid content could indicate that the microalgae cells are disrupted effectively and prove that this is an energy-effective technology. This method provides a possible choice for the commercial production of renewable energy and high-value bioproducts from microalgae. It could reduce energy consumption of disrupting *Nannochloropsis* cells to a large extent and may have a bright future.

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APPLICATION OF HYPERSPECTRAL IN HOT AIR DRYING PROCESS OF PEACH

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Abstract

The aim of this research was to investigate the influence of hot air drying on slices of peach by hyperspectral imaging. The shrinkage of peach slices first increases and then becomes stable with time which is evaluated by computer version analysis. The colour of peach samples becomes dark which is measured by a Chroma-Meter using the CIELAB colour system. The moisture content decreases quickly first and then keep stable which is analysed by a laboratorial HSI system which can acquire the hyperspectral images, and the moisture content of centres is higher than that of the edges. The results indicate that hot air drying has a deep influence on the quality of peach slices.

Introduction

Peach originated in China, gradually spread to various parts of Asia, and then spread to the West through Persia. It is widely consumed because it is rich in many essential nutrients for humans. However, fresh peaches are susceptible to decay due to their high moisture content. At the same time, peach production has seasonal characteristics (Zhu and Shen 2014). Therefore, people use drying technology to process fresh peaches for long-term storage.

Drying is a very common food processing technology, including microwave drying, infrared drying, freeze drying, hot air drying, etc. Drying technology reduces the activity of microorganisms in food through dehydration, reduces the physical and chemical changes of food during storage, and thus extends the shelf life of food. Hot air drying (HAD) is a typical convection drying method that has been widely used to dry various fruits and vegetables and their by-products (Pu and Sun 2017). The effects of hot air speed, drying temperature, and peach slice temperature on the drying process have been studied before (Zhu and Shen 2014), but the physical properties of peach slices during drying have not been studied.

Hyperspectral imaging (HSI), also known as chemical or spectral imaging, is an emerging technology that combines conventional imaging and spectroscopy to obtain spatial and spectral information from objects (Gowen et al. 2007). When compared with RGB imaging, NIR spectroscopy (NIRS) and multispectral imaging (MSI), HIS has many advantages such as it can attain spatial and spectral information at the same time, can have multi-constituent information and is sensitivity to minor components, so HIS is widely used in the quality evaluation of foods like detecting microbial spoilage in meat (Gowen et al. 2007, ElMasry et al. 2012).**The objective of this research is to study the physical changes of peach slices during the hot air drying using hyperspectral imaging.**

Materials and Methods

Sample preparation

Peaches are purchased from a local supermarket (Dublin, Ireland) and stored in a refrigerator at 4-5 ℃ until used. The peaches are sliced into different thickness slices (3 mm, 4 mm and 5 mm), all the slices have the same shape with the same area.

Drying procedure

The peach slices are dried in a convective drying oven. The drying temperature is maintained at 70℃, as previous studies have shown that the suitable temperature is between 60-80℃ (Zhu and Shen 2014). During the drying, all peach slices are placed in the same layer. Each thickness slices are divided into eight groups with different drying times, when they reach the required time, one group of peach slices are used.

Shrinkage evaluation

The shrinkage of peach slices is evaluated using the color image which is captured by a computer vision system. The images of peach slices are captured from the top side before and after drying. The shrinkage of peach slices is calculated as : $\gamma = \frac{v_1 - v_2}{v_1} \times 100\%$ (v_1 is the surface before drying, v_2 is the surface after drying).

Color measurement

The color measurement of peach slices is using a Chroma-Meter which use the CIE LAB color system. There are three parameters are measured in this system: L*, a*, b*, and they represent different values. L* indicates the lightness of sample, a* and b* indicates the color value. Every drying time some pieces of peach slices are used to measurement. By measuring the L*, a*, b*, the indicators total color difference (ΔE) and yellowness index (YI) can be calculated as follows:

$$\Delta E = \sqrt{(\Delta a_t^* - \Delta a_0^*)^2 + (\Delta b_t^* - \Delta b_0^*)^2 + (\Delta L_t^* - \Delta L_0^*)^2}$$

$$YI = \frac{142.86 b^*}{L^*}$$

Where a_0^*, b_0^* and L_0^* are parameters before drying, a_t^*, b_t^* and L_t^* are parameters after a certain drying time.

Hyperspectral imaging system

A reflectance HSI system with 950–1655 nm is used to acquire the hyperspectral images of peach slices. As is shown in figure 1, the system include: an imaging spectrograph, a lens, a camera, an illumination source including two 500 W halogen lamps to illuminate the translation stage by stepping motor and imaging data acquisition software.

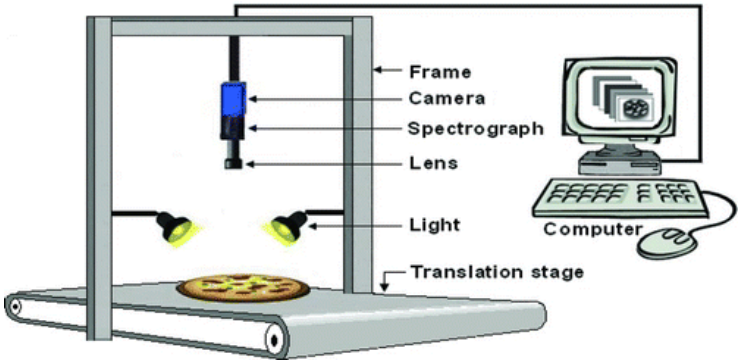

Figure 1. Schematic diagram of hyperspectral imaging system (ElMasry *et al.* 2012)

The peach slices are placed in a container which is placed on the translation stage, when the stage moves, the camera can scan the whole surface of the peach slice, the spectral and spatial information can be captured.

Data preprocessing

Segment the hyperspectral spectrum to increase the contrast between the sample and the background, making the image clearer. Because the spectrum signal is easily affected by factors such as the measurement environment, measurement conditions, and instrument performance, the measured spectrum signal has interference such as noise and spectral line shift, so the original spectrum needs to be pre-processed. Common preprocessing methods include Savitzky-Golay (SG) smooth denoising, multiple scattering correction and Standard Normal Variate (SNV).

Results and Discussion

Shrinkages of surface area

The surface area of peach samples decreased as drying time increased. For the first few times the shrinkages of peach slices will increase quickly, after few times the shrinkages of peach slices become stable. With the shrinkage of peach slices, the shape of them also changes to a irregular shape, this may be due to uneven water loss rate.

Color changes of peach

There will be an obvious colour difference between the fresh and dried samples. Pu and Sun (2017) studied the colour change of mango slices during hot air drying, they found that the yellowness intensity of mango slices increased, ΔE and YI reached the peak value at the fourth hour and then started to decrease. In this study, the color change of peach may have the similar results. During the hot air drying, the value of L*, a*, b*, ΔE and YI will firstly increase and then have a little decrease which indicates that the color changes a lot during the process and the yellowness intensity of peach slices will be enhanced by hot air drying.

Moisture contents during drying process

The moisture content of peach slices will decrease during the drying and at the end of drying this value will become stable. This may be due to the large moisture content of the peach slices in the initial stage and the rapid loss of water, in the later stages, the moisture content reached equilibrium. Since hyperspectral imaging can acquire spatial information, by

analysing this information the peach slices will exhibit uneven drying characteristics which show less moisture at the edges than at the centre because hot air drying results in materials to be dried from exterior to interior.

Conclusions

In this study, hot-air drying was used to dry peach slices, and changes in color, shrinkage, and moisture content were found during the drying process. The non-uniformity of the moisture content change during the drying process can be found through the moisture distribution map generated by the hyperspectral imaging. Whether other drying technologies can improve the non-uniformity of drying and needs further research.

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MONITORING RENNET-INDUCED MILK COAGULATION KINETICS USING NIR SPECTROSCOPY

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Abstract

In cheese manufacturing, the determination of the optimum time for curd cutting during milk coagulation is crucial. Effective control of the coagulation process requires a rigorous and objective inline method to determine the best time to cut the cheese curd. Near-Infrared spectroscopy technology has been applied in various fields in the food processing industry as a process analytical tool for real-time process control. This study aims to investigate near-infrared (NIR) spectroscopy as a process analytical tool to investigate the effect of coagulation parameters (e.g. pH and temperature) on rennet-induced coagulation kinetics of skim milk.

Introduction

Milk coagulation is the process that converts liquid milk into a gel or coagulum, and it is one of the most critical steps in cheese manufacturing. Cheese coagulum is formed based on physicochemical changes in casein micelles (Correa Hernando *et al*. 2011). However, many factors affect the formation of the coagulum, leading to changes in the optimum cutting time. Experiments in this study include the investigation on the rheological and microstructural properties of cheese coagulum, which in turn depend on coagulation factors, milk composition and milk pre-treatment.

In rennet-induced coagulation, optimum control of cutting time is critical (Panikuttira *et al.* 2019), which means that the formed milk coagulum has to be cut when the milk gel reaches its optimum firmness. Therefore, failure in choosing the optimum cutting time can lead to reduced cheese yields, shorter storage times, and a significant impact on cheese quality (Panikuttira *et al.* 2019). However, in most cheese manufacturing plants, milk coagulum is usually cut after a predetermined enzymatic reaction time or managed by experienced cheesemakers based on their subjective assessment of textural and visual properties of the curd (Castillo *et al.* 2000). Thus, the development of inline, non-destructive monitoring technology to determine the optimum coagulum cutting time to increase yield, quality of the final product is crucial.

As a non-destructive inspection method, near-infrared light backscatter technology is one of the most promising in-line methods for monitoring coagulation kinetics and detecting the optimal gel cutting point of rennet-induced milk (Arango and Castillo 2018). Rheological methods are one of the methods that have been applied to determine the properties of cheese gel, such as the storage modulus G' (Lucey *et al.* 2003; Lyndgaard *et al.* 2012), which the cutting time depends directly on. However, these types of measurements are invasive, destructive and unsuitable to be used for online process control. The idea of predicting cutting time that has been applied in many studies was that the shape of measurement curve changes over time (i.e., dynamics), to some extent, contains the information that the best cutting time depends on (Lucey *et al.* 2003; Lyndgaard *et al.* 2012). In this study, NIR reflectance data will be recorded during the milk coagulation process at different levels of coagulation temperature and pH value, and then compared to the rheological parameter (G').

The objective of this study is to investigate the use of NIR spectroscopy to monitor rennet-induced milk coagulation kinetics.

Materials and Methods

Experimental Design

This experiment will investigate the use of NIR spectroscopy sensor to predict the cutting time of milk gel during cheese making and study the effects of different milk coagulation temperatures, rennet concentration levels, and pH values on the milk coagulation kinetics. Different experimental factors will be selected to obtain real-time NIR reflectance data of the coagulation process to achieve the objectives of this study. The milk coagulation process will be monitored using NIR light backscatter obtained from an NIR spectroscopy sensor online. A small amplitude oscillatory rheometer (SAOR) will be used as a reference method for measurement of rennet-induced coagulation kinetics, from which the gel firmness will be recorded.

Materials and Testing Procedure

The experiment will be carried out in a jacketed laboratory cheese-making vat fitted with the NIR spectral sensor. Commercial skim milk will be used for the study. Milk sample will be heated in the vat until the temperature reaches 32°C, and the pH will be recorded. The enzyme (CHY-MAX Plus 200 IMCU/mL) will be added to induce milk coagulation and then agitate for 3 minutes. Similarly, this procedure will be repeated for different temperature levels, pH. Two 20 mL aliquots will be placed in the measuring vats of the NIR coagulation measurement apparatus and the rheometer, respectively, to obtain the optical parameters and the rheological parameters.

Optical Time Parameters Determination

NIR reflectance data from the optical sensor will be collected at 6 s intervals with NIR light of 880 nm after enzyme addition. And an algorithm can be developed to calculate the first and second derivatives of the light backscatter profile. The light backscatter ratio (R), first derivative (R') of light scatter ratio will be derived. The elapsed times since enzyme addition to the maximum of the first derivative is defined as tmax.

Rheological Parameters Determination

Small amplitude oscillatory rheometry (SAOR) will be performed as described by (Abdelgawad *et al.* 2014). Rheological parameters: storage modulus (G') and loss modulus (G'') will be collected to estimate gel cutting time. Gelation time (t_{gel}) is defined as the time when the gels reach a G' = 1 Pa while cutting time (t_{cut}) is defined as the time when the gels have a storage modulus G’ = 30 Pa.

Expected results and discussion

Previous experiments conducted to study similar attributes of milk coagulation provide information on the expected results. Abdelgawad *et al.* (2014) have given a detailed description of the optical and rheological methods used in the study of milk coagulation kinetics. The cutting time and tmax decreased as temperature increases, and as the coagulation pH decreases, which means that the kinetics during milk coagulation is significantly influenced by processing conditions. For rheological cutting time prediction, an algorithm proposed by A. Payne *et al.* (1993) can be implemented.

The optical parameter t_{max} is strongly correlated to the time profile drawn from the rheometer, which is the rheological cutting time, which indicated that the time to the first derivative of the light backscatter ratio (R') could be used to predict the cutting time during the milk coagulation process. The time-dependent parameters obtained from the optical response profile are a function of coagulation rate and change with temperature and coagulation pH. These results indicate that rennet-induced milk coagulation can be monitored using NIR spectroscopy and gel cutting time can be predicted using optical parameters collected from the NIR sensor.

Conclusion

Near-Infrared spectroscopy is an effective inline method to monitor milk gel formation dynamics, which will facilitate automation of coagulation cutting in cheese manufacture. The influence of process variations on coagulation kinetics will also be investigated using NIR spectroscopy.

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HUMAN EXPOSURE ASSESSMENT TO ARSENIC IN DRINKING WATER

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Abstract

Arsenic is an element which raises much concern from both an environment and human health perspective. Elevated arsenic in drinking water has become a public health concern in many countries including Ireland. In Ireland, some drinking water comes from underground water, and there are many private well supplies. This study analyzed water supply types including tap water and bottle water. Rock types can also affect the arsenic content in underground water, and thus affect exposure level. This study collected reported literature data on arsenic levels in water under sandstone and shale and limestone in southeast Ireland. The influence of gender is also compared based on water consumption. This study used the RASP simulation modeling system to estimate arsenic exposure levels in different regions and groups in the south of Ireland.

Introduction

Arsenic is an ubiquitous element in nature, with common oxidation numbers of +3, -3, and +5. Both organic and inorganic forms are highly toxic to humans, and it can be acute and chronic. Arsenic poisoning occurs after exposure to arsenic for an extended period of time. It can cause Nausea, vomiting, shock, death and lead to many serious skin and blood diseases, such as black foot disease, scurvy, and cancers, including bladder cancer and skin cancer (Sambu and Wilson, 2008). According to Sambu and Wilson(2008), arsenic can be present in the underground water through the oxidation procedure, and the use of arsenic pesticides can also lead to arsenic poisoning, as the residual arsenic will infiltrate into soil or runoff into surface water, and can last for a long period and finally enter drinking water sources. The World Health Organization recommended an upper limit of arsenic in drinking water, which should be less than 10 μg/ l, and Tsuji *et al*.,(2014) claimed people should not intake more than 9 μg/kg bw·day. Elevated arsenic commonly occurs in developing countries, because some of them cannot afford advanced removal technology (Mohanty, 2017). However, it also occurs in developed countries, especially in private well water (Karagas, Stukel and Tosteson, 2002). In Ireland, there are also more than 200,000 private wells McGrory *et al*., 2017), and Ireland has seen a recall on bottled water in 2019 because of concern over elevated arsenic levels (Orla, 2019). It is a worldwide problem, so it is important and necessary to analyze risk indicators, and determine groups that are more vulnerable.

The objective of this study was to quantify arsenic exposure through drinking water in the south of Ireland and analyze risk indicators.

Materials and Methods

Exposure assessment is a part of risk assessment, and this quantitative assessment combines reported initial arsenic concentration in water, water consumption, and likely removal of arsenic using removal technology to finally calculate the likely arsenic intake per capita per day, and compare the exposure level with the NOAEL(No Observed Adverse Effect Level) of arsenic. This study uses RASP (RASP, 2020) simulation modeling system to simulate arsenic distribution in drinking water, and compares exposure level between water supply types (tap water and bottle water), rock types (sandstone, shale and limestone), and groups (male and female) in south Ireland.

Arsenic exposure level is calculated by following equation:

Arsenic exposure level (μg/kg bw·day) = Arsenic concentration in water (μg/l) × Water consumption (l/day) × (1 - arsenic removal rate) ÷ body weight (kg)

A framework diagram is presented (Figure 1) to illustrate the steps in this exposure assessment:

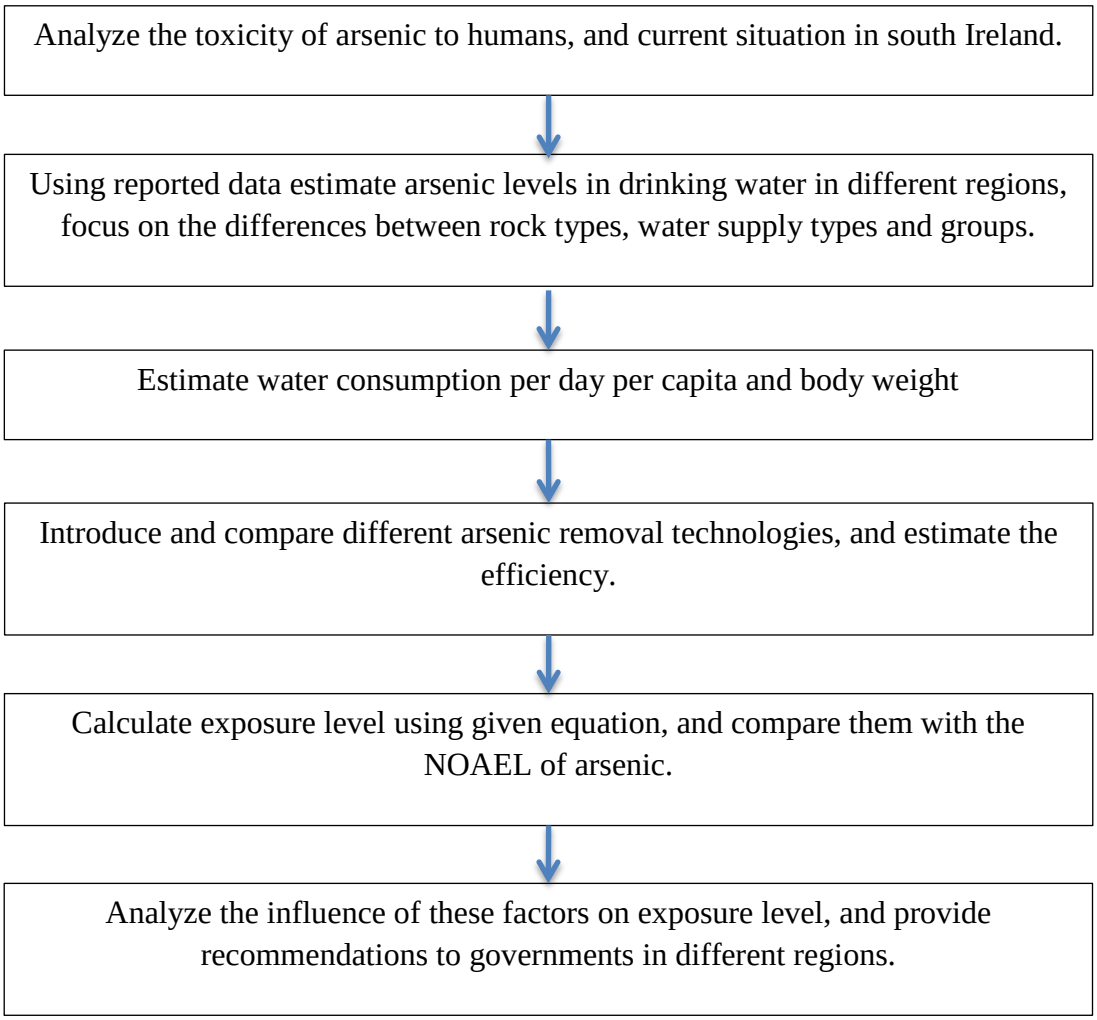

Figure 1. Framework model for exposure assessment of arsenic in drinking water

Results and Discussion

A framework for the model is presented in Figure 1. The data used in the model is derived from existing literature sources or case studies. The arsenic contents in tap water and bottle water are given by McGrory *et al*.,(2018), and the contents in underground water under different rock types are given by McGrory *et al*.,(2017). The water consumption per day per capita is estimated by Dai *et al*.,(2016), and average body weight of male and female are assumed as 70 kg and 60 kg, respectively. The efficiency and effect of arsenic removal technologies are introduced by Agusa *et al*.,(2014) and Ng *et al*.,(2004). The results of the study will indicate which type of rock can lead to higher arsenic concentrations in underground water, and thus increase the exposure level. The comparison between tap water and bottle water will be evaluated and show the difference between water supply types. This study also compares the difference of exposure level between male and female to determine the vulnerable group, and the results can guide populations to choose safe drinking water supplies. The analysis of the case study will assess the effectiveness of some removal technology (e.g. sand filter system), and the result will assess whether the removal technology is effective and essential, so governments or well holders can decide if advanced technology is necessary.

Conclusions

Elevated amounts of arsenic in drinking water have been found in many countries including Ireland. Exposure to high arsenic concentrations may be harmful, and it appears to occur more frequently in developing countries. In Ireland, arsenic can be found in underground water, which may then be supplied as drinking water, and the influential factors can be rock types, water supply types, and removal technologies. Simple filter system (e.g. sand filter system) can also have a significant effect.

This study mainly discusses the situation in south Ireland, and compares the exposure level among different groups, and it can guide the government and water suppliers on remediation actions if necessary, and also provide recommendations for populations with concern about their drinking water. However, there are also many people in Ireland drinking water from private wells, which need to evaluate the contamination level. Therefore, further studies on private well water are essential, and public need raise their awareness of arsenic contamination in drinking water.

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SPECIFICATION FOR A STANDALONE PV SYSTEM FOR A RESIDENTIAL COMPLEX

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Abstract

This research is focused on integrating the best available solar technologies to specify a standalone photovoltaic (PV) system for a residential complex with a small number of houses in Germany. Germany was chosen because it has high solar potential and availability of advanced technology to harness that potential. All available technologies were reviewed and photovoltaic thermal (PVT) solar panels were chosen to fulfil the electrical and thermal demand of the buildings. Standalone photovoltaic power system results in electrical energy that cannot always be used directly as the supply and demand are not always equal to the solar panel capacity, so battery banks, such as the Tesla Power Wall, was also specified. The specification assumed the system would remain completely disconnected to the grid. The proposed system was evaluated to assess how it would help the country achieve its environmental targets. Uncertainty was evaluated by testing the specification with data from five German cities, Hamburg, Dortmund, Kassel, Berlin and München.

Introduction

Well established photovoltaic solar cell technology converts solar radiation into electricity with a relatively low efficiency of around 15%. After conversion, more than 80% of the absorbed solar energy is released into the surroundings. The excess heating of the solar cells leads to a further drop in efficiency. Therefore, to improve the performance PV modules it is important to provide cooldown intervals. However, there is no such problem in hybrid solar technology such as PVT (Photovoltaic Thermal) panels. With these panels, air and water collector systems are integrated to use the excess heat efficiently and conventional silicon modules can be upgraded with polycrystalline silicon modules. It has been shown that a solar PVT system can have better performance than a solar PV system because of the increase in electrical and thermal efficiency of the module (Rawat 2017). **The objective of this research is to specify a standalone renewable energy system for a residential complex of a small number of houses by using system analysis modelling to find and integrate the best available solar technologies.**

Material and Methods

The approach taken was (1) specify the location for the residential complex; (2) review options for electricity and thermal energy conversion; (3) review need for energy storage and time-shifting; (4) select most compelling technologies; (5) model the system; (6) evaluate sensitivity to technology selection; (7) evaluate sensitivity to location; (8) evaluate implications for local policy; and (9) recommend a system specification that is general enough to be implemented for small residential developments.

1. *Location*

Germany was the country selected because it has a wide range of renewable energy options, a large and varied geography, advanced policies for adoption of renewable energy and citizens who want energy decarbonization. The design target for residential housing complex has not been specified yet but referring to Intelligent (2014), the approximate annual unit consumption for residential buildings in Germany at EU level is approximately 220kWh/m^2.

2. *Review of conversion technologies*

A literature review and technology search were conducted using the key words like STRING INVERTER, PV INVERTER, PV CONVERSION. Only sources that could be verified either by peer-review, regulatory oversight or some other independent verification were used. Unsubstantiated marketing claims were excluded from consideration.

3. Review of storage and time-shifting technologies

A literature review and technology search were conducted using the key words POWERWALL, PV STORAGE, THERMAL STORAGE. Similar source restrictions were applied.

4. Selection of most compelling technologies

The following criteria had to be met by the technology selected for evaluation: (1) electricity generation; (2) thermal energy generation; (3) optimum efficiency; (4) electricity storage / time-shifting; (5) thermal energy storage; (6) electricity conversion to work with standard domestic appliances.

5. System modelling

A modelling framework was constructed using HOMER Pro (www.homerenergy.com) to evaluate different technology options. Data were compiled using MS Excel to automate input and scenario testing to validate the best available option in terms of energy efficiency.

6. System evaluation

The most successful option had to meet the demand of the small residential complex with maximum efficiency and minimum energy payback time with no risk of failure even when disconnected from the grid.

7. Sensitivity to location

Five cities (Table 1) were selected to test sensitivity of the specification. Hamburg (north), Kassel (middle) and München (south). These represent the range of latitudes aligned to a longitude approximately through the centre of the country. Dortmund (west) and Berlin (east) represent a range of longitudes along a similar line of latitude with Gottingen in the middle.

Table 1. Solar Potential of different cities for April 2020(Weather 2020)(Deutscher 2020)

Deutsche Städte	Mean sunshine hours	Average minimum temperature (^{o}C)	Average maximum temperature (^{o}C)
Hamburg	276-300	4.7°C	13.3°C
Dortmund	276-300	4°C	13°C
Kassel	300+	3.0°C	12.0°C
Berlin	300+	13.2°C	4.2°C
München	275	2.8°C	12.5°C

8. Policy implications

Germany had the highest solar PV capacity per capita, at 437 watts per resident in 2018 (statista 2018) and is focusing on solar PV technology to replace fossil-nuclear technologies. The annual target set by the German Federal Government to expand PV technology was exceeded in 2019. To achieve the targets set in 2020, there is an ongoing expansion in PV power generation sector (ISE 2020). The policy context was extracted from the review of literature used to find and assess technologies.

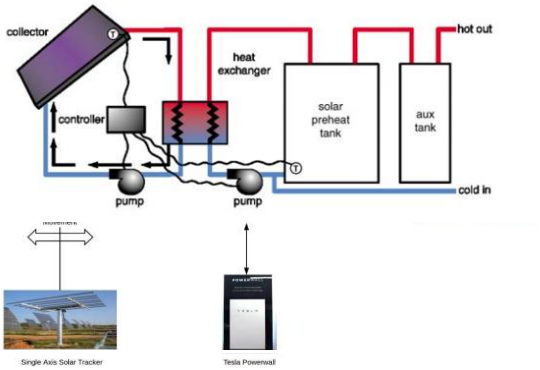
9. Recommendation

Based on the quantitative data, tested for geographical location, a system specification will be recommended.

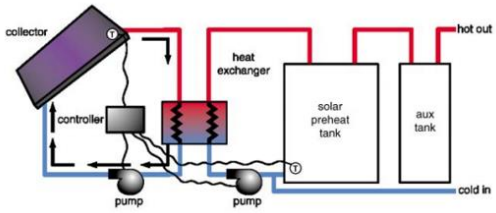
Results and Discussion

The complete literature and technology review are not yet available. Some preliminary results (Table 2) suggest a likely system specification, outlined here (Figure 1). The system will consist of 5 solar technologies that will work in harmony to meet the demand of the residential complex, making it a standalone power generation system. The 4 major components of the system are: (1) water-based PVT panels (Figure 2), (2) a solar tracking system (Figure 3), (3) a power bank (4) water tank storage and (4) an inverter.

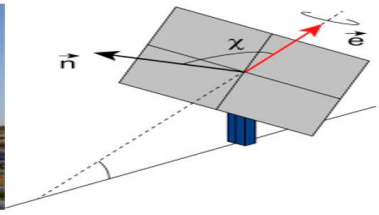
A water type PVT system (Figure 2) would provide both electricity, heating and hot water for the complex. It would need anti-freeze for the winter. In Germany it is possible that a technology like this could supply 80% or more of the energy needed to heat the water, but this need evaluating for standalone use in winter. The energy saving of the system could be up to75%. The photovoltaic cells convert solar radiation into electrical energy with an average efficiency of 15 to 20%. (Ji *et al.* 2014; Energy 2017)



The solar tracking system (Figure 3) is designed to track sunlight and align the PV arrays to maximize the incident sun rays received by modules. This further increases the efficiency of the PV modules.



Solar tracking technology has not yet been implemented worldwide because of cost. To evaluate cost effectiveness, both a multi- and single-axis tracking system will be evaluated. Comparison of both the technologies would be done on economic and environmental parameters.



To time shift thermal energy, a water tank storage system will be integrated. The water tanks are properly insulated to store the generated heat energy throughout the year. Anti-freezing agent would ensure that the heated water can travel via pipelines. There would be an in-depth research on this technology to devise an implementation plan. (Sarbu 2018).

One of the most advanced battery technologies at the moment is the Tesla Powerwall that consists of a rechargeable lithium-ion battery, which could store electricity generated by PVT panels during the daytime. The modelling will indicate whether the Powerwall could be installed in the residential building or whether a different technology will be required.

Ease of upgrade must also be considered in the recommendation. This storage device must make the entire system self-sustainable by allowing time-shifting between day and night and possibly summer and winter.

The final component required is an inverter to allow conventional appliances to be used in the complex. String inverters are the most efficient type of inverters, suitable for household demands. They are thought to be cost effective and environmentally friendly. The system modeling will reveal whether a single or three-phase specification is required, and whether additional battery storage is needed. The energy production and consumption could be monitored over mobile devices. (ABB 2019).

Conclusion

Once the number of houses and load of the residential complex has been specified and calculated and an appropriate system specification drawn up, possible specifications with commercial technology will be modelled with HOMER. The efficiency of each system will be evaluated considering factors including incident sunlight, deterioration of panels, maintenance of panels and requirement for ancillary technology. By comparing the data and performance analysis, the most cost and energy effective system will be recommended for implementation to achieve German policy targets.

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INVESTIGATION OF EFFECTS AND DRYING KINETICS OF DIFFERENT DRYING METHODS ONSEAWEED *ASCOPHYLLUM NODOSUM*

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Abstract

In this study, five drying methods, including air-borne ultrasound assisted fluidized bed drying (USA), ultrasound pre-treatment fluidized bed drying (USP), blanching pre-treatment fluidized drying (HWB), fluidized bed (FBD) alone and oven drying, were employed to dry an Irish brown Seaweed *Ascophyllumnodosum*. Their drying kinetics and energy consumption were studied. Six models were used to describe the drying kinetics, among which model Page fitted oven drying better due to its lowest χ^2 (0.0001), AIC (<-89.76) and BIC (-97.11). All tested models showed high regression coefficient ($R^2>0.99$; $P<0.05$), low RMSE (<0.0189), AIC (<-26.92) and BIC (<-58.88) with exception to model Wang & Singh. No significant difference (P>0.05) was observed on energy cost. Compared with conventional oven drying technique, USA reduced drying time by 76 with comparable energy consumption. Sample water activity after USP was the lowest (0.193). This study demonstrated that FBD had a better performance in terms of energy consumption, drying time and yield and ultrasound assisted may have potential developments in Irish brown seaweed drying process.

Introduction

Global seaweed market is worth over 6 billion US dollars per year. Among which, 85% was related to food products, and the others was contributed by value added extraction products from seaweed such as carrageenan, agar and alginates (Ferdouse et al., 2018). North Atlantic rockweed (*Ascophyllumnodosum*) studied in the paper, as a typical brown seaweed, is commonly harvested in northwest Europe including Ireland, used for animal feed, fertilizer and alginate production (Bertness et al., 2014). Fresh seaweeds are often dried prior to further processing. However, the quality of seaweeds would significantly affected by drying process, especially processed in a high temperature. Low-cost method of drying like solar drying needs a large space and a suitable climate condition. Pre-treatment operations such as hot water blanching, ultrasound, microwave etc., can modify the sample's tissue structure so that reduce the drying time. Compared with widely applied hot water blanching, the non-thermal attribute of ultrasound can improve the final product quality and reduce the drying time. In order to develop a low-cost, time-saving and photochemical-retaining drying technique for seaweed, pre-treatments with ultrasound, microwave and osmosis have been studied in last few years (López-Hortas et al., 2019). Airborne ultrasound assisted (USA) drying also has the ability to increase the water effective diffusivity and reduce the drying time. Ultrasound pre-treatment FBD and air-borne ultrasound assisted FBD were used in this study.

The objective of this study was to determine the effectiveness of ultrasound assisted drying methods on Irish brown seaweed, *Ascophyllumnodosum*, in comparison with other five drying methods. Six models were applied to describe their drying kinetics. The qualities of dried seaweeds were evaluated.

Material and Methods

Seaweed materials and chemicals
Fresh *Ascophyllumnodosum* (moisture content of 73.08% ± 0.29%, w.b.) was harvested from the west coast of Ireland in November 2019. The fresh seaweed samples were washed thoroughly with tapwater to remove impurities, wiped off the surface water using blue tissue and then grounded into the size of approximately 1 to 2 cm in length. The samples were stored at -30 °C before treatment.

Drying methods

Five different drying methods (USA, USP, HWB, FBD and oven drying) were employed to dry the seaweed samples (200 g). Prior to pre-treatment or drying, samples were defrosted and kept overnight at 4 °C. In FBD, the samples were dried in a fluidized bed dryer (Sherwood Tornado M501, Sherwood Scientific, U.K),with a drying temperature at 50°C, air velocity in the drying cylinder at 6.7 m/s. Pulsed air flow was produced by the pulse inside the FDB dryer in order to homogenize the samples inside the dryer. In HWB, the defrosted samples were blanched at 70 °C for 8 min, followed by subsequent drying in the fluidized bed dryer as in FBD. In USP, the defrosted samples were sonicated in 800 ml water using an ultrasound probe (UIP500hdT, Hislscher, Germany), as illustrated in Figure 1b for 10 min. After the pre-treatment in USP and HWB, the samples were filtered and then blotted using blue tissue to dry the surface moisture. In USA, the defrosted samples were dried in a drying set-up, combined using the fluidized bed dryer and an air-borne ultrasound system (RMX 4050HD, QSC, U.S.A) at 20 kHz, as illustrated in Figure 1a. Conventional drying test were carried out introducing seaweed samples in an oven (Gallenkamp Plus II, Gemini, Netherland),at room pressure and 50 °C. Samples were weighed every 10 min for the first 30 min of drying and every 15 min for the next 30 min, and every 30 min for the subsequent one hour, in USA, USP, HWB and FBD. As for oven drying, samples were weighed each hour. Moisture content was determined at 105 °C overnight in an oven (Model 28, Binder, Germany).Then data from five drying methods used in this experiment was plotted about moisture ratio (MR) against time as calculated in Eq. (1)

$$\mathrm{MR} = \frac{M_{td} - M_e}{M_{0d} - M_e} \quad (1)$$

whereM_{td} moisture content on a dry basis at given time, M_{0d} is the initial moisturecontent (db), M_e is the equilibrium moisturecontent (db). Six models shown in Table 1 were used to describe the drying kinetics.

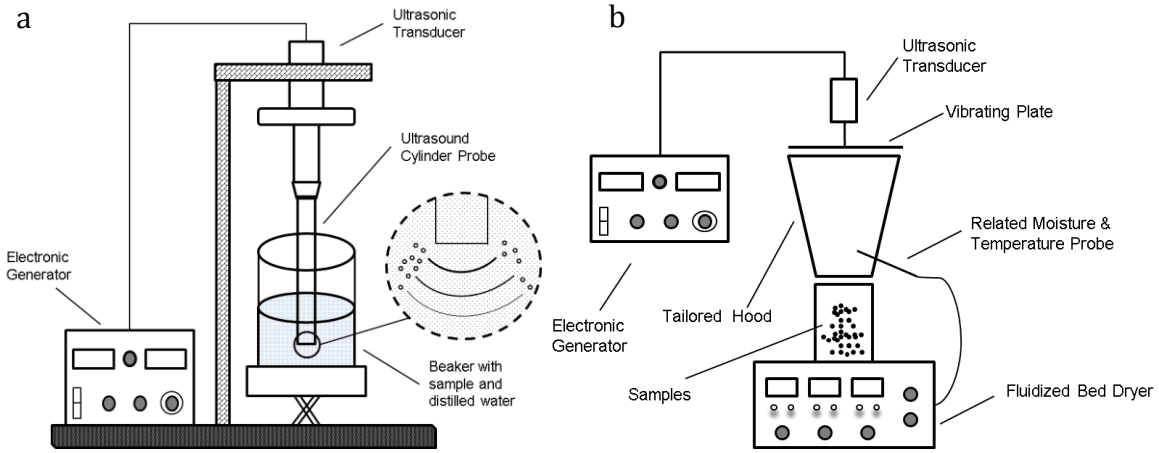

Figure 1. Experiment setups for air-borne ultrasound assisted fluidized bed drying (USA) (a)and sonication pre-treatment in blanching pre-treatment fluidized drying (HWB)(b)

Statistical analysis

All the drying methods were performed triplicate. Parameters of six models were calculated using SPSS (IBM SPSS Statistics 20.0.0). The criteria affecting selection of model was based on the sum square error (SSE; Equation (1)), regression coefficient (R^2), root mean square error (RMSE), chi-square (χ^2), Akaike information criterion (AIC) and Bayesian information criterion (BIC). Effect of the drying methods was tested by one way ANOVA withTukey test in Post Hoc multiple comparisons (IBM SPSS Statistics 20.0.0). The significance level was defined at$P < 0.05$.

Results and discussion

Drying kinetics

Wang and Singh model may not fit the five drying methods in this experiment for their lower $R^2$from 0.77 to 0.93. Model Page fitted oven drying better due to its lowest χ^2 (0.0001), AIC (<-89.76) and BIC (-97.11), as similar results reported by Rahman et al. (2015). In other models they have similar R^2 around 0.99, low RMSE from 0.0056 to 0.0189, AIC (<26.92) and BIC (<-58.88).

Table 1 Parameters of six models for five drying methods

Model	Parameter	FBD	USP	USA	HWB	Oven
Henderson and Pabis	R^2	0.9981	0.9990	0.9980	0.9980	0.9890
	RMSE	0.0182	0.0132	0.0154	0.0187	0.0392
	χ^2	0.0004	0.0002	0.0003	0.0005	0.0019
	AIC	-52.0605	-57.2282	-54.7301	-51.6777	-61.8140
	BIC	-61.9811	-67.1488	-64.6506	-61.5982	-69.1631
Midilli et al.	R^2	0.9990	0.9980	0.9990	0.9990	0.9990
	RMSE	0.0056	0.0153	0.0105	0.0127	0.0106
	χ^2	0.0001	0.0005	0.0002	0.0003	0.0002
	AIC	-43.0372	-26.9243	-32.9302	-29.9134	-78.0016
	BIC	-74.9901	-58.8771	-64.8830	-61.8662	-91.9545
Newton	R^2	0.9980	0.9990	0.9980	0.9980	0.9910
	RMSE	0.0184	0.0134	0.0157	0.0186	0.0434
	χ^2	0.0004	0.0002	0.0003	0.0004	0.0021
	AIC	-57.5558	-62.6593	-60.0995	-57.3106	-60.0063
	BIC	-63.9558	-69.0593	-66.4995	-63.7106	-69.0063
Page	R^2	0.9990	0.9990	0.9970	0.9990	0.9990
	RMSE	0.0116	0.0087	0.0189	0.0128	0.0110
	χ^2	0.0002	0.0001	0.0005	0.0002	0.0001
	AIC	-59.3391	-63.9447	-51.4966	-57.7471	-89.7613
	BIC	-69.2597	-73.8652	-61.4172	-67.6677	-97.1105
Wang and Singh	R^2	0.7730	0.8150	0.8460	0.8240	0.9390
	RMSE	0.1997	0.1843	0.1637	0.1738	0.1039
	χ^2	0.0532	0.0453	0.0357	0.0403	0.0132
	AIC	-13.7739	-15.0631	-16.9571	-15.9980	-40.3843
	BIC	-23.6944	-24.9836	-26.8777	-25.9185	-47.7334
Weibull	R^2	0.9060	0.9990	0.9990	0.9980	0.9990
	RMSE	0.0079	0.0154	0.0130	0.0178	0.0107
	χ^2	0.0001	0.0004	0.0003	0.0005	0.0002
	AIC	-56.1582	-45.4428	-48.1171	-43.1539	-85.2342
	BIC	-73.0971	-62.3817	-65.0560	-60.0928	-95.5064

As showed in Figure 2, MR decreased exponentially in first 10min. Drying by USP was faster than other methods after 27 min, followed by HWB. USA has a subtle drying speed and exceeded FBD after 110 min. It took USP, HWB and FBD the shortest time, around 80 min to reduce moisture content to about 10%. USA needed about 90 min to reach to the moisture content. As a traditional thermal drying method, oven drying spent about 6.5 hours to reach about 10% moisture content.

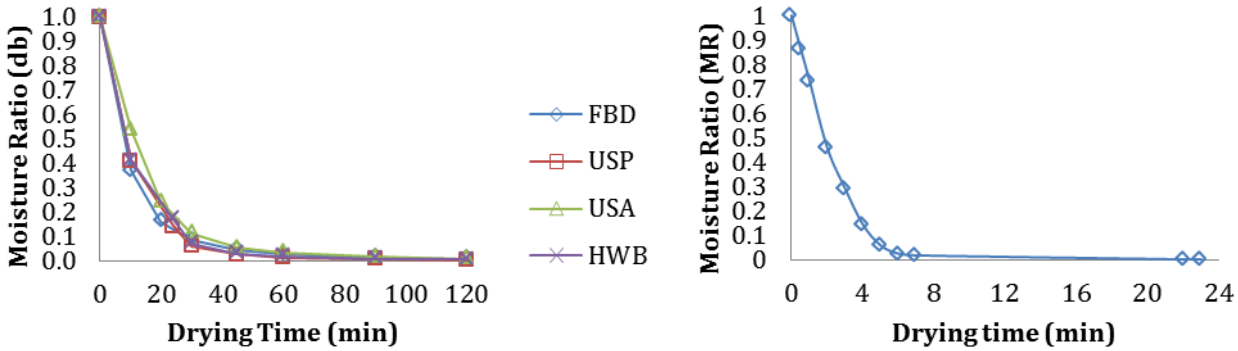

Figure 2. Moisture ratio against drying time in FBD, USP, USA, HWB and Oven drying

In terms of energy consumption, as showed in Table 2, the methods with pre-treatments exhibited lower energy consumption level, implying their potentials of energy saving. Nevertheless, energy consumption for heating up the water bath prior to blanching was excluded in the present study. Although drying processes with pre-treatments are more economic, the product yields are lower than other methods, due to leaching of solids from seaweeds during the pre-treatments, caused by damage of cell structure. Every 200 g of fresh seaweed, USP and HWB lost total solids about 7.65±0.09 and 6.32±0.19 g respectively. Compared with oven drying, as a conventional thermal drying process, USA had comparable energy consumption, but a higher yield. Water activities in the dried seaweed were significantly decreased as original a_w of fresh seaweed was around 0.99. In general, seaweeds driedby methods with pre-treatments had lower a_w. Among methods without pre-treatment, USA resulted ina lowest a_w. FBD is more suitable for this study in terms of energy consumption and yield.

Table 2 Energy consumption, product yield and water activity of dried seaweeds with moisture content of10% (w.b.) usingthe five drying methods

	Energy (kwh)	a_w	Yield (g / 200 g fresh seaweed)
FBD	1.74^{a}	0.351	60.51^{a}
USP	$1.63^{a,b}$	0.193	49.7^{a}
HWB	$1.58^{b,c}$	0.238	50.89^{a}
USA	2.55^{c}	0.321	58.17^{b}
Oven	2.51^{c}	0.373	55.16^{b}

Conclusions

Except Wang and Singh, other five models fitted seaweed drying kinetics well(R^2>0.99). USP method caused the lowest water activity in samples. Though USA saved processing time by 76% than oven drying, their energy consumption was comparable to oven drying. FBD has advantages in energy consumption and production yield. The results of this study were achieved using one setup of airborne ultrasound assisted drying method. Due to the limited setup combination, further optimization setups will be studied to reduce processing time, power consuming and increase value added compound extractions after drying process.

Acknowledgements

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Project Title: The application of using acoustic sensor as process analytical technology (PAT) tool monitor dairy processes

Project Leaders: Prof. Colm O'Donnell, Dr. Norah O'Shea

Abstract

Yoghurt, an essential dairy product, which is mostly produced by milk fermentation process with bacterial cultures. To achieve better quality and yield of the product, emerging process analytical technologies (PAT) based on existing bulk acoustic wave (BAW) sensor was applied. The objective of this study is this study is to measure milk fermentation process and yoghurt using a solid-state BAW sensor. The measured parameter was acoustic viscosity (AV). A rotational rheometer, was applied as reference method during the process for viscoelastic properties. A wireless pH meter was used for real-time pH collection for fermentation. When the process completed, yoghurt made using cultures with different strains were analysed to determine differences in AV, texture profile, syneresis and colour. Current results showed that AV, texture profile, syneresis and colour had obvious differences in yoghurt made from 2 types of culture. AV from BAW sensor had the same increasing trend comparing to G' from rheometer with pH drop where sample had a higher value of G' also had a greater value of AV response during the fermentation process. According to the existing results, it is possible to use sensor based on BAW technology for real-time yoghurt process monitoring, especially for early stage of the fermentation process. It also can be concluded that the sensor can successfully used to detect variation between yoghurts made from different viscosity produced cultures. Which has great potential for application in yoghurt manufacture in the future.

Acknowledgement

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ULTRASOUND AND ENZYME ASSISTED AGAR EXTRACTION FROM *GELIDIUM SESQUIPEDALE*

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Abstract

In this study, agar was extracted using ultrasound-assisted extraction (UAE) and enzyme-assisted extraction (EAE) combined with alkaline and hot water extraction from *Gelidium sesquipedale*. Five enzymes (alcalase, neutrase, papain, cellulase and viscozyme) were used for agar extraction. The yields and physiochemical properties of agar extracts were determined. Compared with conventional extraction methods, agar yield was increased (ca. 10%-18%) by using the combined UAE and EAE with the reduction of extraction duration to 2.5-3 hrs. Results demonstrated that the combination of UAE and viscozyme assisted extraction was the most promising method for agar extraction from *Gelidium sesquipedale*.

Introduction

Agar has many applications in different areas, especially in food manufacturing, medical fields and molecular biology studies (Abdul Khalil et al., 2018; Pereira, 2011; Hii et al., 2016). For agar extraction, *Gelidium sesquipedale* as one of the red seaweed species has been harvested in large amounts along the north coast of Spain, southern coast of Portugal and at the west coast of Morocco (Croce et al., 2015; Rhein-Knudsen et al., 2015).

Conventional extraction methods using alkaline treatment with hot water have been approved in industrial manufacturing for agar extraction, but several drawbacks impeded its development (Rhein-Knudsen et al., 2015; Hii et al., 2016). Therefore, some green techniques such as ultrasound-assisted extraction (UAE) and enzyme-assisted extraction (EAE), are considered to address the limitations of conventional methods i.e., high energy consumption and high carbon dioxide generation (Azmir et al., 2013). EAE worked as a primary treatment process to hydrolyse and degrade the constitutes in plant cell walls. However, the long leaching time under optimal conditions for enzyme pre-treatment will increase the energy consumption and decline operability of the extraction, thereby it is difficult to scale-up.

UAE can be used as pre-treatments to assist enzyme extraction. A study conducted by Sánchez-Camargo et al. (2016) showed that a weakening cell wall was more effective for further treatments to enhance the recovery of biocomponents, thereby increasing the total yield. Additionally, some internal components, such as embedded proteins, will be exposed at the surface due to the cell matrix disruption. Thus, both carbohydrase and protease can be utilized for hydrolysing different components during the extraction. Therefore, the combination of UAE and EAE is considered to be a potential method to overcome the shortcoming of each individual technique. **The objective of this study was to investigate the combination of UAE and EAE for agar extraction from *Gelidium sesquipedale*.**

Materials and Methods

Agar extraction
Fourteen protocols were created for agar extraction from the red seaweed species including a control method based on ultrasonication treatment but without using enzymes; two other control methods using selected enzymes but without using alkaline solvent for pre-treatment; eleven methods based on the combination of UAE and EAE. For the extraction based on the control method described by

Villanueva et al. (2010), with some modifications, *Gelidium sesquipedale* was washed using tap water to eliminate impurities and then put in an oven at 60°C overnight. Dried seaweed was ground into fine powder in 1 mm diameter and prepared for the agar extraction. Agar powder (ca. 40g) was soaked into 1 L pre-heated 0.5% (w/v) sodium hydroxide (NaOH, CAS-No:1310-73-2, EMD Millipore Corporation, USA) solution with an ultrasonic probe at 80°C for 30 min. Algae material was filtered using a double-layer muslin cloth and washed several times with tap water (approx. 12 L) to remove excess NaOH solution until the pH value of permeate reached to 8 - 8.5. The retained seaweed was then soaked into 1 L of pre-heated distilled water at 90°C for 1.5 hr with stirring using an agitator. Afterwards, the hot mixture was filtered using a single-layer muslin cloth to separate crude agar solution and solid residue. Crude agar solution was transferred into aluminium trays as soon as possible and cooled down to the room temperature (~20°C). Those trays were covered using tin foil and then frozen at –30°C overnight. To concentrate the extract, frozen agar solution was defrosted at room temperature to removed extra water using a single-layer muslin cloth. Finally, the concentrated agar was frozen again and then dried using a freeze dryer. Dried samples were kept in a closed plastic bottle and covered using Parafilm at room temperature before characterisation.

The agar yield was determined as percentage of dry seaweed powder using the equation as below:

$$Yields\ (\%) = \frac{\text{Dry agar weight (g)}}{\text{Dry seaweed powder weight (g)}} \times 100\%$$

Characterisation

The extracted agar samples were measured using Nicolet™ iS5 (Thermo Scientific, USA) Fourier transform mid-infrared (FT-IR) spectrometer equipped with diamond crystal attenuated total reflectance (ATR) accessory (iD7 ATR, Thermo Scientific, USA). Based on FT-IR spectral results, the samples with similarities to the commercial agar were selected for further analysis. Sulfate content of agar samples was measured using turbidimetric method, which was modified based on the methods described by Dodgson (1961), Dodgson and Price (1962) and Yarnpakdee et al. (2015). To calculate the sulfate content in samples, apparent viscosity (mPa*s) was measured using a rheometer (Anton Paar MCR 92, Germany) at 65°C and the intrinsic viscosity were calculated. Molecular weight of each agar sample was derived using the Mark-Houwink equation:

$$[\eta] = k \cdot M^{\alpha}$$

Where [η] is the intrinsic viscosity, k and α are the constants and M is the molecular weight of the sample. To obtain the constraints of the Mark-Houwink equation (k and α), agar solution was measured under the same conditions, as described in the study of Tashiro et al. (1996). Additionally, the contents of ash, moisture, fat and protein in each agar sample that were extracted using different extraction methods were measured for compositional analysis. Furthermore, thermogravimetric analysis (TGA) was carried out in this study, which was used to evaluate the thermal stability and decomposition profile of agar extracts.

Results and Discussion

Yields

The comparison of extraction yields were shown in Figure 1. Results showed the extraction yields of crude agar from *Gelidium sesquipedale* were increased significantly using EAE methods. Compared with other selected enzymes, alcalase and viscozyme assisted agar extraction methods, especially the methods combined with UAE achieved high yields. Results also showed agar yields were positively related to the use of NaOH as the pre-treatment method. In addition, the whole extraction time for the combination of UAE and EAE was 2.5 hrs. To provide optimal working conditions for enzymes, EAE was operated at specific temperatures and pH values. The pH values of extraction environment were stabilized before and after enzyme treatments by using buffer solution during EAE.

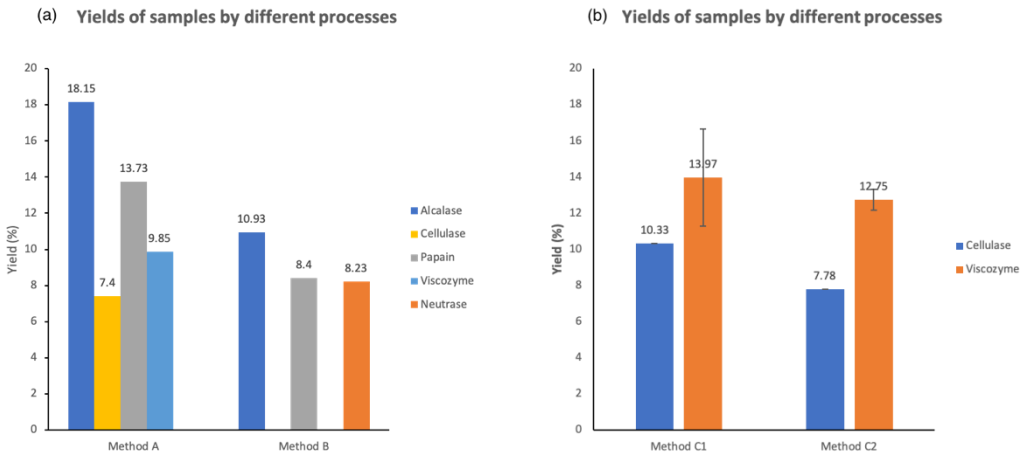

Figure 1. Yields of samples by different processes

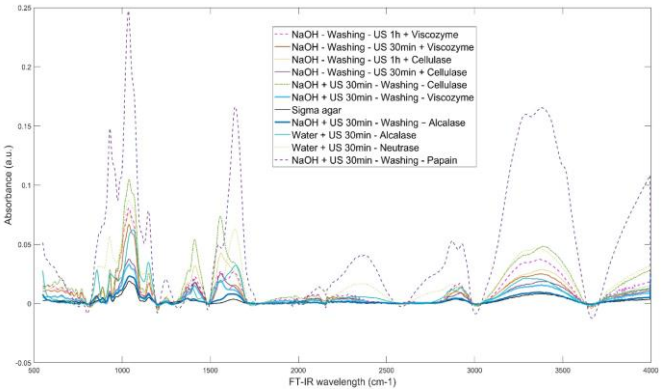

Figure 2. FT-IR spectra of agar extracted by different processes.

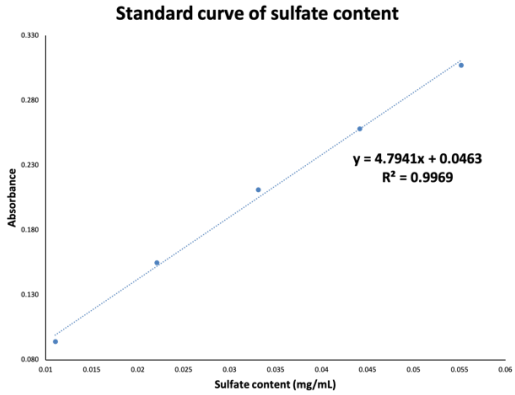

Figure 3. Standard curve of sulfate content

FT-IR

The spectral plots of EAE samples are shown in Figure 2. The spectrum of the sample extracted using method NaOH-US 30min + viscozyme/alcalase has the most similarity to the spectrum of Sigma agar. While the spectra of the samples extracted using method NaOH + US-cellulase/viscozyme have the same spectral shape as that of Sigma agar but with higher absorbance intensities. The spectral shape of agar samples extracted using papain and neutrase was quite different from that of Sigma agar. Therefore, it could be concluded that both papain and neutrase are not the proper enzymes that could be used for agar extraction.

Sulfate content

The standard curve of sulfate concentration is shown in Figure 3. The agar extracted using UAE and EAE had a relatively higher sulfate content and ranged from 4.94% to 8.82%, compared to previous studies (Xiao et al., 2019; Martínez-Sanz et al. 2019); this was possibly due to the low concentration of NaOH (0.5% w/v) used in this study.

Other physiochemical properties (i.e. molecular weight, TGA and compositional analysis) of agar extracts were also investigated in this study. Molecular weight and carbohydrates content of crude agars extracted using UAE and viscozyme were similar to the commercial agar. While the alcalase extracted agars showed an opposite result. In addition, EAE was considered to decrease the thermal stability of agar extracts based on the results of TGA.

Conclusions

Ultrasound and enzyme assisted extraction methods demonstrated advantages in increasing the yields of agar extracts and reducing extraction time. In the current study, agar extracted using the method of

NaOH + US 30min-viscozyme had satisfactory physicochemical properties with a relatively high extraction yields (ca.9.85 – 13.97%). Therefore, this protocol was considered as the most promising method for agar extraction from *Gelidium sesquipedale*.

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EVALUATION OF MICRO-NIR SPECTROMETER FOR CHARACTERISATION OF DAIRY PRODUCTS WITH VARYING LACTOSE CONCENTRATION

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Abstract

The need for lactose-free milk and other lactose-free dairy products has proliferated over the past few decades, due to a condition known as lactose intolerance. This increases the necessity to produce a lactose-free range of dairy products for the lactose-intolerant population worldwide and also implies the need for high quality and sensitive testing to verify the product label. This preliminary study evaluates the potential application of a micro-NIR spectrometer (operating in the wavelength range 1350-1650 nm) to characterise various dairy products with differing lactose content. The experimental design consisted of 3 experimental repetitions with 3 samples in each repetition for seven dairy products bringing the total number of scans to 63. Preliminary results indicate the repeatability of the micro-NIR spectrometer for differentiating the chosen variety of dairy products on the basis of lactose with the exception of the whole cream samples. These initial results suggest that the micro- NIR spectrometer is a promising tool for rapid, on-line evaluation of lactose and lactose-free dairy products due to its repeatability.

Introduction

Milk and its diverse range of dairy products are an essential part of the diet for several million people globally, providing a whole range of significant micro and macronutrients. Globally, 6 billion people consume milk and milk-derived dairy products (FAO 2020). The term 'lactose intolerance' is the incapability to digest the milk sugar lactose, due to a deficiency in producing intestinal lactase, which aids the absorption of lactose (Bahna 1996). Lactose is broken down into two monosaccharide units i.e. glucose and galactose by lactase and these are then readily absorbed in the small intestine, thereby preventing the consequences arising from being lactose intolerant (Vesa *et al* 2000; Szilagyi and Ishayek, 2018). Lactase-deficient individuals, upon consuming dairy products, may experience uncomfortable gastrointestinal symptoms. Common symptoms include diarrhoea, abdominal pain, flatus, bloating, abdominal distention, watery stools and audible borborygmi (Rodríguez *et al* 1979).

The fastest growing segment in the dairy industry is the lactose-free dairy market. By 2022 the lactose-free dairy segment is expected to reach a turnover of €9 billion (Dekker *et al* 2019). Growing demand for lactose-free dairy products calls for high quality and sensitive standard testing to deliver the guaranteed product label within defined specifications. Rodriguez-Otero *et al* 1997 concluded in his review that the NIR spectroscopy is an excellent tool for the analysis of major components such as lactose, fat, protein, and moisture in dairy products without any prior sample pre-treatment. More recently, He *et al* 2007 concluded that Vis/NIR-spectroscopy is an acceptable and reliable technique to predict the sugar content of yoghurt. In another study, de Lima *et al* 2018, proposed analytical methodology to classify lactose-free and ultra-high temperature (UHT) milk using NIR spectra obtained from FT-NIR (833-2500 nm) and ultra-compact NIR (908-1676 nm) along with multivariate classification techniques (PLS-DA, GA-LDA, and SPA-LDA). The results from the study indicated the use of ultra-compact NIR along with multivariate classification techniques are feasible in differentiating regular and lactose-free milk.

The objective of this study is to investigate the repeatability of a micro-NIR spectrometer to distinguish dairy products on the basis of presence and absence of lactose.

Materials and methods

Dairy products

Seven different dairy products were used to achieve the objective of the work, including: whole milk (WH), lactose-free milk (LH), plain Greek yoghurt (WY), no-added sugar yoghurt (SY), lactose-free yoghurt (LY), fresh cream (WC) and lactose-free cream (LC). Three different batches of the dairy products were purchased at a local store over the duration of 3 weeks i.e. one batch per week and stored at refrigerated conditions at 4^{o}C. This methodology was followed in order to study the stability of the dairy products and to observe any impact on the experiment caused due to the different batches used for the investigation. The nutritional value of the seven different dairy products, obtained from the product labels, is summarised in Table 1.

Table 1. Sugar and fat content of the various dairy products.

Average values (per 100 ml)	Whole milk (WH)[1]	Lactose - free milk (LH)[1]	Plain Greek yoghurt (WY)[2]	No-added sugar yogurt (SY)[3]	Lactose-free yoghurt (LY)[4]	Whole cream (WC)[1]	Lactose-free cream (LC)[4]
Carbohydrates (g)	4.7	3.4	7.3	3.0	5.5	2.6	2.9
of which sugars (g)	4.7	3.4	6.8	3.0	5.5	2.6	2.9
Fat (g)	3.5	1.5	9.5	5.0	2.2	38.0	36.1
of which saturates (g)	2.2	0.9	5.9	3.6	1.4	24.0	23.1

[1]Avonmore, Glanbia Ireland, [2]Tesco Ireland Ltd., [3]FAGE International S.A., [4]Arla Foods, Leeds.

Sample preparation

There was no prior pre-treatment or dilution carried out before scanning the samples. The store-bought dairy products were firstly transferred into 12 vials (2 mL) for each type of dairy product using beakers, plastic pipettes, 2 mL luer (BD Plastipak) and BD microlance (18G x 1$^{1/2}$", 1.2 mm x 40 mm). 12 vials were prepared for each type of dairy product because 3 vials were used for internal repetition, another 3 vials to check the temperature of the sample and extra 6 vials to accommodate any experimental errors. The vials containing samples were then stored in a refrigerator with temperature of 4^{o}C. For each set of sampling and testing, a pair of vials was taken out. A digital probe thermometer was used to check if the sample reached the ambient temperature (20^{o}C) and the samples took approximately 25 minutes to reach 20^{o}C from refrigerated conditions (4^{o}C). Then, 0.15 mL of the sample was sucked out of the vials using a luer and needle, and then transferred into a Grace Bio-Labs Press-To-Seal silicone spacer (round, 13 mm diameter, 2.5 mm depth) attached to an Academy Microscope glass slide (76 x 26 mm, thickness 1.0-1.2 mm, ground edges, 45^{o}) for testing.

NIR spectrometer specifications and settings

The NIRONE Sensor S, micro-NIR spectrometer (Spectral Engines Oy, Helsinki, Finland) with tungsten halogen bulb was used. The light source of the spectrometer generates considerable amount of heat during scanning. This spectrometer operates in a range from 1350-1650 nm. During scanning the sample, the spectrometer was held in an inverted position covering all the edges of the spacer, facing the sample. The readings are recorded in 3 s interval and for 10 data spectral points. 10 spectra were recorded for each sample in the same central point.

Experimental procedure

For every pair of vials removed from the fridge, one vial was used to check the temperature of the sample, while the other one was used for the actual testing itself. This approach was strictly followed in order to avoid contamination of the samples prior to testing. The weight of the glass slide with the spacer was measured prior to transferring the sample and as well as after the transferring the sample to it using a mass balance measuring the weight in grams up to 4 decimal points, to calculate the mass of the sample. The mass of the sample, spacer and glass slide was also measured at the end of every scan in order to calculate the weight loss (water loss) of the sample after scanning using equation (1). For spectral measurements, initially the dark (0% lamp intensity) and white reference (100% lamp intensity) measurements were taken and subsequently the sample was scanned. The spectra were

collected using 'SensorControl' software and spectral data stored in the text file format. The data were imported into MATLAB R2018b (The MathWorks Inc, Natick, MA, USA) using an in-built function. The reflectance of the spectra was calculated using equation (2).

$$\% \text{ Weight loss} = \frac{(\text{Weight of the glass slide with spacer and sample} - \text{Weight after scanning the sample})}{(\text{Weight of the glass slide with spacer and sample} - \text{Weight of the glass slide with spacer})} \text{x}100 \quad (1)$$

$$\text{Reflectance of the spectra} = \frac{(\text{Spectra data of the sample} - \text{Black reference})}{(\text{White reference} - \text{Black reference})} \quad (2)$$

Subsequently, reflectance was converted into pseudo absorbance (log(1/reflectance)) for easier interpretation of absorbance peaks in the spectra.

Results and discussion

The experiment was conducted over a span of three weeks, scanning one batch per week to observe the variation of lactose content in different batches purchased from the store, where each batch is referred to as individual external repetition. Each external repetition comprised of three internal repetitions to accommodate experimental errors and also to observe the intra-batch variations among the prepared samples. Therefore, each week's experiment consisted of 21 scans along with their respective weight loss observation. Fig. 1 represents the weight loss percentage of seven different dairy products for the three external and internal repetitions for all the 63 samples calculated using equation (1). For Fig. 2 the plots were obtained by normalizing the spectra by using the white and black reference as per equation (2) yielding the reflectance spectra. In both the Figs. 1 and 2 red represents external repetition 1, green depicts the second external repetition and blue represents the third external repetition.

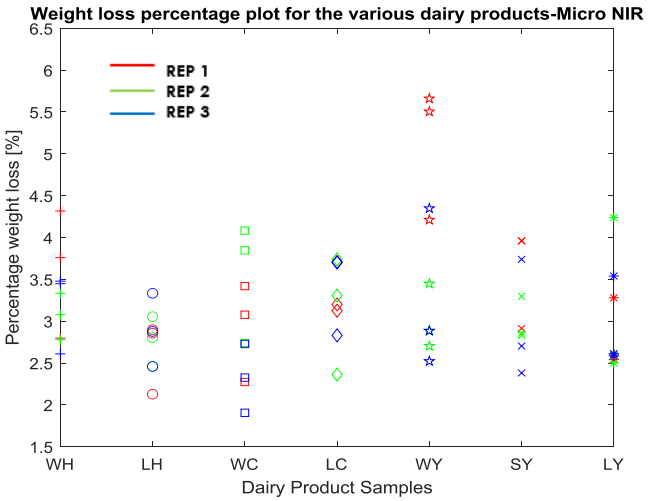

Figure 1. Weight loss percentage plot for micro NIR spectrometer for the three repetitions (all samples).

From, Fig.1, the highest variation in water loss percentage can be observed for WC and WY over the three external and internal repetitions. The spectra for WC exhibit

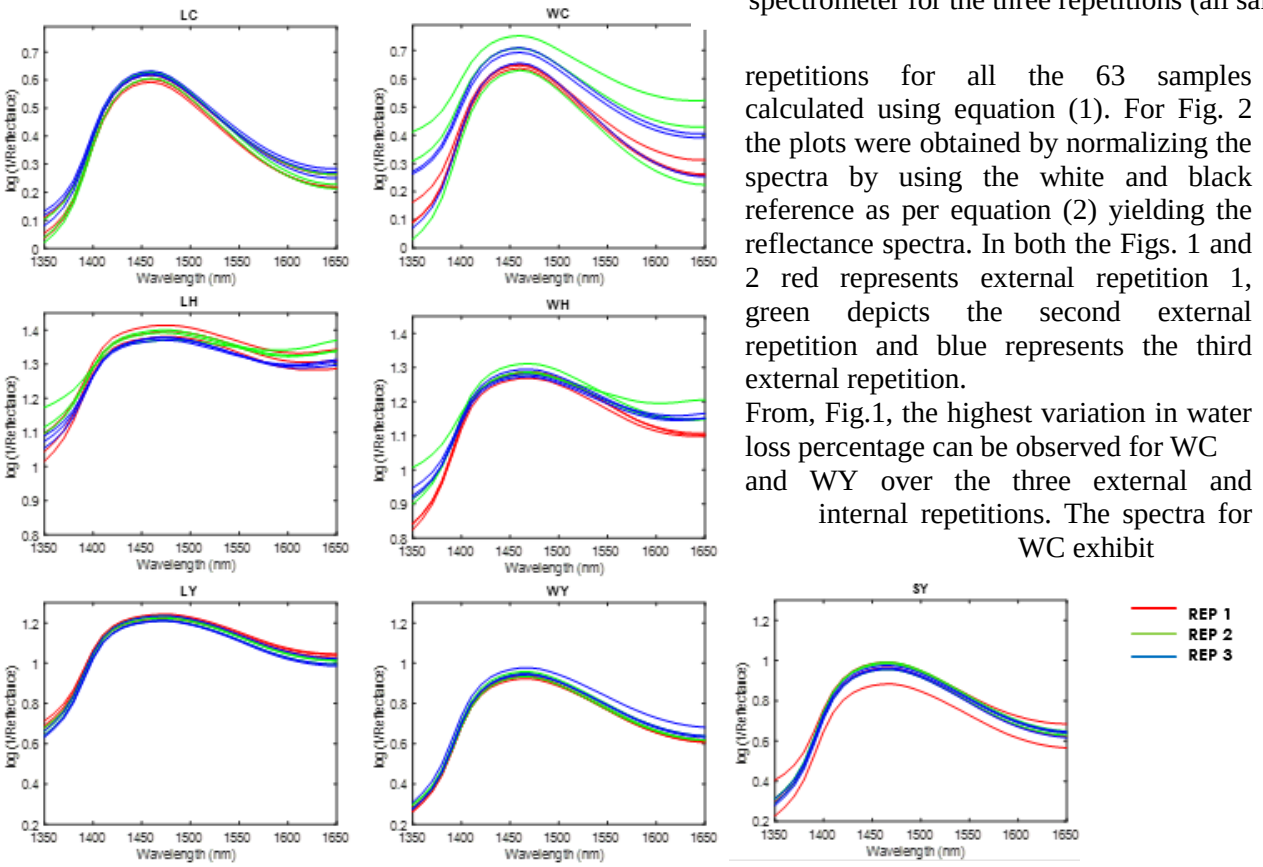

Figure 2. Pseudo absorbance mean plot for the various dairy products for the three external and internal repetitions.

Table 2. Intensity at peak and wavelength position at peak of the dairy products (The values represent mean of the external repetitions ± standard error).

Dairy products	Whole milk (WH)	Lactose free milk (LH)	Plain Greek yoghurt (WY)	No-added sugar yogurt (SY)	Lactose free yoghurt (LY)	Whole cream (WC)	Lactose free cream (LC)
Maximum intensity	1.2852 ± 0.00386	1.387 ± 0.00623	0.9440 ± 0.0072	0.9629 ± 0.0088	1.2254 ± 0.0047	0.6765 ± 0.0157	0.6166 ± 0.0061
Wavelength at peak (nm)	1470	1473.33 ± 1.925	1468.89 ± 1.11	1468.89 ± 1.11	1470	1460	1460

considerable variation, which could be related to the high variation in water loss as reported in Fig. 1. This implies, with exception to whole cream that the variation in the percentage weight loss or water loss doesn't have a negative impact on the spectra. From consideration of Fig. 2 and Table 2, it is evident the maximum intensity of the pseudo absorbance peaks are higher for the lactose-free range of dairy products with the exception of cream (the standard deviation and standard error was highest for WC, relates to the larger variation exhibited for this sample, as previously described). The wavelength position at peak for all the dairy products are closer to 1470 nm except for cream which is observed at 1460 nm. The key observation from these results is that, for all samples with the exception of WC, the heat generated from the micro-NIR sensor seems to affect weight loss considerably, but not the spectra. The variation over time whilst collecting 10 spectra for each sample may also impact the spectra. Hence, the above methodology followed in conducting the experiment infers that the NIR spectra is stable during the time frame of scanning the sample.

Conclusions

In summary, the micro-NIR spectrometer used to measure dairy products on the basis of presence and absence of lactose, demonstrates high repeatability with the exception of whole cream. The micro-NIR sensor is a relatively new technology that can be utilized to characterize various dairy products with varying lactose content due to its high precision and accuracy along with an added advantage of scanning the samples without any pre-treatment.

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EVALUATION OF A FLUORESCENCE AND INFRARED BACKSCATTER SENSOR TO MONITOR RENNET INDUCED COAGULATION OF LOW FAT MILK

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Abstract

Coagulation is a crucial step in the cheese manufacturing process, as the coagulum has to be cut with the correct firmness to obtain a high quality final cheese product. The aim of this research was to evaluate a fluorescence and infrared backscatter sensor to monitor and control rennet induced coagulation of low fat milk at different temperatures (30, 33 and 36°C) and enzyme concentrations (0.050, 0.060 and 0.075 ml/kg). Rheological measurements were used as a reference method to determine the time required for milk gels to reach *G'* values of 0.5, 1, 5, 10 and 15 Pa. Time parameters extracted from the fluorescence and infrared profiles were used to develop a linear rheological prediction model for each temperature, able to predict the times at which gels reached the selected *G'* values, as well as culminating in one general nonlinear rheological prediction model valid for the range of enzyme concentrations and temperatures analysed. The nonlinear model, which yielded a standard error of prediction of 1.44 minutes and a ratio of prediction to deviation of 6.25, was used to construct an enzyme assistant model to predict the enzyme concentration required in the next vat to reach 15 Pa in 30 minutes. This research showed that the fluorescence and infrared sensor has the potential to monitor and control rennet induced milk coagulation in the cheese manufacturing industry through rheological prediction models and by employing the enzyme assistant concept.

Introduction

The global cheese industry has been predicted to grow around ten percent in the next five years. Consequently, there is an increasing interest towards finding innovative solutions able to successfully control and monitor, with real-time measurements, the processes involved during cheese manufacturing.

The cheese making process starts with raw milk pasteurisation previously to undergoing coagulation, where it experiences a transformation in texture from liquid to gel due to the addition of the enzyme rennet. The curds formed during coagulation are cut and the whey is expelled. Subsequently, the curds are milled and salted ready to be pressed into the desired form before the ripening stage (McMahon and Brown 1984). Controlling and monitoring the coagulation stage of the cheese manufacturing process is essential to deliver a high quality final product. Control mechanisms were previously physical, visual or mechanical (storage modulus, *G'*, with rheometer) (Troch *et al*. 2017), but recently plenty research has been conducted on the introduction of Process Analytical Technology (PAT) tools to monitor milk coagulation, such as fluorescence and infrared backscatter sensors (Panikuttira *et al*. 2018). The determination of cutting times can be achieved using rheological prediction models that include time parameters extracted from the optical profiles (Panikuttira *et al*. 2019a; 2019b).

The main objectives of this research were twofold: firstly, to develop rheological prediction models for selected *G'* values in order to evaluate a fluorescence and infrared backscatter sensor capable of monitoring rennet induced coagulation of low fat milk at different temperatures and enzyme concentrations; and secondly, to develop an enzyme assistant model able to determine the enzyme concentration required in the next vat to achieve the desired gel strength at the desired time.

Materials and Methods

Experimental design
A balanced 3 ×3 full factorial design (three levels of temperature and three levels of enzyme concentration, both treated as fixed effects), with 3 replicas per cell (27 experimental units in total), was employed for the acquisition of rheological, fluorescence and infrared time parameters.

Coagulation
Rennet induced coagulation of low fat milk was performed at three different temperatures, *T* (30, 33 and 36°C) and at three different milk masses (160, 200 and 240 g) corresponding to three different enzyme concentrations, E_0 (0.075, 0.060 and 0.050 ml rennet per kg milk), since the volume of added rennet was kept constant at 0.012 ml.

Oscillatory rheology
A stress rheometer (MCR 92, Anton Paar GmbH, Graz, Austria), taken as the reference method, was employed to monitor the change in storage modulus (*G'*) every 10 seconds for a period of 45 minutes from the point of rennet addition.

Fluorescence and infrared backscatter sensor
A FluorLite CoaguLite sensor (Reflectronics, Lexington, KY, USA) was used to monitor fluorescence and infrared light backscatter changes during the rennet induced coagulation process. The emitted fluorescence was recorded at 350 nm (induced by ultraviolet light at 280 nm) and the infrared light backscatter at 880 nm. The sensor was attached to the bottom of a small 100 ml vat with water circulation surrounding it to maintain a constant temperature throughout the experiment. The voltage responses were collected at 3 second intervals, using a DAQ system, for a period of 45 minutes from the point of rennet addition.

Pre-treatment of optical sensor raw data
For the pre-treatment of the fluorescence (*F*) and infrared (*R*) profiles, the software MATLAB R2019b (The MathWorks, Inc., Natick, MA, USA) was employed to obtain the first and second derivatives of both original profiles using the Savitzky-Golay method, with a window size of 81 points, for noise reduction of the signals. Time parameters were extracted from the profiles, which were the times corresponding to the maximum and minimum values from the first and second derivatives of *F* and *R*: F'_{tmax}, F'_{tmin}, F''_{tmax}, F''_{tmin}, R'_{tmax}, R'_{tmin}, R''_{tmax} and R''_{tmin}.

Development of calibration models
Five *G'* values (0.5, 1, 5, 10 and 15 Pa) were selected for each of the 27 experimental units to obtain the corresponding measured gel times, resulting in a total of 135 observations. A calibration set that contained 90 of them was used to build the rheological prediction models. The remaining 45 random and independent observations were employed to evaluate and validate the prediction performance of the calibration models. In the case of models at a fixed temperature, the calibration and validation sets were comprised of 30 and 15 observations, respectively. Several rheological prediction models were developed by performing a series of nonlinear and stepwise multiple linear regression analyses in order to predict gel time (PT_{gel}). Hence, the measured gel time (MT_{gel}) by the rheometer was the dependent variable, whereas *G'*, E_0 and the optical time parameters were the independent variables. Statistical analyses were undertaken using the software package IBM SPSS Statistics for Windows, Version 26.0 (Armonk, NY, USA). All statistical tests were two-tailed and *p*-values < 0.05 were considered statistically significant.

Evaluation of rheological prediction models
The performance of regression models was estimated by statistical prediction indices such as coefficient of determination (R^2), Lin's concordance correlation coefficient (CCC), standard error of calibration (SEC), standard error of prediction (SEP), ratio of prediction to deviation (RPD) and range error ratio (RER). Generally, higher values of R^2, CCC, RPD and RER, and lower ones of SEC and SEP indicate a relatively greater precision of a model.

Results and Discussion

Rheological prediction models

Equation 1 shows the linear rheological prediction model that was built with the 90 observations from the calibration set.

$$MT_{gel} = -32.068 + 2.431 * F'_{tmin} + 0.892 * G' + 187.587 * E_0 \quad [1]$$

The R^2 for this model was 0.91, the SEP 2.76 minutes and the RPD 3.24. For it to be usable in any application R^2 and RPD should be higher than 0.98 and 5 respectively (Pu *et al*. 2020), hence specific linear rheological prediction models were built at each analysed temperature (equations 2-4), all of which showed R^2 values higher than 0.98 and RPDs higher than 5.

30°C $$MT_{gel} = 36.766 + 1.386 * G' - 254.811 * E_0 \quad [2]$$

33°C $$MT_{gel} = 1.484 + 0.754 * G' + 1.615 * R''_{tmax} \quad [3]$$

36**°C** $$MT_{gel} = -1.544 + 0.537 * G' + 1.314 * R''_{tmin} \quad [4]$$

Although the prediction performance of the three latter models was excellent, a satisfactory nonlinear rheological prediction model, valid for temperatures ranging from 30°C to 36°C, was constructed (equation 5). The time parameter F'_{tmin} appeared as with the general linear model, suggesting that fluorescence signals are really sensitive to changes in temperature and infrared ones are better at predicting cutting times at fixed temperatures.

$$MT_{gel} = 1.123 * F'_{tmin} + G'^{0.724} * \left(1 - 10.087 * \left(\frac{T - 36}{T}\right)\right) - 26.278 * E_0 \quad [5]$$

Figure 1 shows PT_{gel} values calculated using equation 5 against MT_{gel} values recorded by the rheometer. The R^2 for this model was 0.98, the SEP 1.44 minutes and the RPD 6.25, which revealed that it fit the data very well and had a greater prediction performance than the general linear model.

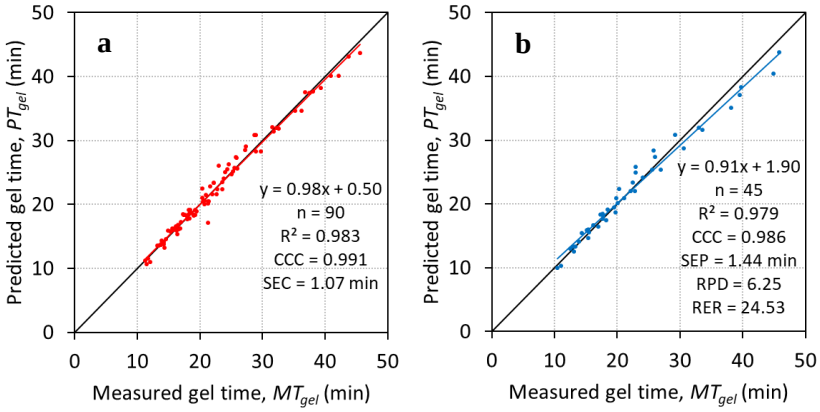

Figure 1. Predicted gel time (PT_{gel}) using the nonlinear rheological prediction model against measured gel time (MT_{gel}) for (a) the calibration and (b) validation set.

Enzyme Assistant

As industries seek to control coagulation to achieve consistent cutting times, and thus a steady state stream for downstream operations, a model able to use information obtained from a previous vat to predict the optimum conditions for the subsequent vat would be valuable. Therefore, the predicted times to reach 15 Pa obtained with the nonlinear rheological model were used to create the linear regression model shown in equation 6. This enzyme assistant model can predict the rennet concentration required in the next vat in order to reach 15 Pa in 30 minutes, assuming that the temperature between vats stays constant.

$$30 - PT_{15G'} = -125.908 + 3.433 * T + 212.413 * E_0 \quad [6]$$

The enzyme required for the next vat was calculated by multiplying the ratio between the concentration when the predicted time is equalled to 30 minutes and the concentration when using the predicted times from the optical sensor, by the concentration in the initial vat. Figure 2 shows the differences between next vat and initial enzyme concentrations against all the 27

experimental observations taken as conditions for the initial vat. The left region of the graph shows positive differences, meaning that the enzyme concentration required in the next vat has to be increased to meet the specification of 15 Pa in 30 minutes, whereas the enzyme concentration has to be decreased for the conditions depicted in the right region (negative differences).

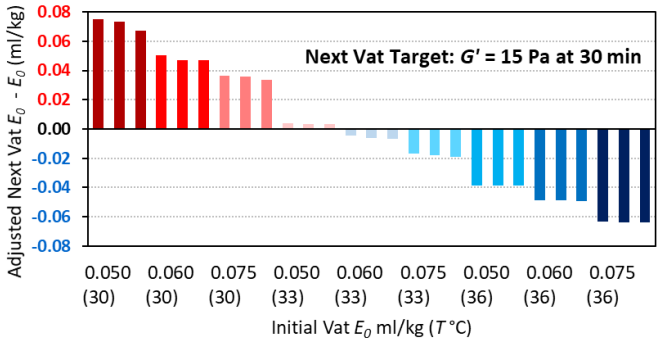

Figure 2. Difference between next vat and initial enzyme concentration against initial enzyme concentration for a next vat target of 15 Pa at 30 minutes.

Conclusions

A fluorescence and infrared backscatter sensor was evaluated as a potential PAT tool to monitor rennet induced coagulation of low fat milk at different temperatures and enzyme concentrations. The time parameters extracted from the optical sensor were employed for the development of three accurate linear rheological prediction models, at 30, 33 and 36°C, able to predict gel times for selected *G'* values, as well as culminating in one nonlinear rheological prediction model with an excellent prediction ability and valid for the range of enzyme concentrations and temperatures investigated. Furthermore, an enzyme assistant model capable of predicting the rennet concentration required for the next vat to achieve the desired firmness at the desired time was created by using the predicted gel times obtained from the nonlinear rheological prediction model. In conclusion, this study highlights the potential of an in-line fluorescence and infrared backscatter sensor unit as a PAT tool in the cheese manufacturing industry able to monitor and control milk coagulation and coagulum cutting time, over a range of temperatures and enzyme concentrations, through real-time measurements, rheological prediction models and by employing the enzyme assistant concept.

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FEASIBILITY OF MARINE ENERGY FOR A SPORTS FACILITY ADJACENT TO THE SHANNON ESTUARY

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Abstract

Ocean energy has a huge potential and can play a significant role in the energy market in the future. In this paper will be discussed and analysed partially the working principles of different ocean energy technologies, their efficiency, sustainability, and feasibility. Also, in the current assignment, a potential ocean energy system that will generate electric energy will be discussed as a possibility of designing and integration into a sports centre facility that is located in the Republic of Ireland.

Introduction

The ocean energy sector comprises different kinds of technologies that harvest energy from the oceans. Nowadays, many international specialists are working on the development of these technologies. There are several different methods for generating energy with the help of seas and oceans. The most important potential energy resources are found in wave and tidal phenomena, gradient salinity, temperature gradient-thermal energy, and others. However tidal and wave energies represent the two most advance types of ocean energy technologies(Magagna and Uihlein 2015).

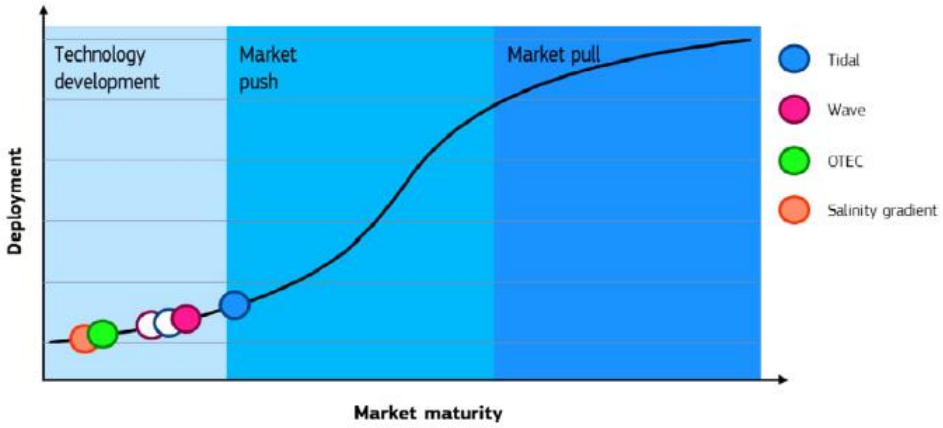

Figure 1: Support mechanisms according to market maturity and deployment level (Magagna 2015).

Although the potential of ocean energy is immense, at the present time its technologies are still in developing stages and there are just several significant and successful mature projects. Moreover, in the main report the governmental policies and strategies which refer to renewable energy sources as ocean energy will be examined. The technical challenge of this paper is to find the most efficient and suitable ocean energy system as an alternative source that will supply electricity for a sports centre complex.

The objectives of this study are to investigate and understand better ocean energy technology and to integrate an alternative wave or tidal energy system into a sport centre facility.

Materials and Methods

Wave energy systems capture the movement of ocean and sea waves and use it to create energy – in the majority of cases electricity. The energy created depends on the speed, height and frequency of the wave, as well as the water density (OCEANENERGY-EUROPE 2020).

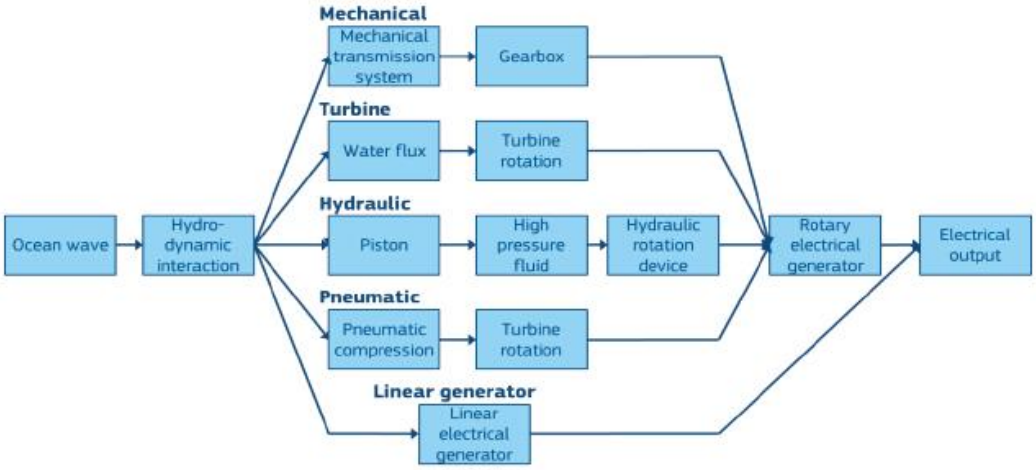

Figure 2: Wave energy conversion methods in electricity (Magagna 2015).

Tidal energy is created by the permanently changing gravitational pull of the moon and the sun on the seas and oceans. Tides are always in movement, that is why it is the most predictable, valuable and clean source of energy. Tidal stream technologies capture the kinetic energy of the currents coming in and out of tidal areas(SEAI 2018).

Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity using of a high surface temperature of the water with the low temperature of the water at a certain depth. OTEC pumps a huge amount of deep cold seawater and surface seawater to run a power cycle for generating electricity. OTEC is firm power 24/7, environmentally sustainable and available to generate significant level of energy(Farshid Zabihian April 2014).

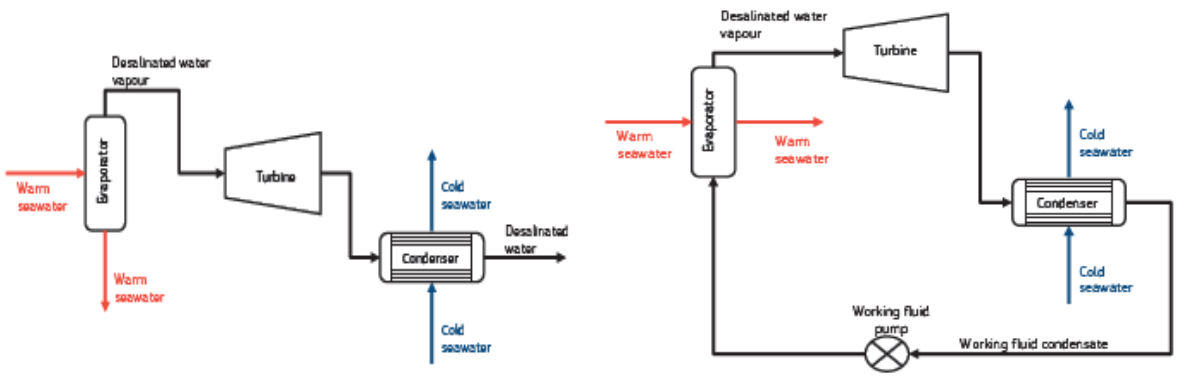

Figure 3: a) Simplified open-cycle OTEC process flow diagram, b) Simplified closed-cycle OTEC process diagram.

If to compare with wave energy, the energy available from OTEC is one or two orders of magnitude higher. However the thermal efficiency is quite low; the theoretical maximum efficiency is 6 or 7% (Meisen 2009).
Salinity gradient power is the energy created from the difference in salt concentration between two fluids, commonly fresh and salt water, *e.g.*, when a river flows into the sea. The total technical potential for salinity gradient power is estimated to be around 647 gigawatts (GW) globally. It is enough to satisfy nearly one quarter of global electricity consumption for 2011(IRENA 2014).

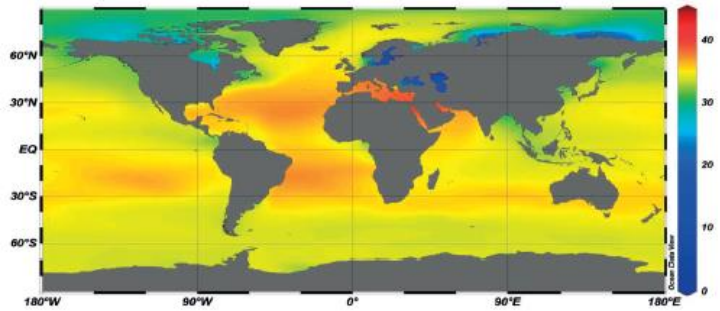

Figure 4: Salinity gradient resources: Salinity at surface level (Magagna 2015)

The second part of the project is more technical. The main objective is to design and implement an alternative renewable energy system for sports facilities complex, which will generate electricity through harvesting ocean energy. The most important parameters will be taken into consideration in order to find the most efficient and suitable kind of technology for producing and supplying green energy from the generators to the sports complex building. Hence it will reduce greenhouse gas emissions (GHGs) and the energy efficiency level of the building will rise considerably.

Results and Discussion

The current research will enrich readers knowledge about ocean energy; will provide information about the provenience of these natural phenomena; how people try to develop and implement seas and rivers energy systems in their daily life during the history; will discuss advantages and disadvantages of different methodologies and technologies of harvesting wave and tidal energy.
Regarding the technical part at the current stage of this thesis it is difficult to predict any kinds of results. Nonetheless, it is expected to find a great technical and effective energy solution for the chosen building. The energy consumption of the sports club for which an alternative system will be designed and integrated is 0,318 GWh/yr. A comparison among ocean energy technologies will give a good understanding of which system is more appropriate to the current case.

The examined sports centre complex is located on the banks of the Shannon River on the west part of the Republic of Ireland, where it is emptying its fresh water into the salt Atlantic Ocean water. Therefore, it will be an attempt to design a salinity gradient energy system. Also, the location is appropriate, and the river can suit into its waters some tidal energy technologies.

The energy system is going to be designed to generate more energy than current electricity consumption, in case the sports centre extends its territory in the future. Even if one of the major issues of ocean energy technologies is the availability of grid in the proximity of proposed projects, in our case it will be assumed that the site has a grid connection and it is located near the water. Hence the energy distribution cost generated from the renewable energy system will be considerably lower. Also, it is an admitted scenario to supply with power our sports complex from the grid when it is needed. However, the main source of energy should be renewable which is unlimited and comes from natural phenomena, that does no harm to the environment and contributes to the reduction of GHGs emissions.

Conclusion

The result of the study showed that ocean energy is a great source of clean energy. Although nowadays there are not so many very successful big projects, scientists from all over the world work intensively on ocean energy technologies development. Nevertheless, there are many efficient small and medium scale energy systems. In this research several methods of harvesting ocean energy will be analysed and investigated. One of the most suitable and feasible will be chosen for being integrated into a sport club energy system.

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FEASIBILITY OF HYBRID RENEWABLE ENERGY SYSTEM FOR AN OFF-GRID LOCATION IN THE WEST OF IRELAND MODELLED USING HOMER SOFTWARE

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Abstract

Demand for hybrid renewable energy systems are continuously growing due to both legislative efforts to reduce carbon emissions and development of off-grid remote communities. A technological and economic feasibility study was developed for the town of Kilrush, Co. Clare in relation to the implementation of a hybrid renewable energy system to aid the Irish Government's requirement to adhere to European legislations and decarbonize its economy. Models were produced within the HOMER Pro software to analyze the feasibility of constructing such a system. Investigations were conducted to determine if a system could be configured which would be capable of providing 100% renewable energy to the town along with producing configurations which would produce carbon emissions yet would be within the confines of government budget. Results indicate that a technological and economic configuration can be found, yet not simultaneously. Further refinements are recommended to produce more accurate representations of economic and technological models.

Introduction

Anthropogenic climate change through colossal greenhouse gas emissions is widely considered as one of the most significant challenges to human life on this planet. From this, civilians in Myanmar are being forced from ancestral lands in order to escape from dying croplands which are failing due to temperature rises caused by climate change (Borras *et al.* 2020). Rural citizens in Australia have spoken up about concerns of extreme weather conditions under an infrastructure which hasn't been adapted to account for these effects (Austin *et al.* 2020). Alternative extreme weather patterns from changes in climate result in antagonistic effects toward food production through hazards such as extreme flooding resulting in agricultural land becoming waterlogged (Harkness *et al.* 2020).
Ireland boasts an abundance of potential renewable energy sources which could be used to offset traditional methods of power generation which can be used to adhere to European Legislation which requires nations to decarbonize their economies. Renewable energy directives have been issued for members states within the EU as a method of establishing a reliable and well-funded means of domestic energy production. Such directives which have been issued include Directive 2009/28/EC (European Parliament 2009). This directive prompted the production of energy within member states to achieve at least 20% of total energy needs by 2020. By December 2018, a revised directive was enforced which was part of the Clean Energy for all Europeans package (Capros *et al.* 2018). From this, Directive 2018/2001/EU came into effect (European Parliament 2018). Requirements from this directive stated that the renewable energy target for the EU would be at least 32% by 2030, with possible revisions by 2023 (European Parliament 2018).

The objective of this study is to produce a technological and economic feasibility study of a hybrid renewable energy system to be implemented within a town on the west coast of Ireland

Materials and Methods

To produce the environmental system required by the HOMER software, a large quantity of data was collected to produce a climate model which was uploaded into the software package. Data relating to solar radiation, wind speed, and hydrokinetic variables such as flow velocity and wave heights. This study attempts to provide a techno-economic feasibility study for the town of Kilrush, Co. Clare located on the Clare peninsula in the west of the Republic of Ireland. No Met Éireann weather stations exist in this specific location. To account for this fact, this study's data was compiled from a collection of weather facilities located throughout the region. Data was collected from a range of stations, which also allowed for data to be collected which ranged through periods of time. Data was collected from five weather stations in the surrounding area over a 10-year timespan from 2009 to 2019.

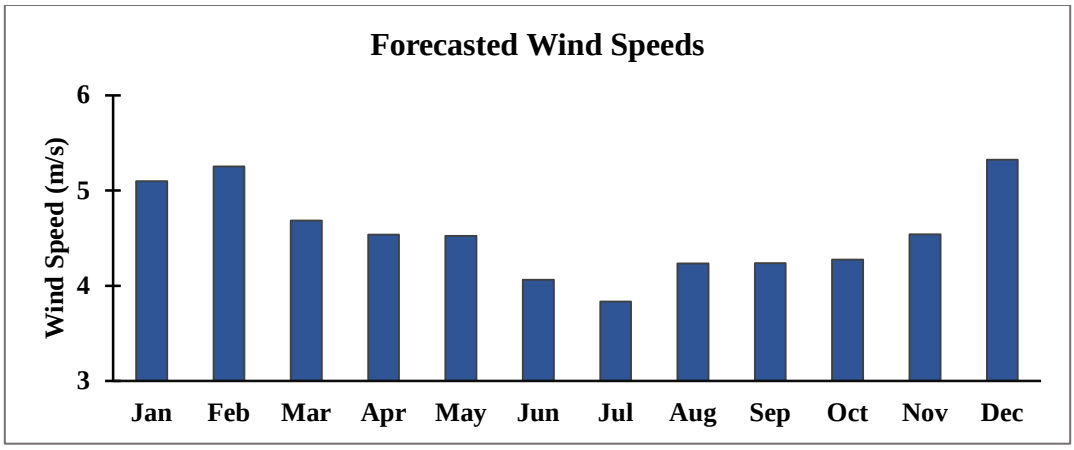


Figure 1. Forecasted wind speeds (m/s) to be used for modelling purposes

While data which pertains to the climate of the vicinity of investigation is important, a second aspect which was addressed was the consumption data of residents and industry within the area. Obtaining this data allowed for the model to have a specified load demand which was to be reached. Collection of data was done through multiple organizations to compile a comprehensive dataset of historical data. Similarly to climate data, historical energy demand data was gathered to allow a forecast to be produced which would be the conditions the model would operate under. This allowed a model to be formulated which could be used to determine the viability of the hybrid renewable energy system over a period of time.

Modeling and configuration of the system was done using the HOMER Pro x64 software developed by NREL. The climate and energy data were imported into the software to produce an environment under which the software could produce a model. Within the system, a configuration which included entirely renewable technologies. Such technologies included wind turbines, flat panel photovoltaic systems, and biomass resources to provide heating demand. Sensitivity analysis was conducted under technological aspects including quantity of specific technologies employed in the area along with economic sensitivity analysis to investigate should the cost of the system be within specified budgets.

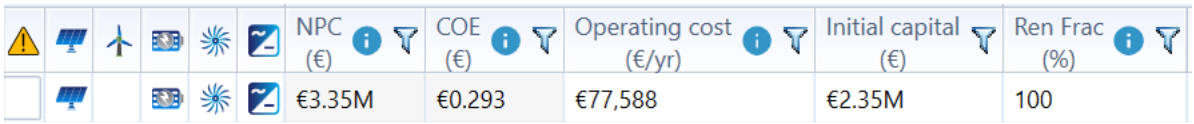
Results were analyzed using two system approach. The first would investigate if the technologies supplied could deliver energy to meet the demand of the town, the second would determine if the technological solution provided was economically feasible. A technological solution was considered a successful option if the configuration produced was capable of meeting demand using entirely renewable technologies. This was considered an ideal solution at a fundamental level, providing proof of concept that such a renewable system was achievable for this application. An economically viable solution was deemed to be applicable

if the configuration could provide at least 35% renewable energy while adhering to Irish Government budgets for such a project

Results and Discussion

Preliminary results are discussed below which were formulated by constructing a model which was comprised of locally sourced data from Met Éireann but used energy data sourced from a similar peer reviewed publication which produced a model of a similar scope (Agyekum and Nutakor 2020).

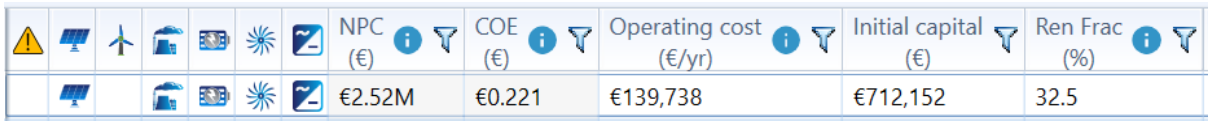
Technological Feasibility
Such a configuration was determined which would consist entirely of renewable technologies along with batteries to handle periods of intermittency throughout the operation lifetime. This system can provide 100% renewable energy to meet the demands of the town, while also producing excess electricity which can be sold back to the national grid for a return on investments. However, such a system requires a sustainable upfront capital cost for implementation, costing €1.6M initially with a total net present cost of €3.36M. While such a solution could provide benefits to the local economy through employment, results of this study are related only to the scope of immediate cost and energy generated



NPC (€)	COE (€)	Operating cost (€/yr)	Initial capital (€)	Ren Frac (%)
€3.35M	€0.293	€77,588	€2.35M	100

Figure 2. Technologically feasible configuration produced within the HOMER Pro x64 software

Economic Feasibility
An economically feasible configuration was found which could be implemented for a net present cost of €2.52M, with an initial capital requirement of €712,152. This configuration includes the use of an AC generator which operates by burning natural gas as a fuel source. Since this method requires the combustion of natural gas a means of generating electricity, it is unable to provide 100% renewable energy to the locale, offering only 32.5% renewable energy.



NPC (€)	COE (€)	Operating cost (€/yr)	Initial capital (€)	Ren Frac (%)
€2.52M	€0.221	€139,738	€712,152	32.5

Figure 3. Economically feasible model produced from configuration which includes an AC generator

Conclusions

The discovery of a renewable configuration which can provide 100% renewable energy to a town provides evidence that such a system is achievable from a technological viewpoint. This discovery confirms the technologically feasible aspect of this study. Producing a configuration which is also capable of being produced for an initial capital cost which is inside the allowed budget offers promising results in the economic feasibility. Refinements to specific model parameters and more thorough local environmental and energy data would lead to the creation of a more accurate representation of configuration which could be implemented in this area.

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ECONOMIC AND ENVIRONMENTAL ANALYSIS OF MACROALGAE PRODUCTION IN IRELAND

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Abstract

With a growing world population and the demand for food and energy likely to increase, seaweed is an untapped biomass resource that can help meet this need. Oceans cover 70% of the earth's surface, and seaweed biomass has a clear advantage over resource-intensive land-based biomasses while providing many ecosystem services such as carbon capture. There is growing interest throughout Europe in growing seaweed to meet these future resource needs. However, the development of this industry in Europe is economically challenging as the supply chain is immature and involves labour-intensive processes. This project aims to examine the financial and environmental costs of producing seaweed in Ireland and potential revenue to be made on the voluntary carbon offset market (VCOM). An economic and environmental life cycle assessment of seaweed cultivation will be conducted to evaluate the break-even point and environmental impacts. The carbon capture potential will be quantified accounting for energy inputs into production processes, and the carbon accumulated in the biomass valued from the VCOM.

Introduction

Macroalgae, or seaweed, cultivation is a massive industry worldwide producing 32.9 million tonnes in 2017, but the production of cultured seaweed is low in Europe and Ireland with the majority of tonnage produced from wild stocks (FAO 2017). Seaweed cultivation in Asia accounts for 99% of the worldwide production with China producing just under half of this quantity (FAO 2018).

The interest in seaweed has grown in Europe with the European Commission recognising it as an area of huge potential growth with the possibility to strengthen the blue economy and bioeconomy (European Commission 2018; Hasselström *et al.* 2020). The reason for this is that seaweed has a competitive advantage over land-based biomass in that it does not require any land, freshwater, fertilisers, herbicides or pesticides for growth (Duarte *et al.* 2009; Hasselström *et al.* 2020) as well as having high growth rates compared to these other photosynthetic organisms (Fernand *et al.* 2017). Seaweed cultivation also provides many ecosystem services such as nutrient bioremediation, ocean acidification mitigation and a climate mitigation service capturing carbon (C), with global seaweed communities taking up 1.5 Pg C/year (Krause-Jensen and Duarte 2016; Duarte *et al.* 2017). Further carbon savings can be made through the substitution of resource-intensive products with sustainably produced seaweed-based products (Duarte *et al.* 2009; Duarte *et al.* 2017) or reduction in ruminant methane production by introducing seaweed into animal feed (Maia *et al.* 2016). This study will examine the cost involved in large scale seaweed aquaculture in Ireland and the economic potential of this practice. It will explore the potential monetary benefit that can be made from the VCOM. The VCOM enables companies to offset their greenhouse gas (GHG) emissions by paying for verified reduction projects such as renewable energy developments or GHG capturing systems, compensating for unavoidable emissions in the company's processes. It works independently of regulatory markets such as the EU emission trading scheme (ETS) which sets a cap on emissions of heavy energy-using installations allowing companies to trade these caps and buy a limited number of credits from emission-saving projects

The objective of this study is to determine the economic viability and environmental impacts of large-scale seaweed cultivation in Ireland concerning tonnage necessary to break-even, the environmental cost of producing this seaweed and the potential revenue to be generated from the carbon offset market for seaweed farmers.

Materials and Methods

The assessment will consist of two parts; economic and environmental assessment based on data from Bantry Marine Research Station (BMRS) and carbon capture potential based on literature. Economic and Environmental LCA: The modelled system stimulated using Gabi software will focus on the production phase comprising of hatchery, seeding, maintenance and harvest for *Alaria*, a brown seaweed grown in Bantry (Figure1). The system starts at hatchery growth and ends at wet harvested biomass from cradle to gate. The function of this system is to produce wet biomass. The functional unit will be 1 kilogram of wet biomass. This biomass will be sold at market price and used for various uses which are outside the scope of this study. The study is based on primary data sourced from BMRS and supplemented by published literature to fill gaps in data. Production techniques and cultivation system used will reflect the BMRS set-up. The study will estimate the cost involved, energy requirements and GHG emissions related to seaweed production in Ireland to allow the GHG emissions involved in the production to be included in the carbon capture calculations.

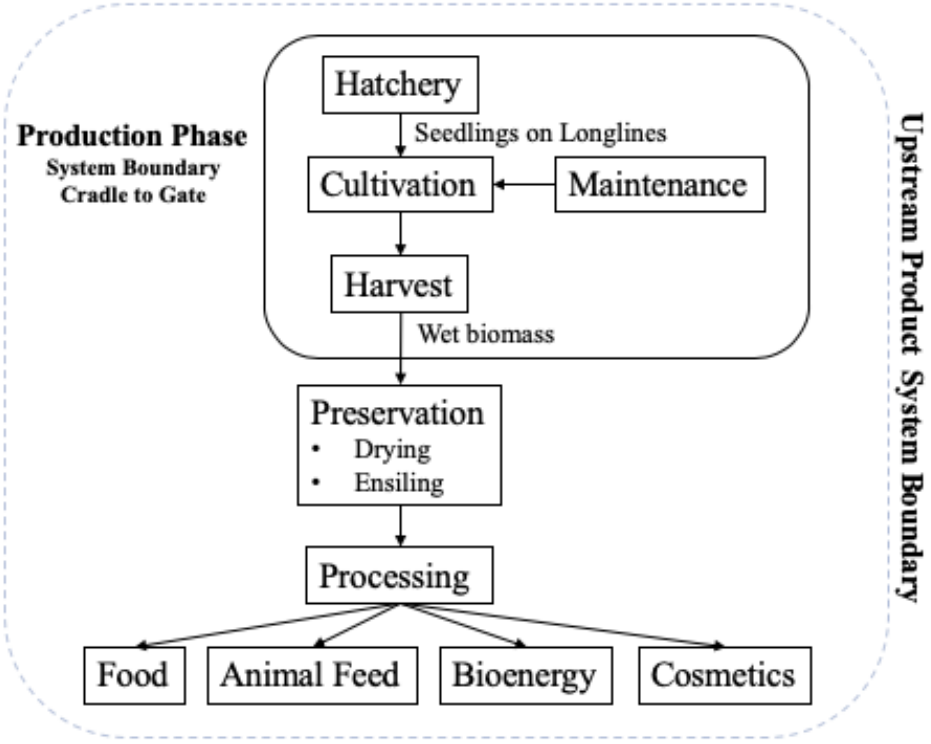

Figure 1. System boundary Cradle to Product. This study focus is on the Production Phase (Cradle to Gate).

Carbon Capture Potential: The amount of carbon captured in the seaweed biomass will be calculated using a series of assumptions. A dry weight to wet weight value is assumed based on previous studies accounting for a conversion ratio of 0.10 (Sondak and Chung 2015; Sondak *et al.* 2017; Froehlich *et al.* 2019). The percentage of carbon stored in *Alaria* will be assumed based on information gathered from the literature. This percentage in harvested seaweed dry weight varies among and within species (Sondak *et al.* 2017). Previous literature assumed an average C content of 30% for any seaweed species, an informed approximation from literature value (Sondak *et al.* 2017). A molecular weight conversion factor of C to CO_2 per unit of weight of dry matter taken as 3.67 in line with other studies (Sondak and Chung 2015; Froehlich *et al.* 2019). The following calculations are carried out to estimate the carbon captured and CO_2 sequestered:

Kg of Wet Biomass x 0.10 x 0.30 = Biomass Captured Carbon
Biomass Captured Carbon x 3.67 = CO_2 Sequestered

CO_2 sequestration, however, depends on (a) temporary storage in growing biomass, (b) the energy use and carbon emissions of post-harvest processes, (c) the life-length of storage in products, and (d) whether seaweed biomass products lead to the substitution of other energy, food, and materials with a higher carbon footprint (Duarte *et al.* 2017; Hasselström *et al.* 2018; Hasselström *et al.* 2020).
This paper focuses on the monetary value of (a) that can be achieved on the VCOM once (b) is accounted for in the calculation based on results from above environmental LCA. The value of per tonne of CO_2 on the EU ETS is currently holding at €25 (EMBER 2020). This value will be used to estimate potential revenue that can be achieved from the VCOM.

Results and Discussion

As this study is ongoing it is difficult to ascertain the exact results. However, the results will shed some light on vital information for the seaweed industry in Ireland. The economic analysis will identify the number of hectares of sea area that will need to be acquired for a sole seaweed grow out farm to break-even. This information will highlight the scalability of this industry in Ireland and any potential social issues that might arise from the necessary scalability such as cost incurred due to loss of recreational grounds (Hasselström *et al.* 2020).

Environmental data will be able to highlight how carbon-intensive seaweed production is in Ireland. This information will link to the Farm4More research project currently being undertaken in UCD. A deliverable of this project is to determine the feasibility and performance of seaweed ensiling which if successful will further improve upstream processes, bypassing the energy-intensive process of drying lowering the environmental impact of this developing industry (Figure 1).

Seaweed carbon capture and sequestration potential has been overlooked in the past but research in this area is growing (Krause-Jensen *et al.* 2018). The potential revenue quantified from the carbon captured will be evaluated against the cost to see if it improves the feasibility of seaweed production in Ireland. The results will highlight the carbon intensity of this step in the seaweed value chain. This will be important for quantifying offset carbon credits through seaweed product substitution that may be explored in the future.

Conclusion

Most studies exploring seaweed aquaculture have either focused on development of this industry for a business enterprise purpose or for a climate mitigation purpose. This study will develop the link between both of these enterprise proposals with a sole focus on carbon offset payback for farmers. Algae biomass is continually seen as a biomass of the future that can be developed sustainably. The results of this study will be able to identify the potential role of seaweed carbon capture in providing an extra revenue stream to farmers. The results will provide the first step in determining the feasibility of upscaling seaweed production in Ireland while accounting for the overall energy/carbon input needed to produce this biomass-based on primary data from an Irish seaweed farm.

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EXTENDING THE LIFE OF SOLAR PV SYSTEMS: A FEASIBILITY STUDY

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Abstract

Solar PV is now the fastest growing energy technology in the world. Although the widespread adoption of a renewable energy system is considered to be beneficial, the sector faces numerous challenges on the horizon. Solar PV waste is estimated to reach 78 million tons by 2050, and little research has been completed on end-of-life management outside of traditionally inefficient recycling technologies. Using HOMER Pro software, various scenarios were modelled in this study to determine the economic feasibility of extending the lifetime of solar PV systems, so as to prevent waste. Results indicate economic feasibility in: novel approaches to tiered commercial ownership; extending the life of residential systems beyond 25 years; and repurposing of solar modules for solar desalination purposes.

Introduction

Solar photovoltaic (PV) power has seen rapid research and development in recent years to meet the increasing energy demand required by unprecedented population growth and economic development (Comello *et al* 2018). Due to the global nature of irradiance levels, favorable government incentives and dramatic decline in overall system cost, adoption of solar PV systems has been extraordinary, with global capacity increasing from 3.7 GW in 2005 to 225 GW in 2015 (Kabir *et al* 2018). Solar PV has been one of the fastest growing energy technologies in the world, with expected installations of 80 GW annually from 2020, 143 GW from 2030 and 206 GW from 2040 onwards (Breyer *et al* 2017).

Although this formidable growth of the solar PV sector over the coming years will enable a certain degree of energy price security against the expected price volatility of fuels (Sica *et al* 2018), it also brings new challenges. Perhaps the greatest threat to the integrity of solar PV systems moving forward relates to the economic and environmental sustainability of the supply chain, with increasing focus being placed on the end-of-life management of PV modules.

At present, the solar PV sector largely follows a linear economy model from cradle to grave, with little economic incentive for establishing a circular economy model (Baharwani *et al* 2014). While management of waste PV modules has not been a high priority in the past (Xu *et al* 2018), the short 25-year life span of systems, as decided by the standard manufacturing warranties, coupled with increasingly stricter waste regulations demands further research (D'Adamo *et al* 2017). The amount of PV waste reached 250,000 t globally by the end of 2016 and is widely expected to reach 78 million t by 2050 (IRENA, 2016).

The EU Waste Framework Directive (2008/98/EC) indicates a preference for prevention and repurposing of waste over recycling and disposal. While the majority of solar PV end-of-life management research focuses on recycling (Chowdhury *et al* 2020), limited work has been completed on the favorable management practices of prevention and repurposing of solar PV waste. In view of this finding, a key objective of this study was to synthesize scenarios that would satisfy preferable waste management practices in relation to PV systems, namely a proposed cascading ownership and operation model.

The objective of this study was to determine the economic feasibility of extending the operating life of both commercial and residential solar PV systems through novel approaches to ownership, operation and end-of-life management.

Materials and Methods

Data Collection
An extensive literature review was undertaken to understand the current situation with regards to solar PV end-of-life management and also to identify gaps in the literature in relation to prevention or repurposing of solar PV waste. A data management plan was completed prior to commencement of research to consolidate the collection and storage practices of all data in this study. Empirical data was sourced from peer-reviewed journals, public databases such as those provided by the Sustainable Energy Authority of Ireland (SEAI) and from industry where appropriate. This will enable the development of a number of cascading ownership scenarios by which the PV material is repurposed and reused.

HOMER Pro

The Hybrid Optimization of Multiple Energy Resources (HOMER) Pro program will be used to model the proposed elongated lifetimes of the solar PV system scenarios. A key factor in using this software is the ability to utilize it as an analysis tool after modelling. Another benefit of using this software is that the electrical load requirements can be created and/or altered as desired, allowing for precise results in relation to specific scenarios. HOMER Pro can process vast amounts of technical and financial data, thus making it an appropriate tool when hypothesizing and modelling novel approaches to operation, maintenance and ownership of renewable energy systems.

Electrical Load Requirements
The electrical load requirements will be generated manually using data from organizations such as SEAI to gain accurate and realistic data. The HOMER Pro simulations will model a decrease in load requirement with respect to time, matching a hypothesized increase in home energy efficiency over the proposed extended lifetime of the solar PV systems.

Sensitivity Analysis
Using HOMER Pro, sensitivity analysis will be performed over several variables (Table 1).

Table 1. Sensitivity analysis descriptions.

Sensitivity Analysis	**Brief Description**
REFIT	Alterations to future feed-in-tariffs
Inverter Replacement Rate	Rate at which the inverter is refurbished or replaced.
Maintenance	Rate at which BoS components are replaced
Panel Replacement Rate	Rate at which PV modules are refurbished or replaced
Capital Cost	Alterations to the amount of capital required to purchase or take over ownership of the system
System Size	Variable system sizes will be analyzed to determine optimal longevity and performance of the system

Economic Analysis
HOMER Pro will be used as the primary analysis tool to assess the economic feasibility of the various elongated ownership models. Net present cost (NPC), an economic tool used to equate the total cost of a renewable energy system over time to the total cost today, will be of primary concern when analysing residential models (Dodds *et al* 2015). Payback time will be of great significance when analysing the proposed commercial ownership model, where a general equation can be visualised in the following formula.

Payback Time (years) = Cost of System (€) / Annual Savings or Profits (€)

Results and Discussion

As research is on-going and the majority of work is to be completed in June 2020, expected results will be presented and discussed in this section, as will key findings in the literature review thus far.

Literature Outcomes

In keeping with the manufacturing warranties present in the market, it is widely common in the literature to assume an average operating lifetime of 25 years for analysing future quantities of solar PV waste (Weckend *et al* 2016). While a significant number of optimization modelling research has been conducted, limited modelling has been completed to anticipate an extension to this widely accepted lifetime, which could lead to a significant reduction in forecasted solar PV waste. It is expected that an increase in home efficiency will lead to a lower residential electricity load requirement in the coming years, thus enabling a solar PV system to remain viable, even with large reductions in panel efficiency levels.

Additionally, the lifetime of solar PV modules has turned out to be longer than estimated. Some research has proved that the rate of degradation in the efficiency of crystalline silicon PV modules was approximately 0.5% per year, compared to the linear optimal performance guidelines of 1% as is industry standard (Jordan and Kurtz 2012) (Figure 1).

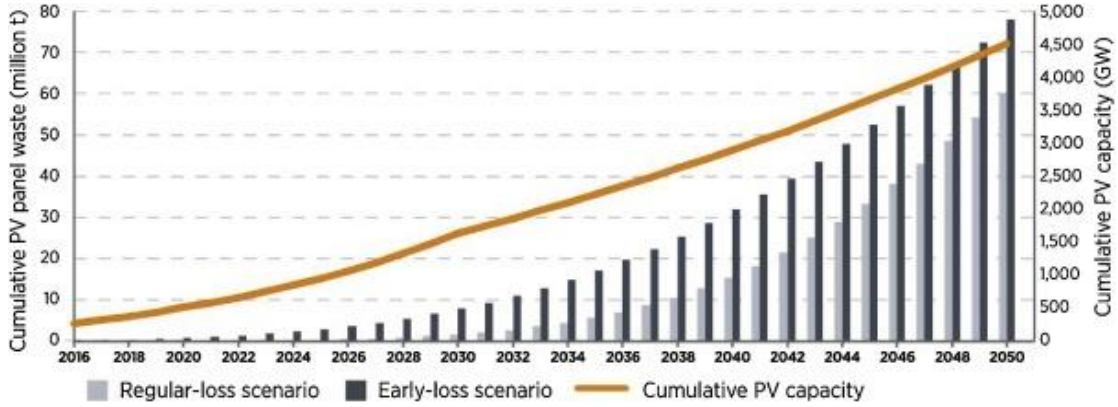

Figure 1. Cumulative PV panel waste leading up to 2050 (Mahmoudi *et al* 2019).

While most of the literature encompassing the end-of-life management of solar PV waste is focused on recycling technologies and associated patenting trends (Statista 2018), numerous studies have described the low profitability of recycling such waste and highlighted the requirement for further research into alternative waste management practices (Ardente et al 2019, D'Adamo *et al* 2017). Therefore, it seems intuitive to model scenarios that aim to either prevent waste generation or repurpose the waste into an economically productive alternative system, such as a proposed solar powered desalination system to co-address the impending problem of globally declining freshwater sources (Ahmed *et al* 2019).

Tiered Ownership

While commercial solar PV enterprises have been a topic of great interest (Liu *et al* 2015), novel approaches to ownership models are not well documented, and the concept of tiered ownership appears non-existent in the literature. The results thus far suggest that tiered ownership of commercial solar systems may be favourable in terms of shortened return on investments and minimisation of risk (Figure 2).

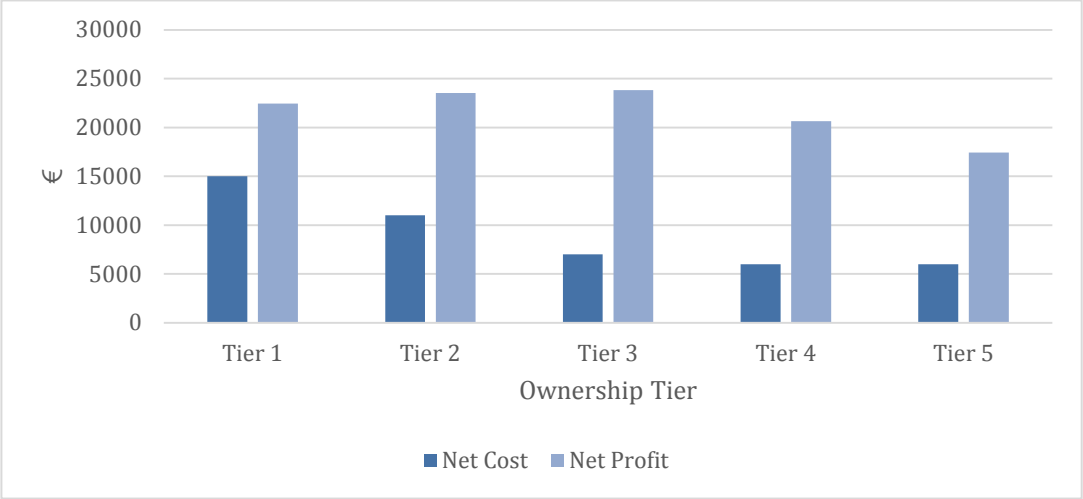

Figure 2. Proposed tiered ownership of a 20 kW solar PV system. Ownership is assumed to be for periods of 10 years. While net profit maintains relatively stable for 50 years, net cost decreases substantially between tiers towards simply maintenance and replacement costs.

Conclusions

Both the initial and expected results thus far suggest that extending the lifetime of both commercial and residential solar PV systems may be economically feasible under certain assumptions and scenarios. Tiered ownership appears to offer significant value, both economically and from an asset management point of view, to commercial ventures. With regards to residential systems, increased maintenance coupled with an expected increase in home energy efficiency will likely lead to an extension of the traditional lifetime of 25 years. Solar PV waste forecasts of 78 million t by 2050 also appear to be unrealistic.

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IDENTIFICATION OF A POTENTIAL FRAMEWORK FOR SMEs TO MEASURE THEIR SUSTAINABILITY PROGRESS

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Abstract

Now, in the Decade of Action, all sectors of society are called upon to accelerate the rate of progression required to deliver the United Nations Sustainable Development Goals (SDGs) by 2030. Progress to date is limited, with insufficient focus on, and support of, bottom-up initiatives in small businesses and organisations that would help mainstream sustainability in society. This paper finds that a lack of knowledge, leadership and practical guidance are barriers to such engagement and identifies an opportunity for a national, freely available sustainability toolkit.

Introduction

The SDGs were adopted by all members in 2015 with a target of completion by 2030. The concept of "sustainable development" is not new – one of the most widely-used definitions was coined back in 1987 as development that "meets the need of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). The seventeen goals developed by the UN (Figure 1) provide a blueprint to bring that vision of sustainability to life, now and into the future. They are a call to action for all countries and all people, to engage in the transformative change required to assure the viability and resilience of the future, for people and for the planet (United Nations 2015).

Figure 1 United Nations Sustainable Development Goals

While the SDGs and their corresponding targets are defined at government level, the 2030 Agenda recognises the necessity of involving everyone, public and private sectors, civil society, philanthropic organisations and "all available resources", in order to achieve the objectives that are ambitious, hard and will often mean uncomfortable choices (United Nations 2015).

In the OECD, small and medium-sized businesses (SMEs) with 0-250 employees, account for 99% of all businesses, 70% of jobs and contribute between 50-60% to value creation (OECD 2017). Their potential to influence the sustainability agenda is therefore substantial.

The objective of this study is to identify a potential framework suitable for small businesses and / or organisations in Ireland to operationalise the SDGs (sustainability) and monitor progress on an ongoing basis.

Materials and Methods

A literature review was conducted primarily using Science Direct and Google Scholar alongside general Google searches. Initial search keywords used were "sustainable", "SDG", "measure", "implement". Subsequent search keywords used were "sustainable", "SDG", "scorecard", "toolkit", "framework", "business" and "SME" however never more than three of these were used at the same time in a variety of Boolean search strings. Due to the lack of suitable data found with the above methodology, specific web searches were then performed on targeted entities – Irish business networks, authorities and sports organisations.

Results and Discussion

Overview of progress made towards the SDG goals and targets to date
Despite adoption by 193 member countries, progress against the SDGs, as measured by the United Nations at a global level, is slow. The 17 SDGs are underpinned by 169 targets (United Nations 2015), and of the 21 targets due globally by 2020, only 3 are fully achieved or on-track to be achieved, 7 are identified as having progressed but insufficiently to meet the target, 6 have either made no progress or have regressed, one has no data and the remaining 4 show mixed results (United Nations 2020). Lack of data is a significant barrier with only half of the indicators having data available, and only 19% of data required, available (Dang and Serajuddin 2020).

In Ireland, the Voluntary National Review (VNR) of SDG progress in 2018 identified good progress in just 7 SDGs, though did not make clear whether even these were on track. Public awareness was noted as increasing, but at 36% remained below the EU average (Government of Ireland 2018). Notably, a workshop held with key stakeholders on the draft VNR identified a need to focus more on implementation, implementation quality and on results. The stakeholder group also recommended greater inclusion of actions of local government, civil society and community groups rather than focusing mostly on top-down actions (Government of Ireland 2018).

There are few statistics readily available concerning progress by bottom-up groups in Ireland, Europe or globally, be they community groups, businesses or other categories, though it is reported that increasing numbers of SMEs aspire to sustainable business practices in the hope of increasing resiliency, while also providing additional social and environmental benefits (Caldera *et al.* 2019).

In 2018, a survey undertaken by Ibec with the support of the EPA identified a "significant information deficit amongst Irish businesses" with less than 40% of companies stating awareness of the Circular Economy framework in the EU (Ibec 2019). The proportion drops to less than 30% for companies that employ less than 50 people (small businesses), a sector that accounts for 47.7% of engaged persons in Ireland (Sobey and O'Shea 2018).

The survey concluded with one-third of respondents identifying what in their view is the single, most effective action that could be taken by a cohort, a subset of which is shown (Table 1). For individual companies 50% identified education, while 73% called on the EPA to take on more of an education / advisory / leadership role.

Table 1 Action categories identified by survey respondents as priority (Ibec 2019)

Individual companies can:	Educate/raise awareness with staff	34%
	Educate/raise awareness with suppliers and customers	16%
	Have senior management championing change	14%
	Lean the operation	12%
	Invest in circular innovation, research and development	12%
	Increased use of reusable/recyclable materials	8%
	Employ dedicated staff	4%

Ireland's Environmental Protection Agency can:	Increase education and host workshops	24%
	Provide more guidance and advice to businesses	20%
	Take a more proactive leadership role	18%
	Be consistent in messaging	11%
	Increase communication to improve public awareness	11%
	Incentivise good behaviour	9%
	Provide additional supports and funding	7%

Availability of frameworks / toolkits / checklists / metrics
Supporting a sustainable agenda requires choosing the "best" options. Choosing the "best" option implies utilising a method of comparing one option against another and measuring outcomes, hence the need for methodology and metrics (Darton and Klemeš 2015), and by inference, the practical value of frameworks and toolkits to support them.

A literature review has shown that there is very little practical information freely available for small companies and organisations wishing to embark on a sustainability initiative. This is corroborated by research conducted by Dublin Chamber that identified issues such as a lack of clarity as to what sustainability means, what sustainable practices are, and how to quantify and measure progress as barriers to businesses embarking on a journey of sustainability (Chamber Press Office 2020). As a result Dublin Chamber took the step of launching a new Sustainability Academy in February 2020. The initiative is aimed at bringing businesses from 'aspiration to action', providing training and advisory workshops at a cost to members and non-members.

In its broadest definition, sustainability encompasses environmental protection, social development and economic development (United Nations 2005), and what is evidently missing is a central repository of resources to educate, advise and provide simple and consistent frameworks / toolkits to aid implementation of sustainability principles.

Best practice
In the course of this research, the most suitable examples of publicly available resources were found in sport rather than in business. In 2014 the Fédération Équestre Internationale published a handbook to empower the organisers of equestrian events to manage events consistent with principles of sustainability (Fédération Équestre Internationale 2014). The handbook educates, provides structure and includes checklists for ease of use. The International Olympic Committee has also demonstrated leadership publishing a number of guides in its "Sustainability Essentials" series, with the specific aim of developing common guidelines, methodologies and tools to help other organisations develop their sustainability programmes (IOC 2018).

For SMEs in Ireland, while the UN SDG framework is robust and comprehensive, it is unwieldy and neither intuitive nor easily applied to business in its current form. An approach combining the UN framework with identified best practice resources could lead to the definition of a SME-specific toolkit with appropriate metrics, actions, checklists and guidance derived for each SDG.

Conclusions

Lack of data has proven a significant barrier to the achievement of progress on the SDG targets. Top-down progress is limited both globally and in Ireland. Bottom-up progress is rarely measured or monitored, in part due to a lack of knowledge, leadership and simple, freely accessible tools. Yet small organisations and businesses have huge potential to drive the sustainability agenda, an opportunity that is largely being missed.

Rather than rely on disparate, private initiatives such as Dublin Chamber and Ibec, there is an opportunity for government to centralise sustainability initiatives under a single sustainability authority, and fill the knowledge and skills gap with a free, national toolkit: a toolkit in the likeness of sporting equivalents, that recognises different pathways, and translates the SDGs to the appropriate

level of goals and measures for the audience, be it individual citizen, club, SME or other, ensuring the availability and timely reporting of indicator data, and ultimately the achievement of the sustainability targets.

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INTEGRATION OF OCEAN ENERGY INTO THE EXISTING GALWAY WIND PARK INFRASTRUCTURE

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Abstract

The ocean energy resources in Galway Bay, off the coast of Spiddal will be assessed in this study. In stream tidal and an oscillating buoy energy converter technology will be considered for the area to determine what technique has the higher energy output and which would be more cost effective. Environmental and social feasibility analysis of the study area will be applied to both technologies and this will contribute to the final decision. It is considered that tidal could be the most cost effective as the technology has existed longer than wave and in theory should be cheaper, but it cannot be confirmed at this stage. Energy peaks will be experienced in the winter for both technologies as storms cause turbulent waters. Spring and summer's energy outputs will be highly reduced as waters are calmer.

Introduction

This project focuses on the integration of ocean energy into the existing Galway Wind Park (GWP) grid network. Tidal energy and wave energy potentials will be examined off the coast of Spiddal in the Galway Bay. Potential electricity outputs will be calculated to compare the two technologies and each system should be given a cost/kWh. The lower cost/kWh will be the more economically viable option, and this will factor into the overall decision. Other key aspects that will heavily influence the technologies suitability are environmental impacts on the surrounding area, flora and fauna (marine and terrestrial), and social impacts on the local population. In theory the daily energy outputs will be sold to the grid and an innovative sink will be assessed for nightly energy outputs, as these are off peak times and the selling price is greatly reduced. There is less demand for the off-peak energy outputs as homes and businesses are closed. It is important to utilise all energy produced to ensure maximum efficiencies, reduce electricity waste and improve the systems cost effectiveness. Unused energy results in lost revenue and a higher cost/kWh. An energy storage option will be suggested to reduce production stresses during peak energy use times.

Approximately 71% of the earth's surface is covered by water, of which close to 97% is salt water (NOAA 2019). Coastal regions are beginning to realise the mostly untapped energy resource that lies within the waterbodies (Wilberforce et al. 2019). The energy that is stored within the oceans is indirect solar and geothermal energy, 99.99% and 0.01% respectively (Khan *et al.* 2017). Tidal power is an attractive renewable energy as it is more predictable and consistent than other renewable energies allowing a forecasted energy output (Segura *et al.* 2017). The gravitational pull of the moon combined with the rotation of the earth and sun causes the sea water levels to rise and fall forming the twice daily tides (Haigh 2017). Locations on Earth closest to the moon experience a bulge in water bodies known as the high tide (Haigh 2017). Other locations experience a stretching of waterbodies know as low tide. Surface waves are generated by friction of the wind over the ocean and most wave resources are offshore. The energy within an ocean wave is dependent on wind speed, wind direction, distance the wind has been blowing over the ocean (fetch) and water depth (Al-Habaibeh *et al.* 2010). In stream tidal energy and an oscillating body Wave Energy Converter (WEC) are the technologies considered in this project. In stream tidal is the most feasible type of tidal energy converter for the area, as it is used by fisheries, tourism and for other recreational purposes. An oscillating body WEC can imitate wave movements effectively maximising energy conversion.

The primary objective of this project is to compare the potential wave and tidal energies available off the coast of Spiddal, Galway and identify which technology is most feasible for development.

Materials and Methods

The Marine Institute of Ireland and the Sustainable Energy Authority of Ireland (SEAI) have recorded a series of oceanographic data off the coast of Spiddal, Co. Galway (Galway Bay). A waverider buoy and floating sea station were deployed in 2006 and have been recording data to reflect real conditions (Marine Institute 2020). This data will be used to calculate the potential energy in the local ocean resource for both tidal and wave energy scenarios.

Data analysis

The dataset is to be significantly reduced to accurately represent the daily tidal ranges and wave characteristics. The dataset accurately represents oceanographic conditions for the four seasons and the sample size will be reduced to 5 years. Excel data analysis tools will be used for this task. A large range of data headings have been recorded by the buoy, but the main data points of interest for this project are:

Tidal energy – current speed, current direction.

Wave energy – wave height, wave direction, wave speed, wave period.

Calculating potential energies

Potential energies for both techniques will be calculated without models and rely on two principle formulas seen below.

Tidal: $P = \frac{1}{2} \rho A V^3$ where,

A is swept area of rotary blades $\frac{\pi d^2}{4}$ (m^2)

ρ is density of water (kg/m^3)

V is velocity of water (m/s)

Wave: $E = \frac{1}{64} \frac{\rho g^2}{\pi} H^2 T^2$ where,

ρ is density of water (kg/m^3)

g is the gravitational effect (9.81 m/s)

H is significant wave height (m)

T is wave period (s) (Bahaj *et al.* 2011).

Conversion efficiencies for tidal and wave energy will be applied to the theoretical potential energy giving the technological potential energy output. Formulas in Excel will be used for calculating the potential energies of the reduced sample size.

Price comparison

Using HOMER Pro software (UL, Boulder, Colorado, USA) a price per KWh will be estimated for both technologies. Tidal and wave energy loads will be used in simulating the cost of energy. Economic feasibility could play an important role in this project.

Energy park design and feasibility

Environmental, economic, social and technological aspects will be considered in the final stages of the project in deciding which energy conversion method would be suited to the area. A feasibility report will be written addressing important issues that could disrupt planning and likelihood of the development.

Expected Results and Discussion

Potential Energies

Winter experiences the roughest seas, largest swells and the biggest storms providing the highest potential energy resource to be extracted from the ocean. Storms transfer wind energy into oceans that can be converted by the energy systems increasing outputs. North Atlantic storms occur regularly in winter and should be visible on the data scatter plots. Summer months will experience the calmest

waters providing the lowest potential energy outputs (Guillou and Chapalain 2018). The data should display some of the intermittency issues associated with all renewable energy systems as seen below in Figure 1.

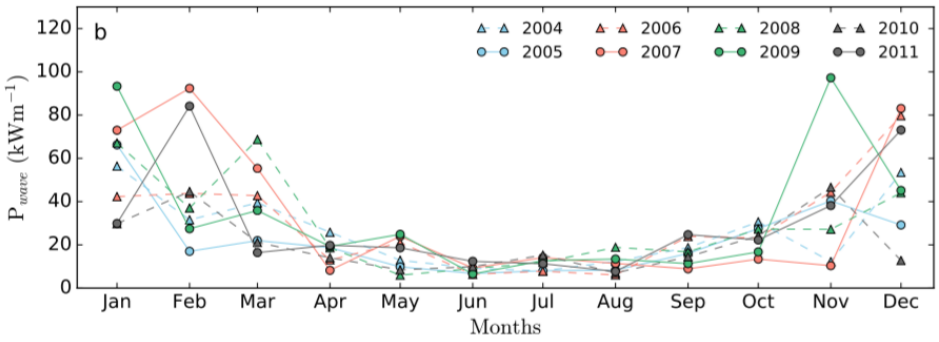

Figure 1. High wave energy outputs in Winter, low wave energy outputs during Spring and Summer over a period of 8 years (Guillou and Chaplain 2018).

It is hard to judge at this time which technology could give the higher energy output. As the test site is located in a bay, the energy in the ocean is reduced as the surrounding landmasses can obstruct wind flows and disrupt the waters natural waves. There is a head difference of 3 - 6 m between the high and the low tide in Galway Bay and reported Spring tidal current velocities up to 0.8 m/s (SEAI 2016). Conversion efficiencies of both technologies will play a vital role and it will be crucial that the conversion technique is capable converting a high percentage of the available resource, if that resource is low.

Cost

As tidal energy has operated as a commercial renewable energy system since 1980s, it could prove to be cheaper than wave energy (EDF 2020). Wave energy is a recent renewable energy technique that has only reached commercial scale a small number of times. Wave energy projects generally lack investments as they can be seen as high risk due to the age of the technology. Funding for projects can cease as they are costly, and investors can lose interests as small pilot trials may provide little initial returns.

Excess energy generation

As demand for energy decreases during off peak times, a solution for the excess energy produced by the system will be suggested, providing there is excess energy. Energy produced at off peak times will sell for a fraction of the price at peak times and can mean that producing the energy can be cost ineffective, costing more to produce it than the price it will be sold for. Storage of excess energy is a common solution, but each method has its pros and cons. As the ocean is a more predictable source of energy, baseline energy production could be guaranteed. To improve the efficiency of the system and maximise the potential economic gains from the proposed development, an energy sink will be proposed to utilise the guaranteed excess energy. Proposals for the energy sink could be factories operating shift work or charging of electric vehicles, as Ireland is beginning a shift towards electric vehicles.

Conclusion

Tidal energy is a proven conversion technique and wave energy is a promising technique that could enable Ireland's sustainable future through its vast untapped resources. This project will highlight the advantages and disadvantages of both techniques and will discuss each application to the study area. As results have not been formulated for this project, precise concluding remarks cannot be made, but there is optimism for the potential applications of these technologies in the Galway Bay.

Acknowledgments

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An investigation into the feasibility of integrating seaweed biorefinery and steel enterprises

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Abstract

Seaweed as a biomass can be seen as an efficient and potentially high substitute for fossil fuels to cope with future energy shortages and sustainable development strategies. This study will investigate the production processes and energy consumption of existing steel producers. The case of a mature seaweed biorefinery will be used to replace the traditional energy supply chain and to match the existing steel production craft. This will be as the initial design scheme to provide a target enterprise - Anshan steel group.

Introduction

The consumption and use of fossil fuels in a variety of industrial and non-industrial sectors has caused significant concern among governments and the public about the environment, human health and future well-being (Dorian et al., 2006). Clean energy consumption and growth contribute to sustainable development and can be regard as a catalyst for energy security, sustainable development and social, technological, industrial and economic development (Ermis et al, 2007). Therefore, restrictions on the use of fossil fuels and the transformation of energy types are very necessary. The gradual introduction of sustainable sources of energy and their rational allocation with conventional sources of energy are appropriate for today's transition phase, thus slowing the rate of conventional energy depletion. Steel enterprises as an energy intensive industry consume plenty of coal, coke and natural gas, consequently, release countless greenhouse gas and noxious gas (He et al., 2017). Since 1996, China has become the world's largest steel producer and the steel industry has become the third largest industrial energy user in China (Chen et al., 2014). Although the research on seaweed biofuel in academia and industry is still in the preliminary stage, seaweed as a kind of biomass of low carbon economy still has the future and development potential.

The study serves as a blueprint for integrating two previously unrelated industries, biorefining and heavy metal smelting, to meet production needs and achieve sustainable, low-carbon and environmentally friendly development.

Materials and Methods

Algae have unlimited applicability as an important source of sustainable biofuels in a renewable future. It can metabolize various waste streams like domestic wastewater, carbon dioxide from industrial flue gas (Marc, 2012). Seaweeds are single-celled photosynthetic microorganisms that grow in both salt and fresh water and convert sunlight, water and carbon dioxide into algae biomass, protecting us from global warming through photosynthesis (Demirbas, 2010). Algae can be classified by pigment: brown seaweed (*Phaeophyceae*); red seaweed (Rhodophyceae) and green seaweed (Chlorophyceae). In terms of abundance, it can be divided into three important categories: the diatoms (*Bacillariophyceae*), the green algae (*Chlorophyceae*), and the golden algae (*Chrysophyceae*) (Demirbas, 2010).

In modern smelting, steel and iron are made in the blast furnace (Melouk et al., 2013). The biggest difference between the two is their own carbon content. The coal is heated and

carbonized to form coke, which is then mixed with the grated raw material (iron-rich ore) and reheated to form sintered pellets (Price et al., 2002). In the process of coal treatment, gas will be produced for the next blast furnace refining, commonly known as blast furnace gas. Tar, benzene, sulfur and other by-products are further refined into chemical products. The sintered pellets and the limestone (reducing agent) are fed into the blast furnace and heated to melt by the blast furnace gas. Oxygen is transported to the furnace through the blower and redox reaction occurs with the pellets, liquid molten iron is formed at the bottom of the blast furnace (He and Wang, 2017). After removing impurities floating on top of the molten iron, it can be used to cast pig iron or transferred to steel ladles for steelmaking. High pressure and high purity oxygen are blown into the steel ladle, and most of the carbon in the molten iron is removed by the chemical reaction of oxygen and carbon to form carbon dioxide, resulting in stronger and more malleable steel. Finally, according to the different uses of steel, there will be different steel product classification, roughly divided into: steel wire, steel sections, steel plate, cold rolling plate, hot rolling plate, alloy steel, etc (Ansteelgroup Products information, 2015). In summary, a large amount of coal resources is consumed during the refining process and a large amount of greenhouse gases and dust are discharged into the atmosphere with the high-temperature flue gas.

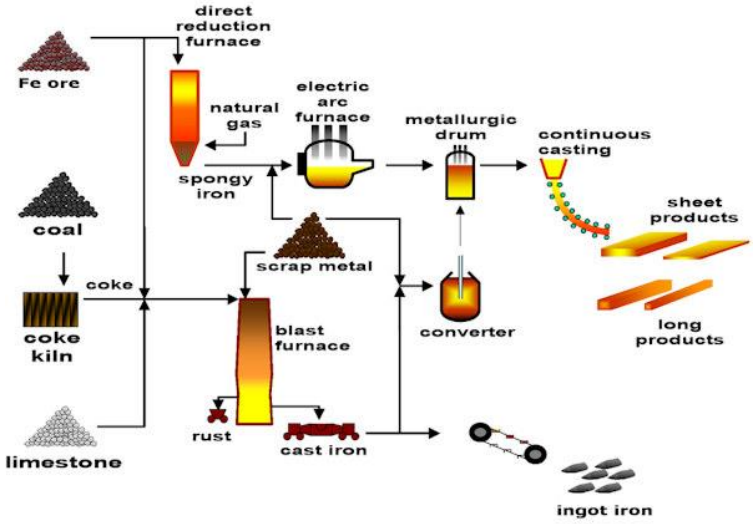

Figure 1. Steel Manufacturing Process (www.steelfeel.com)

Macroalgae is a highly productive biomass that takes up no land resources compared to traditional agriculture and purifies water quality (seawater, wastewater). It can be converted into bioethanol which can replace fossil fuels through biorefineries. It is compatible with the excellent property of driving the carbon cycle and mitigating the fuel crisis (Sahoo et al., 2012). The market for bioethanol soared from less than 1 billion litres in 1975 to 86 billion litres in 2010. When the seaweeds are mature, the harvested seaweeds are shipped ashore by boat for drying. According to Segthetta et al. (2016), the dried seaweeds are transported by road to biorefinery and there are five mainly steps: raw material handling, hydrolysis, fermentation, solid and liquid phases were separated from the fermentation broth, the liquid phase was distilled to obtain 99.5% (w/w) ethanol, and the solid phase was spray-dried to recover the protein, allocation of bioethanol, fertilizer, etc. Finally, when these biomasses are converted into products, the biofuel burns and releases carbon into the atmosphere. The carbon then dissolves in seawater to support algae growth. Importantly, the bioethanol produced can partially replace coal for blast furnace heating (Iniyan et al., 2020). In the following work, I will choose a site beside the existing specific steel mill. Simulate the construction of an algal biorefinery and collect the fuel consumption required in the smelting

process of a particular steel enterprise. The annual capacity of biorefinery was estimated by simulation, and the value of the substitution of biofuels for fossil fuels was evaluated in order to assess the economic and environmental viability of the integration of biorefineries and steel mills.

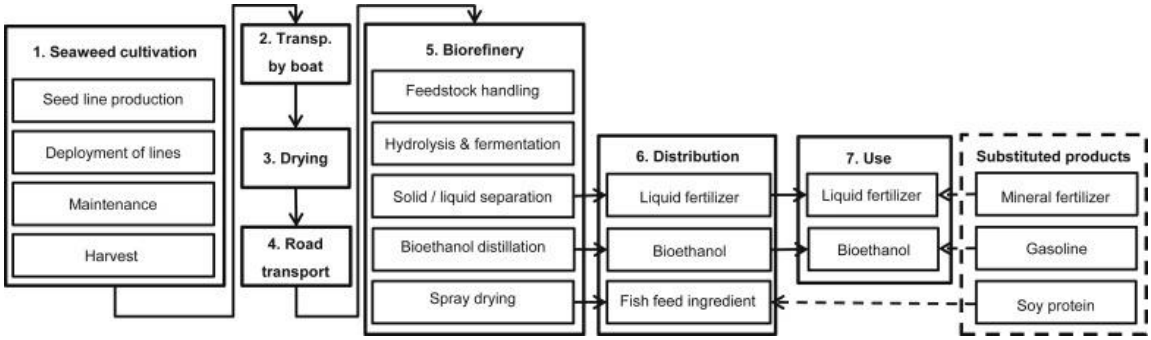

Figure 2. The Biorefining Process of Algae - From Cradle to Grave (Segthetta, M et al 2016)

Results and Discussion

To cater to the development of the market, Chinese steel mills have adjusted their strategic decisions and gradually shifted production from inland areas to coastal areas. The transportation of raw materials and finished products has been facilitated, which also lays a foundation for the reform and upgrading of the energy structure. For example, BaoWu group, Anshan steel group BaYuQuan branch such cases. Because of its location near the sea, the algae do not need the previous drying process in the treatment stage, directly by the sun to dry the algae. At the present stage, the integration of steel enterprise and biorefining, two previously unrelated concepts, is only from the theoretical level, still in a blank stage in practical application. The study is a bold guess, or a preliminary approach, that will lead to a massive collection of operational data for both in subsequent work. From the data level to find out the feasibility and advantages of the combination. Find out the limitation and bottleneck on the level of technology and legal policy, discuss the direction to be solved in the future.

Conclusion

Human development must not come at the expense of the environment. Searching for clean energy which can replace fossil fuel and applying it effectively are the further promotion of current development. The integration of biorefinery into the steel production process, once achieved, will be a milestone in the history of the industry. In the short term, this will achieve the goals of energy conservation, emission reduction, green operation for steel enterprises and may bring economic benefits. In the long term, this will promote the realization of human destiny community and create valuable environmental benefits for the world.

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THE EFFICIENCY OF SOLAR ENERGY FOR HEATING HOUSEHOLD WATER

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Abstract

Solar water heating systems are a well-established technology nowadays. However, these kinds of systems are mainly used in areas where solar radiation is high. For this reason, this project consists in the design of a solar water heating system in Dublin, Ireland, where solar irradiation does not usually reach high levels. A parabolic trough solar collector will be used as a receiver as it is more efficient and needs less solar irradiation, obtaining at the end temperatures of 60-75ºC in the hot domestic water.

This project will result in an increase of the renewable energy share and the reduction of the CO_2 emissions and costs associated with heating water as this system is expected to cover a 50-60% of the usual energy demand for heating water.

Introduction

The scarcity of fossil fuels combined with the environmental problems associated with them is causing a migration of energy systems from conventional systems, based on fossil fuels, to renewable energy systems.

One of the most important renewable energy sources is solar energy, which uses the Sun in order to generate energy. Solar energy can be used for different purposes as it can be used to produce electricity as well as heat. With only a 6.5% of renewable share in heating, Ireland has the second lower renewable share in heating and cooling and is behind its renewable energy targets (SEAI, 2019) (European commission, 2019). In addition to that, homes are the biggest contributors to heat emissions with almost a 50% of the emission share (SEAI, 2018). For this reason, the design of a solar water heating system in order to cover part of the energy used for heating household water would be helpful in order to increase the renewable share and helping it to reach the targets, reducing the CO_2 emissions associated with heating and cooling.

In household applications, cold water enters the system and is heated in the receiver by the Sun. Once is heated, the hot water is stored in an insulated storage tank until it is needed. When water is going to be used, it will be heated by an auxiliary heater to the desired temperature if it is needed and it will go to the domestic hot water system. This solar heating will cover a fraction of the energy used for heating the water, reducing the emissions associated with heating.

The objective of this study was to design a solar water heating system in order to cover the 50-60% of the total energy demand for heating household water.

Materials and Methods

For the realisation of this project, the different components of the system will be designed taking into account some assumptions. First, a parabolic trough collector will be used as it is more efficient in climates where solar irradiation is low. Secondly, as the majority of solar water heating systems for household applications are direct systems, the system of this design will be considered direct as well. Finally, the temperature of the incoming water will be considered 10ºC and it is going to be heated until temperatures of 60-75ºC.

Solar reflector
As the study takes place in Dublin, where solar irradiation levels are not usually high, the solar reflector will have a parabolic trough design instead of the usual flat plate collector, as its efficiency is higher.

The solar reflector is responsible of how much energy would be absorbed by the receiver tubes and it will depend on its sizing and characteristics. This absorbed energy can be calculated by the equation below, where S_g is the energy absorbed by the receiver, n_c the reflector efficiency, which is assumed to be 0.9, A_r the area of the receiver and I the solar irradiation.

$$S_g = n_c a_g A_r I$$

In addition to that, the system performance and the energy losses must also be calculated in order to obtain the heat absorbed by the receiver (Islam, et al., 2015).

Receiver
The receiver is composed by two different components, the receiver tube and the cover. The receiver tube will contain the fluid, in this case water, and it is made out of stainless steel. The cover, which is made out of glass, is used to protect and insulate the receiver tube (Marefati, et al., 2018) (Nation, et al., 2017). The receiver dimensions are shown in the table below.

Table 1: Receiver sizing

Parameters	Receiver Tube	Glass cover
D_{in} (m)	0.05	0.14
D_{out} (m)	0.06	0.15
Thickness (m)	0.005	0.005
Emissivity	0.94	0.95
Absorptivity	0.92	0.02
Thermal conductivity ($^{W}/_{mK}$)	14.4	0.8

Storage tank
The storage tank will have a capacity of 150 litres. The increase of temperature obtained in the system will depend of this storage capacity as it can be seen in the equation below, where ΔT is the increase of temperature, S_g the energy absorbed by the receiver, V the volume of the tank and C_p the specific heat of the fluid, in this case water.

$$\Delta T = \frac{S_g}{V C_p}$$

Pumps
The efficiency of the pumps is a really important issue when designing this kind of systems as the energy consumption of this component should be low in order to increase the efficiency of the system.

Results and Discussion

According to the literature and analysis that has been performed, there are several expected results for this project.

Efficiency of parabolic trough collectors
Flat plate collectors are the cheapest and most common type of technology used for SWHS. However, as this study takes place in Dublin where solar irradiation levels are low, the usage of this kind of solar collectors may not be the best option.

For this reason, this study will focus on the feasibility of parabolic trough collectors in SWHS. Furthermore, although these types of collectors have higher initial and maintenance costs associated with them, their efficiency is higher. This allows the parabolic trough collectors to generate more heat with shorter payback times in Northern European climates.

Temperature increase
Temperature increase is calculated by the amount of heat absorbed by the system, which is obtained by the use of diverse equations. The heat is dependent on the energy absorbed by the receiver. However, is important to take into consideration factors such as the collector efficiency and the heat losses of the system as they reduce the amount of useful heat used for increasing the water temperature.

The water temperature is expected to increase from 10ºC (the temperature of the incoming water) to 60-75ºC, which will be the final temperature of the water to be consumed (SEAI, 2019).

Energy savings
In an average household in Ireland, water heating is estimated to represent 19% of total household heating demand. This project expects to find that SWHS-type systems can support between 50 and 60% of the energy demand associated with heating water. Moreover, it is estimated that the use of this system can result in a 10% cost reduction in total annual energy costs for Irish households.

Conclusion

Lastly, this study demonstrates that parabolic trough receivers are more efficient than flat plate receivers when operating in climates with low solar irradiance levels. Once the water temperature obtained by the usage of this system reaches the desired point, this project showcases that the system can meet energy demand of up to 60% associated with water heating. Furthermore, the SWHS system represents a well-established method for generating renewable heating with a small carbon footprint for these types of climates. For future projects, similar systems should be translated into larger-scale applications in order to provide buildings with district heating.

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EVALUATION OF THE ENERGY CONSUMPTION WITHIN THE UCD BELFIELD CAMPUS AND SUGGESTIONS FOR EFFICIENCY IMPROVEMENT MEASURES

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Abstract

This project evaluates the energy consumptions in the UCD campus and the suggestions of measures on how to improve efficiency. Energy consumption trends show that Buildings account for 40% of total energy consumption and 35% of the total CO_2 emitted in the EU. As expected, the majority of the energy consumed within the campus can be allocated to the electricity and heating demands. The conclusions drawn from this study will outline the areas of high energy consumption concentration, potential energy savings and payback periods of potential investments.

Introduction

Consideration of challenges concerning energy consumption and efficiency of a building (residential, commercial or institutional) allows for signification energy savings in the long run which can be beneficial to the group/firm/individual that own the building, group/firm/individual occupying the building as well as the environment. In the study carried out by Reuter et al. (2020), they concluded that the benefits of energy efficiency can be categorised into three major groups namely:

- environmental (e.g. energy savings, emissions),
- economic/finical (e.g. GDP, employment), and
- social (health, energy poverty)

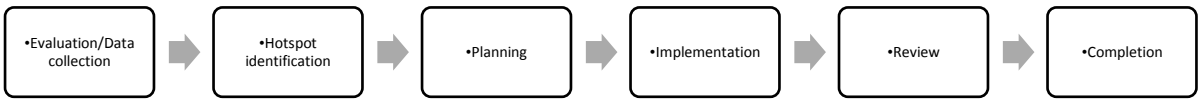
However, the main deliverables from this project will be centred around the financial and environmental impacts of the energy being consumed with the UCD Belfield campus. Being able to properly manage a assess the energy consumption trends plays a major role in this study as it provides the foundation for the efficiency analysis.

There are a number of factors affecting energy consumptions trends within the campus such as; climate, human traffic, insulation quality of the buildings, condition of technologies and occupant behaviours. With these factors under consideration, optimal solutions and practices to prevent energy losses will be examined and presented in this study.

The objective of this study is to evaluate the energy consumption within the UCD Belfield campus and suggestions of possible efficiency improvement measures.

Materials and Methods

This study will be carried out with the aid of the UCD buildings office as they will be able to provide the most useful data for its success. To properly conduct this study the progression plan below will be utilised.



The first step of this project will involve the evaluation of the current state of the technologies and the collection of data from energy audits. Using this information, the energy consumption hotspots within the university will be further evaluated in order to outline a suitable plan. Suggestions on possible improvements backed by credible energy savings calculations and payback periods where application will be the main outcome of the study. These will be reviewed before implementation and after implementation to ensure a successful project closure.

The main calculation that will be utilised for this project are further explained in the below subsections.

Energy savings calculations

The results of this calculation represent the expected payback on the energy consumption after an investment or practice is implemented.

Energy savings = Energy consumption before – Expected energy consumption after

$$\text{Specific Energy savings} = \frac{\text{Energy savings}}{\text{Area of the space within a specific building}}$$

Pay back Period

The calculation is carried out to deduce the period of time required for any financial investment to be recovered in an equivalent amount in savings. For this project, it will be assumed that value of the initial invest will remain the same over the years as the savings are made.

$$\text{Pay back period (PBP)} = \frac{\text{Initial investment}}{\text{Period Net savings incured from investment}}$$

Results and discussion

A significant proportion of the results from this study will be derived from a secondary source (i.e. Energy audit reports from the buildings office). The expected results will be similar to the format presented in the studies of Hyseni et al.

Table 1: Table of results from energy efficiency analysis (Hyseni et al. 2019)

Name of the Building	Total energy consumption			Specific energy consumption			Investment costs	Net savings	Period PBP	CO_2 reduc.	Spec. invest.
	Before	After	Savings	Before	After	Savings					
	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/m^2,a]	[kWh/m^2,a]	[kWh/m^2,a]	[€]	[€/year]	[y]	[t/year]	[€/m^2]
Pulmo & Dermatology clinic	716,451.20	340,721.70	375,729.50	217.99	103.67	114.32	151,478.00	22,975.20	6.6	133.38	46.09
Infectious disease Clinic	660,579.77	327,763.99	332,815.79	101.69	50.46	51.23	168,528.80	25,975.50	6.5	118.15	25.94
Institutes Building	1,253,960.60	535,870.00	718,090.60	369.9	158.07	211.83	407,436.00	66,538.20	6.1	254.92	120.19
Orthopedic clinic	909,929.97	360,224.69	549,705.29	284.53	112.64	171.89	250,880.80	35,489.50	7.1	195.15	78.45
Neurology Clinic	1,188,966.47	511,703.26	677,263.21	464.44	199.88	264.56	246,876.10	38,252.60	6	240.43	96.44
Orthoprothetic clinic	332,250.90	81,589.00	250,661.90	296.12	72.72	223.41	120,975.00	23,521.40	5.1	88.98	107.82
Psychiatric Clinic	1,304,371.20	320,652.40	983,718.80	503.42	123.76	379.67	389,936.70	51,152.70	7.6	349.22	150.5
Public Health Institute	1,137,255.90	252,564.40	884,691.50	257.15	57.11	200.04	331,191.80	43,536.20	7.6	314.07	74.89
Dentistry Faculty	1,068,677.50	455,832.00	612,845.50	234.2	99.9	134.3	204,460.00	40,891.00	5	217.56	44.81
Clinic Center Technical Service	1,100,642.60	190,949.60	909,693.00	786.62	136.47	650.15	244,599.00	34,536.00	7.1	322.94	174.81
Gynecological Clinic	6,311,736.97	2,821,949.64	3,489,787.3	308.49	137.92	170.56	967,826.00	223,654.00	4.3	1,238.8	47.3
Emergency Clinic	1,848,975.37	835,800.04	1,013,175.3	275.9	124.72	151.19	332,485.00	55,187.00	6.0	359.68	49.61
ORL Clinic	2,661,729.33	1,580,606.17	1,081,123.1	230.23	136.72	93.51	386,501.00	73,557.00	5.3	383.8	33.43
Medical Faculty	727,014.30	443,575.22	283,439.08	422.68	257.89	164.79	192,857.60	34,526.20	5.6	100.62	112.13
Surgery Clinic	2,598,324.00	1,919,004.00	679,320.00	242.79	179.31	63.48	384,592.00	78,580.00	4.9	241.16	35.94
Internal Clinic	2,254,510.00	1,482,190.00	772,320.00	543.26	467.57	75.7	403,330.0	139,750.00	2.8	274.17	69.83
Totals	**26,075,376**	**12,460,996**	**13,614,379**	**346**	**151**	**195**	**5,183,953**	**988,122**	**5.85**	**4,833**	**79.26**

The results above (table 1) show the expected format of the outcome of this project should follow. They will be categorized by building names and corresponding energy consumption data accompanied with the cost saving, net savings, emission reduction, and calculated pay-back periods. Similar to the table above, totals of all the calculations will also be presented.
The significance of these results will be further be discussed in this section of the report. Also, limitations faced during the course of this project will be highlighted in the final report.

Conclusion

On closure of this project, the results will be evaluated and reviewed based on the methods and calculations used for this project. After assessing the methods and deliverables of the project, it will be related back to the objective of the study which is to evaluate the energy consumption within the UCD Belfield campus and suggestions of possible efficiency improvement measures.

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CONVERSION OF AGRICULTURAL WASTE STREAMS TO FOOD: A CASE STUDY OF MUSHROOM INDUSTRY

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Abstract

Agricultural wastes are nutrient-rich biomass that if left to accumulate or much worse, be burnt on the soil, can cause serious environmental problems. Several approaches have been taken to recycle these wastes, and mushroom cultivation has proven to be a successful and cost-effective biotechnological method in converting these lignocellulosic materials into healthy and useful foods that will sustain food security for people in developing countries. This study reviews literature on how agricultural wastes can be recycled via mushroom cultivation, to promote a circular economy. International case studies on experiments concerning substrates used for mushroom cultivation were also discussed.

Introduction

Proper disposal of agro-industrial waste is one of primary concern in the world today. Agricultural residues such as wheat and rice straw, grape pomace, wood sawdust and chips, corn husks, coffee pulp, sugarcane bagasse and banana leaves are rich in lignocellulosic compounds which make them quite difficult to handle and break down. They are typically left to decompose in the field via composting or burned which leads to pollution and risks of respiratory diseases (Nicolcioiu *et al.* 2016). There has been an increasing interest in the research of lignocellulosic biomass in recent years due to its renewable nature and the gradual transition to a circular economy (Adebayo and Martínez-Carrera 2015).

The cultivation of mushrooms provides an opportunity to use these renewable resources to produce edible, protein-rich foods that will support food security in developing countries. Air pollution associated with burning agricultural waste may also be limited by the technology (Udayasimha and Vijayalakshmi 2012). Agricultural wastes and by-products comprise mainly of cellulose, hemicellulose and lignin which are beneficial for mushroom cultivation. Consequently, the mycelia of mushrooms contain abundant enzymes that allow them to access, by degradation, the nutrients present in these residue components.

Edible mushrooms are regarded as healthy foods. They provide us with an extra high-quality food product, and supplement our diet with high-quality proteins, fiber, minerals, and vitamins that can directly benefit our health and fitness. China is the main producer of cultivated, edible mushrooms (Philippoussis 2009). Other mushroom growing countries include Malaysia, India and Ireland (Mohd Hanafi *et al.* 2018). Some of the most widely consumed mushrooms include the *Agaricus bisporus, Lentinula edodes, Pleurotus* species and *Volvariella volvacea*. *Agaricus bisporus* is the most commonly grown, representing about 30% of total production (Rinker 2017). Increasing attention is being given to the cultivation of mushrooms due to their medicinal properties and low cost production (Julian *et al.* 2019).

Thus, the aim of this study is to provide an overview from recent literature on how by-products and waste from the agro-food industry can be recycled via mushroom production to promote a circular economy with international case studies from Europe and Africa discussed.

Methodology

Scopus, ResearchGate and ScienceDirect were used as databases for this study and literature sources were screened to determine how relevant they were to the study. To do this, the titles and abstracts of

several articles were reviewed to determine if they will be included in the review. Studies were evaluated based on the following criteria:

- If the study clearly addresses the subject matter.
- If the study uses valid methods to address the subject.
- If the results of the study are valid and applicable to the project.

About 20 papers were chosen to be used and preference was given to recent articles published in peer-reviewed journals, although some books were also included.

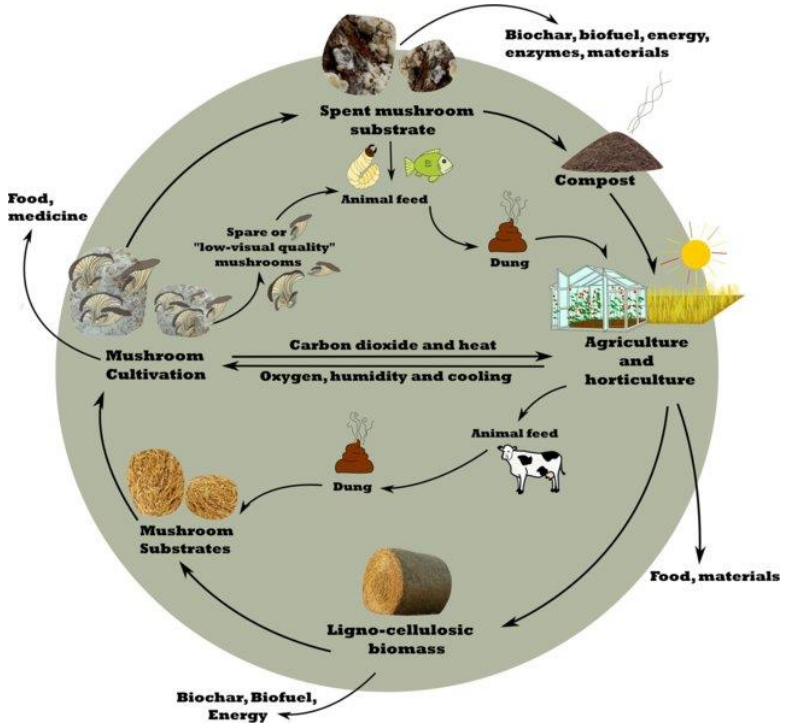

Figure 1. Mushroom cultivation in the circular economy (Grimm and Wösten 2018)

Results and Discussion

Mushroom production involves a number of different operations including the selection of an acceptable fruiting culture of the mushroom, preparation of spawn and substrate, inoculation of the substrate, crop care and harvesting. The mushroom substrate is prepared correctly by adding water, possibly incorporating additional nutrients, and then further processed by sterilization or pasteurisation. When finished, the substrate is "inoculated" by uniformly mixing bits of mycelium-covered spawn into it. Given appropriate conditions, the mycelium will begin to expand rapidly consuming and decomposing the organic material in a process known as "colonization" When the substrate is completely colonized, the mushrooms are ready for harvest which means it has been completely stabilized and accepted by the mycelium (Elenwo and Okere 2007; Philippoussis 2009).

After the harvest of mushrooms, what remains is called Spent Mushroom Substrate. It represents the remainder of the composted substrate after cultivation. 1 kg of mushrooms will produce approximately 5 kg of SMS (Aziera *et al.* 2015). The spent mushroom substrate, could be used for one or two other rounds of mushroom production after enzyme extraction, followed by using the SMS as fertilizer, feed, a biofuel source or a sustainable alternative to plastics. The SMS can also be composted for use as substrate for the production of other agricultural products and the cycle continues (Grimm and Wösten 2018; Mohd Hanafi *et al.* 2018).

Table 1. Composition of some agro-industrial waste used for mushroom production.

Substrate	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Region	Reference
Wheat straw	37.8	26.5	17.5	China	(Kamthan and Ishita 2017)
Sugarcane baggasse	35-40	20-25	18-24	India	(Kamthan and Ishita 2017)
Coffee husk	43.0	7.0	9.0	Central and South America	(Çavuşlar Atila 2019)
Vine shoots	34.0–60.8	17.0–21.0	20–22.92	Europe	(Philippoussis 2009; Çavuşlar Atila 2019)
Corn cob	45	35	15	Nigeria	(Singh and Satapathy 2018)
Sawdust	37.7–49.5	10.7–25.0	26.1–29.5	Europe, Canada	(Philippoussis 2009)

It is necessary to meet the necessary nutritional requirements in optimum concentration for high yield of mushroom production, because specific work has recorded low yield when nutrients in a medium are either in low or high concentration (Philippoussis *et al.* 2001; Thongklang and Luangharn 2016).

International case studies

Nigeria: Odonye (2019) grew the oyster mushroom, *Pleurotus ostreatus* on five different substrates (cassava peels, banana leaves, saw dust, yam peels and groundnut shells) for four weeks. The substrates were exposed to temperatures ranging 22-30 °C. Cultivation on these substrates resulted in mushrooms with high protein and fibre content. The mushrooms grown with groundnut shells had the highest protein content while the highest fibre content was found in those grown on composted banana leaves.

Europe: Çavuşlar Atila (2019) grew shiitake mushrooms on oak sawdust, grape pomace, green walnut hull, olive press cake, and tea waste. The species were grown at temperatures between 15°C to 17°C and humidity levels of 85-90%. Spawn running time was from 45.4-51.8 days. After harvesting, the highest yield (282.9 g kg^{-1}) and biological efficiency (70.7%) was observed when grown on a OS+GP substrate combination.

Conclusions

The growing of mushrooms may be a valuable tool not only to reduce the environmental impact of agricultural wastes but also to turn them into new resources for the continuous production of value-added edible food products. The leftover from cultivation (SMS) can then be used for a range of applications. This in turn, will contribute to more food, increased employment, better living standards, climate change mitigation and an overall circular economy.

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ASSESSMENT OF HEAT PUMP TECHNOLOGY FOR HEATING RESIDENTIAL BUILDINGS IN IRELAND

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Abstract

This study highlights the feasibility of heat pumps for renewable heating in Ireland. It begins with a walk through the background for the study; which is awareness of the impacts of conventional heating. The study highlights the awareness on international bodies on the impacts and the resolutions and policies taken to mitigate those impacts. It further expands on the technology of heat pumps under the efficiency, sustainability and economic value. The result of the study allows for a conclusion that there is a possibility of the technology featuring in the heating of residential buildings in Ireland.

Introduction

Countries in Europe, such as Ireland, have to deal with warm summers and the rest of the seasons are relatively cool. This has led to various heating solutions connected to radiators in a number of different accommodations. As the times have changed and advances in technology made, it is becoming more pertinent to review such heating solutions under its sustainability. Global agreements such as the Paris Agreement of 2015 have made countries and industry players to initiate the departure from fossil fuel to more sustainable solutions which further highlight the importance of the matter at hand.

The energy trends as documented by the Sustainable Energy Authority Ireland (SEAI) show that the CO_2 emissions from energy used for heat increased by 6.4%. A further breakdown of the increment show that there was a 7% increment from both the use of oil and gas while there was a 4% increment in the use of both coal and peat as precursors for heating in Ireland (SEAI 2018). A contrast discovered in the report was the decrease of 14% in the CO_2 intensity of electricity coupled with the increase of 2.9% in electricity generated. A further look into the renewed efficiency of electricity generation in Ireland shows a trend with an increase in renewable energy technology and a decrease in the use of fossil precursors such as coal and peat. These trends initiate a question as to why heating solutions are not electrically powered devices.

In order to find a solution to the above question, the heat pump technology has been considered. Heat pumps are electrical devices that extract heat from energy sources and convert it to useful heat. These heat sources may be from the ambient air, underground heat or waste heat from industrial processes. Heat pumps as a technology has been in play since the 90's as Scandinavian countries such as Sweden used it with their excess electrical supply to provide heating (David *et al.* 2017). These heat pumps were used in district heating capacities with waste heat from industries as the energy source to provide warmth. Heat pump technology has evolved to become a cleaner stand alone technology and this can be seen with extinction of refrigerants that pose a health risk. Therefore it can be considered as an effective and efficient technology that recirculates environmental heat to provide environmentally friendly heating to residential, commercial and industrial buildings (Hein and Karl 2006).

The objective of this study is to assess the feasibility of using heat pump technology to replace conventional heating of residential buildings in Ireland.

Materials and Method

To fully determine the feasibility of the heat pump technology, it is only proper to analyze the technology on account of its efficiency, sustainability and financial implications.

Coefficient of performance

To compare the abilities of an air source heat pump (ASHP) to conventional heat sources in buildings, the efficiency of the system must be reviewed. Coefficient of performance (COP) is considered the ratio of useful heat produced by the heat pump to the actual amount of energy required to produce such useful heat. To effectively determine the coefficients of performance of the technology a few factors need to be considered such as the temperature of the low-energy source (ambient air), the temperature of delivered useful heat, the working fluid used and the characteristics of components of the heat pump system (Hepbasli and Kalinci 2009).

Environmental impacts

The environmental impacts related to the use of the heat pump technology arise from the sources of electricity used to power the technology. This is because the heat source used as a precursor is gained from sunlight and so the process has a net carbon emission of zero and virtually limitless (Staffell *et al.* 2012). Audits of the trajectory of electricity generation in the Republic of Ireland show that there is restructuring of energy systems to include more sustainable energy systems such as wind energy. There was a 14% drop in the CO_2 Intensity of electricity and a 2.9% increase in electricity generated in 2019. Analysis of the increase in electricity generated shows an increase of 16% in wind generation and a 44% & 3% drop in coal and peat respectively (SEAI 2019). The graph labelled Figure 1 shows renewables on a steady rise while coal and peat have been on a steady decline.

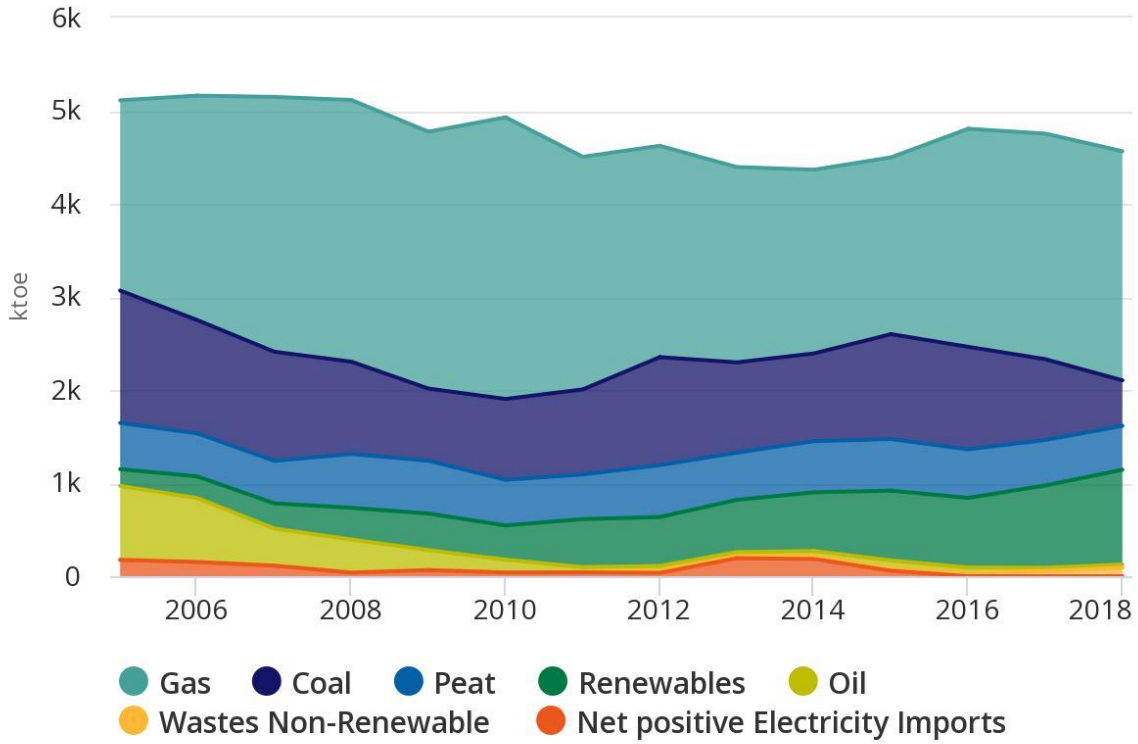

Figure 1: Graph showing the primary energy inputs to electricity generation by fuel type in Ireland (SEAI 2019)

Energy payback time

Technology payback time can be considered as the time taken to recoup the investments of a technology. In the feasibility assessment of the heat pump technology it is necessary to consider the financial implications associated. To fully consider the financial implications of the air source heat pump, an analysis of the capital cost, maintenance cost, and running cost has to be done. Relative to the other associated costs, the capital cost of procuring a heat pump is significantly higher than that of conventional heating while the running and maintenance cost compared to conventional heating is considerably lower (Staffell *et al.* 2012).

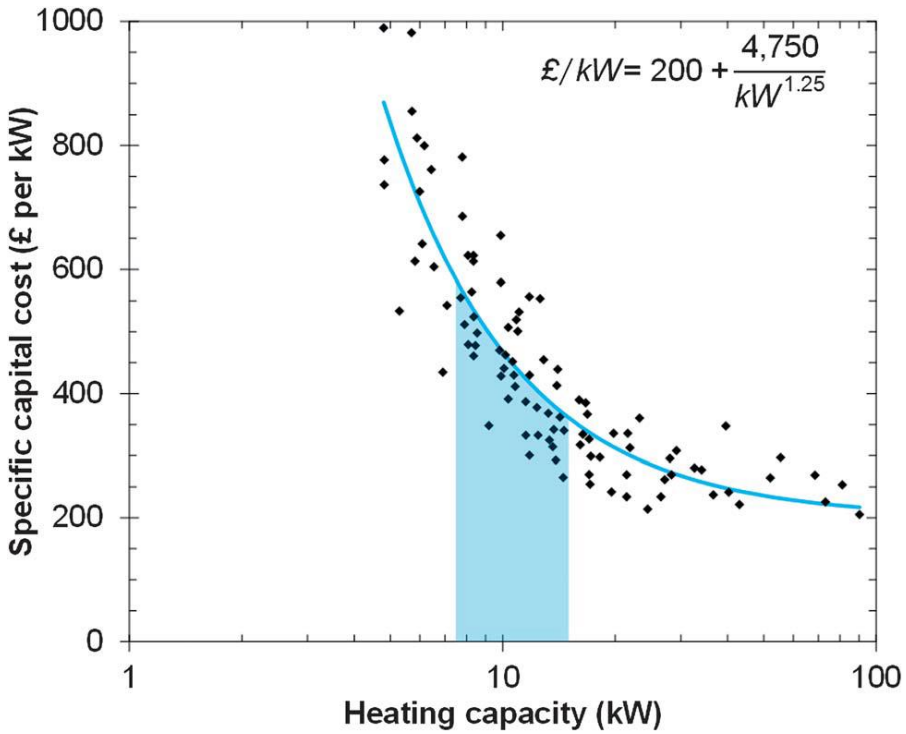

Figure 2: Capital cost per kW of heating capacity for all types of heat pump from European manufacturers. The approximate range of capacity suitable for UK homes is highlighted (Consulting 2007; Staffell *et al.* 2012)

Results and Discussion

The data calculated from the analysis of the heat pump technology on account of its efficiency, sustainability and financial implications would be compared with the present conventional heating data. The expected results would show that there is a possibility of heat pumps as a technology for heating residential buildings in Ireland.

The result is expected to produce coefficient of performance in the range of 2.8-3.4 and this range changes relative to the factors listed previously. Table 1 reflects data obtained from an experiment using heat pumps in the United Kingdom which shares a similar climate with the republic of Ireland. The results would show that during the winter (December, January and February) lowest source temperature would produce the lowest efficiency because of the increase in temperature lift as compared to other seasons. The major drawback to the air source heat pump (ASHP) is the freezing of the evaporators during the period when it is needed the most (winter season). This leads to a reduction in efficiency of the heat pump and leads to an increment in the electricity used and running cost. A review of (Bertsch and Groll 2008)

provides an in-depth analysis of different combinations of heat pump technologies that would perform effectively and efficiently at temperatures as low as -30ºC.

The expected results of the environmental impact and financial impacts of the technology as compared to conventional heating sources would show that over a lifetime of 20 years, there would be better performance and savings from the heat pump than its counterparts (Staffell *et al.* 2012).

Table 1: Example of data sets that were obtained from a test run in the United Kingdom which shares a similar climate as the Republic of Ireland (Staffell *et al.* 2012)

Month	Source Temperature T_{in} (°C)	Source Temperature T_{out} (°C)	Lift ΔT (°C)	Heat Demand Q (MWh)	Estimated Monthly COP
Jan	3.4	42.0	38.6	2.36	3.08
Feb	3.7	42.1	38.4	2.35	3.09
Mar	5.5	42.1	36.6	2.35	3.22
Apr	7.8	43.7	35.9	1.36	3.28
May	11.3	44.9	33.6	1.02	3.45
Jun	13.9	50.9	37.0	0.46	3.19
Jul	16.0	55.0	39.0	0.33	3.05
Aug	15.7	52.5	36.9	0.40	3.20
Sep	12.9	49.9	37.0	0.50	3.20
Oct	9.9	44.2	34.3	1.20	3.40
Nov	6.0	42.5	36.5	2.01	3.23
Dec	4.2	42.0	37.8	2.46	3.13

Conclusion

The study has completely assessed the feasibility of the heat pump technology under its efficiency, sustainability and economic value in Ireland and has come to the conclusion that it is a technology that would feature a lot in the renewable heating sector for a long time to come. The technology has been analyzed to be fully sufficient to perform under the climates in the Republic of Ireland. The results of this study were achieved by mathematical simulations and the results are a function of available data. The study should be experimented under actual physical constraints to confirm the results.

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FEASIBILITY ANALYSIS OF GRAVITATIONAL HYDRO VORTEX GENERATOR SYSTEMS IN IRELAND'S INLAND WATERWAYS

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Abstract

Gravitational water vortex turbine (GWVT) is an ultra-low head turbine the extracts energy from an artificially induced gravitational water vortex in the basin of a cylindrical or conical configuration. This means that there is a substantial and constant flow of harvestable kinetic energy in the Irish inland water body network which can be used to power, if not a large network, a mid range series of domestic housing. Since 2006, the hunt for greener forms of technology has led to significant research and development in the field of hydro-kinetic generation devices which emphasize on converting the kinetic energy in naturally flowing water to usable electric energy. The technology is fairly simple and involves creating a conical basin at various points of flow in the water body and channelling the water through a turbine with a Savonius blade setup in order to extract the energy from it. These technologies are currently being employed in Asia and Europe with around 22 documented sites being installed in these countries. The efficiency of the turbine ranges from 50%-55% which is much lower than conventional hydro energy systems but the energy density that can be achieved with these systems is much higher than the conventional systems due to the constant flow of the water. In this study, all such factors will be considered and a detailed model will be constructed on HOMER pro software to aid in the feasibility analysis of the hydro kinetic device and to shed light on the energy economics of the technology.

Introduction

Gravitational Hydro Vortex Turbines are classified as ultra-low head micro hydropower systems with an operational head of 0.7m - 2m (Rizwan *et al* 2018). This technology does not require large reservoirs of water neither does it require large installation areas. The flowing water is channelized into vertical pools of water in a circular cross-sectioned basin with an orifice at the bottom to create a vortex under gravitational forces. This setup can be compared to the effect of draining a filled bathtub or sink, where the flow of water into the drain under the effect of gravity causes a temporary vortex.

To harness this energy, conventional turbines like Kaplan or Pelton turbines can be used but in this study Savonius turbines are used as the construction is simpler and also to facilitate movement of aquatic life through the turbine without causing them harm. Hydropower is on of the most commonly used renewable sources of energy and accounts for 16.6% of the globally generated renewable energy (Timilisina *et al* 2018). Considering these number, hydropower is one of the most under utilised forms of energy and has extensive potential for future use. It is predicted that by the end of thee year 2060, the human civilisation will rely heavily on hydro power, upto 50% (Ak *et al* 2017).

Hydropower potential can be classified into pico (< 0.005 MW), micro (< 0.1 MW), mini (< 1MW), small (< 10MW) and large (> 10MW). In addition to this, off-grid electrification in rural areas is one of the main driving factors for the adoption of the smaller hydropower systems (Timilsina et al 2018).

The objective of this study is to determine the feasibility of hydro-vortex turbines in Ireland's inland water network system.

Materials and Methodologies

A Gravitational Hydro Vortex turbine consists of a basin, which is a large conical or cylindrical cross sectioned construction which naturally channels the flowing water into a vortex and is in turn connected to a turbine and blades setup which is used to generate the electrical power.

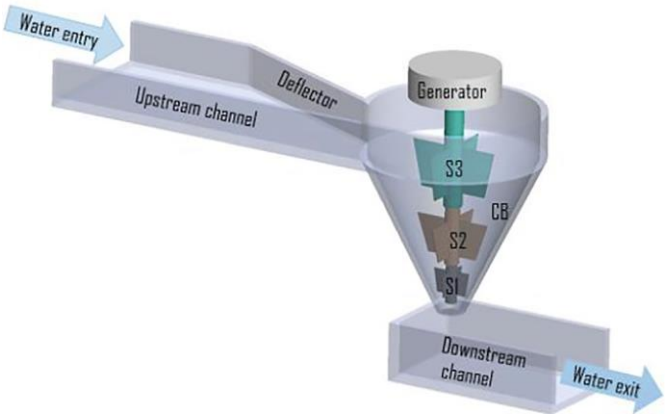

Figure 1. A schematic sketch of a GWVT setup (Rizwan *et al*. 2018).

As shown in the figure, the difference in head is created by the difference in height between the two flows of the water and this setup turns the blades of the turbine. The blade profile plays an important role in this setup as it decides the power that can be generated and based on the application it could be a single stage or a multi stage turbine wheel as shown in figure 2.

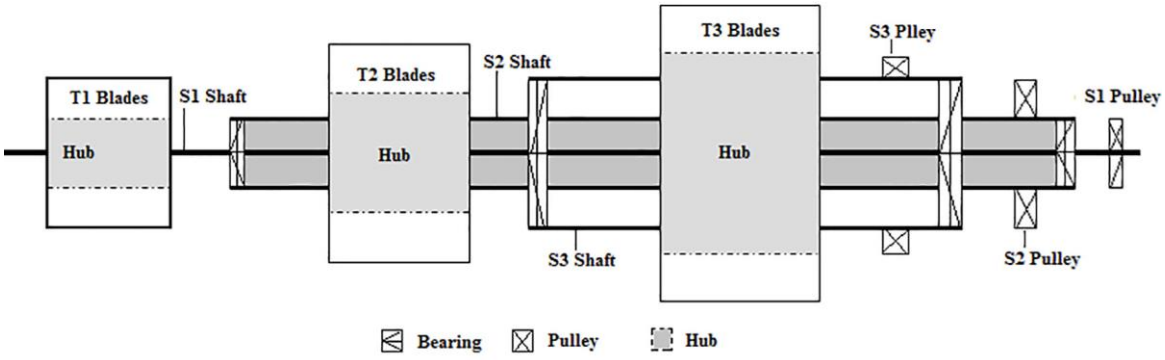

Figure 2. Blade profile.

A detailed study will be conducted on the different types and shapes of turbine wheels with the primary focus being on preserving the wildlife, if any, that passes through these water channels in order to avoid loss of valuable fauna. A complete model will be built on HOMER pro software which will provide us with a detailed analysis on the energy economics. The cost of equipment and the operational and replacement costs will be sourced from previous studies and existing global examples. Along with the equipment, it is necessary to study the existing water channels and water bodies in Ireland to determine the feasibility of the technology.

A detailed list of the water bodies and their water levels can be obtained from a real-time Irish website, www.waterlevel.ie which provides a geographical as well as real time update on the water level of each of the inland water bodies in Ireland. Since we are considering out system to be a micro level generator, we consider a head height between 0.7m and 2m, therefore an in-depth analysis will be carried out on each and every one of the possible water bodies to determine if they would suit the purpose, based on the data available from the website.

Discussion and Possible Outcomes

The objective of this study would be fulfilled in 3 stages :

i) How many water bodies can actually handle such a technology and generate usable energy.

ii) What would the potential impacts be on the wildlife.

iii) A model on HOMER pro software would give more clarity on whether this is an economically feasible solution when compared to investments being made to it.

In addition to this, extensive literature reviews will be undertaken in order to understand the technology and to assess global examples to get a clearer picture of their shortcomings and possible failure points as well as the potential to implement this technology on a global scale. Upon further investigation, internationally published research papers like Campbell 2010, Bozhinova *et al.* 2013 and Williamson *et al* 2014, provided a plethora of invaluable information which would significantly assist in examining global examples to understand the feasibility of this technology better.

The HOMER model that will be constructed will be based off experimental models that were constructed in various sites globally and the data for the flow rates and cost of equipment will be taken from Irish databases. A sensitivity analysis of power density vs. head height will be applied to the model to determine the economic viability at various cases as shown in figure 3.

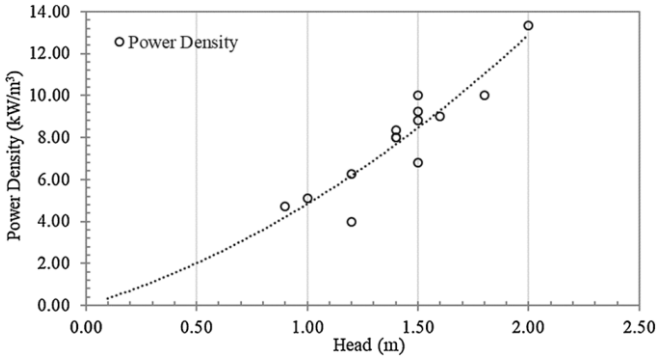

Figure 3. Graph showing head vs. power density

These tools would ultimately provide a clear picture of the feasibility of the technology in all three aspects as mentioned above, considering various turbine blade designs to improve the movement of wildlife through the system.

Conclusions

Once all the possible scenarios are assessed a possible solution can be arrived at considering the environmental, economic aspects as discussed earlier. The HOMER model would additionally provide clarity on the environmental economics of the study.

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LIFE CYCLE ANALYSIS OF A PORTABLE ANAEROBIC DIGESTION UNIT FOR BRITISH HOUSEHOLDS

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Abstract

In recent years, major changes have been identified in municipal solid waste (MSW) management technologies in the UK. They were in terms of diverting MSW from landfilling for strategic utilization of MSW for producing value added products through anaerobic digestion (AD). Though, these technologies are effective and implementable, it must be demonstrated to be environmentally sustainable. This paper focusses on determining the overall environmental impacts of utilization of MSW for the production of biogas and bioelectricity via anaerobic digestion (AD) in comparison with conventional methods (landfilling). The LCA results showed that anaerobic digestion (AD) process uses five times less energy and emits almost insignificant (0.022 CO_2 Kg Eq-) amounts of CO_2 compared to the landfilling process (2.56 CO_2 Kg Eq-). This can be attributed to the raw material extraction and its uses involved in construction, maintenance, and transport during landfilling process. Moreover, among all the impact categories considered, marine aquatic ecotoxicity potential (MAETP) was found to be higher in both landfill and anaerobic digestion process. The system expansion of the current process by replacing the inorganic fertilizer with the digestate (an organic fertilizer) produced by the anaerobic digestion process, on the agricultural farmlands has avoided burdens especially in terms of marine aquatic ecotoxicity potential with - 3300 kg DCB Eq-.

Introduction

Food waste (FW) has been significantly increasing worldwide due to the immense rise in population and urbanization. Usually, FW comprises a major fraction of the total municipal solid waste (MSW). Introduction and implementation of the 1999/31/EC EU landfill directive in the United Kingdom (UK) has substantially decreased the amount of municipal waste going to the landfill and led to major changes in the waste treatment technologies towards the utilization of waste for producing value added products by means of anaerobic digestion (AD) (DEFRA, 2010).

AD has been widely used for treating organic fraction of municipal solid waste (OFMSW), especially the food waste (from households and restaurants' kitchens). Food waste is rich in nutrients and energy, along with harmful microorganisms, which is a serious threat to human life and environment. The effective management of biomass would mitigate the environmental problems and threats to human health. Therefore, it is important to investigate the environmental burdens from waste generation and the benefits achieved from waste utilization by employing AD in the place. Life cycle assessment (LCA) is the best tool available to identify and quantify the environmental burdens of waste utilization methods (Boldrin et al., 2011; Evangelisti et al., 2014).

The objective of this study is to determine the potential environmental impacts and the energy requirements of a portable anaerobic digestion unit in comparison with the traditional method of landfilling for biogas and bioelectricity production from household food waste for the Royal borough of Greenwich in London, UK.

Materials and Methods

Goal and scope
The current project focusses on biogas and bioelectricity production from AD and landfilling of household food waste (FW) in the Royal borough of Greenwich, London. The population is estimated to

be approximately 245,000 and generating around 440 kg's of household food waste per person (Royal Borough of Greenwich, 2012). The organic fraction of the MSW is assumed to be 33%, which estimates the total production of organic fraction of municipal solid waste (OFMSW) to be 35,574 tonnes/year (Evangelisti et al., 2014). In this study, the main components included are AD, FW landfilling and combined heat and power (CHP). These components will be analyzed using LCA for emissions and their impacts on the environment, considering the functional unit of 1 MJ of biogas produced from household food waste (FW).

Figure 1. demonstrates the life cycle "cradle to grave" system considered for the biogas production from FW through anaerobic digestion (AD) and landfilling, followed by heat and power recovery via combined heat and power (CHP) plant. The AD system combines with CHP for heat and power generation, whereas landfilling relates to gas recovery for electricity generation. This study assumes to recover only electricity, but not heat from either of the AD or landfilling systems. The system boundary also includes the transportation of FW from the borough to South East London, Bermondsey, which is 15 km away from the borough.

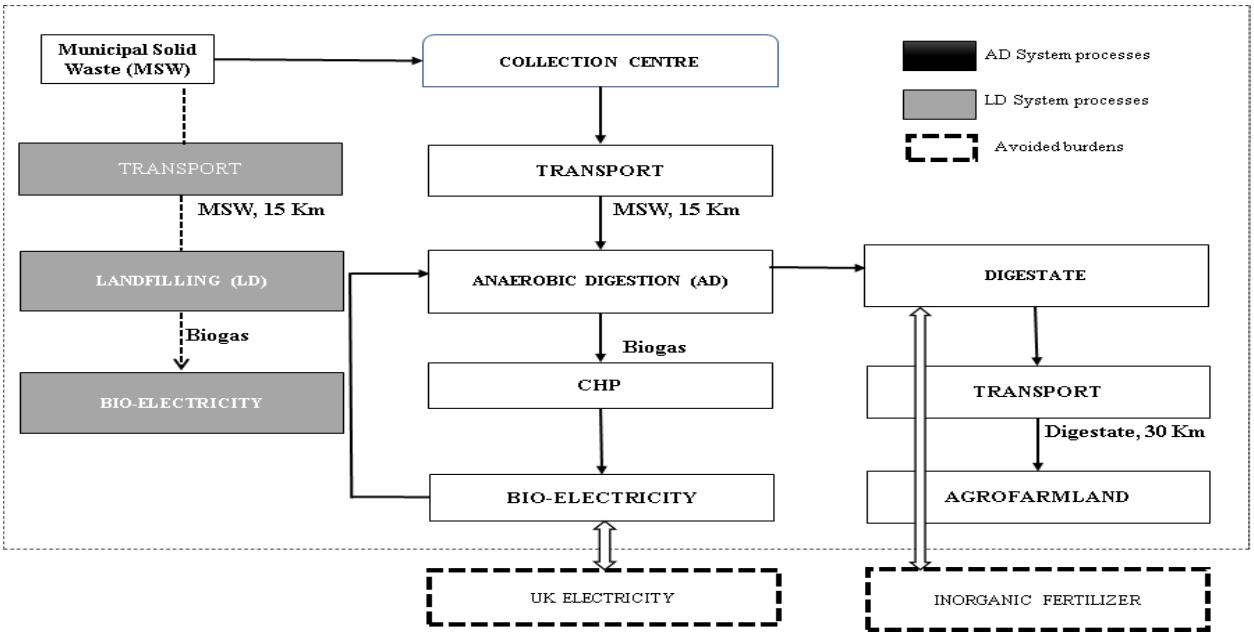

Figure 1: System environment for biogas and bioelectricity production from anaerobic digestion (AD) and landfilling (LD).

Life cycle inventory

This section accounts for the raw material extraction, use and its associated emissions involved in the life cycle of landfill and anaerobic digestion for both biogas and bioelectricity production. The raw materials involved in both landfill and AD processes were collected from the work by Evangelisti and colleagues (2014), and from GaBi database. The biogas to bioelectricity conversion values and diesel usage were adopted from GaBi database. Whereas, the remaining inputs were adopted from the work of Evangelisti and colleagues (2014). AD process uses electricity and steam for running and maintaining the bioreactor and the values were adopted from the work of Evangelisti and colleagues (2014). However, the electricity and heat required for the CHP plant were not considered in the study. Landfill doesn't employ electricity directly, but energy demand from background processes like construction and maintenance of the landfill pits were considered and adopted from GaBi database. Transportation was used at two sites in the simulated models. First, involving transport of OFMSW from the Greenwich borough to biogas conversion plant or AD plant at South East London, Bermondsey with a distance of 15kms. Then subsequent transport via truck was employed to transport the AD digestate to the agricultural farmlands nearby at a distance of 30kms. The truck databases including diesel usage and its associate emissions were taken from GaBi database.

Allocation

The system boundary of the AD processes was expanded to introduce systems (UK electricity and inorganic fertilizers) from outside to avoid their burdens by replacing them within the system. Here, the bioelectricity generated from biogas was reused within the system to meet the energy requirements of AD processes by replacing the UK grid electricity. In the same way, digestate which is considered waste can be used as organic fertilizer on the fields, replacing the inorganic fertilizers. This study believes that doing this would avoid the burdens of the outside system if it is replaced by the by-products of the current system (bioelectricity and AD digestate). Therefore, three different scenarios were developed using AD process. The first scenario employs reusing of bioelectricity replacing the UK's grid electricity (AD-B); the second scenario utilizes organic fertilizer (digestate) to avoid burdens of inorganic fertilizers (AD-OF) and the third scenario employs both bioelectricity and digestate (AD-B-OF). The energy requirements and environmental impacts were found be lower for all the three scenarios in comparison with the AD process without system expansion.

Life cycle impact assessment

The life cycle impact assessment (LCIA) was performed using CML methodology. The impact categories mainly considered in the study were global warming potential (GWP, kg CO_2 Eq-), acidification potential (AP, kg SO_2 Eq-), eutrophication potential (EP, kg PO4 Eq-) and marine aquatic ecotoxicity potential (MAETP, kg DCB Eq-).

Results and Discussion

The LCA results as shown above (Figure 2.) indicate landfill as the most energy intensive process in comparison with AD process for production of biogas and bioelectricity from food waste. The AD process was found to have significantly lower (0.022 CO_2 Eq-) global warming potential (GWP) than the landfill process (2.56 CO_2 Eq-). Since the background process contributed largely to the CO_2 emissions for the landfill process, the GWP surged higher than AD process (Figure 2(c)). Moreover, the contributions from the leakage of methane during biogas production from landfill was also one of the reasons for this higher GWP. Among all the impact categories considered (AP, EP, MAETP and GWP), marine aquatic ecotoxicity potential MAETP (in kg DCB Eq-) was found to be higher in both landfill and AD process (Figure 2(b)).

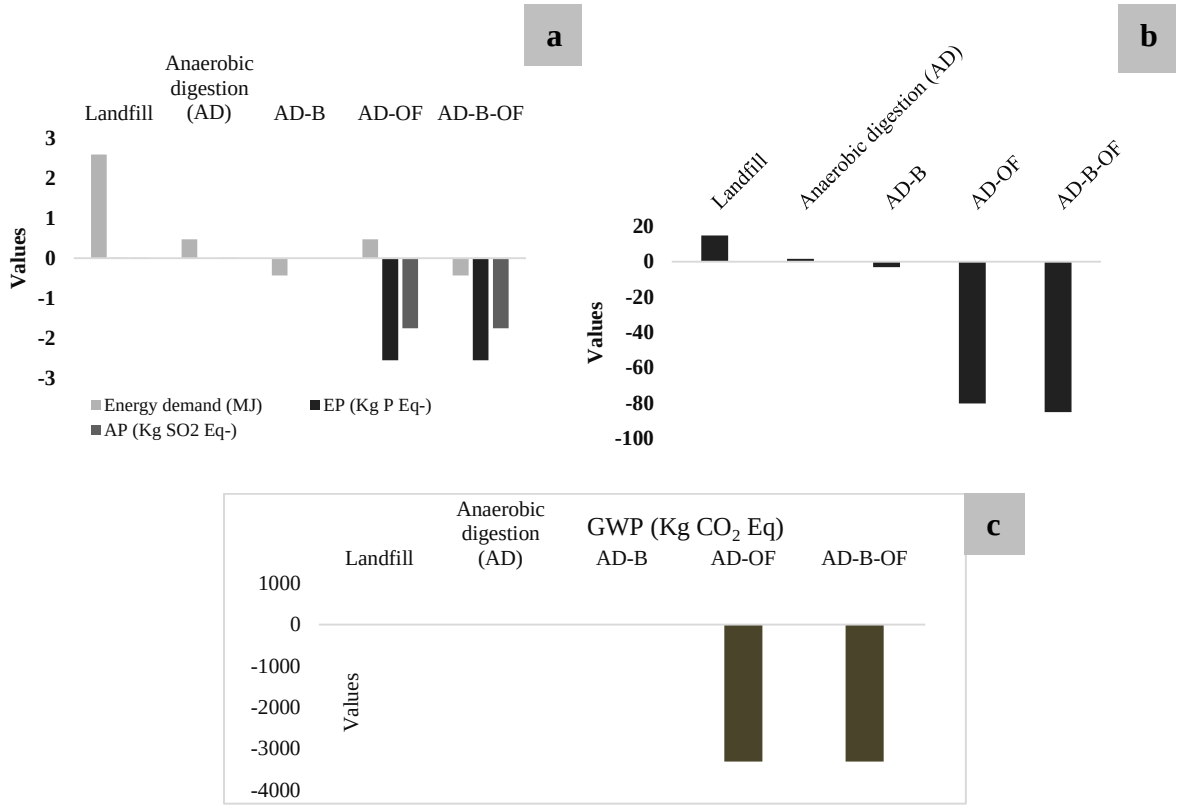

Figure 2.: Primary energy demand and environmental impacts (a), marine aquatic ecotoxicity potential MAETP (kg DCB Eq-) (b) and global warming potential GWP (kg CO_2 Eq-) (c) of different scenarios modelled for biogas and bioelectricity production from food waste.

Conclusions

The LCA analysis revealed that anaerobic digestion (AD) process was more efficient than landfill in terms of both energy demand and environmental impacts. It is also evident from the LCA study that by employing bioelectricity and AD digestate instead of the UK's grid electricity and inorganic fertilizers, there is a significant reduction in energy usage as well as in the environmental emissions. Hence, it can be concluded that the portable anaerobic digestion system which reuses the bioelectricity produced and uses the digestate as an organic fertilizer will result in considerable savings in energy and emissions for the household consumers in the Royal Borough of Greenwich.

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ENERGY GENERATION FROM AGRICULTURAL WASTE

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Abstract

The amount of waste generated in the world is increasing day by day and hence, it is very important to manage the same in an effective manner. The project here focuses on the generation of energy from agricultural waste (biomass) such as oat straw and oak wood . This project is a part of Agri Bio Circular Economy (ABC Economy) which focuses on developing sustainable energy from waste. The data for different biomasses is collected from two counties, Monaghan and Tipperary. In this process the most valuable output is determined and a comparison of two technologies is carried out. The two technologies in this study are gasification and pyrolysis. The energy output from the two technologies is determined through simulation process and the most valuable energy output is determined from the waste materials.

Introduction

Ireland, along with Denmark and Luxembourg, has the EU's most ambitious greenhouse gas (GHG) emissions reduction target; reducing emissions by 20 per cent by 2020 compared to 2005 (Sustainable Energy Authority of Ireland, 2017). Action leading to the achievement of energy goals helps reach, but does not guarantee, the binding EU GHG emission cap (Sustainable Energy Authority of Ireland, 2017). Emissions goals also cover agricultural and waste management emissions, which currently account for 34 per cent of the overall GHG emissions from Ireland (Sustainable Energy Authority of Ireland, 2017). Hence, waste management is a major concern in the modern world. The effective use of waste is an emerging requirement. The use of waste or renewables to generate energy can reduce the use of fossil fuels for the same, which can in a way reduce GHGs while producing energy. The process of converting waste to energy is an important requirement as it enables conversion of the different kinds of waste such as wastewater sludge, agricultural and livestock waste, food waste and urban solid waste to energy, while reducing the amount of waste disposed of or released to atmosphere (Richard *et al*., 2018)

This project focuses on agricultural waste as these are assumed to have a high energy content and are available in Monaghan and Tipperary. Agricultural waste also has costs associated with disposal (Salman Zafer, 2019). Therefore, waste may have strong economic and consumer value in the energy conversion cycle for heat and power generation and even the production of fuel for transportation (Salman Zafer, 2019). There are many technologies to convert waste to energy which otherwise go to landfill (Richard *et al*., 2018). There are five common biomass processing technologies based on direct combustion (for power) (Salman Zafer, 2019). They are anerobic digestion, fermentation, oil extraction, pyrolysis and gasification (Salman Zafer, 2019). For decades anerobic digestion has been used to produce methane for on-site heating or energy generation (Richard *et al*., 2018). This project focuses on two waste-to-energy process; pyrolysis and gasification. Gasification is a process which is carried out in a limited amount of oxygen or air. In this process oxygen allows some amount of combustion to take place but not completely. Pyrolysis is a process that takes place at a high temperature in the absence of oxygen (Paul Breeze, 2017).

The objective of this study is to assess the feasibility via process simulation to generate energy from agricultural waste by pyrolysis and gasification to determine which technology produces the most valuable output.

Methodology

This Project focuses on two processes; gasification and pyrolysis. The energy density and physical properties of biomass are important for the consideration of feedstocks and need to be understood to suit a feedstock and processing technology (Salman Zafer, 2019). In this project the two technologies are compared, analysed and conclusion is made which is the best technology to generate valuable energy.

Gasification Process

Gasification is by definition the conversion of a solid or liquid fuel to a gaseous energy carrier with a useable heating value that can be used for a variety of purposes (IEA Bioenergy, 2018) One of the major advantages of gasification as regards conventional combustion is the versatility of product gas applications. The gas produced by gasification can be used in kilns or furnaces as fuel to replace other conventional and mostly fossil fuels (IEA Bioenergy, 2018). Over decades, gasification has been used worldwide on a commercial scale to produce coal gas for heating, illumination, and cooking. It has been used by the chemical, processing and fertilizer industries for over 80 years and by the electricity industry for more than 35 years (Vishal Soni and Vatsal Naik, 2016). However, gasification is now being adapted in small scale applications too.

Pyrolysis Process

Pyrolysis is a thermal decomposition process which occurs at a range of 300-1300 °C in the absence of oxygen. The product yield in pyrolysis is affected by temperature range, feedstock, heating rate and the type of reactor used (Hayelom *et al*., 2017). Synthetic gas generated from the conversion of waste using pyrolysis can be used in gas or steam turbines for electricity generation (AZoCleantech, 2013). Biomass pyrolysis can be performed at relatively small scale and remote locations that improve the energy efficiency of the biomass resource and minimize transportation and handling costs (Salman Zafer, 2018).

Four main processes which will be carried out in both pyrolysis and gasification processes are:

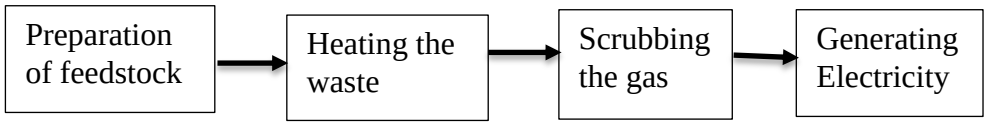

Figure 1: Processes inside pyrolysis and gasification

Method and Data Collection

There are 3 main steps in this Study

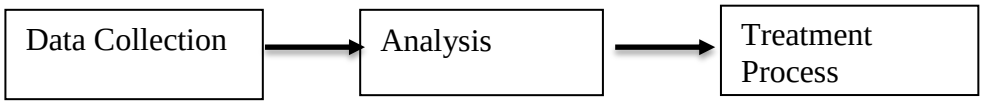

Figure 2: Procedure in the study

Data Collection

As the comparison and analysis of the two the processes have to be done through oat straw and oat wood as a feedstock. In this study the required data for oat straw and oak wood was initially collected from the ABC Economy project. The data was collected from 2 counties; Monaghan and Tipperary. These are two counties with different types of agricultural production.

Table 1: Data sources (Teagasc,CSO, Ireland's National Forest Inventory 2017, ICT Biochain)

Fuel Properties	Unit	Oat Straw (Crop Data)	Oak Wood (Forest Data)
Proximate Analysis			
Moisture content	wt% (ar)	8.2	
Ash content	wt%	5.4	5.3
Volatile matter	wt%	73.9	76.0
Fixed carbon	wt%	12.5	18.7
Ultimate Analysis			
Carbon	wt%	43.7	49.7
Hydrogen	wt%	5.3	5.4
Nitrogen	wt%	0.5	0.2
Sulphur	wt%	0.1	0.1
Oxygen	wt%	39.9	39.3
Total (with halides)	wt%	103.2	100.0
Calorific Values			
Net calorific value (LHV)	MJ/kg	16.0	18.3
Gross calorific value (HHV)	MJ/kg	17.4	19.5

Analysis: The waste materials are analysed to find out which waste material is suitable for a particular technology. As different feedstock has different characteristics and energy coefficients to generate energy it is very important to analyse which feedstock is suitable for a particular technology.

Treatment Process: A comparison will be done with the simulation output of the two technologies. Here the simulation will be carried by using the Aspen Plus software. An analysis will also be made to decide which one is the best by considering the energy content in each output.

Results and Discussion

The comparison of two processes are very important to be carried out, to determine which is most optimal. For this comparison the simulation of the two processes are being done. As gasification and pyrolysis processes do not have much differences other than the amount of oxygen or air for combustion, the analysis will be quiet challenging. The research can be a contribution to the agricultural areas to determine which technology is better to provide a valuable energy output.

In this study, the expected result is that there will be high energy output from agricultural waste. This can help to simulate and analyse which technology is a better way to convert energy from waste. In both technologies a simulation process flow chart is expected to initiate with a reactor where the decomposition takes place in the gas phase with no heat loss to the

surrounding. The reaction product obtained are further cooled and separated into solid, liquid and gas phase by series of two condensers (Chaiyot *et al*., 2019). Over here, the comparison is mainly expected to be between the amount of energy output, the effect of moisture content and effect of temperature (Abtin *et al*., 2012)

Conclusions

As the population of the world rises, so will the demand for energy and goods and therefore the amount of waste produced. Generating energy with the produced waste especially in the farm land is a reasonable approach and also will help to meet the GHGs emission target . This research work focuses on the generation of energy from the agricultural waste. The study also focuses on analysing best technology for the production of energy in this context by comparing gasification and pyrolysis process.

Acknowledgements

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MICROPLASTICS IN THE SOILS OF BELFIELD CAMPUS

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Abstract

Microplastics have received increased societal attention because of their association with environmental problems. The influence of microplastics on soil quality and function cannot be ignored. This study is assessing the prevalence of microplastic contamination in the soils of the University College Dublin (UCD) Belfield Campus, which was divided into three zones according to time and function. Soil samples are being examined by microscopic and infrared techniques to detect different types of microplastics in the soil of each zone. It is expected that six different types of microplastics will be present in the soil: polyethylene; polypropylene; polyvinyl chloride; polymethyl methacrylate; polyethylene terephthalate; polystyrene, but it is not clear how concentration will vary with land use zone.

Introduction

Due to its versatility, durability, good ductility, and low price, plastic polymers have become a constant component of everyday objects in peoples' lives. The world has produced about 9.1 billion tonnes of plastic products in the past 50 years, with an annual growth rate of 8.7%. (Geyer et al 2017) Due to the huge production volume and low waste disposal rate, used plastic waste products (such as polyethylene, polypropylene) will degrade into smaller plastic fragments (microplastics) in the environment (He et al 2018). Microplastics refer to fragments less than 5 μm maximum diameter. Due to their small size, microplastics are difficult to find and currently it is difficult to explain what specific impact they have on the environment they occupy (He et al 2018).

The impact of microplastics on the environment can be divided into two broad, general categories: impact on the ocean and impact on the soil. Since 1970, articles on the impact of microplastics on the ocean have been published (Carpenter and Smith, 1972), and in recent years, due to the increasing attention of microplastics, publications on microplastics have increased rapidly (He et al 2018). This shows that the detection and evaluation technology for microplastics in the ocean is relatively mature. There are relatively few reports on the impact of microplastics on the soil. There are some reports that indicate the impact is more serious than the impact on the ocean (Kim and An, 2019).

The source of microplastics in soils is relatively complex. The ways in which microplastics enter the soil include transportation of particles and fibers in the air, unseparated microplastics through sewage treatment plant sludge, the rubbish generated from road washing or tire wear and composting applications (David et al 2019). Microplastics entering the soil will not only affect the structure and density of the soil but also the microorganisms in the soil, potentially leading to toxicity and ecological problems. The damage of microplastics to the soil is irreversible, so it is an environmental problem that cannot be ignored.

The objective of this study is to understand the relationship between campus use and the prevalence of different types of microplastics in the soil of the UCD Belfield Campus.

Methods

Classification

Microplastics can be further divided into microplastics and nanoplastics according to the diameter of the particles. When the diameter of the particle is less than 100 nm it is classified as nanoplastic, and when the diameter of the particle is between 100 nm and 5 μm, it is called microplastic (Kim and An, 2019). Microplastics can also be divided into primary microplastics and secondary microplastics according their probably source. Particles associated with daily necessities such as cosmetics are called primary microplastics (Paul et al., 2019), while those caused by degradation of particles due to aging of the material by ultraviolet light, mechanical action, and oxidation are called secondary microplastics (Paul et al., 2019).

Sampling method

The sampling of the Belfield Campus was based on dividing it into 3 parts according to the age of the campus buildings and the function of the area, as shown in Figure 1. According to Möller et al. (2020), the best sampling method is to select 5 specific locations in each area with different functions, then select 6 specific sets of samples of the same volume from the same soil depth in each location. The total number of samples in this project is 90.

Figure 1. UCD Belfield (University College Dublin, 2016)

Microplastic detection

There are many reports on detection methods for microplastics in soil samples, but there is no standard method. The use of thermogravimetric analysis-mass spectrometry (TGA-MS) using cysteine as an internal standard is commonly used (David et al 2018). The advantage of this method is that it does not require complex pre-processing of samples and the detection results are accurate (David et al 2018). The disadvantage is that the ability to detect different types of microplastics in the sample is limited and specialist laboratory equipment is required. For this project, a combination of infrared spectroscopy and microscopy will be used to detect microplastics in the soil samples. First, both methods require sample pre-processing. The soil sample is dried, disaggregated to separate mineral and organic particles, sieved, and the microplastics separated by a combination of floating, filtering and centrifuging. After pretreatment, the larger particles in the pre-treated samples will be examined using microscopy. By observing the sample through a high magnification microscope, the number of particles in the sample, the degree of aging, and the type of microplastics can be determined. The infrared spectrometer is used to detect the smaller particles in the pretreated samples. Figure 2 is a

schematic diagram of infrared spectrum detection. The curve marked "polystyrene" in the figure is the standard curve. By comparing the peaks of the detection curve (spectra 1) and the standard curve, the type and quantity of microplastics in the sample can be observed. The advantage of these two methods is that the detection accuracy is high, but the disadvantage is that the detection requires pretreatment, the single detection amount is small, and the detection time is long. Other soil sample microplastic detection methods include fast infrared detection and mass spectrometry. The detection accuracy for these is low and the detection time is long, so they are not suitable for this project.

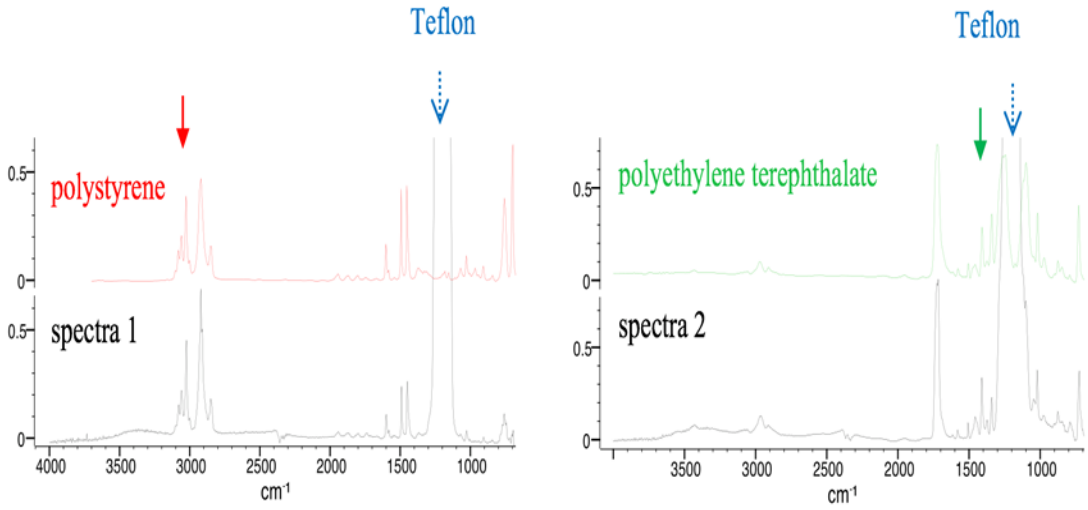

Figure 2. Infrared spectrogram (Carlos, 2020)

Results and Discussion

Expected result

The expected results of this project are shown in Figure 3. This result was obtained from soil testing in southeast Germany. The testing process was similar to the methods for this project. A total of six different types of microplastics were obtained: PE, polyethylene; PP, polypropylene; PVC, polyvinyl chloride; PMMA, polymethyl methacrylate; PET, polyethylene terephthalate; PS, polystyrene. According to the results, the average sample contained most PE and least PMMA, with PE being the most prevalent.

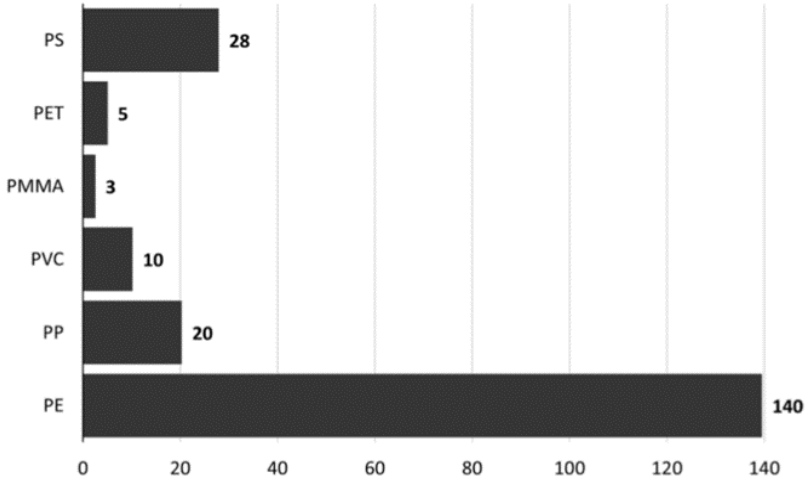

Figure 3. Microplastic content in German soil study (Piehl et al., 2018)

Conclusions

With the increase in plastic waste, microplastics have become a problem that people have to face. Understanding the impact of microplastics on the soil is a priority. In this study, microscopic and infrared technologies will be combined to detect microplastics in the soil of UCD Belfield Campus by zone. The project is currently in the early stage of the experiment, and the expected results are available for reference. The expected results indicate that there are six different particles in the soil, namely polyethylene; polypropylene; polyvinyl chloride; polymethyl methacrylate; polyethylene terephthalate; polystyrene. It is not yet clear whether they will vary by campus zone.

Acknowledgements

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SUPPLY CHAIN MANAGEMENT STRATEGIES FOR EFFICIENT FEEDSTOCK SUPPLY TO BIOREFINERIES

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Abstract

Among several actions needed for the development of a circular bioeconomy is the efficient management of the supply chains of biorefineries, which are closely related to the availability of sustainably sourced biomass. Several models based on Geographical Information Systems (GIS) and Operation Research methodologies are now being used for strategic, planning, and operational decisions. However, the development of supply chain designs for hybrid anaerobic digestion (AD) systems is still lacking. A systems thinking approach will be adopted, separating the research in two main phases; firstly to better understand the system, and secondly to address its challenges and opportunities. The role of reverse logistics as a critical enabler within the circular economy will be taken into account for the development of a framework and model for Supply Chain Management, defining the mechanisms of an efficient grass and seaweed-silage biofeedstock supply, considering its embedding environment, demand fluctuations, government incentives, and uncertainty.

Introduction

The supply chain is directly related to the efficient management of supply chains flows, i.e. information, products and funds (Chopra, Sunil & Meindl 2016). For a biorefinery, that means finding optimal decisions for hierarchical processes across the full chain, including strategies to ensure an efficient supply of sustainable biomass feedstock to be transformed into marketable products. It is through the biorefineries that the conversion of biomass into value-added products such as food, feed, biochemical, and bioenergy occurs (Ubando *et al.* 2019).

The creation of new biorefineries is among the several actions adopted by the European Commission in seeking for the development of a circular and sustainable bioeconomy, along with better understanding ecological boundaries, boosting local rural, coastal and urban economies (EC 2018). Bioeconomy has become an essential part of countries and institutions strategies worldwide to address sustainable development goals, technological innovation, biodiversity protection and commitment to climate change mitigation (Birner 2018). Besides, many efforts are being placed to develop novel biorefinery concepts to produce bio-based products which are also sourced from non-food crops feedstocks. This is partly also based on attempts to overcome the food vs. fuel debate of first-generation biomass, and other sustainability-related concerns of feedstocks such as possible indirect land-use change (ILUC) effects (Levidow 2013). Hence, the use of grass and seaweed-silage represents an important step in overcoming such concerns as alternative feedstock sources that could also contribute to countries emission reduction targets. According to several scholars, the utilisation of macroalgae or grass as raw material for biorefineries constitute a great potential for processing green biomass into marketable products (Lehahn *et al.* 2016; Herrmann *et al.* 2015; Savonen *et al.* 2019). However, strategies for upscaling production and management strategies in the supply chain to attend future demands for hybrid AD systems is still lacking.

The objective of this project is to develop a framework and model for Supply Chain Management, defining the mechanisms of an efficient grass-silage and seaweed biofeedstock supply system for biorefineries.

Material and Methods

To gain a deep understanding of the system investigated, the research will be divided into two phases: The first phase will incorporate a diagnostic research design about the system analysed (Figure 1). First, a thorough literature review on supply chain management in the bioeconomy will be conducted, reviewing at the same time the role of reverse logistics as a critical enabler within the circular economy. Second, the focus will rely on the two feedstocks: grass and seaweed-silage. The embedding environmental conditions for upscaling the supply of these biomass resources will be included. From the cultivation from grass and seaweed, up to its delivery to a novel refinery concept. This includes the value chain of both bioresource in the upstream stages of the biorefinery, since it is not clear yet, which mix of products will better maximise the value of the biomass in this case (Barbier *et al.* 2019). Hence, it includes the stages of cultivation, harvesting, transport, pre-processing, storage, and delivery to the biorefinery. This approach will enable the identification of key barriers, bottlenecks, and enablers to further develop this sector, along with the identification of institutional challenges such as government incentives as well as potential conflicting areas. Considering that the supply of biomass is geographically sensitive (Yue *et al.* 2014), the study will be contextualised in Ireland, holding optimal conditions for upscaling the supply of both grass-silage and seaweed (O'Keeffe *et al.* 2011; Monagail and Morrison 2020).

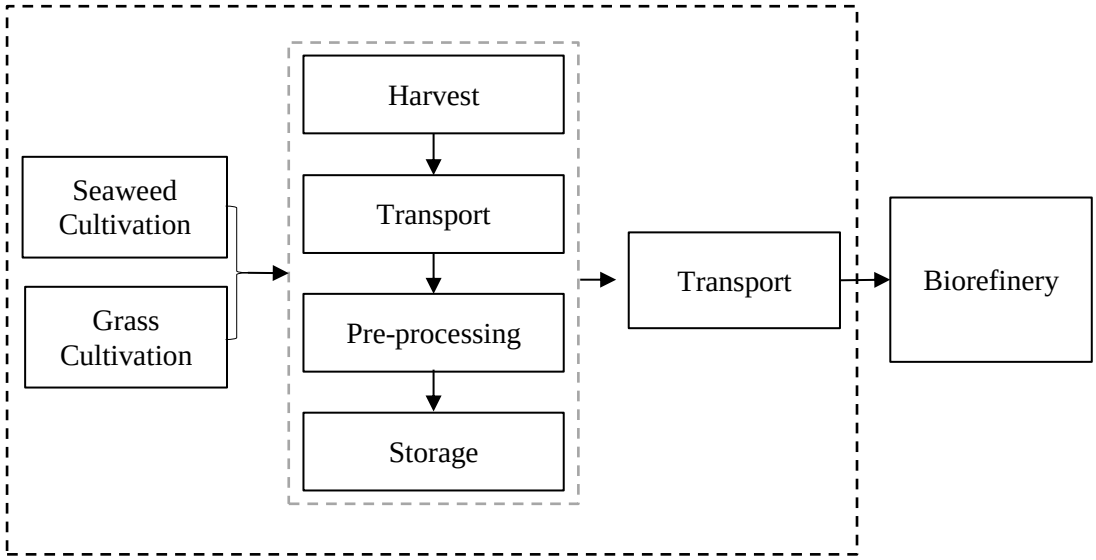

Figure 1: Diagram of the supply chain process and definition of the system boundaries

Based on the findings of the first stage, the second phase of the research will include the development of the supply chain management framework. Supply chain management is an interdisciplinary field, being broadly recognised by its value on firm's performance, but more recent approaches involving the integration of processes and more holistic thinking are becoming more important (Sweeney *et al.* 2015). Such an approach will be adopted, in association with non-linear production models based on concepts of the circular economy, such as reverse logistics and industrial symbiosis.

The two-phase approach is based on soft system thinking where the analysis of such complex systems needs to be understood in depth. First asking the "what's", "who's" and "why's" before searching for the "how". For example, what are the problems and constraints? who are the stakeholders? why it does not work? And finally, how it can be improved, be more

efficient, solved (Mingers and White 2010; Reisman and Oral 2005). The best methods to be applied are still in defining stages and dependent on the specificity of the research questions.

Expected outcomes

Biorefineries based on hybrid anaerobic digestion systems, represent innovative pathways to convert biomass to value-added products. However, the expansion of such biorefineries will depend on numerous factors, including, but not only, efficient supply chain management strategies, which account for feedstocks sourced as economically viable, environmentally sound and in socially responsible manners; new government incentives; and a high degree of cooperation among stakeholders. Sustainability gained a central role in the supply chain context (Moreno-Camacho *et al.* 2019) and applies at the same time to the origin of biomass sources, as well as to the biorefinery sustainability performance. It is worth mentioning that the validity of sustainable feedstocks depends on the analysis of complex systems, often involving a variety of trade-offs, which are not only ecological but also economic and social (Binder *et al.* 2010).

Furthermore, the use of non-food biomass does not mean a distancing of the agricultural fam but rather an opportunity in identifying and sharing unvalued resources. This will demand the active participation of actors from coastal and rural areas, displaying their vital importance in the development of a sustainable bioeconomy. Thinking in an integrative manner, upscaling the supply of such seaweed and grass-silage feedstocks could increase employment rates in rural areas and also help farmers and aquafarmers to diversify the sources of their revenues (EC 2018). Nevertheless, the identification of barriers, trade-offs and to avoid unwanted impacts and conflicts must be considered in designing biorefinery supply chains. The design relies on the strategic level, foreseeing long-term impacts, which will be fundamental in determining the planning activities and later on operational decisions regarding daily activities of the production process (Chopra, Sunil & Meindl 2016). Such integrative perspective is rather rare in the mainstream research of supply chain designs (Correll *et al.* 2014) and this study seeks to advance in adopting such systemic approach, where technical, environmental, and socio-economic aspects are holistically taking into account in biorefineries supply chains.

Conclusions

It is expected that efficient supply chain management strategies for grass and seaweed-silage biofeedstock embrace a systemic perspective and contribute to innovative technologies so that the highest value of such biomasses are transformed into more ecological and socio-economically beneficial products.

Acknowledgements

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LIFE CYCLE ASSESSMENT OF A GRASS-SILAGE FED BIOREFINERY AND A BIOCHAR PRODUCTION FACILITY

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Abstract

The increase in food production due to global population growth is leading to a rise in agriculture's contribution to total global greenhouse gas (GHG) emissions. Cattle farming contributes the majority of emissions to the agriculture industry due to the emission of gases such as methane (CH_4) and nitrous oxide (NO_x) arising from grass cultivation and enteric fermentation. The Farm4More project works on decreasing these emissions by developing novel feeding strategies that simultaneously maximise animal performance. To achieve this objective, two products are currently being developed, these are; biochar for decreasing CH_4 emissions, and a grass-silage press-cake which decreases nitrogen (N) and phosphorus (P) emissions. Production of these two feed additives is energy intensive. Therefore, it is necessary to assess the environmental impacts of both products a through the application of an international standard life cycle assessment (LCA). The initial stage of this LCA study has being defined by stating its goal and scope. The goal is to evaluate the GHG emissions reductions of each product and the scope is from the acquisition of raw materials to the product's end use.

Introduction

The exponential increase in the world's population will cause global protein demand to duplicate by 2050 (Henchion et al., 2017). An increase in food production will be needed to satisfy this demand while increasing agricultural environmental impacts. A hotspot for these impacts are cattle emissions that currently represent 15% of global GHG emissions (Gerber et at., 2013). Emissions from this sector arise from grass cultivation, enteric fermentation, and manure emissions. The EU LIFE Farm4More project looks into developing animal feed strategies that decrease these emissions while maximising animal performance. For such purpose, two products are being developed, a biochar feed additive that reduces CH_4 emissions, and grass-silage press-cake for reducing N and P emissions. Biochar is a form of charcoal that is a by-product of burning wood waste in the absence of oxygen (Kloss et al., 2012). Due to its surface area, biochar captures CH_4 produced in the rumen when being fed to cattle (Winders et al., 2019). This is of particular environmental interest since cattle's enteric fermentation releases large CH_4 quantities which on a CO_2-equivalents basis are of 3.1 Gt per year (Gerber et al., 2013). The Farm4More project looks into producing low-cost biochar that reduces CH_4 emissions while being fed in small dosages. The production of grass-silage in Ireland is widely used due to the grass surplus during the summer which can be used during the winter when cattle is kept in-house (McEniry et al., 2013). Nevertheless, the N and P concentrations of this feed are considerably higher than the ones that cattle can digest. Due to this N and P surplus, cattle emits considerable amounts of nitrous oxide, ammonia, nitrate, and phosphate to the environment (Einarsson et al., 2017). In order to reduce these emissions while maintaining the nutritional value needed on cattle's diet, the Farm4More project is developing a novel biorefinery processing technology that reduces the concentration of N and P in grass-silage.

Both the biochar and the low N and P grass-silage production require energy intensive processing technologies. Therefore, although CH_4 emissions are reduced as well as N and P, there are emissions arising from the processing of these novel animal feeds which need to be taken into consideration. The balance which will dictate the real mitigation potential of the Farm4More products will be calculated through a LCA to be performed over the whole life cycle of the products. **The objective of this initial report is to describe each of the Farm4More processing technologies and define the goal and scope of the LCA to be performed.**

Materials and Methods

The methodology of this LCA will follow the international standards for this type of study. Such standards for an LCA have been granted by the International Organization for Standardization through the 14040:2006 and 14044:2006 documents. On these standards, LCAs are divided into four stages, these are 1.) Goal and scope, 2.) Life Cycle Inventory, 3.) Life Cycle Impact Assessment and 4.) Interpretation.

Description of the system studied

Farm4More will investigate two technologies which aim to maximise animal performance while decreasing GHG. These technologies include an organic grass-silage fed green-biorefinery which will produce organic animal protein feeds and a biochar production facility which will produce an animal feed additive.

Grass-silage press-cake production:

In the case of the grass-silage press-cake production, Farm4More's green-biorefinery focuses on producing a sustainable low-cost organic animal feed. This is expected to be accomplished by coupling biomass pre-treatments with simple processing. As seen in Figure 1, the system is divided into three parts, 1.) biomass production 2.) biomass processing and 3.) product end use.

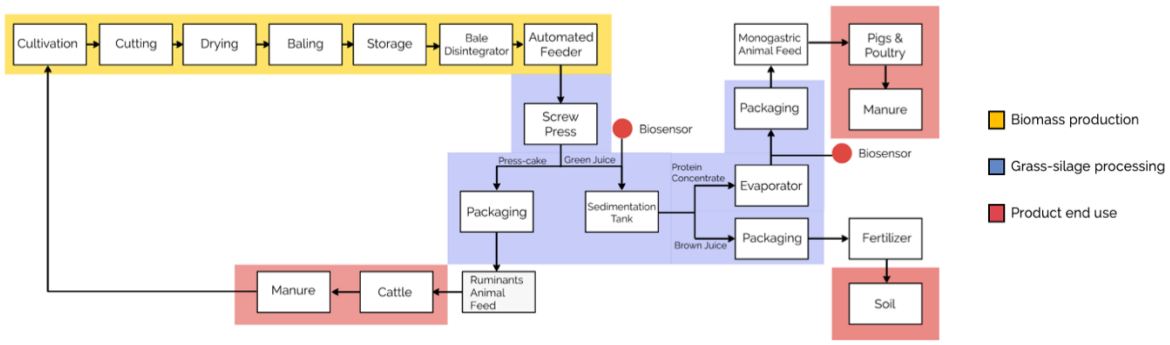

Figure 1: Grass-silage-fed biorefinery flow sheet

1) Biomass production: Grass-silage high availability and preserved quality make it an ideal substrate for the Farm4More biorefinery process. In conventional beef and dairy farming, circa. 25% of a farm's grassland areas is set aside for ensiling. The production of grass-silage by ensiling ensures that sufficient fodder is made available to cattle for the winter months (McEniry et al., 2013). The potential to preserve grass means that cattle production can be maintained all year round, which has the same implications for a green-biorefinery deployment. Running a green-biorefinery all year round as opposed to a seasonal basis, means that the operation time of the unit is maximised, while plant size and thus costs are minimised.

The type of grass used needs to be decided, based on many factors which include; protein content, dry matter digestibility, soil requirements, and nutrients content. After cutting, the grass is left from a couple of hours to a day to dry in order to reduce the moisture content. To finish this stage of the process, a baling tractor is used to produce one-ton bales wrapped in polythene sheets. Bales are stored for approximately six months and then opened by a bale disintegrator, followed by an automated feeder that takes the grass silage to the next stage, processing. The LCA performed will assess the environmental impacts associated with each of the production stages by taking into consideration the data listed below.

2) Grass-silage processing: A screw press is used to isolate the precipitated proteins in a liquid fraction called "green-juice", while the remaining solid fraction is called "press-cake". The latter, due to a protein content that is mostly fibre associated as well as due to lower concentrations of N and P,

is ideal to maximise ruminant's performance while mitigating climate change. In the case of the green juice, it undergoes further processing through a sedimentation tank and an evaporator in order to isolate the amino-acids and produce a high-content protein powder suitable for replacing the high carbon-footprint soybean meal that is currently used in monogasts' diet. The LCA applied will consider the environmental impacts of this stage which mainly include GHG emissions associated with the machinery used and to transportation.

3) Product end use: At this stage, both products are packaged under conditions that decrease deterioration. The monogastric animal feed product will be shipped locally, nationally and internationally depending on the end user's location, while the press-cake product will be fed to ruminants locally. Animal feeding trials will be conducted for both products, to assess the reductions in emissions that can be achieved. The LCA of this stage will verify these reductions which are mainly associated to N and P.

Biochar production facility:

In the biochar case, The focus of the Farm4More project is to develop an affordable way of producing biochar so as to ensure commercial viability. This cost decrease will be attained by developing a simplified process which still produces high-quality biochar. In addition, the unit is expected to be small enough so that it can fit into a container and be deployed. The process can be split into three parts as seen in figure 2, these are 1.) biomass pre-treatment, 2.) biomass processing, and 3.) product end use.

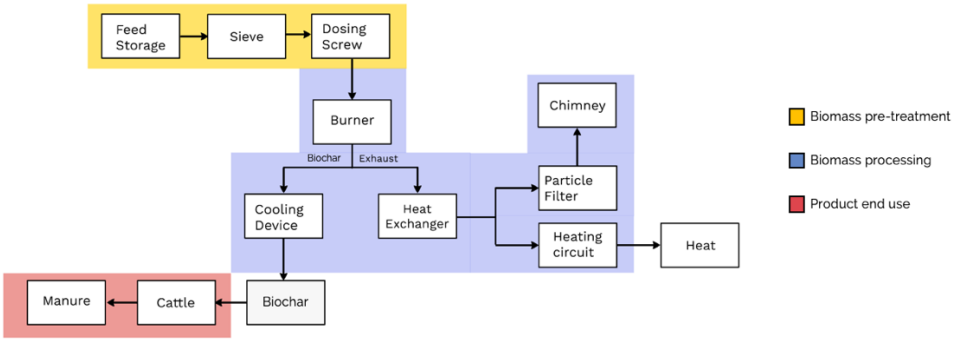

Figure 2: Biochar production flow sheet

1) Biomass pre-treatment: The feedstock of the biochar production unit includes but is not limited to wood chips, husk, straw, and sawdust. Before processing it, the feedstock undergoes a sieving pre-treatment in order to regulate the burning stage. It is then fed to the burner through a drying screw. Since the feedstock used is agricultural waste, the LCA performed is expected to demonstrate that the environmental impacts associated with its production are minimal.

2) Biomass processing: As mentioned previously, pyrolysis is the chemical process used in order to produce biochar (Kloss et al., 2012). In this process, feedstock is burnt at high temperatures and in the absence of oxygen. The resulting solids rapidly undergo a cooling stage and biochar is produced. This system requires extensive amounts of energy which contribute significantly to the environmental impacts of the process. The simplistic design of Farm4More's novel biochar technology will minimize its energy demand while maintaining biochar quality. LCA will be applied, so as to verify the reduction in GHGs that this technology can affect.

3) Product end use: The biochar will be then packaged and shipped to end users as an animal feed additive. Animal feeding trials will be conducted to identify the dosages of biochar required to maximise animal performance and effect GHG emission reductions. The outputs of the feeding trials will be used as input data in the LCA.

Goal and scope

The findings of this study will be used to demonstrate how reductions in GHG emissions will be achieved by implementing Farm4More's animal protein-production technologies, strategies and methods. This study is expected to be used by Farm4More stakeholders in order to identify opportunities for mitigating the environmental impacts of the protein-production model. The results of this study will be disseminated at a local, national and international level through the channels being developed by Farm4More's stakeholders, which include international associations, policy actors and industrial partners.

In the case of the biorefinery, the function of it is to develop an animal feed that maximises animal performance while decreasing GHG emissions for both ruminants and monogasts. For the biochar production facility, the function of the system is to produce economically viable biochar that can be commercialised as an animal feed additive that reduces GHG emissions from cattle. The functional unit to be used for both studies will be kilograms of protein in the product. Due to the reduction in GHG emissions occurring after the products are used, the system boundary of this study will be of a cradle-to-grave approach.

Conclusion

Cattle farming emissions contribute approximately 15% towards global GHG emissions. This share is rising due to increasing food production. The Farm4More project is developing animal feed-additives that reduce these emissions while increasing cattle's productivity. A LCA is being performed over the production of these additives with the purpose of quantifying its positive and negative environmental impacts. For such, the first stage of the LCA has being defined in this report, which includes the goal and scope of the project. The goal has being defined as to prove the GHG mitigation potential of the Farm4More products. The scope is from the acquisition of raw material to the products end use. With this initial stage of the project being defined, the upcoming stages which include data collection and interpretation will be performed in a more accurate way.

Acknowledgments

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DEVELOPMENT OF A WHOLE CELL EXCLUSION BIOSENSOR WHICH IS ABLE TO DETECT BUTYRIC ACID

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Abstract

The quality of grass silage leachates produced by a novel grass silage fed dry-batch reactor depend on the quality of the input substrate used. High quality grass-silage will have low butyric acid and high lactic acid concentrations. Leachate quality will depend on the lactic acid -butyric acid ratio where by high quality leachates will be redirected to a biorefinery where high value products will be produced; while poor quality leachates will be redirected to an anaerobic digestor where lower value biogas will be produced. The speed and accuracy with which sensory data can be obtained and deduced with regards to the output stream will ensure that correct and efficient redirection, will be applied. To this end, the development of a whole cell biological sensor that can accurately and rapidly detect butyric- and lactic-acid concentration in the leachate stream from a grass silage fed dry-batch reactor was investigated.

Introduction

There is a need for a paradigm shift in the use of our resources and waste. Currently biorefineries are used to convert biomass into higher value products, such as lactic acid, amino acids, and carbohydrates. This research is part of the UCD led MSCA-ITN AgRefineproject, which aims to produce a novel three phase bioreactor (TPB) which will be able to convert grass or seaweed into high to low value products such amino acids, lactic acids, bio-succinic acid and biogas, depending on the quality of the input substrate, supplied. The TPB's first phase bioreactor will process the grass or seaweed silage to produce green juices/leachates. The quality of these leachates needs to be determined in real time to ensure correct redirection to a number of potential downstream processes. These downstream processes include a 2nd phase bioreactor which produces biogas which is a lower value product, from poor quality leachates; a 3rd phase bioreactor which produces high value products such as amino acid, lactic acid and carbohydrates from high quality leachates; and a novel bio-succinic acid production process which requires good quality leachates. Leachate quality depends on the ratio of butyric acid and lactic acid and needs to be monitored continuously. Hence, this project aims to produce an upstream online monitoring system necessary to ensure that the TPB is operated optimally, this monitoring system is able to detect either butyric acid or lactic acid with the exclusion of all other carbohydrates and fatty acids present in the leachate.

The objective of this project is to develop whole cell exclusion biosensors which will provide real time sensory data of the chemical composition of bioreactor produced output streams

The proposed whole cell exclusion biosensors will be based on the biosensors developed by Sweeney *et al.* (2015). The biosensors developed by Sweeney *et al.* (2018) are able to detect ethanol, acetic-, propionic, L-lactic and formic-acid. These biosensors are made of two parts, one parts consists of an immobilised microorganism which can solely catabolise one of the afore mentioned metabolites, the second part consist of a dissolved oxygen probe which detects the concentration specific oxygen consumption resulting from the catabolism of the afore mentioned metabolites. The biosensors in this study need to be able to detect D-lactic- L-lactic- and butyric

acid, therefore *E. coli* based biosensor strains need to be engineered to be able to metabolise D-lactic- L-lactic- and butyric-acids as sole carbon sources, respectively. Lactate dehydrogenase is an enzyme which converts lactic acid to pyruvate. *E. coli* possesses numerous lactic dehydrogenases with LldD being L-lactic acid specific however, the *E. coli* strain's D-lactic acid dehydrogenase can also accept L-lactic acid as substrate Sweeney *et al.* (2018) which means that a D-lactic acid specific lactate dehydrogenase is being screened for. A successfully screened D-lactic acid specific lactate dehydrogenase will then be cloned into the microbial strain used in this study, afterwards this strain will be tested for its performance.

The *E. coli* strain used in this study is unable to metabolise butyric acid as sole carbon source, however, all enzymes needed to catabolise butyrate are all present. These enzymes are expressed from a single operon which is not activated when growing on butyric acid as sole carbon source. Hence, the repressors of this operon will be deleted to enable expression when growing on butyric acid as sole carbon source. Additionally, the native promotor will be replaced by a strong constitutive promotor to ensure sufficient expression, afterwards the engineered strain will be tested for its performance.

Materials and Methods

Microbial strains and strain construction

Numerous microorganisms will be scanned for their ability to utilise butyrate and D-lactate as their sole carbon source. Potential genes will be transferred to an engineered microbial strain by using a CRISPR-Cas9 method adapted from Jiang *et al.* (2015). Two microorganisms which have a specific D-lactate dehydrogenase have been found, but only enzymes with high enough rate of reaction will be implemented in the genetically engineered microbial strain.

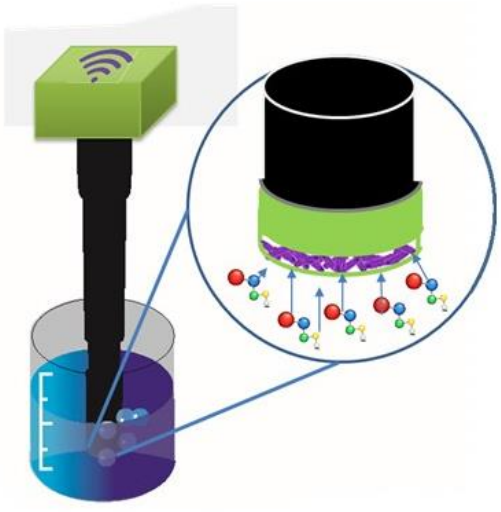

Figure 1: Schematic presentation of a BOD biosensor.

Construction of the biological sensor

The design developed by Sweeney *et al.* (2015) which was adapted from Liu and Mattiasson (2002) will be used to construct the *E. coli* based biological sensors for this study (Fig. 1). These biological sensors will detect the oxygen consumption when the engineered microbial strains

oxidise either butyrate or D-lactate. The performance of the sensors will be analysed by correlating the oxygen data with the concentration of either butyrate or D-lactate, successful sensors will be able to detect a significant change in oxygen concentration at relative low concentrations of either butyrate or D-lactate.

Results and Discussion

Experiments are still in their initial setup phase but there is correlation expected between the oxygen consumption of the engineered strain Vs time slopes and the specific butyrate and lactate concentrations. Two D-lactic acid specific lactate dehydrogenase were found which have a sufficient protein sequence homology with the microbial strain used in this study for genetic integration.

Conclusion

It is evident that there is still a lot of research needed to develop a biosensor which is able provide real time sensory data of the chemical composition of the streams exiting the third phase of the three phase biorefinery. However, the provision of this biosensor will ensure the online quality control of the lactic acid production.

Acknowledgements

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Léa Braud, M.Eng.Sc.

Project Title: Environmental Life Cycle Assessment of Phycocyanin Production from *Spirulina* in a Concept of Biorefinery

Project Leader: Dr. Fionnuala Murphy

Abstract

Life Cycle Assessment (LCA) has been used for more than 15 years to assess environmental impacts of algae systems. However, only a few studies have investigated the effect of seasonal variations on LCA results. Temporal distributions of biogenic carbon (C_{bio}) flows and greenhouse gas (GHG) emissions are often ignored in inventory data. Therefore, this study evaluates whether temporal variations of C_{bio} flows and GHG emissions affect the environmental benefits of algal biorefineries in the frame of the SpiralG (BBI, H2020) project.

The newly built SpiralG biorefinery will be the first capable of producing 10 metric tons of phycocyanin per year from European produced *Spirulina* biomass. An LCA study will be conducted from cradle-to-grave to identify the process steps responsible for the greatest environmental impacts. A comprehensive, transparent, and reproducible Life Cycle Inventory (LCI) methodology based on the Brightway2 LCA framework will be developed to account for algae system dynamics. C_{bio} flows and GHG emissions temporalities will be defined for relevant system processes and used to conduct a dynamic LCA of the SpiralG biorefinery. Finally, static and dynamic LCA results will be compared to evaluate the effect of temporalities on the environmental impacts of phycocyanin production.

The analysis of the data collected in the *Spirulina* cultivation and processing plant to-date has shown that nutrient use and biomass drying are responsible for the greatest environmental impacts of the static system. These impacts could be reduced by using heat from anaerobic digestion plants and effluents as nutrient source. Considering temporal variations is challenging due to the estimation of C_{bio} flows and GHG emissions timing as well as the selection of relevant processes to include temporal distributions and appropriate time resolutions. In addition, C_{bio} flow modelling depends on the end-of-life of the algae-based products. In the case of the SpiralG biorefinery, phycocyanin will mainly be used as natural blue pigment to replace synthetic dyes in food products and as antioxidant in cosmetics. In addition, the main co-products, i.e proteins and carbohydrates, will be transformed into feed and agricultural products.

To conclude, this research addresses the need to consider temporal information in inventory data over the complete life cycle of phycocyanin production.

Ciara Beausang, BSc, MSc

Project Title: The Consequences of Implementing Anaerobic Digestion of Agricultural Feedstocks in Ireland: An Environmental Assessment

Supervisor: Dr Fionnuala Murphy

Abstract

Assessing the sustainability of agricultural feedstocks is very timely given the expected uptake of anaerobic digestion (AD) in Ireland in the coming years. AD is viewed as a potential mitigation strategy to reduce greenhouse gas emissions in both the energy and agriculture sectors. However, the interactions between these sectors and emissions must be considered carefully. The overall objective of this research is to examine the environmental impacts of using agricultural feedstocks in AD in Ireland. Consequential life cycle assessment will be used to provide a prospective approach to investigate potential unintended consequences of diverting the use of feedstocks from conventional systems. The environmental consequences of using poultry litter in AD in Co. Monaghan will be assessed. Poultry production is highly concentrated in Co. Monaghan, accounting for over half of the poultry produced nationally. The sustainability of biomethane produced from grass and manure in Co. Tipperary will be examined. The most significant resource for biogas production in Ireland is grass silage and manure. The potential of AD for sustainable food production in horticulture in Dublin will be determined. This study will seek to optimise all outputs from the AD system to provide a sustainable means of food production. The effectiveness of consequential life cycle assessment as a tool to inform policy will be reviewed. This research is potentially very valuable to a variety of stakeholders including policymakers and researchers in energy, climate and food sustainability.

Selected Recent Publications

Beausang, C., McDonnell, K., Murphy, F. (2020) ‘Anaerobic digestion of poultry litter – A consequential life cycle assessment’. *Science of the Total Environment*, 735, 139494

John Walsh, BE, M.EngSc., MBA

Title: Developing a national energy policy to enable a sustainable bio-energy industry in Ireland

Project Leader: Prof. Shane Ward

Abstract

Access to low cost, sustainable and reliable forms of energy is fundamental to Ireland's economic competitiveness and social well-being. To address the challenge that climate change poses, the EU and Ireland have committed to transition their energy systems to one that produces net zero carbon emissions before 2050. As a form of energy, bioenergy uniquely offers a broad range of social, economic and sustainability benefits however it has a complex supply chain and its use needs to be tightly regulated. To successfully leverage the broad range of social, economic and sustainability benefits that bioenergy offers will require the design and development of a comprehensive national energy policy.

The objective of the study is to: Research and assess the key technical, policy, and commercial drivers that will enable the successful development of a sustainable bioenergy industry in Ireland. To review the key policies that enable renewable energy technologies. To develop the optimum policy package and instruments to develop a sustainable bioenergy industry in Ireland in the three key energy modes of transportation, heating and electricity generation.

A literature review of Irish and international journals has been carried out. A techno-economic model of the Irish energy system has been developed to assess the potential for bioenergy in the transition to a zero -carbon energy system. This model is being used to assess potential pathways to 2050 and the effect that the design of energy policy will have on the future energy system. To evaluate and assess the effect that energy policy design will have on the bioenergy industry a supply chain market model has also been developed. An analytical framework has been developed to integrate the output from the two models. The framework is being used to evaluate and assess interdependencies and trade-offs between different policy tools and designs in order to develop a policy framework that optimizes the potential social, economic and sustainability benefits from the bioenergy industry in Ireland.

Bioenergy has the potential to be the cornerstone of a sustainable low carbon energy system for the transport and heating sectors, but careful policy design needs to be considered so that in the long term its use is carefully targeted. Policy instruments need to evolve quickly to facilitate the transformation of the energy system to meet it carbon reduction roadmap, in many case new policy instruments will be required. Bioenergy carbon capture and storage offer the potential for negative emissions but will require a new package of energy policies and instruments. Policy uncertainty is currently limiting investment in bioenergy and the industry is not developing to meet its potential. BECCS offers the potential to generate significant negative emissions and to extend the horizon to sustainably use biomass in the electricity generation sector.

IRELAND'S GEOTHERMAL POTENTIAL: A FEASIBILITY STUDY OF A SUSTAINABLE BUSINESS NETWORK

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Abstract

Geothermal energy is a renewable and clean resource, available at varying depths all over the world. Ireland has shallow reserves, that are relatively unexploited. The hypothesis that utilising a geothermal reserve to heat, and/or power a corporate network could be economically and environmentally sustainable is addressed through a feasibility study and environmental model. Potential ventures that may utilise such a facility include vertical farms, biofuel research and company expansion. Existing literature suggests the most suitable location would be that of an urbanised area in rural Ireland, with a geothermal reservoir of a relatively high heat grade.

Introduction

Ireland is currently undergoing an "energy transition", in order to meet environmental targets in 2030, and to achieve a low carbon energy network in 2050 (DCCAE 2015). With these increasing pressures from European policy, sustainable business has never been so pertinent.

Geothermal energy is generated beneath the Earth's surface as radioactive isotopes decay, and the heat is unevenly distributed (Olasolo *et al.* 2016). This can be loosely categorized as shallow, deep and intermediate. Certain depths are better suited to different technologies and carry greater energy efficiency at higher temperatures, however, even low enthalpy heat can be converted into electricity with the correct infrastructure and planning (Delhaye *et al.* 2019). At present, shallow reserves are widely utilized in Ireland in the form of ground source heat pumps, for residential temperature regulation purposes only (Pasquali *et al.* 2019), and under European Union climate and energy policy, geothermal is recognised as a "safe, reliable and environmentally benign" renewable energy source (Dumas 2015).

Previously, large scale geothermal heating and power generation projects in Ireland been characterized by their requirement for large capital investments, high risk levels associated with environmental disruptions and their tendency to produce negligible amounts of energy compared to other renewable energy systems (ŚwiĄtek 2020). However, taking a cyclical approach, and creating sustainably controlled environments for otherwise energy intensive projects could present the potential for a corporate network, where participating businesses can invest and work towards a carbon neutral energy supply. Heating and energy demands must be considered in order to assess feasibility, as shallow grade heat reserves require a cascade system in order to provide district heating and electrical generation, which is that of integrating different stages of technologies specific to heat and power applications (Rubio-Maya *et al.* 2015). Implementation of such a system also offers the opportunity to improve resource recovery and provide waste water treatment through reinjection, which is often considered a defining factor in the success or failure of a geothermal power development (Rivera Diaz *et al.* 2016).

The objective of this study is to assess the feasibility of a geothermal plant at a suitable location facilitating heat and/or power for a corporate network.

Methods

Data Collection

A literature review was carried out in order to conduct secondary research to assess the current and previous insights into the hypothetical issue being posed, that is, would such a geothermal facility be feasible in Ireland. This information will then shape the nature of the empirical research to be carried out. Data required for empirical analysis will be sourced online, from peer-reviewed journals, public databases such as geologic records available from SEAI and environmental information from local county councils.

Technical Methods
MATLAB will be used to create the model, with large amounts of data being collated on Microsoft Excel. The model will take into account: Reservoir depth, heat grade and heat flux, and data available on SEAI website. Feasibility analysis will pose the following hypotheses: A form of geothermal facility can power a corporate network, and that a cascade system would be possible to implement, where a reserve is exploited for both electricity and district heating. MATLAB can be used to carried out statistical evaluation of this, and to address the environmental impacts of the development (Lindfield and Penny 2012). Comparisons may be carried out between statistics of existing facilities with similar applications.

Results and Discussion

In order to consider the feasibility, a literature review is an important tool to investigate previous research on the topic. Various technologies must be studied in order to conclude the most suitable for the proposed geothermal facility. The demand is the most important aspect of design, as this will influence the scale and nature of the system (Rubio-Maya *et al.* 2015).

Food Production
Given current population projections, the demand for food is set to increase by up to 70% over the next 50 years. This demand, accompanied with climate change, will revolutionise food supply chains and innovate food production approaches (Specht *et al.* 2019). Vertical farming is the practice growing of crops in an enclosed, controlled environment (Al-Chalabi 2015), and the sustainable nature of geothermal heat presents as an ideal site for such a venture. As overfishing threatens marine ecosystems, aquaculture is another growing industry which also requires highly controlled conditions that may be accommodated by a geothermal resource (ŚwiĄtek 2020).

Research
Companies and academic institutions that require specific facilities, such as those associated micro-algae production for biofuel extraction, may make use of a controlled environment with temperature moderated by geothermal heat. Algae derived diesel is an efficient alternative to fossil fuels, requiring less land and having strong carbon capturing properties (Carneiro *et al.* 2017). The most prominent challenge to microalgal growth is maintaining water temperatures above 15^{o}C, therefore large scale commercial operations are generally restricted to areas with year round warm conditions (Shang *et al.* 2010).

Irish and Multinational expansion
Start-ups with a focus on sustainability, or existing Irish companies that strive to improve their carbon output may find a geothermal facility would be an attractive alternative to fossil fuel use, and provide a corporate base outside of city centres. Multi nationals may also be drawn to this aspect. Many companies aspire to the CDP A-list, a carbon disclosure project that scores companies based on their environmental disclosure effort. This grade has influence on internal external financial decisions that are to be considered “carbon responsible” (Andrew and Cortese 2011).

Best Available Techniques
Best Available Techniques or BAT, is a standard adopted to reduce environmental impact. From initial review of the literature, an effective model is that of Altheim, in Austria, where implementation of the Organic Rankine Cycle provides 1,000 kW of electrical power, from a reserve of 106^{o}C that is 2300 m deep (similar to Irish conditions) while simultaneously providing district heating to public

amenities and 650 residences. (Rovira *et al.* 2020). Fluid is reinjected at 65^0C, through a two phase low enthalpy system, minimising wastes produced and contributing to the cyclical nature of the plant (Rivera Diaz *et al.* 2016).

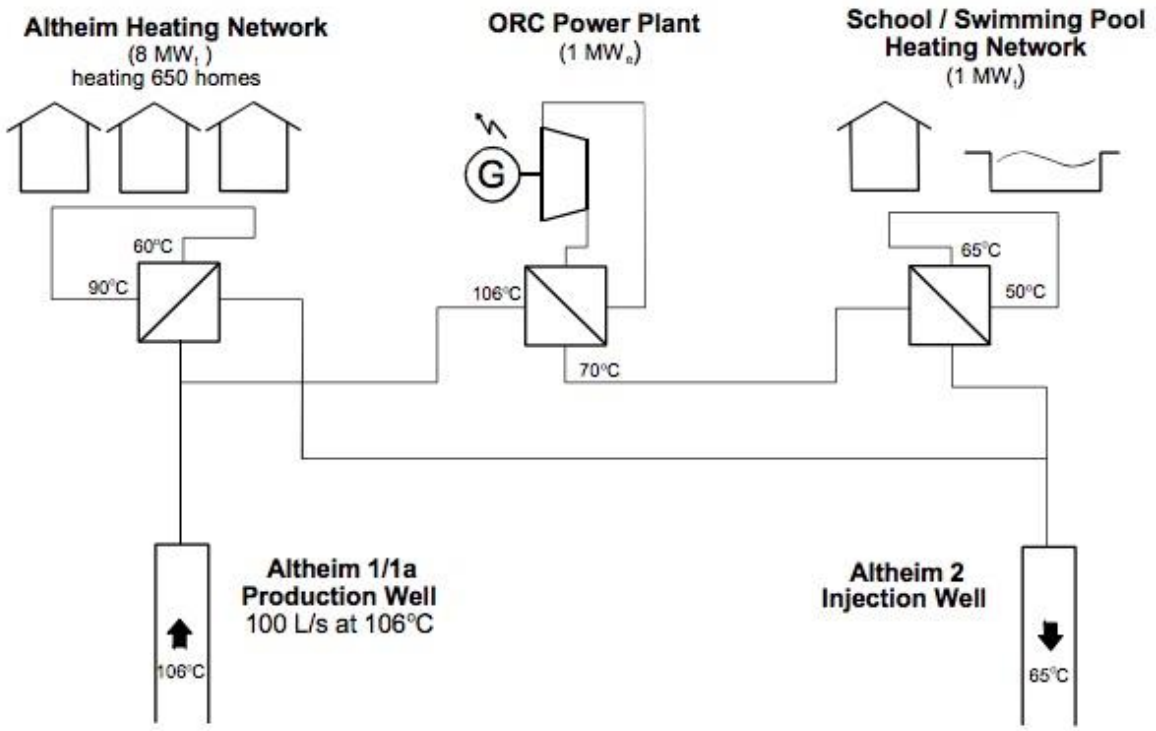

Figure 1. Schematic of ORC plant in Altheim, Austria (Rubio-Maya et al. 2015).

Fig 1 illustrates the distribution of energy, temperature requirements and demands of the community in Altheim. A similar model can be conceptualised for the business network, where the energy is separated between heating purposes for buildings, controlled environments, and power generation.

Conclusion

The most relevant users of the facility are start-up companies with a focus on sustainability, centres of research and existing businesses interested in investing in a carbon neutral future. The secondary research conducted through the literature review has indicated an ideal location would have a geothermal reservoir with a relatively high heat grade and located near an urbanised area of rural Ireland, as to minimize environmental impacts of the development. Similar environmental studies show that power generation of up to 1,000 kWt is possible using ORC technologies in a cascade system. The proposed development would reduce incidences of emigration from rural Ireland, increase socio-economic status of the area and provide a base for companies beyond cities. Further research may assess the economic feasibility for expansion, broadband access and residential development sizes.

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AGRI BIO CIRCULAR ECONOMY FOR GENERATING VALUE FROM WASTE: EMERGING TECHNOLOGIES

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Abstract

Conversion of biomass into high density fuels has received much attention since last two decade. The availability of biomass and EU Greenhouse Gas Emission Targets has encouraged Agri Bio Circular Economy (ABC) to generate value from waste using technologies such as incineration, gasification, and pyrolysis. This study focuses on analysis of emerging technologies such as hydrothermal carbonisation and microwave induced pyrolysis that will assist the ABC Economy in determining the best options for generating energy from biomass. This research assesses the economic, operational, and environmental feasibility of these technologies and their compatibility with respect to the biomass available counties Tipperary and Monaghan, Ireland.

Introduction

Increasing demand for energy and shortage of fossil fuels can be compensated by introducing technologies abiding circular economy principles (European Commission, 2018). There is a major challenge in energy and agriculture sector of greenhouse gas (GHG) emission reduction. Ireland is committed under European Union (EU) Renewable Directive 2009/28/EC, to increase contribution of energy by renewable energy source of 40% in electricity generation, 12% in heat production and 10% in transport sector by 2020 (Department of Communications, Climate Action & Environment, 2020). Furthermore, Ireland must deliver a 20% reduction in non-emissions trading systems (ETS) GHG emissions by 2020, relative to 2005 levels (Department of Communications, Climate Change & Environment, 2020*).* Ireland generates 5 million tons of agricultural waste (Taffese *et al.* 2008) and 10% of all food waste is generated during primary production (Carl Jensen *et al.* 2016). There exists a significant opportunity to harness this biomass to build a sustainable circular bioeconomy system which can be used to generate valuable fuel to contribute to achievement of the GHG emission reduction targets. Gasification and pyrolysis are the most common technologies adopted for biomass waste treatment (Paulina *et.al* 2020). Incineration requires proper process control otherwise it may lead to emission of hazardous compounds like furans and dioxins (Green Tumble 2018). Although gasification is the most widely used technology for thermal treatment of biomass, the operating energy, cost, and the capital cost involved prove to be a challenging option for large scale gasification plants (Kerester, 2014).

The preceding decades witnessed hydrothermal processes being actively implemented all over the globe, specifically in the developed regions (Sabzoi Nizamuddin *et.al* 2017). Their optimum usage is primarily for converting biomass into valuable solid, liquid, and gaseous fuels (Sabzoi Nizamuddin *et.al* 2017). The production and quality of fuels from HTC depends upon several parameters like temperature, feed type (biomass), residence time, pressure, and catalyst. In Microwave Induced Pyrolysis (MIP) treatment of biomass is carried out with the electromagnetic radiation induced by microwave using convection principle where the heating is due to absorption of electromagnetic waves which causes an increase in temperature within the molecules of biomass (Sabzoi Nizamuddin *et al* 2018). Pyrolysis processes can be initiated at relatively lower temperatures by microwave heating (200–300°C) (Zhang *et.al* 2017b).

The objective of this study is to assess environment, economic, and operational feasibility of HTC and microwave induced pyrolysis on biomass available in counties Tipperary and Monaghan.

2. Methodology and Materials

2.1 Methodology

The methodology implemented this project is shown in Figure 1. The flow diagram represents the steps for proposal of emerging technologies for the Agri Bio Circular (ABC) Economy project. Literature for waste into energy were searched on 'One search' of UCD library and 'Google Scholar' searches like upcoming technologies for waste into energy, HTC technology for dry and wet biomass, Microwave Induced Pyrolysis were searched, and details were added in this report. Refined searches from international journals and research articles related to waste to energy technologies are collected (mentioned in the reference list) and will be critically studied to determine the feasibility of both technologies along with their control parameters (temperature, pressure), types of catalyst, and susceptors (in case of MIP), reaction temperature, residence time and type of feed material. Compliances of local and international regulatory bodies for environment and energy like EPA, SEAI (Sustainable Energy Authority of Ireland), Department of Communications, Climate Change & Environment) with respect to the proposed technology will be studied in detail.

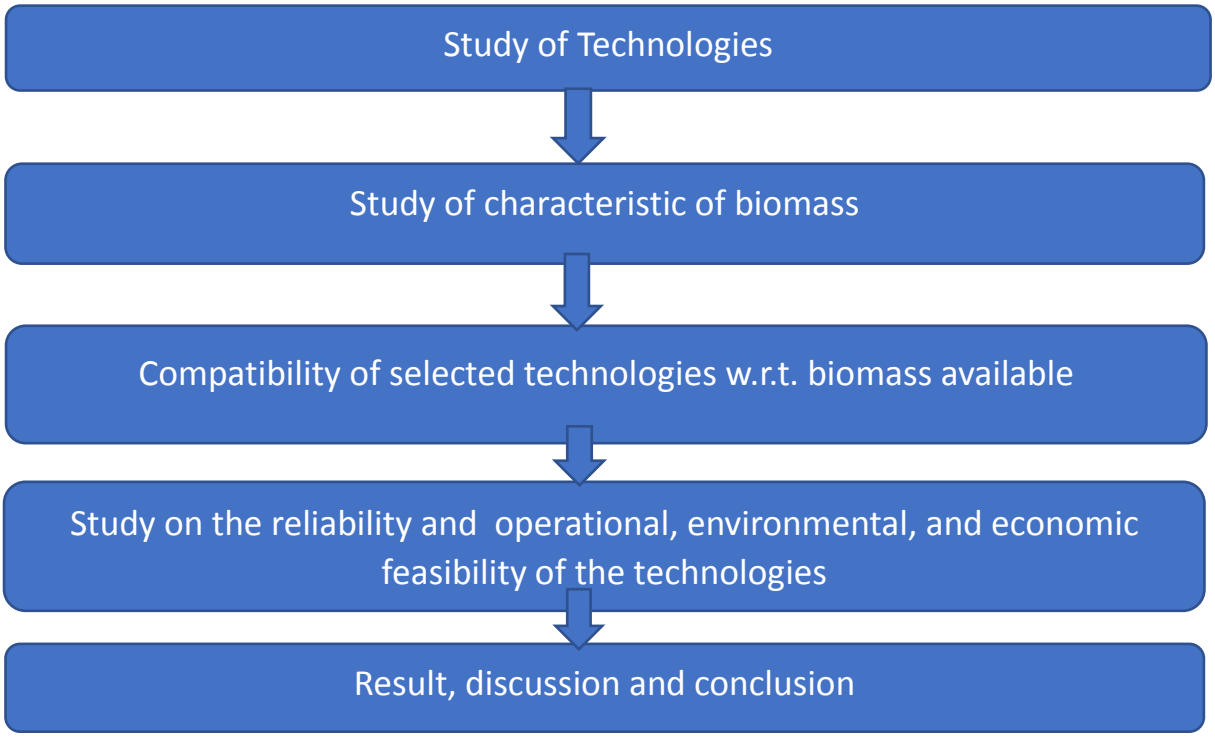

Fig 1: Flow chart of methodology

2.2 Materials and data collection

ABC Economy focuses on two counties: Monaghan and Tipperary. The data regarding biomass availability and their characteristics were obtained from project reports which included various sources like SEAI Bioenergy Map, EPA statistics, CSO and Phyllis . The biomass mainly includes tree branches and tip (diameter-7cm) of tree species like spruce, lodgepole, pine, conifers; agricultural waste of crops like wheat, barley, oat, rapeseed straw, mushroom offcuts and spent mushroom compost; animal livestock and poultry manure. Table: 1 represents the characteristic of feedstock from additional data sources.

Results and Discussion

Prediction of feasibility for the selected technologies

Hydrothermal carbonisation (HTC) and microwave induced pyrolysis (MIP) are the developing technologies which have the potential for optimum generation of energy from biomass. Energy

extensive process in HTC is eliminated which can reduce the power consumption also the char obtained holds the same quality of the conventional coal which make HTC feasible technology. The percentage of syngas obtained from MIP is 55.9% which is quite high compared to conventional pyrolysis which is 37.655 (J.A. Menéndez et.al 2013) also the contamination in liquid (oil) by-product and solid by-product (char) is lower than conventional pyrolysis (J.A. Menéndez et.al 2013). Since the reference study on the biomass from MIP and HTC study holds almost the same characteristics of the biomass selected for this thesis, it is expected that MIP treatment and HTC for the biomass at the selected counties of Tipperary and Monaghan will prove to be feasible options (environmental, economic and social) for providing high quality clean energy fuel at low operational and capital cost.

Conclusion

The research data on microwave pyrolysis of biomass has proven to be an effective, low-temperature route to valorise biomass in terms of solid and liquid fuels, and to produce valuable gas streams (notably hydrogen and syngas) as the studies aimed at a detailed description of the mechanisms of activation and interaction of microwaves with characteristic of biomass in the counties of Tipperary and Monaghan. One of the key difficulties will be comparing the research done on different technologies and under different operating conditions, as many variables are at play, and understanding how these will affect comparison of the pyrolysis of biomass (itself variable geographically and seasonally) and the analysis of the products (very complex and comprehensive) is a significant challenge. Therefore, both HTC and MIP have potential and are promising technologies for generating value from biomass. HTC is mostly influenced by the feedstock types as well as loading and processing conditions and can work efficiently at moderate temperature whereas, MIP appears as the most feasible of the thermochemical conversion techniques; capable of generating high temperatures with minimal energy.

Acknowledgement

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PRELIMINARY FINDINGS ON THE DISTRIBUTION OF LEAD IN DRINKING WATER IN EIGHT DIFFERENT WATER SUPPLY ZONES IN DUBLIN

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Abstract

The demand for clean drinking water is increasing with global development. Lead is a dangerous neurotoxin that can be dissolved in water. Many historic water supply networks contain lead fixtures, and insufficient water treatment can result in corrosive action, sometimes causing a lead crisis in certain supply catchments. This preliminary work explores the data available on measured lead levels of drinking water within different supply zones in Dublin obtained from the Irish water website (www.water.ie). At present, the accepted control methods in developed countries are maintaining aging infrastructure and monitoring legal lead levels in drinking water on regular intervals. According to European Union (Drinking Water) Regulations, 2000 (S.I. No. 439 of 2000), the acceptable lead level in drinking water is 10µg/L. Excess intake of lead has drastic health effects on a community, pregnant women and young children, the most vulnerable to exposure.

Introduction

Lead (Pb) is a dangerous contaminant of drinking water, being attributed to many negative health impacts when ingested. In fact, there is technically no "safe" level of lead exposure (Bellinger 2016). However, the EU Regulations and US EPA indicates that consumption of more than 10 µg/L in drinking water is dangerous for human (US EPA 2007). Contamination usually occurs from aging distribution infrastructure in use across the public water network (Docherty and Kariuki 2019). Other sources of contamination include paints, storage methods and contaminated soil, although these cases have reduced significantly in the developed world since the 1970s due to stricter legislation (Warniment et al. 2010). Under normal conditions, lead from infrastructure will not dissolve in water. However, the softer the water, the more likely lead is to bind with carbonates, and if there is a high pH compounds can become more soluble.
Laboratory practice for lead detection is generally based on atomic spectroscopy, whereas rapid on-site detection methods may employ calorimetric, biosensor based and/or electrochemical techniques but can yield less accurate results (Tang et al. 2018). Ion selective electrode technology can be used for detection and provides a fast, inexpensive, and accurate solution to be explored when considering the development of water screening (Tang et al. 2018). In Tasmania, a study was conducted where sources of contamination were identified using lead isotopic compositions, by matching these to isotopic analysis of samples of a contaminated water supply (Harvey et al. 2015). There are multiple health consequences associated with lead contamination. Consumption of lead is especially dangerous in pregnant women, leading to increased risk of miscarriage and stillbirth (Edwards 2014). Young children are also at risk, from congenital defects leading to high infant mortality rates (Dhimal et al. 2017). Areas of low socio-economic class and developing countries are most affected by these negative impacts (Kasozi et al. 2019). Despite the recognised risk associated with lead in drinking water, recent reports indicate its presence/persistence in some regions of the water supply. As per The Irish Times report on April 15th, 2019, the lead concentration in drinking water was nearly 15 times over the legal limit near Sutton Dart Station, Dublin (Zone 1).

The objective of this preliminary study was to analyse the reported lead contamination level in drinking water of different water supply zones in Dublin.

Materials and Methods

Data collection and analysis

This research paper explores the reported lead content in drinking water in different water supply zones in Dublin obtained from the Irish Water website (www.water.ie) from September 2014 to January 2020.

In July 2019, the US EPA established a rapid, low cost and comparatively simple technique using a portable analyzer for lead testing and this method provides accurate results in comparison to the EPA 200.8 method (ICP-MS).

EPA Ireland recommends the use of Atomic Absorption Spectrometry [B/C/D] method for accurate lead testing. For carrying out the experiment, Letters B/C/D has been used to indicate an increasing sophistication of the technique and/or equipment used whereas Letters [B/C/D] implies that this method can be carried out at different level of instrumentation in a special laboratory. In the European Union, mandatory lead limits are strictly advised to be followed as per the Drinking Water Directive (98/83/EC).

Result and Discussion

To analyse the lead level in each zone, an area from each zone has been selected to study and specify the lead concentrations in drinking water. All zones have different concentrations taken at different sampling times.

Table 1: Area analysed from each zone for lead concentration in drinking water

Zones	Area
Zone 1	Booterstown
Zone 2	Goatstown
Zone 3	Dolly mount
Zone 4	Neilstown
Zone 5	Raheny
Zone 6	Ringsend
Zone 7	Glenageary
Zone 8	Sandyford

Table 2: Lead Concentration in 8 different Zones in Dublin obtained from the Irish Water website during the time period September 2014-January 2020

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	Year	Mont	Zone 1	Year	Month	Zone 2	Year	Month	Zone 3	Year	Month	Zone 4	Year	Month	Zone 5	Year	Month	Zone 6	Year	Month	Zone 7	Year	Month	Zone 8
2	2018	Feb	2	2019	Sep	0	2019	Oct	< 0.1	2019	Dec	0	2019	Aug	0	2019	Sep	2	2019	Oct	0	2019	Apr	0
3	2017	Oct	< 0.1	2019	Aug	0	2019	Sep	2	2019	Oct	0	2019	Jun	0.1	2019	jun	0.1	2019	Jul	1	2019	Apr	0
4	2017	July	0	2019	June	4	2019	Aug	2	2019	Jun	0	2019	Apr	52	2019	Mar	0	2019	Jun	0	2018	Oct	0
5	2017	June	< 0.1	2019	May	41	2018	Oct	3	2019	May	< 0.1	2018	Oct	0.1	2018	Nov	1	2019	May	0	2018	Jur	< 0.1
6	2017	May	0	2019	Apr	0	2018	Sep	< 0.1	2019	Apr	0	2018	Aug	0	2018	Oct	8	2019	Mar	0	2018	Apr	0
7	2017	Feb	0	2018	Oct	< 0.1	2018	Aug	4	2018	Oct	0	2018	Jun	23	2018	Sep	0.1	2018	Oct	0	2017	Oct	< 0.1
8	2016	Oct	0	2018	Sep	24	2018	Apr	5	2018	Jun	0	2017	Apr	0.1	2018	Apr	5	2018	Jul	0	2017	Jur	20
9	2016	July	0	2018	Aug	0	2017	Nov	4	2018	Apr	0	2017	Oct	0	2018	Mar	0	2018	Jun	0	2017	May	0
10	2016	June	0	2018	June	1	2017	Apr	4	2017	Oct	< 0.1	2017	Jun	0	2017	Nov	4	2018	May	0	2017	Apr	< 0.1
11	2016	May	0	2018	May	0	2017	Mar	0	2017	Jun	0	2017	Apr	8	2017	Sep	1	2018	Feb	1	2017	Mar	5
12	2016	Feb	0	2018	Apr	1	2016	Oct	2	2017	Apr	< 0.1	2016	Oct	1	2017	May	0	2017	Oct	0	2016	Oct	0
13	2015	Oct	0	2017	Oct	0	2016	Sep	0	2016	Oct	< 0.09	2016	Jun	15	2017	Apr	4	2017	Jul	0	2016	Aug	< 0.09
14	2015	Aug	0	2017	Aug	0	2016	Jun	< 0.09	2016	Sep	< 0.09	2016	Apr	0	2016	Oct	2	2017	Jun	0	2016	Jur	1
15	2015	July	0	2017	June	< 0.1	2016	May	15	2016	Jun	< 0.09	2015	Nov	0	2016	Sep	0	2017	Apr	0	2016	May	< 0.09
16	2015	Mar	1	2017	May	< 0.1	2016	Apr	2	2016	Apr	0	2015	Oct	0	2016	May	0	2017	Feb	0	2016	Apr	< 0.09
17	2015	Feb	1	2017	Apr	< 0.1	2016	Mar	0	2015	Nov	0	2015	Aug	0	2016	Apr	2	2015	Oct	0	2015	Jur	< 0.09
18	2014	Oct	< 0.09	2016	Oct	0	2015	Jun	0	2015	Oct	< 0.09	2015	Jun	0	2015	Nov	0.09	2015	Jul	0	2015	Jur	< 0.09
19				2016	Aug	< 0.09	2015	May	0	2015	May	< 0.09	2015	Apr	0.09	2015	Oct	1	2015	Jun	0	2015	May	0
20				2016	June	< 0.09	2015	Apr	< 0.09	2015	Feb	0	2015	Feb	14	2015	Sep	0	2015	May	0	2015	Mar	0
21				2016	May	22	2015	Mar	5	2014	Nov	< 0.09	2015	Jan	0	2015	Mar	6	2015	Feb	0	2015	Mar	< 0.09
22				2016	Apr	7	2015	Feb	86	2014	Oct	< 0.09	2014	Dec	0	2015	Feb	8	2015	Sep	0	2015	Feb	< 0.09
23				2015	Nov	0	2015	Jan	1				2014	Nov	0	2014	Nov	1	2015	Aug	0	2015	Jar	0
24				2015	Oct	0	2014	Nov	< 0.09				2014	Nov	0	2014	Nov	0.09	2015	Jun	0	2014	Nov	< 0.09
25				2015	Sep	< 0.09	2014	Oct	1										2015	Apr	< 0.09	2014	Oct	< 0.09
26				2015	Jun	< 0.09													2015	Mar	0			
27				2015	Apr	< 0.09													2015	Feb	0			
28				2014	Nov	0																		

As per the data collected from Sep'2014 to Jan'2020, the reported lead levels in the drinking water of Zone 1, Zone 4, Zone 6, Zone7 were under 10µg/L. Therefore, these zones are considered as safe zones over the years. The most affected zones are Zone 2, Zone 3, Zone 5 and Zone 8. The highest lead concentration was recorded as 86 µg/L in Zone 3 on Feb'2015 followed by Zone 5, recorded as 52 µg/L on April'2019 and in Zone 2, recorded as 41 µg/L on May'2019. Zone 8 is comparatively safer as the highest lead level concentration was recorded as 20 µg/L.

In Table 3, the calculated mean and standard deviation of lead levels reported in the time period September 2014-January 2020 summarises the data. The highest standard deviation was found for Zone 3 while Zones 7 and 4 had both the lowest Mean level of lead and the lowest standard deviation.

Table 3: Zonal Mean and Standard Deviation for lead levels reported in the time period September 2014-January 2020

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
N	14	18	16	11	23	23	25	12
Mean	0.28	5.55	8.12	0	4.93	1.97	0.08	2.16
Standard Deviation	0.61	11.51	21.10	0	11.98	2.58	0.27	5.79

Conclusion

Lead is one of the major contaminants in Irish drinking water. As per the EPA Ireland report, over consumption of lead (more than 10 µg/L) by humans, specially consumed by pregnant ladies can act as a toxic poison and can cause severe health issues for them as well as for the infants. As per the Irish water website, out of 8 Zones, 50% of the zones have lead level ranging from 0-10µg/L which is safe whereas other 50% of the zones were significantly affected with at least one incidence of lead contamination ranging from 14-86 µg/L. The recorded data is somehow exceeding the limits and to control the lead contamination in the drinking water supply, Irish Water has a Lead Mitigation Plan because it is estimated that 180,000 buildings in Ireland are over 40 years old and pipes need to be replaced in order to control the lead contamination in Irish drinking water.

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HUMAN COMFORT INDEX MAPPING FOR IRELAND

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Abstract

Comfort affects human life and activities. In pursuit of energy efficiency and comfort, civil infrastructure planning can and perhaps should be influenced by the spatial distribution of human comfort conditions. This paper aims to investigate the influencing factors of human comfort in Ireland and the relationship between civil infrastructure design and human comfort based on human comfort index maps. The historical bioclimatic data in this paper were collected from the Irish Meteorological Service and Environmental Protection Agency, and to quantify human comfort, two bioclimatic indices were used to develop human comfort maps. These were interpreted in light of current infrastructure and future plans.

Introduction

Human comfort affects individual satisfaction and productivity. Outdoor comfort is always determined by the current weather in the short term, and climate in general. Therefore, it is necessary to investigate the influence of climate on human comfort. According to Mesquita and Sousa (2009), bioclimatology is a science that studies the relationship between climate and biology. For example, Lin and Matzarakis (2008) investigated the impact of bioclimate on tourism. The results of the study provided recommendations to government agencies to improve regional tourism potential. In addition, human comfort index maps may be used for planning or design of civil infrastructure. This paper aims to study the influencing factors for human comfort in Ireland and the relationship between civil infrastructure planning and human comfort. Fanger (1970) demonstrated thermal comfort can be affected by metabolic rate, cloth index, air velocity, mean radiant temperature, dry-bulb temperature, and water vapour pressure. Weather and climate can determine air temperature, relative humidity, and air velocity. The historical data of these parameters can be obtained from the Irish Meteorological Service. Based on these data, bioclimatic indices can be calculated to quantify human thermal comfort. Geostatistics are a class of statistical methods that describe the distribution of a property in space (Ahmadi and Ahmadi, 2017). Geostatistical analysis of thermal comfort will be performed using ArcGIS software. The resulting human comfort index map for Ireland will be used to understand the specific factors influencing human comfort in Ireland with respect to topography, elevation, and latitude. Moreover, the impact of human comfort on civil infrastructure planning will also be discussed.

The objective of this study is to map human comfort index for Ireland and to assess the impact of human comfort on civil infrastructure planning.

Materials and Methods

Historical data collection

For this study, the historical data of air temperature, relative humidity, and air velocity were collected from the Irish Meteorological Service (Met Éireann) and the Environmental Protection Agency (EPA). In order to extrapolate the data to cover the whole Ireland more accurately, the data from the observation stations in fig 1 were processed using geostatistical methods.

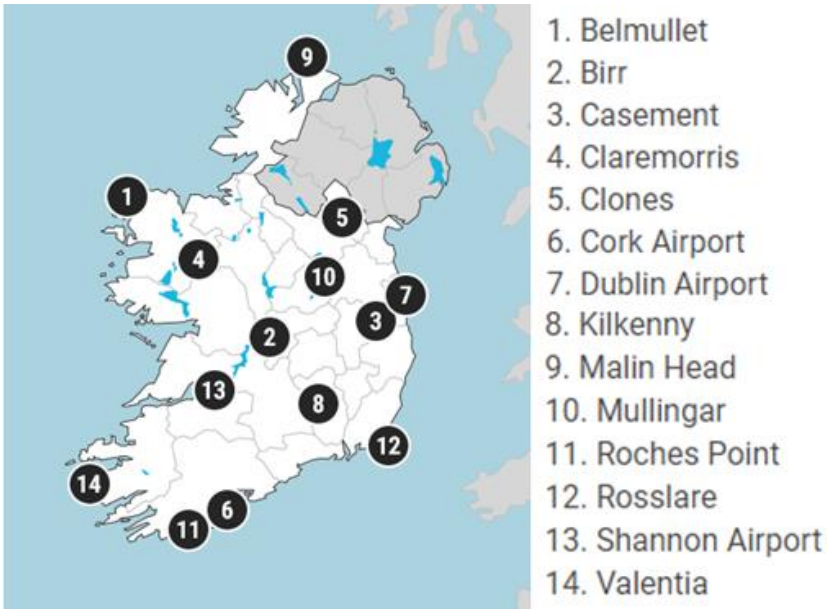

Figure 1. Ireland weather observing stations (The Irish Meteorological Service, 2020)

Bioclimatic index

Two bioclimatic indices were used to evaluate human thermal comfort: the temperature humidity index (THI) and the wind chill index (K). According to Emmanuel (2005), THI describes the thermal load degree in different meteorological conditions, which is suitable for outdoor environment. It can be calculated by equation 1,

$$\mathrm{THI} = 0.8\mathrm{T} + \frac{RhT}{100} \quad (1)$$

Where T is air temperature in ℃, Rh for relative humidity (%)

Wind chill index, proposed by Siple and Passel in 1945, describes the loss of energy a human can tolerate. It is calculated as a combination of wind speed and air temperature using equation 2,

$$\mathrm{K} = 1.163 \times (10.45 + 10V^{0.5} - V)(33 - T) \quad (2)$$

Where T is air temperature in ℃, V for wind speed at 10 m above the ground in m/s.

To evaluate human comfort based on these indices, Tseliou et al. (2010) quantified the indices to judge the actual thermal sensation votes (ASV) in Table 1.

Table 1. ASV and indices (THI and K) thermal sensation scales: range and median values (Adapted from Tseliou et al., 2010).

ASV	THI (℃)		K (W/m^2)	
	Range	**Median**	**Range**	**Median**
Very cold	⩽−1.8	−1.8	⩾1050	1050
Cold	−1.7–12.9	5.6	700–1049	874.5
Neither cold nor warm	13.0–19.9	12.5	350–699	524.5
Warm	20.0–26.5	23.3	175–349	262.0
Very hot	⩾26.5	26.5	⩽174	174

Mapping method

In order to map the distribution of the bioclimatic indices, ArcGIS software was used to implement geostatistical and deterministic estimation methods.

Results and Discussion

Mapping results

At this stage, a human comfort map for Ireland has not yet been produced. However, there is a similar comfort map for Iran shown in Figure 2 (Ahmadi and Ahmadi, 2017).

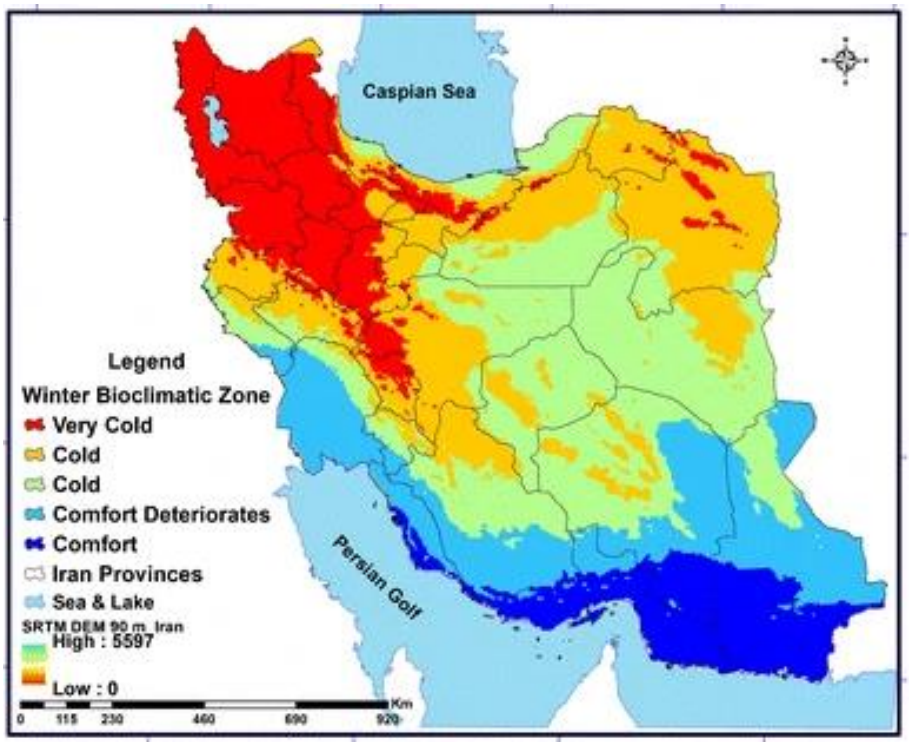

Figure 2. Mapping and spatial distribution of seasonal bioclimatic conditions in Iran (Ahmadi and Ahmadi, 2017)

In Figure 2, the region in dark blue is the most comfortable place in winter in Iran. The direct influencing factor is that the south of the country is closer to the equator, and the temperature in the south is higher than that in the north in winter. However, the influence of latitude is seasonal. The comfort zone will shift from the south to the north in summer. For the impact of altitude, the altitude of northwestern Iran is so high that only in summer this area meets comfort conditions. Overall, the country enjoys climate diversity, and the comfort zone changes with different seasons.

Conclusion

The human comfort index mapping method had been introduced. Based on the comfort map, the influencing factors of human comfort could be analysed such as topography, altitude, and latitude. For Iran, it is obvious that different seasons affect temperature changes and thus changes in comfort zones. Southern and northwestern Iran is more comfortable in winter and summer respectively. The main limitation at this stage is that the human comfort maps for Ireland have not been completed. For the further study, the specific influencing factors on human comfort for Ireland will be investigated. In addition, the relationship between human comfort and civil infrastructure planning will also be discussed.

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COMPARISON OF THE LIPID COMPONENTS FOUND IN GREASE TRAP WASTE FROM DIFFERENT RESTAURANTS

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Abstract

The discharge of fats oils and grease (FOG) from food service establishments (FSEs) is a major contributor to the formation of fatbergs and blockages. To prevent this, FSEs are required to install grease traps to reduce FOG release directly into pipes. In this research project the topic of interest is the lipid content of FOGs produced by FSEs in Dublin. FOG samples from grease traps of FSEs that serve a variety of cuisine will be collected. It will be of interest to note if certain cuisines produce waste with a higher lipid content or specific lipids that may in turn lead to blockages. A simple solvent extraction method will be used to quantify the total lipids. Specific characteristics of the lipids will be determined using chemical techniques. It is predicted that FSEs serving fried foods, or those that use high volumes of oil in cooking will have a higher lipid content. Overall, the results may vary due to variability in food types produced and cleaning methods across the different FSEs**.**

Introduction

FOGs are the by-products produced during cooking processes. FOGs are generated domestically, commercially and on an industrial level (Del Mundo and Sutheerawattananonda 2017). Commercial food service establishments (FSEs) and restaurants are the primary producers of FOG and consequently often contribute to the occurrence of blockages within sewers and drains (Gurd *et al.* 2019). If severe enough, these blockages can build up and lead to the formation of a fatberg, which is a congealed deposit of FOG as well as flushed non-biodegradable solids (Collin *et al.* 2020). Such blockages can be very expensive to maintain and have negative environmental and health effects. In the UK alone between £15-50 million is spent per year by UK water companies in efforts to deal with and control FOG blockages (Williams *et al.* 2012).

Grease traps are grease interceptors that are installed within the pipes of FSEs. In Dublin it is mandatory for these units to be installed in FSEs and restaurants as a method to reduce the amount of FOGs being released into sewers. This reduces the occurrence of blockages (Tran *et al.* 2018). In grease interceptors, the flow of entering wastewater is reduced which allows FOG to merge and rise to the top of the unit, where they are skimmed off and disposed of accordingly (Gurd *et al.* 2019). This grease trap waste (GTW) has the potential to be used as feedstock in the production of biodiesel. It is a sustainable source, generated in significant quantities and also contains a large concentration of lipids (Tran *et al.* 2018). The lipid content found in GTW can be composed of a variety of different types of lipids; fatty acids such as linoleic, oleic and palmitic fatty acids, as well as free fatty acids. The characteristics and lipid content of GTW can vary across different FSEs, influenced by the type of food prepared and served and the different cleaning practices employed. (Trentini *et al.* 2019).

The objective of this study is to produce a comprehensive evaluation of the lipid fraction in grease trap samples and determine the amount and specific characteristics of the lipids within the grease trap waste from various cuisine from the different FSEs.

Materials and Methods

Sample Collection

The samples that will be analysed in this study will be taken from the grease trap units of different types of restaurants. It is hoped to sample grease traps from a wide variety of cuisine, for example, fried food/fast food restaurants, Indian, Italian and salad bars. The type and number of restaurants that will be analysed has not yet been established. This will be completed at a later stage. The samples will be taken via a scraping mechanism off the top of the GTW. As mentioned previously, the FOG accumulates at the top of the grease trap unit and so it is here the samples will contain the highest yield of lipids.

Total Lipid Quantification

A simple solvent extraction will be employed to determine the total lipid content in weight. The solvents that will be used will be methanol and dichloromethane. This method has been adapted from a method on lipid extraction from fish muscle. To do this the following steps will be carried out:

1. 5 g of the GTW sample will be taken and ground.
2. 1.5 g of GTW sample will be placed into centrifuge tubes and placed on ice. 5ml of methanol will be added and the tubes shaken. Next 2.5ml of dichloromethane will added and the tube will again be shaken.
3. The tubes will be kept on ice for approximately 30 minutes. The samples will be shaken every five minutes to facilitate extraction.
4. The samples will then be spun in a centrifuge for 5 minutes at 7000 rpm (8°C).
5. Supernatant will be extracted.
6. 1ml of methanol and 2 mL of dichloromethane will be added to the remaining sample. Shake the tube until the precipitate dissolves.
7. The sample will be centrifuged for 20 minutes at 7500 rpm (8°C).
8. The supernatant extracted in step 5 will then be added back to the sample.
9. 7.5ml of dichloromethane and 2.5 mL of distilled water will be added to the sample and supernatant and the tube shaken.
10. This sample will then be placed in the centrifuge for 10 minutes at 4200 rpm (8°C).
11. Once the samples have been removed from the centrifuge the upper phase of the sample will be removed from the tube using a pipette. The lower phase which contains the lipids will then be transferred to 15 mL glass tubes.
12. The extracts will be stored for 24 hours at -80°C.
13. Pastry aluminium capsules will be labelled and placed in an oven for 10 minutes at 105°C and then transferred to a desiccator until cooled. The capsules will then be weighed.
14. 100 ul of lipid extract obtained in step 1 will be added to the capsules and places in petri dishes.
15. The petri dishes will then be placed on a hot plate at approximately 50°C within a fume hood. This is to ensure evaporation of dichloromethane is complete.
16. The capsules will then be cooled in a desiccator with silica gel and then weighed again. The weight difference will be noted as the extracted lipid content.
17. The lipid concentration will then be calculated using the formula L = (p2-p1)/v1, where L is the lipid concentration, p1 is the initial weight, p2 is the final weight and v is the volume (reagents).
    The proportion of lipids within the GTW sample can then be calculated by:
    (L x V x 100) / M

Where L is the lipid concentration, V is the volume of dichloromethane used in the extraction and M is the amount of GTW used in extraction.

Results and Discussion

Prediction of Results

As laboratory research for this report has yet to take place, the expected results will be discussed.

Knowledge of the lipid content of GTW is important regarding FOG deposit and blockage formation. Blockages form as a result of the process of saponification of lipids. Fatty acids undergo hydrolysis to yield free fatty acids which react with calcium present in wastewater to form a soap like compound. Palmitic acids have been shown to increase the speed of soap formation (also known as saponification), which creates a sticky texture, encouraging further accumulation of blockages. The presence of oleic acids results in a larger number of solids forming. In a situation with higher oleic acids to palmitic acids, harder deposits are formed. Palmitic acid has been documented as the most common fatty acid detected in deposits of FOG (Del Mundo and Sutheerawattananonda 2017) and so this would be a fatty acid expected to be determined within the GTW samples for this study. Palmitic acid is believed to be derived from fry oil used in cooking (Gross *et al.* 2017). Thus, it would be expected that restaurants using a large volume of fry oil would have a higher content of palmitic acids and thus a higher total lipid content in their GTW.

It is expected to see variability in the results across the different restaurant types. The components of wastewater flowing into grease traps varies depending on the type of meal prepared by the FSE and on the cleaning practices employed in the establishment. The size of the FSE will also impact the contents of GTW and lipid content (Gurd *et al.* 2019). Variability of FOG produced from different kitchens was documented in a report by Gurd *et al*. 2019 and a figure taken from this report highlighting this variability can be seen below in Figure 1.

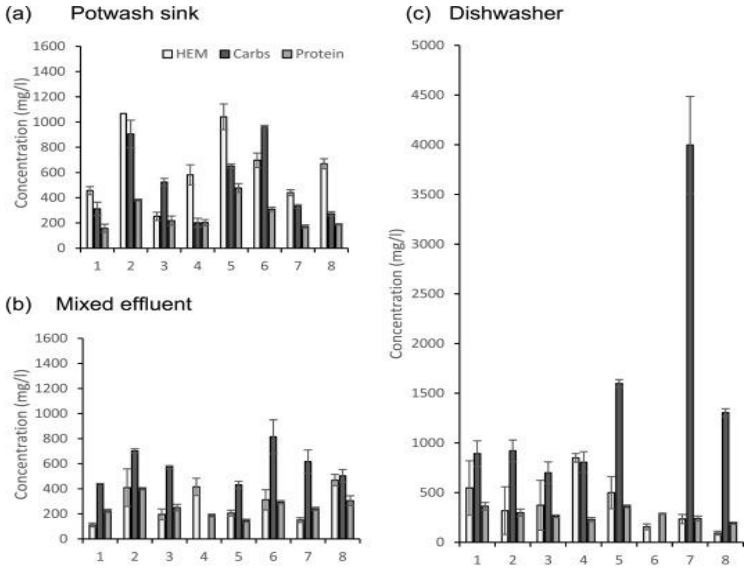

Figure 1. The above graphs represent the variability in the amount of different compounds (FOG, carbohydrate and protein) in (a) pot wash sink, (b) mixed effluent and (c) dishwasher. FOG are represented by HEM and are depicted as the white bar in each graph (Gurd *et al.* 2019).

Wastes that are rich in FOG have the potential to be used as a feedstock in energy recovery, due to their high calorific value. However, in order for FOG wastes as feedstock to become standard practice, analysis of the waste quality and volume is needed (Collin *et al.* 2020). Another issue in relation to GTW being used as an energy source, like biodiesel for example, is contamination. Contamination of GTW that occurs naturally would require GTW to undergo pre-treatment prior to use. As GTW contains large numbers of free fatty acids pre-treatments such as esterification or glycerolysis would be required (Tran *et al.* 2018). Knowing more information on the lipid content of GTW may influence the fluidity of such pre-treatments and contribute to the standardisation of using GTW as an energy feedstock.

Conclusions

FOG produced in food preparation and trapped within grease traps have a high lipid content. The number and types of lipids in GTW can influence the type and frequency of blockage formation. It is also important to understand the type and total amount of lipids present in GTW when considering GTW as a potential feedstock for biofuel. This research will highlight the total lipid content in GTW in varying restaurant types, using simple solvent extraction and thus contribute to this knowledge. It may indicate certain food types and restaurants more likely to contribute to blockage formation, particularly if there was no grease trap installed. This could encourage standard installation of grease traps in FSE that serve food that yield high lipid contents in GTW.

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RISK ASSESSMENT OF ARSENIC IN DRINKING WATER - A GIS STUDY

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Abstract

Elevated levels of arsenic in drinking water have become of great universal concern with regards to potential health risks. Arsenic in water may be due to the increased levels in the environment, which directly or indirectly may increase the level of arsenic in groundwater. In this study a number of datasets have been collected and carefully examined to identify the potential risk zones throughout the Republic of Ireland. The key risk components of increased arsenic levels related to geology, pedology, aquifer type, groundwater vulnerability and climatic zones which are evaluated using geostatistical methods, taking guidelines from the Irish Environmental Protection Agency (EPA) sample database to overcome some of the geographical restrictions. The inverse distance weighting (IDW) and local indicator of spatial association (LISA) methods were used to estimate the risk in the study area. It is anticipated that the arsenic exposure levels differ with the geochemical compositions of the bed rock type, climatic pattern and also from anthropogenic activities, including industrial discharges. Any important variances in arsenic levels in the environment will be distinguished from amongst diverse groundwater vulnerability groups as defined by the Geological Survey of Ireland. This study will contribute to management and policy directions for the protection of groundwater resources at EU level. It will guide future research focused on understanding arsenic deployment processes to guide future development including, testing and treatment requirements of groundwater resources.

Introduction

Arsenic (As) is ubiquitous in groundwater, soil and sediments as a result of natural processes including mineral weathering, dissolution and geothermal activities (Manning et al., 1998;, Yamamura et al., 2013). Anthropogenic sources include insecticides, pigment production, leaded gasoline manufacture, fossil fuel combustion, mining and electronic industries. Of these, mining and the use of groundwater abundant in arsenic for crop irrigation are the main sources of higher levels of As in the environment (Ehlert et al., 2014). Despite its toxicity, there are many microorganisms capable of tolerating exposure to and growth in the presence of arsenate [As(V)] or arsenite [As(III)]. Arsenic in groundwater used as a source for drinking water poses a human health problem world-wide (Naujokas et al., 2013). The dense population, traffic, industry and economic activities result in an increasing amount of contaminants being discharged to the urban environment. Consequently, a variety of environmental problems have emerged, of which toxic metal pollution is a major issue, especially in urban soil and street dust (Han et al., 2006;, Shi et al., 2008;, Thornton et al., 2008).

The objective of the study is to identify possible arsenic clusters through spatial mapping techniques and characterise the risk zones of arsenic within the Republic of Ireland using spatial distribution within GIS.

Materials and Methods

The study area lies within the political boundary of the Republic of Ireland with the land area of 70273 Km^2. In Ireland 25% of public drinking water is derived from groundwater sources (Daly, 2009) rising to 100% in certain localities (McGarrigle et al., 2010). Public and other regulated water supplies data are collected to understand the compliance with Drinking Water Regulations.

Basic data sets required to develop the framework include topography (digital elevation model [DEM]), soils, land use, meteorological data, and population census data. Catchment parameters will be identified and developed using ArcGIS (based on geographic information system), which provides graphical representation and permits model construction focused on digital map data. The data for the study has been collected from various reliable sources such as Geological Survey of Ireland (GSI), Ordinance survey of Ireland (OSI), Environment Protection Agency (EPA) and other government organization for climatic data and other statistical information. The statistical information collected are then converted into data layer. (Figure 1)

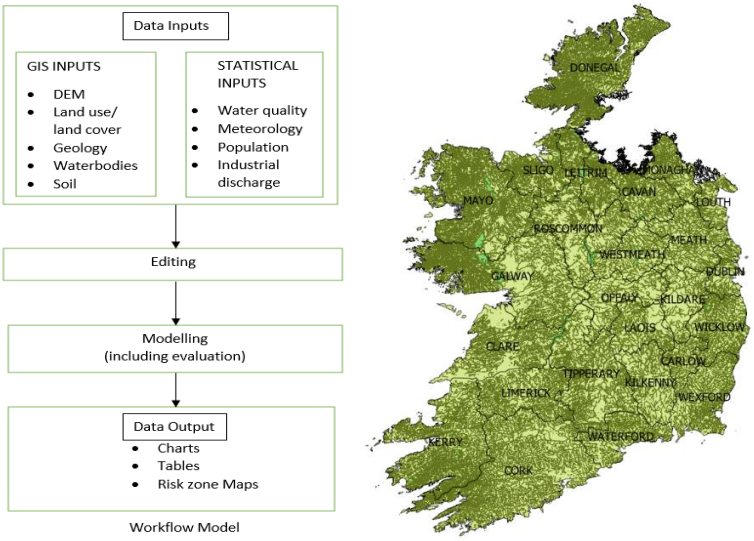

Figure 1: Model Framework, showing model inputs and data requirements

Statistical analysis

In order to determine potential controlling factors on arsenic concentrations GSI databases were examined including the 'National Generalized Bedrock Map (Rock Unit Group)', 'Bedrock Aquifer,' and 'Groundwater Vulnerability' maps (GSI 2020) Since the primary aim of this investigation was to explore existing data to discover if there were statistically significant differences between the arsenic levels in groundwater across various geological and hydrogeological classifications, appropriate handling of non-detect data was essential to avoid biased results. The water chemistry data for arsenic has been systematically collected over a period of 20 years (2001-2020) by the Environmental Protection Agency (EPA 2020). The climatic investigation report for the period of 20 years (2001 – 2020) from the Met Eireann (Met Éireann 2020) was used.

In the GIS platform, spatial interpolation techniques, such as inverse-distance (ID) methods, can be applied to the data to provide estimates of values at unsampled locations. Inverse distance methods attribute a weight to each sample which is inversely proportional to the distance that is between the sample and the location of the estimate (Srivastava, 2013). Local Indicator of Spatial Association (LISA) or Local Moran's I statistic, a class of local statistics, will be performed.

Exposure assessment

Potential levels of arsenic in water were evaluated to assess human exposure. A world-wide compilation of arsenic contamination indicates that the primary source of arsenic in Ireland may be anthropogenic in origin, even though, mineralization related with Zinc and Lead Sulphide deposits are also considered to be the possible risk sources (Murcott, 2012). The World Health Organization (WHO) and EU have set the maximum concentration of arsenic in drinking waters at 10 $\mu g\ L^{-1}$ (EC, 2007; WHO, 2011) and in

Ireland, a lower arsenic concentration of 7.5 μg L^{-1} is set as the groundwater threshold value (GTV), i.e. 75% of the Irish legal limit for arsenic in drinking water at 10 μg L^{-1} (Craig and Daly, 2010;, European Communities (EC), 2010).

Risk assessment using GIS

Geostatistics and Geographic Information System (GIS) are valuable tools to examine the distribution of pollutants and analyse the level of pollution in large scale regions (Wang et al., 2015). The framework model (Figure 1) will be developed at a scale of 1:50000. However, there have been limited studies in this area which include a validation stage for model predictions. Model components include weather, hydrology, erosion, sedimentation, and stream/pond/reservoir routing. The data layer will be interfaced with ArcView extension software that provides capabilities to streamline GIS processes tailored toward hydrologic modelling. This helps to automate data entry, communication and editing between GIS and the hydrologic model (Pandey et al. 2005).

Results

An initial framework has been developed within GIS. Environmental contamination can be described as active in either coldspots or hotspots with the aid of Spatial Analysis (Zhang et al., 2008b). A trend analysis model will be developed to identify the potential risk zones. The risk will be characterized by high, medium, and low sensitivity levels. A risk map for the selected study area will be developed. The regions exhibiting notably high levels of arsenic concentrations will be marked potential risk zones.

Conclusion

This study provides the introductory stages towards the formation of a reference assessment on arsenic in environmental media within the Republic of Ireland. Arsenic is not persistently rising in the environment throughout Ireland, but the occurrence of regional hotspots of contamination warrant further detailed investigations. The health risk of arsenic intake through drinking and using groundwater will be assessed. If there is a possible high concentration of arsenic, then removal methodologies could be used as remediation. Also, this study helps to identify the geochemical conditions that are conductive to arsenic mobilization in groundwater within these rock types, further detailed regional geochemical studies need to be established. While there are studies focusing on arsenic within the EU, this study represents a statistical methodology in defining the spatial distribution of arsenic at a nationwide scale.

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ASSESSING THE RECOVERY POTENTIAL FOR DEGRADED MARINE PLASTICS BASED ON THEIR PHYSICO-CHEMICAL COMPOSITION

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Abstract

Plastic litter is currently present in all of the world's major ocean basins, contributing to plastic pollution globally. Plastic found in the marine environment is derived from mis-managed plastic waste which is particularly relevant for coastal populations. This occurrence is an indirect result of the continually growing virgin plastic production industry. In order to tackle this issue, recovery must be implemented at the production level. Following this, economic incentives could play a vital role in the recovery of degraded plastics. In this study, FTIR will be used to determine changes to the molecular structure of three degraded plastic polymers; polyethylene (PE), polyethylene terephthalate (PET) and polypropylene (PP). From this, suitable disposal methods for degraded plastics which would produce the highest economic yield will be determined.

Introduction

Plastic marine litter is one of the key environmental issues of the 21st century and contributes 60 – 80% of all marine debris (Iñiguez, Conesa and Fullana 2019; Kerscher 2019). There are approximately 150 million tonnes of macro and micro plastics in oceans, with an additional 10 million tonnes entering the marine environment each year (Kerscher 2019). Plastic production is a major contributor to global climate change as it is made from non-renewable resources e.g. crude oil (Harding et al. 2007). The plastic production process itself releases CO_2, while additionally contributing to fossil fuel depletion (Harding et al.2007). A large number of further impacts also occur for example microplastics entering the food chain which poses a threat to human health (Kerscher 2019). Plastic debris also poses a threat to marine wildlife as it contributes to marine animal deaths following entanglement or ingestion of plastic fragments (Kerscher 2019). An estimated 6300 million tonnes of plastic has been generated in total between 1950 and 2015, with only 9% being recycled, 12% being incinerated, and 80% being left to accumulate in landfills and the environment (OECD 2018). As plastic waste has a value and can be traded as a commodity, there is potential to introduce economic incentives for governments to recover plastics (Al-Salem, Lettieri and Baeyens 2009, Plastics Europe 2020). In this research, potential introductions to legislation which could significantly improve plastic recovery will be discussed. An example of this could be seen through further enforcement of the Producer Pays Principle (EPA 2020).

As plastic is currently present in all of the world's major ocean basins, it is also of interest to assess the recovery potential of degraded plastics. When plastic polymers enter the marine environment, they are exposed to UV radiation, oxygen, bacteria and mechanical erosion which contribute to changes in their physical properties and molecular structures (Min, Cuiffi and Mathers 2020). In this study, the molecular and physical properties of three degraded polymers; polyethylene (PE), polyethylene terephthalate (PET) and polypropylene (PP) will be compared to those of their non-degraded counter parts. This will determine significant changes in the chemical composition of degraded plastics. From this, the waste management method with the highest economic yield can be determined based on the level of degradation of each polymer.

The objective of this study is to assess the most economically feasible method to recover marine plastics based on their level of degradation, while determining the potential to generate value from those wastes.

Materials and Methods

Samples

Three types of commonly used plastic; polyethylene (PE), polyethylene terephthalate (PET), and polypropylene (PP) are the focus of this study. Degraded samples were collected from Carnsore Point, County Wexford in January 2020 for analysis. The non-degraded counter parts of each sample were obtained prior to disposal, generally coming directly from a supermarket. Samples were also qualitatively categorised according by age/time spent in the marine environment (0 – 12 months, 1 - 5 years, and 5+ years) based on levels of physical degradation such as levels of surface erosion, cracking and UV degradation (Andrady 2015; Degli-Innocenti 2014; Min, Cuiffi and Mathers 2020; Min et al. 2020). Where expiration dates were present on items e.g. PET plastic bottles, the date was used as denotative to the time-period that the samples were present in the environment (Ioakeimidis et al. 2016).

FTIR Analysis

Samples were analysed using Attenuated Total Reflectance (ATR) Fourier Transform Infra-Red (FTIR) spectroscopy (Nicolet 6700, Thermo Fisher, USA) (Cai et al. 2018; Ioakeimidis et al. 2016). This method was used to identify the presence of functional groups which could be attributed to environmental degradation. Ranges of the spectra were set from 4000 to 500 cm^{-1} (Cai et al. 2018). Three different points (central point and two different edge points) of each sample were analysed. Each sample collected consists of a single plastic polymer, however a single polymer can be used to make a variety of items. Therefore, a representative from each type of plastic polymer was chosen e.g. a single use plastic bottle to represent PET. This decision was made based on how universally used an item was, with the most used items being chosen for analysis. As samples were also categorised by age, the analysis was carried out for all age categories. The spectra of degraded plastics were compared to the spectra of their non-degraded/virgin plastic counterparts.

Literature review

Using existing literature, spectra results were used to determine the fate of degraded marine plastics i.e. whether they were most suited to re-use, recycling, fuel generation or incineration. From this, the most economically feasible and potential profit yielding methods for degraded plastic disposal were identified.

Expected Results

It is expected that the chemical properties of the degraded samples will differ from those of their non-degraded counterparts. FTIR spectra is expected to produce new absorption peaks for degraded samples following exposure to UV radiation and oxygen. The new absorption peaks indicate the development of new hydroxyl (OH) and carbonyl (C=O) groups at ~3,300cm^{-1} and ~1700 cm^{-1}, respectively (Cooper and Corcoran 2010). It is expected that chemical weathering i.e. photo-oxidative degradation will increase based on time spent in the marine environment. This could result in increased absorbance intensity of hydroxyl and carbonyl groups in the FTIR spectra. Variation between results are expected based on the type of polymers under analysis.

Discussion

It is widely known that in order to reduce plastic pollution, virgin plastic production must be reduced and recovery and recycling must be promoted. A number of Directives are in place in Ireland which could be altered and enforced to aid the issue of plastic pollution. Examples of such include the Packaging Waste Directive (94/62/EC), the Waste Framework Directive (2008/98/EC) and the Integrated Pollution Prevention and Control Directive (1996/61/EC). The Waste Management (Farm

Plastics) Regulations, 2001, are a primary example of how economic incentives can be used to promote plastic recovery. These regulations require each purchaser of farm plastic to pay the producer a refundable deposit based on the weight of plastic purchased. The producer will then return a proportion of the deposit to the purchaser based on the condition that the farm plastic is returned. Alternatively, each deposit paid by the purchaser to the producer could be used to off-set the cost of recycling or other appropriate method of disposal. If the plastic purchaser cannot provide proof of payment for the deposit, then they are responsible for the total cost of disposal. This regulation could be implemented for all major plastic producers. If enforced it would make a significant reduction to overall plastic waste, having a knock on effect on plastic entering the marine environment. A number of further legal efforts have been made by the United Nations (UN) to specifically tackle the issue of marine plastic pollution. Examples of such include the 1972 Convention on the Prevention of Marine Pollution by Dumping Wastes and other Matter, the 1996 Protocol of the London Convention (London Protocol) and the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL) (IUCN 2020). Although laws exist, they are not being enforced due to limited financial resources to support them (IUCN 2020). If compliance is not mandatory, the issue of plastic pollution will not be mitigated.

Following recovery at the production stage, the issue of plastic which is already present in the marine environment must be addressed. Plastic is a valuable resource which can be recovered, with a number of non-profits and small businesses using recovered marine plastics to make valuable products. A company called Upgyres based in Vancouver specialises in recovering, treating and upcycling plastic waste from oceans. Even small start-ups are contributing with Jacks Eyewear in the UK producing glasses frames from recycled plastic. The key issue with plastic re-use and re-purposing is that it must undergo rigorous sorting and pre-treatment. Plastics must be separated according to plastic type, undergo shredding and grinding, sorting according to colour, rinsing, de-odourising, mixing with 1% anti-oxidant and be turned into pellets which can be used to create a ‘new’ item (Upgyres 2014).

While this is a feasible method to re-use marine plastics, it is tedious process with high costs, making it an unappealing production strategy for producers and consumers. Recycling and re-use of plastic are the most effective actions available to reduce the environmental impacts of open landfills and open air burning, however it must be incentivised to become feasible (World Economic Forum 2020). As virgin plastics made from oil are currently cheaper than renewable alternatives, governments must implement tax or fees on polluting plastics in order to make recycled plastics cheaper (World Economic Forum 2020).

Following re-use and recycling, other treatment methods are available which could be economically beneficial such as waste to energy technologies. Plastics can be used to generate energy through incineration or to produce fuel through hydrothermal carbonisation. Despite being controversial , waste to energy processes such as incineration does benefit communities by providing heating for homes and businesses. The implementation of hydrothermal carbonisation plants could be equally, if not more beneficial by boosting a countries economy through the production of a new fuel source.

It is feasible for the waste management strategy of degraded plastic to be altered based on levels of degradation. Even if the physical and chemical composition of the plastic has been altered significantly, it can still generate energy through incineration if more complex methods are not possible.

Conclusion

The negative environmental impacts of plastic pollution are widely known, however this alone is not enough to incentivise countries to remove and treat plastic which is already present in the marine environment. This research takes a different approach, exploring the economic incentives for

countries to remove and recover plastic waste. The suitability of adding value to recovered marine plastic waste will be assessed based on the level of degradation of the polymers. This research will also examine how existing legislation can be enforced to improve plastic waste recovery, therefore reducing the quantity of plastic entering the marine environment. This would provide an at source solution for plastic waste recovery while also discussing the recovery of pre-existing plastic litter.

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DESIGN OF TEMPERATURE, HUMIDITY AND AIR QUALITY SENSOR BASED ON RASPBERRY PI FOR STUDENT RESIDENCES

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Abstract
Abnormal temperature regulation in indoor buildings will bring uncomfortable experience to occupants. The measurement of temperature and humidity in buildings usually requires some instruments for accurate detection. This project will use Raspberry Pi's intelligent modules and temperature, humidity and air quality components to detect the indoor environment so that the residents can easily understand and adjust the basic environmental parameters in the room.

Introduction
Electricity devices are wide used in current society in current building, there are different equipment, for example to adjust the windows, stoves, boilers also heaters. The reason of that is to free hands for human being and to prevent the energy waste. The European Commission in 2016 has shown that cooling and heating in households account for half of European energy consumption. This is a good opportunity for the application of intelligent control systems. Air pollution and temperature value is necessary to be monitored for people living or working in residents. With the construction of infrastructure and the development of the Internet of Things, environmental issues, especially indoor environmental issues, have greatly affected the development of intelligent monitoring systems. The intelligent monitoring system hesitates for its low price and high operability, gradually replacing the method of manual recording, which greatly improves the accuracy of the data.

The objective of this research is to explore the feasibility of using Raspberry Pi in UCD student apartments to control the environment parameters of dormitory.

Materials & Methods

In the UCD student apartments, whether it is Merville or Belgrove (Fig. 1), there is only one heater set next to the window, but there is no visual equipment that relies on numerical references to adjust the temperature, which makes the dormitory environment an unknown space. Students only rely on their own feelings and experience to regulate temperature, and their behaviour that rely on physical perception to adjust can be very inaccurate. Everyone's control of temperature is different, and in some special cases, such as colds or fever, the body's perception of temperature and the surrounding environment is very weak. By the same principle, under unknown circumstances, students cannot always know whether the indoor environment of the apartment is healthy and provide proper ventilation (mainly refers to the carbon dioxide concentration). Therefore, the visualization of the necessary environmental

parameters of the dormitory is a very important measure. This not only helps students make simple environmental adjustments at any time, but also the cloud processing and cloud archiving of data can better help the school manage the dormitory apartment.

Figure 1. Heater in the Belgrove residence

A. Equipment assembly stage:

MQ135 Gas Sensor: It is mainly used for the detection of air quality parameters. The specifications are 5V voltage and 40mA current. It can effectively detect nitrogen oxides and other gases in the air. The role of this sensor in this article is mainly to detect the concentration of carbon dioxide in the room.

DHT11 Temperature and Humidity Sensor: It is used to detect the temperature and humidity in the environment. The reason for selecting this component is that it has fast response and high sensitivity. It can transmit data quickly after connecting with Raspberry PI.

Raspberry Pi: Raspberry Pi is a series of small single-board computers. It is a processor for scientific research and teaching developed by the British Raspberry Pi Foundation. When the Raspberry Pi is connected to the computer, you can write programs directly in the programming language. The Raspberry Pi will process the data collected by the sensor according to the written program, and the final data will be presented on the computer.

Connection: The connection of each component requires the use of a "male-female" wire. The sensor element is connected to the corresponding connector of the Raspberry Pi. After the connection is successful, connect the Raspberry Pi to the power supply. The sensor will light up to remind the tester. Next, you need to connect the Raspberry Pi to a computer or other programming device for programming. After the programming is completed, the final test data will be displayed on the screen.

B. Data analysis stage

At this stage, the previous data collection has been completed, and now there will be a lot of data. MATLAB will be used to analyse the data and discuss the fluctuations of the data in different situations. At the same time, in the process of data collection, some experimental variables will be appropriately changed, and compare the data collected through different experiments to discuss and summarize.

Results and Discussions

Saha et al. (2018*)* had already made air and temperature and humidity sensors to monitor the indoor environment, and through investment, the cost of making a simple temperature and humidity sensor is not expensive. The average price can be controlled below 100 euros. Also, Saha's conclusion also mentioned that this is a low-cost detection method. These data can be uploaded to the cloud for real-time monitoring to reduce the pressure on data collection.

The main body of this study is to discuss the impact of the installation of temperature and humidity sensors on the students in the UCD student dormitory, so the following two results may occur.

1. The cost and benefits of installing a temperature and humidity sensor in economic evaluation are far greater than the energy waste caused by adjusting the heater under unknown circumstances.

2. The cost and benefit of installing a temperature and humidity sensor in the economic evaluation is less than or equal to the energy waste caused by adjusting the heater under unknown circumstances.

Conclusion

Through the Raspberry Pi, preliminary collection of indoor environmental data is possible, but since the sample size of the collected times is not enough, the accuracy of the data needs further experimentation. And as a low-cost means can afford the waste of energy, it is recommended to promote this indoor environment regulation

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Rhea Chhaya

Project Title: Development of a feed chain risk assessment to assess the increase in risk from mycotoxins as a result of climate change and potential transfer to dairy products for human consumption

Project Supervisor: Prof. Enda Cummins

Abstract

Mycotoxins are naturally occurring toxins produced by fungi. Their occurrence and production is subject to interactions between environmental conditions and plant physiology. Mycotoxins can form at two stages in the production chain. One is pre-harvest, where in contamination in the plant occurs due to contaminated soil, crop damage by insects, birds or animals or weather conditions such as droughts. The second stage of contamination occurs at any stage post-harvest from storage to consumption where the toxins produced in the first stage could also increase. Post-harvest contamination generally occurs due to grain storage conditions such as poor moisture and temperature control or pest infested storage silo. Mycotoxins have been categorized according to their chemical structure and can be carcinogenic, immunosuppressive, hepatotoxic and nephrotoxic as well as cause fertility problems in humans and animals. Oral transmission of mycotoxins by humans occurs by consumption of contaminated vegetables and crops, or through the consumption of animal products. Food safety authority bodies across the world have placed regulatory limits on the concentration levels of mycotoxins such as aflatoxin, ochratoxin A, deoxynivalenol, zearalenone, fumonisin, patulin, etc. Of the major mycotoxins, currently only the levels of aflatoxins and ochratoxin are regulated in milk and milk products. Contamination of dairy products occurs when cattle are fed contaminated feedstuff. Rumens carryover some amount of mycotoxins present in the feed. Aflatoxin B_1, one of the major mycotoxins of concern in dairy products due to its link to hepatocellular cancer, is metabolized to Aflatoxin M_1 and in the ruminants gut. Aflatoxin M_1 is also linked to hepatocellular cancer. The value of the carryover is higher when compared to other mycotoxins, and mycotoxins such as ochratoxin have less toxic metabolites. The current risk of mycotoxin exposure from dairy products in northern Europe are far less when compared to that in southern and central Europe. This is due to cooler climate in northern Europe and southern and central Europe having a more conducive climate for these mycotoxins. In context of climate change, with more temperature and precipitation extremes, early crop maturation times, the risk of aflatoxin spreading to crops in northern Europe is predicted to increase, thus increasing the risk of contaminated dairy and dairy products. The importance of mitigating the contamination at source arises due to the difficulty to destroy mycotoxins at processing stages down the dairy supply chain. A risk assessment taking into account different climate change scenarios across Europe will be developed to understand the potential risks from mycotoxins in the future and prepare for appropriate strategies to mitigate it. For the project, data on temperature, precipitation and mycotoxin occurrence in crops across Europe will be collected from literature. Mycotoxin transfer at different stages in the production chain will be calculated using transfer equations found in literature. The final exposure model will be probabilistic and consider temperature and precipitation changes expected in the future. The risk to humans from mycotoxins will be categorized with the use of disability-adjusted life year (DALY), hazard index (HI) and risk of hepatocellular carcinoma (HCC).

Acknowledgements

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Zhihao Yuan, BE, M.EngSc.

Project Title: Evaluation of current state of the art on human health impacts of microplastics in marine ecosystem

Project Leader: Prof. Enda Cummins

Abstract

Up to 2010, the total weight of global microplastics (MPs) has reached 490,000 tons due to industrial emissions and surface runoff. MPs are widespread in various marine ecosystems. MPs are generally defined as plastic pellets, fibers and chips with a diameter of less than 5 mm, classified by their origin. The objective of this study is to assess risk of MPs in current marine ecosystem on environment and human health while analyzing its mechanism and toxicological properties. Quantitative and qualitative analysis methods were used to assess food safety risks and priority list of polymers. Monitoring of MPs in marine systems has been unified by the Marine Strategy Framework Directive (MSFD) in Europe. The size of MPs uniformly uses 5 mm as upper limit, and the lower limit is determined by the specific situation. Standards on sampling locations, depth, tools and weights vary widely. Because MP is detected in the food chain from invertebrates (bivalves) to vertebrates (fishes), aquatic organisms are the main pathway for human exposure to MP pollution. Due to aging of plastic, 80% of MPs is less than 2.5 mm. At the same time, 80% of MPs are white and transparent since MPs confuse hunting behavior of marine organisms. First, MPs enter the food chain and accumulate to higher nutritional levels. Second, MPs in human digestive tract have a strong potential for mechanical damage and leaching of toxic monomers and additives. Third, because MPs has a large surface-to-volume ratio, MPs adsorb pollutants and pathogenic biofilms. In addition, the main route of human exposure to MPs is gastrointestinal absorption. This study uses a hazard level model to classify hazards of polymers into 5 hazard levels (I-IV) with a coefficient of 10. Although the main polymer types in MP are PE and PP, the most important source of MP pollution risk is PVC. The PE family is a product with least damage and highest yield. So far, MPs accumulation has been found in various regions of the world and even in remote oceans. In order to improve risk assessment of MPs, the following points need to be taken: 1) A reliable and unified method for assessing MPs pollution levels. 2) Develop new technologies and develop strategies to prevent discharged plastics from entering aquatic system. 3) Develop environmentally friendly polymers, "green" additives and pesticide chemicals.

COMPARING AIR QUALITY MONITORING IN IRELAND WITH EUROPE UNDER THE NATIONAL EMISSIONS CEILINGS DIRECTIVE

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Abstract

The National Emissions Ceiling Directive (NECD)(2016/2284/EU) requires members to submit an annual report on several monitored atmospheric pollutants. It is intended that monitoring for these pollutants will occur on sites representative of sensitive habitats across Europe. This will inform Europe and member states of long-term ecological effects of air pollution. Ireland has a specific air pollution problem, where it has exceeded its emissions target for ammonia since 2016. The implementation of abatement strategies is imperative if Ireland is to meet emission reduction targets in years to come.

Introduction

The National Emissions Ceiling Directive (NECD)(2016/2284/EU) requires that all member states within the EU monitor and report on several pollutants such as ammonia (NH_3), nitrous oxides (NO_x) and sulphur dioxide (SO_2). These pollutants, particularly NH_3, can cause severe environmental damage in areas which are considered as sensitive habitats. Locating appropriate monitoring sites to represent these sensitive habitats is one of the reporting obligations under the NECD. Reporting of NH_3 and other pollutants allows for the assessment of progress in reducing air pollution across the European Union (EEA, 2016).

In Ireland, approximately 99% of all ammonia emissions originate from agricultural activities (EPA 2019). Irelands NECD emissions reduction target for NH_3 has been set at 112 kT from 2020 – 2030. In 2017, Irelands NH_3 emissions were 118.5 kT and have been steadily increasing since 2016 due to the expansion of the dairy sector (EPA 2019). In the absence of abatement strategies, NH_3 emissions alongside other pollutants, will continue to increase. The "Abating Ammonia in Agriculture" or the "Triple A" project, funded by the Department of Agriculture, Food, and the Marine (DAFM), aims to quantify the potential of a number of abatement techniques on reducing Irelands ammonia emissions through landspreading. As part of this project, an up-to-date national ammonia concentration model including recent agricultural expansion will be generated which will allow for the detailed assessment of critical level and load exceedances on sensitive habitats as outlined by the Habitats Directive and the NECD.

The objective of this study was to analyse European data submitted under the NECD and compare with Ireland's submission.

Materials and Methods

Compilation of Original NECD submissions from 2019

Submissions from each member state were gathered from an open source online repository at the EIONET Central Data Repository. Deposition and concentration data from each submission were taken from the appropriate sections and compiled into an excel sheet. This data included dates which samples were taken, the x and y coordinates of monitoring locations and the pollution data for NH_3/NH_4, NO_2, NO_3 and SO_2 for each site. Each member state submitted data which was obtained at different time periods e.g. hourly, daily, monthly, or yearly. Where applicable, data was averaged as monthly data and compiled in the master excel sheet as such.

Examining the Variation in Data Submitted per Member State

Once the original NECD submissions for 2019 were compiled into one master document, details of each submission for each member state were compiled into a table which highlighted the variation in each submission. These included the number of years over which monitoring was carried out, how many site locations there were for each member state and the total number of measurements which were recorded for each pollutant at each site for each year.

Results and Discussion

The total number of measurements for each pollutant, which were taken from each year at each monitoring site, are also shown in Table one. Ireland (IE) had the highest number of deposition measurement submissions at 27,436 while Croatia, Malta, the Netherlands, and Portugal (PT) all submitted no measurements for deposition pollutants.

Hungary (HU) submitted the highest number of concentration measurements with a total of 2877 submissions. Belgium (BE), Cyprus, Czechia (CZ), Germany, Denmark (DK), Finland (FI). France, Greece (GR), Italy (IT), Poland (PL), Sweden (SE), Slovenia (Sl) and Slovakia (SK) all had no submissions for concentration data.

Although it may seem that some member states reported significantly more than others, there are several factors which should be taken into consideration. These include the number of years over which data was monitored and how many monitoring locations were in each member state.

As can be seen in Table one, each member state had a variation in the number of site locations, as well as the total number of years in which the data was recorded. France had the highest number of monitoring years at 28 years in total ranging from 1992 to 2019. Six member states submitted data from only one year, such as Cyprus (CY) for 2017, and Croatia (HR) for 2018.

The number of monitoring sites varied greatly from member state to member state. Germany (DE) and the Netherlands (NL) had the highest number of monitoring sites at 72 locations. France (FR), Lithuania (LT) and Malta (MT) had the lowest number of site locations at only one location for each member state.

Table 1: Detailed analysis of each monitoring site and pollutant measurement numbers submitted per member state

			Total Number of Measurements**	
Country	**Number of monitoring site locations**	**Number of years over which data was obtained**	**Deposition**	**Concentration**
BE	31	4	25050	0
BG	4	4	1188	366
CY	2	1	162	0
CZ	14	6	9523	0
DE	72	3	435	0
DK	4	3	77	0
EE	2	N/A*	14	2
ES	15	9	177	141
FI	3	1	468	0
FR	1	28	2045	0
GB	10	4	6141	1256
GR	3	11	110	0
HR	2	1	0	4

HU	6	1	24	2877
IE	3	27	27436	491
IT	6	N/A*	102	0
LT	1	3	341	108
LV	3	1	184	27
MT	1	1	0	2
NL	72	N/A*	0	239
PL	5	2	552	0
PT	12	4	0	29
RO	14	2	2159	210
SE	4	6	3440	0
SK	8	2	1080	0
Sl	7	2	414	0

** N/A shows member states that did not provide dates with their monitoring data*
*** Averaged as monthly data measurements where applicable, as highlighted in methodology*

From analysing the data presented in Table one, a comparison can be made between Irelands performance in reporting compared to other member states. Ireland submitted the highest number of deposition data measurements when compared to other EU member states, with Belgium 2nd and Czechia 3rd. In comparison, Ireland ranks 3rd for the number of concentration measurements submitted in the same report, after Hungary (1st) and Great Britain (2nd).

Although Ireland submitted the highest value of deposition measurements, and the third highest for concentration measurements, Ireland ranks joint 12th for its number of monitoring sites (3 in total) with Latvia, Finland, and Greece. Ireland has the 2nd highest number of years over which the submitted data was collected (27 years) after France (28 years) and before Greece (11 years).

Although it may seem like Ireland submitted a vast quantity of measurements for the 2019 NECD submission, these comparisons show that Ireland needs to increase its number of monitoring sites. It is anticipated that all member states are examining their national monitoring framework, and are ensuring sufficient monitoring locations to accurately represent air pollution impacts on sensitive habitats (such as those in the Natura 2000 network).

Conclusions

This preliminary study of the data submitted under Article 10 (4) of the National Emissions Ceiling Directive shows that there is a need for EU member states to harmonise their monitoring and reporting on air pollutants. This data will be examined further in future work to determine statistical variation in data, and will also feed into the DAFM funded Triple A project. It may also assist in the development of Irelands new National Ecosystem Monitoring Network for air pollution.

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Ciaran Monahan, BSc

Project Title: Risk ranking of antimicrobial sources and ARO exposure assessment

Project Leader: Prof. Enda Cummins

Abstract

The development of antibiotic resistant organisms (ARO) in water bodies poses a risk to public health, creating a risk of a persistent infection which does not react to antibiotic therapy.

The project aims to quantitively assess the relative risk of antibiotic resistance development posed in natural water bodies by comparing different antibiotic classes and by comparing different industries, namely health and agriculture. Subsequently, it aims to assess the risk posed of encountering resistant organisms when people using water recreationally.

This study uses risk quotient (RQ) methods. Using administration and sales data for different antibiotics in different industries, as well as half-life data and excretion rate data, predicted environmental concentrations for antibiotics in Irish waters can be generated via Monte Carlo modelling. These predicted concentrations are compared to concentrations above which resistance formation is predicted, and thus, a risk quotient is generated.

Results are currently in a preliminary state; the model has been constructed, and initial testing allows comparison of different antibiotic classes within each industry. Subsequent work will progress this further, allowing for the comparison between antibiotics and between industries. A literature review, covering different risk assessment methods and detailing antibiotic pollution pathways and resistance formation, is under review for publication shortly.

This study, once completed, will provide an insight into the levels at which antibiotics are consumed, and at which they enter our waters, as well as the relative risk posed by each class and industry. Sensitivity analysis within the model will assist identification of key areas of action to reduce amounts of antibiotics released.

Maria-Pilar Byrne, BSc, MSc

Project Title: Understanding the fate of urease inhibitors in the dairy processing supply chain.

Project Leader: Dr. Tom O' Callaghan (Teagasc)

Academic Supervisor: Prof. Enda Cummins (UCD)

Abstract

One-third of Irish national greenhouse gas emissions are produced as by-products of agricultural activities. Agriculture contributes to almost 90% of Irelands nitrous oxide emissions. The use of ammonium-nitrate based fertilizers, in particular, is associated with the emission of nitrous oxide. Urea is an alternative cheaper source of nitrogen and has much lower nitrous oxide emissions, however, nitrogen losses also occur from urea due to ammonia volatilization, resulting in the production of ammonia gas. Ireland has made various commitments to reduce both nitrous oxide and ammonia emissions, including commitments to the Kyoto and Paris agreements as well as our national clean air strategy. Concurrently, Food Wise 2025 and Origin Green initiatives aim to sustainably increase agricultural production. In recent years protected urea products containing urease inhibitors in particular N-(n-butyl) thiophosphoric triamide (NBPT), have shown promise in mitigating both nitrous oxide and ammonia emissions allowing for both industrial and environmental targets to be achieved. Although there are many benefits associated with the use of urease inhibitors, little is known about their ability to inadvertently enter the food chain, an event which may pose future food safety challenges. This issue was highlighted in 2013 when the nitrogen stabilizer DCD became a residual contaminant in New Zealand dairy products which resulted in food safety and trade reputation issues. There was no maximum residual limit in place for DCD in dairy products at the time. In order to ensure there are no future food safety related issues surrounding NBPT it is necessary to understand the fate of NBPT across the dairy processing supply chain. The objective of this research is to map the potential entry, partitioning and fate of NBPT and other inhibitors and nitrogen stabilizers in the dairy processing chain. This study looks at the behavior and partition of NBPT during centrifugal separation of spiked milk samples. It looks to understand the behavior of NBPT spiked milk samples during thermal processing and the behavior of NBPT spiked milk samples during evaporative concentration processes and to assess the behavior of NBPT spiked concentrated milk samples during stabilization by spray drying. This research could be used to guide regulations and develop maximum residual limits for urease inhibitors and other nitrogen stabilizers to ensure high quality sustainable dairy products while eliminating any potential future food safety issues.

Acknowledgements

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Aishwarya Ray, BSc Biotechnology, MSc

Project Title: Ensuring Food Safety in grass systems using NBPT urea.

Supervisor: Prof. Enda Cummins

Abstract

Urea is one of the most commercially used fertiliser worldwide due to its efficiency and cost effectiveness. However, urea can be lost in the form of gaseous ammonia emissions which could lead to increased greenhouse gas emissions. To minimize ammonia volatilisation losses, urease inhibitors like NBPT (N-(n-butyl) thiophosphoric triamide can be used. NBPT shows potential in helping the EU reach its target of 40% greenhouse gas reduction by 2030. NBPT slows down urea hydrolysis, giving rain water enough time to move urea into the soil thus reducing ammonia gas losses. The objective of the study is to carry out a risk assessment of potential public health implications arising from the consumption of food products derived from livestock grazing pastures that were fertilized with NBPT treated urea. This study aims to assess if pastures treated with NBPT coated urea may lead to any residues of NBPT in foods of animal origin (e.g. milk from grazing cows). The method employed for quantification of NBPT in milk is the probabilistic risk assessment approach. Using Monte Carlo Simulations, multiple exposure scenarios can be modelled to result in a probability distribution of NBPT in milk. The result from the modelling can then be used to quantify any potential risk to humans from consuming NBPT through milk (risk characterization). This can then guide risk management strategies if any potential for risk exists. In the current study, another inhibitor compound called Dicyandiamide (DCD) was used to test the developed model. The results show good prospect for the developed model to be used for NBPT quantification in the food chain. The study is currently in its preliminary stage and data collation for NBPT is ongoing.

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Gopaiah Talari

Project Title: Development of a decision support system (DSS) and white paper to assess the risk from hazards as a result of climate change in food safety

Supervisors: Dr. John O'Brien, Prof. Enda Cummins

Abstract

Technology is being developed to handle vast amounts of complex data from diverse sources and origins. The term "Decision Support Systems (DSS)" refers to computerised multidimensional data management systems that support stakeholders in making use of modern data-driven approaches to identify and solve problems, and to enable enhanced decision making.

Food safety information in the food supply chain is scattered, and interactions between environmental factors and food contamination and foodborne diseases are very complex and dynamic and therefore challenging to predict. Despite the rapid development of food safety monitoring data, current quality assurance tools are insufficient in dealing with the emerging threat of contaminants in the food supply chain.

This project focuses on hazards in the food supply chain, on web-based technologies, and on data mining approaches for food safety. Also, integration of big data and DSS in the food industry, government and regulatory agencies by incorporating predictive models to assess the impact of climate change on process-related contaminants in the food supply chain will be explored.

The project will lead to a White Paper on predictive modelling tools to monitor food chain vulnerability due to the influence of climate change, with a focus on the European dairy industry. This White Paper will be aimed at all stakeholders, providing them with a set of recommendations to ensure food safety and sustainability in production scenarios affected by climate change conditions. The White Paper and DSS will be of particular interest to regulators, industry and policy decision-makers alike and aim to help ensure Europe's sustainable lead position with regard to food production and safety on an international scale.

ASSESSMENT OF NUTRIENT PROVISION IN LONG-TERM EXPERIMENTS ON SOIL CARBON SEQUESTRATION RATES

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Abstract

Soil carbon (C) sequestration is dependent on organic matter (OM) input to the soil. In this preliminary meta-analysis the C-input and nutrient supply in continuous cropping systems on the soil organic carbon (SOC) sequestration rate per year and the total soil C stock is reviewed. The fertiliser management is assessed for its ability to supply adequate ratios of nutrients to stabilise SOC. The results show that SOC sequestration was consistently higher when C-rich inputs were available, the average SOC sequestration rate was 3.77 t/ha/yr compared to the average sequestration rate of 0.58 t/ha/yr from inorganic fertilizer treatments alone. Based on the stiochiometric ratio for stabilised SOC, N deficiencies were evident in most treatments receiving OM inputs. It is proposed that alteration to the N and P supply could increase SOC without further increasing C-inputs in arable land. This would facilitate higher SOC sequestration rates and a shorter time period to build up the soil C stocks in intensive cropping systems.

Introduction

Soil organic carbon plays an important role in food security and has the potential to offset fossil-fuel emissions (Lal *et al.*, 2004). Globally, soils have been estimated to have the potential to increase soil C stocks to the benchmark set by the Paris Agreement of 0.4% per year (Minasny *et al* 2017). Best management practices to increase soil C are based on increasing inputs of organic matter to the soil. However, evidence from long-term studies does not always present positive soil C sequestration over time (Keel *et al* 2019). It is frequently shown that SOC sequestration increases with C-input but the factors influencing the variation in C conversion from organic matter input to stable SOC are not well understood. Kirkby *et al.* (2014) demonstrated that the rate of sequestration of C-rich crop residues into stable SOC is largely controlled by adding supplementary nutrients in a constant stoichiometric ratio (C:N:P:S = 10,000:833:200:143). Organic matter inputs in cropping systems are crop residues remaining in the field post-harvest, applications of organic manures, and green manures grown as fallow crops to increase organic matter inputs and soil fertility between cropping cycles. Harder to calculate and only sometimes estimated are the C-inputs from the growing crop in litter fall or root turnover. Data from long-term studies show treatments with applications of organic matter (FYM, green manure, compost, straw) as part of the agronomic fertilizer (NPK) are optimal to increase the SOC sequestration rate in the soil (Hua *et al* 2014; Zhang *et al* 2016). However, nutrient supply is rarely considered as a factor controlling C conversion between treatments.

The objective of this study is to investigate (i) the SOC sequestration rates associated with combined applications of organic and inorganic fertilizer, (ii) the 0.4% C sequestration rate based on total soil C stock and (iii) the nutrient provision compared to the stoichiometric C:N:P.

Material and Methods

Meta-Analysis

In this preliminary meta-analysis data was collected from long-term continuous cropping systems in Asia. Research articles were included in the analysis if they had the following data; c content in organic inputs (mass of C concentration (t/ha)), nitrogen and phosphorus in organic manures and inorganic fertiliser (mass of N & P (kg/ha), rates of inorganic fertiliser application (kg/ha)), initial soil C stock and total C stock (t/ha) as reported in final year of experiment. Experimental detail and reporting of results varied across studies. In particular, nutrient inputs were not the focus of the studies and data was extracted from the text, summary tables and plots as necessary. Data processing was required in order to calculate total C, nitrogen and phosphorus inputs. The following treatments

were selected for inclusion, manure only (C,N,P), inorganic fertiliser only (N,P), combined organic inputs (C,N,P) and combined organic and inorganic fertilizer inputs (C,N,P). Treatments varied widely across studies. Control treatments (receiving no inputs) were not included as the objective here was to examine the SOC sequestration response to C and nutrient inputs only. Soil C stock reported represents length of experiment in years.

Data analysis

The following parameters were calculated; SOC sequestration rate per year (t/ha/yr) = total C stock change (t/ha) /number of years of experiment. The SOC sequestration rate of 0.4% (t/ha) = total C stock (t/ha)/100 x 0.4. The C:N:P ratios are based on total inputs of C, N and P and calculated as N/C and P/C. None of the studies provide data on sulphur to enable C:N:P:S. Potassium is not included in the C:nutrient stoichiometry.

Results and Discussion

Effect of organic matter input on SOC sequestration

The cropping management selected for study as a starting point in meta-analysis on C nutrient supply is continuous cropping, also known as double cropping. This system is fertilised twice with either no fallow or a short fallow period, and therefore there is a more continuous supply of nutrients to the crop residues or other organic amendments. All treatments reviewed report a positive SOC sequestration rate and increasing year-on-year C stock, apart from a single fertiliser treatment (Hai et al., 2014). Long-term application of OM with/without inorganic fertilizer leads to a higher soil C stock (14.85 to 37.27 t/ha) compared to fertilizer only (10.15 to 27.0 t/ha) (Table 1). A trend in increasing C-inputs with increasing C stock is evident across all treatments within individual studies. This trend is enforced by the data collected from Fan et al. (2004) that shows three treatments with equal inputs of N and P increased soil C stock with increased C-inputs (i.e. 3.50, 4.56 and 5.40 t/ha in C-inputs resulted in 15.6, 19.8 and 24.7 t/ha in C stock). There is a departure from this trend in the data from Singh et al. (2014), where the C-inputs (4.2 t/ha) from a FYM + Straw + Fertiliser N treatment fail to increase soil C stock, beyond the FYM + Fertiliser N treatment (2.2 t/ha), a deficit supply in P might explain this, particularly evident here as the fertiliser used was an N-fertiliser only (urea). Higher C-inputs such as the 9.8 t/ha added in the wheat-maize rotation (Gai et al., 2018) were shown to significantly boost the soil C stock (37.27 t/ha in 22 years) by increasing the SOC sequestration rate per year (0.90 t/ha/yr). A weaker relationship between soil C-input and SOC sequestration rate was observed in the metadata (Figure 1), and may be due to a variation in SOC sequestration rate in response to nutrient supply across treatments.

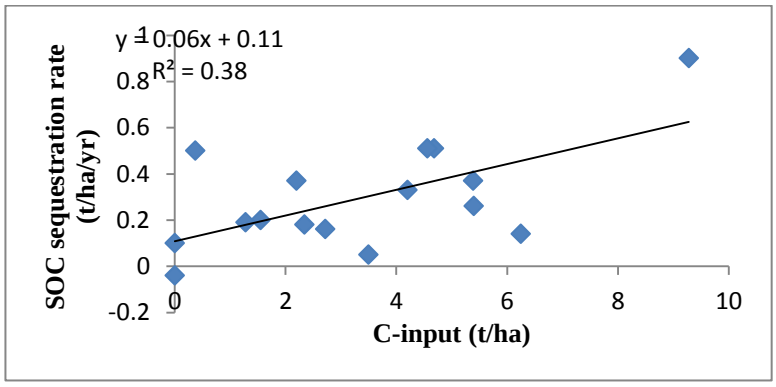

Figure 2: Soil C-input verses (t/ha) SOC sequestration rate (t/ha/yr).

Impact of nutrient supply on SOC sequestration

The range in SOC sequestration rate per year reported here is 0.16 to 0.90 t/ha/yr. This is a considerably higher C stock than the 0.4% rate set by the Paris Agreement across all studies reviewed. This demonstrates that intensive continuous cropping systems have a high SOC sequestration potential.

Table 1: Total C, N and P inputs, SOC sequestration rates and carbon nutrient ratios in continuous cropping systems.

Author	Years	Crops	Fertiliser Treatment	C (t/ha)	N (kg/ha)	P (kg/ha)	C stock (t/ha)	0.4% rate (t/ha)	SOCseq[#] (t/ha/yr)	C:N:P (1.0:0.0833:0.02)	Nutrient provision
Zhang et al. (2016)	30	Wheat-Maize	Fert NP	2.72	352	176	22.40	0.09	0.16	1.0:0.130:0.065	Surplus
			FYM	5.39	352	240	27.60	0.11	0.37	1.0:0.065:0.044	Deficit (N)
Hua et al. (2014)	29	Wheat-Soybean	Fert NP	1.55	180	90	22.74	0.09	0.20	1.0:0.12:0.06	Surplus
			Str + Fert NP	0.37	180	90	31.49	0.13	0.50	1:0.05:0.02	Deficit (N)
			FYM + Fert NP	4.68	249	149.	31.77	0.13	0.51	1:0.05:0.03	Deficit (N)
Hai et al. (2014)	26	Rice-Rice	Fert NP	0	180	90	27.00	0.11	-0.04	NA	NA
			* + Fert NP	6.25	106	60	31.80	0.13	0.14	1:0.02:0.01	Deficit (N,P)
			^ + Fert NP	2.34	106	60	32.70	0.13	0.18	1:0.05:0.03	Deficit (N)
Gai et al. (2018)	22	Wheat-Maize	Fert NP	1.28	305	150	22.39	0.09	0.19	1.0:0.26:0.13	Surplus
			FYM + Fert NP	9.28	675	150	37.27	0.15	0.90	1.0:0.07:0.02	Deficit (N)
Fan et al. (2014)	20	Wheat-Maize	Fert NP	3.50	300	59	15.60	0.06	0.05	1.0:0.09:0.01	Deficit (P)
			Comp + Fert NP	4.56	300	59	19.80	0.08	0.26	1.0:0.09:0.01	Deficit (P)
			Comp + Fert NP	5.40	300	59	24.70	0.10	0.51	1.0:0.09:0.01	Deficit (P)
Singh et al. (2004)	12	Rice-Wheat	Fert N	0	150	0	10.15	0.04	0.10	NA	NA
			FYM + Fert N	2.2	150	35	14.85	0.06	0.37	1.0:0.07:0.02	Deficit (N)
			FYM + Str + Fert N	4.2	176	3.3	14.60	0.06	0.33	1.0:0.4:0.0	Deficit (N,P)

SOCseq, SOC sequestration rate per year; Fert NP, Fertiliser nitrogen & phosphorus; Fert N, Fertiliser nitrogen (urea); Str, Straw; Comp, Compost; FYM, Farm Yard Manure.

*Double rice cycle (GM + FYM + straw), ^Single rice cycle (GM + straw)

[#]SOC sequestration rate is calculated on soil C stock change over reported period (total C stock – initial C stock). This is different to the soil C stock reported (initial C stock + soil C stock change).

The C:N:P calculated shows that further SOC sequestration is impeded by N deficits in organic fertiliser applications or both organic and inorganic fertiliser applications, and to a lesser extent P deficit. Here it is important to note that fertiliser management is designed to meet the crop needs, but it is the ratio of nutrient supply, rather than the total mass that is of interest here for stabilising SOC. Therefore, long term C-input with stoichiometric balanced nutrients presents as a strategy to manipulate the SOC sequestration rate and the proportion of C-input converted to SOC.

Conclusions

This preliminary meta-analysis in continuous cropping systems demonstrates soil C sequestration is largely controlled by total C-inputs. Organic inputs are C-rich and can create a N deficiency in the ideal C:N:P ratios required for stabilising SOC. Altering N and/or P would increase the potential for enhanced SOC sequestration rates without having to increase C-inputs further. Manipulation of the C:N:P ratios to increase the C conversion rate is not widely acknowledged and requires experimental study to show that this is a feasible mechanism to increase soil C stocks.

Acknowledgements

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EVALUATION OF RELATIONSHIP BETWEEN SOIL ORGANIC CARBON AND PHYSICAL SOIL QUALITY PARAMETERS

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Abstract

A preliminary meta-analysis based on long term field experiments was conducted to investigate the quantitative relationship between soil organic carbon (SOC) and physical soil parameters, bulk density (BD), mean weight diameter of soil aggregates (MWD) and soil porosity (φ). Data was collected from topsoils in arable production. Results showed trends between SOC and soil physical soil properties (R^2=0.44, 0.53, 0.24 for BD, MWD, porosity) and variability in the data was assumed to be due to differences in soil type. An annual increase of 0.4% in SOC concentration produced a positive response for all soil properties (-0.0012 g cm^{-3}, +0.0068 mm, +0.0372 % for BD, MWD and porosity). This demonstrates that a quantitative relationship between SOC and soil function exists.

Introduction

Soil quality is the capacity of a soil to function, within ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). A barrier to using soil quality to assess agricultural productivity and sustainability is the lack of a quantitative relationship between soil quality and soil function. Soil organic carbon is a widely acknowledged biochemical indicator of soil quality (Koch *et al*., 2013). However, SOC has declined globally, whereby intensive agricultural practices have led to a depletion of up to 25 to 75% in most soils of the world (Lal, 2013). This has increased the complexity of the soil quality and soil function relationship.

Globally, soils have been estimated to have the potential to build up soil C stocks by a rate of 0.4% per year (Minasny *et al.*, 2017), the benchmark set by the Paris Agreement. However, to incentivise farmers to make adaptations to current soil management necessary to increase soil C stock, it is important to demonstrate the benefit of increased SOC to soil quality. Soil organic carbon is linked to many soil physical, chemical and biological properties (Panakoulia *et al* 2017). Here a preliminary meta-analysis was conducted to collect data on SOC and soil physical properties from long-term experiments to produce a global dataset.

The objective of this study was to (i) determine the quantitative relationship between soil organic carbon and individual physical soil quality parameters and (ii) demonstrate the impact of annual SOC sequestration at the 0.4% rate on physical soil quality parameters.

Materials and Methods

Data collection
Data was compiled from a range of long-term experiments in arable production to produce a global dataset. Treatments considered were fertilizer and manure application, tillage practice (zero, minimum, conventional), crop rotation and mulching. Data from topsoil (variable depths from 0 to 30 cm) was included. The long-term studies included are given in supplementary Table 2.

Relationship between soil organic carbon and soil physical parameters

Soil physical parameters included in the study are BD (g cm^{-3}), MWD (mm), and φ (%). Bulk density is an indicator of soil compaction, MWD is used to measure aggregate stability and porosity is the total soil volume that can be filled by water and/or air. The relationship between SOC and each soil physical parameter was plotted. The 0.4% SOC sequestration rate was calculated to establish the rate of change of soil physical parameters in the global dataset.

Results and Discussion

Relationship between soil organic carbon and physical soil parameters

The SOC concentration range was 2.7 to 41.2 g kg^{-1} for BD and porosity and 2.7 to 52.6 g kg^{-1} for MWD. The low range of SOC values observed is particularly low for agricultural soils, considering the threshold for agricultural production is ~ 20 g kg^{-1}. Low values of SOC (< 20 g kg^{-1}) were found in all of the countries among which lowest values were from India followed by China. The relationships between SOC and physical soil properties demonstrate that physical soil properties respond to increases in the SOC concentration. A negative correlation was observed between SOC and BD (R^2 = 0.43, Figure 1). A positive correlation was observed between SOC and MWD of soil aggregates (R^2 = 0.53) and between SOC and soil porosity (R^2 = 0.24). The variability in each plot is attributed primarily to differences in soil types.

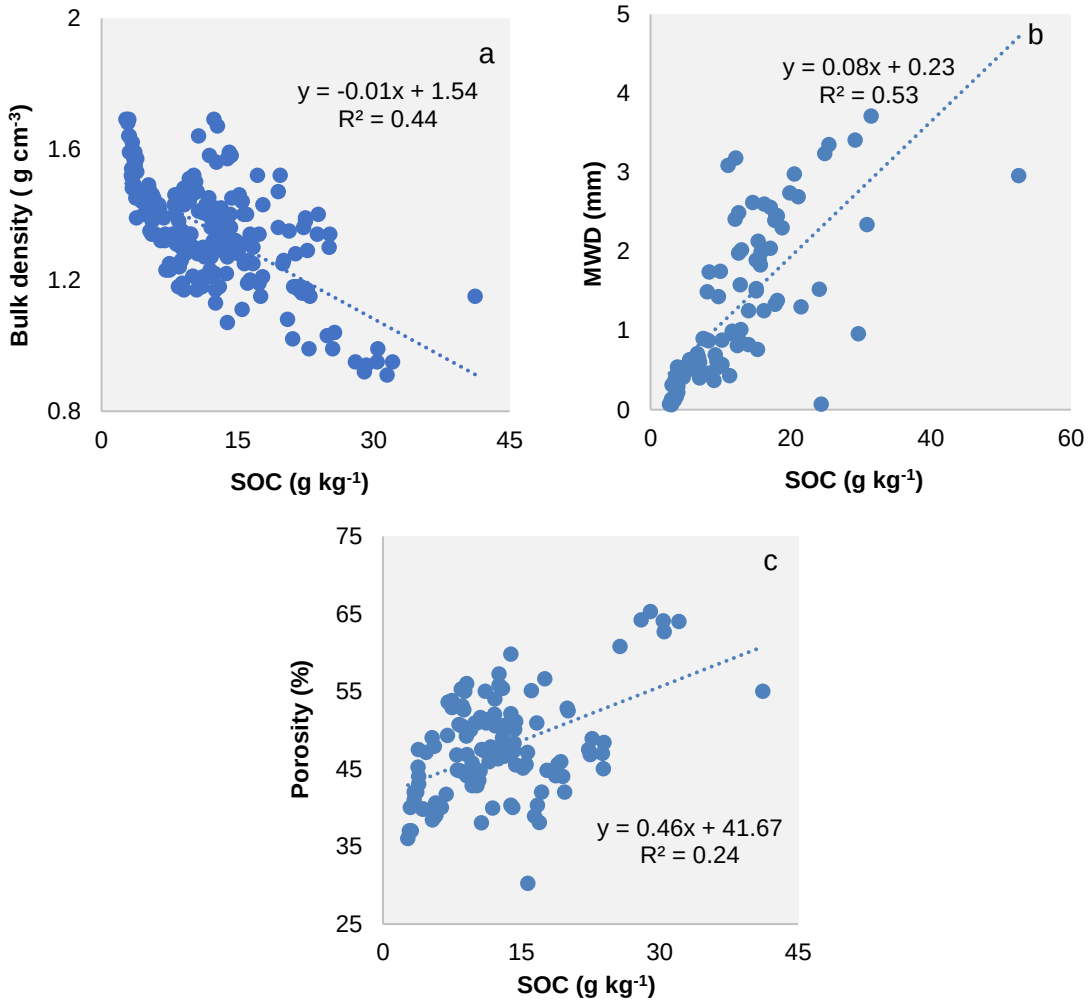

Figure 1. Relationship of soil organic carbon concentration with (a) bulk density, (b) mean weight diameter of aggregates and (c) porosity.

Impact of increasing soil organic carbon on soil physical parameters

Soil organic carbon is found to decrease the BD and increase porosity of soils by enhancing biological activities (Zhangliu et al 2009; Xin et al 2016) and improving soil aggregation (Rasool et al 2008). Improved MWD by SOC is attributed to production of binding agents by promoting microbial activities (Brar et al 2015) and aggregates stabilization (Rasool et al 2008). Here, the 0.4% SOC sequestration rate was calculated on concentration rather than soil C stock. This serves to demonstrate the effect of a unit increase in SOC concentration on soil properties. The rates of change in physical soil properties per annum if a 0.4% increase in SOC concentration is achieved are given in Table 1.

Table 1. Impact of 0.4% annual increase in SOC on soil physical properties.

	Initial SOC (20.00 g kg^{-1})	SOC + 0.4% (20.08 g kg^{-1})	Difference
BD (g cm^{-3})	1.23	1.23	-0.0012
MWD (mm)	1.94	1.94	+0.0068
φ (%)	50.96	51.00	+0.0372

Conclusions

In this preliminary meta-analysis on a global dataset, the quantitative relationship between SOC and BD, aggregate MWD and soil porosity was established. A unit increase in SOC concentration of 0.4% positively changed BD, aggregate MWD and soil porosity. Experimental study on different soil types is required to examine the dynamic change in soil properties as a result of increasing soil C stock over time. This will produce more accurate data to estimate the time required to make a target change in physical soil function possible.

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Supplementary data

Table 2. Location of long-term experiments used in the meta-analysis.

Literature sources	Location
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Riley et al. (2008) *Agric Ecosyt Environ* 124(3), 275-284.	Norway
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SUSTAINABLE BIOMASS SUPPLY CHAIN DEVELOPMENT FOR THE IRISH BIOECONOMY

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Abstract

Europe's agriculture sector is facing a sustainability crisis due to the combined challenges of depleting fossil resources and increasing environmental pressures through waste generation (700 million tonnes/yr). Currently, in Ireland the agricultural sector is the major contributor to the overall greenhouse emissions, accounting for 30% of the total emissions. Therefore, this emphasizes that a sustainable approach is required for agriculture, adopting resource efficiency measures that can deliver cost savings and environmental benefits.One of the aims of this project is seeking the potential availability of agricultural waste in Ireland to meet the needs of the developing bioeconomy and improve the development of agricultural waste valorisation value chains. Furthermore, this project incorporates Geographic Information Systems (GIS) through the development of a spatial database that includes the Irish transportation network. This will bring a more realistic calculation of environmental burdens from agri-waste valorisation paths. Optimisation of the supply chain will also benefit from the spatial database, especially regarding the determination of location and size of the new processing plants, and biomass mobilisation aspects such as biomass transportation routes, collection and allocation planning.

Introduction

The considerable increase in energy demand, food and material unsustainable consumption and production, and anthropogenic wastes generation are the major issues that world is facing these days besides climate change. According to World Resources Institution (https://www.wri.org/), the planet population will be 9.6 billion people by 2050, consuming the equivalent of 1.6 planet's resources, with a consequent high amount of wastes generated. Results of the unsustainable consumption and production patterns are resource depletion, climate change, air and water pollution, loss of biodiversity and of fertile soil, amongst other environmental, social, and economic challenges. (Zabaniotou and Kamaterou, 2019). A new approach to sustainability has been proposed in Europe. This encompasses the bioconomy model, as a pathway to involve with challenges of sustainable production and consumption. (Maina et al., 2017). Bioeconomy is the generation of renewable biological resources and try to valorize these resources and convert them to food, animal feed, bio-based products, and bioenergy (European Commission, 2012). Irish agricultural sector has a great impact, and its effect on holding social, cultural, and economic relevance in the nation's past, present, and future, cannot be denied. Currently agriculture affects employment rates and national gross domestic product (GDP), improving the most considerable output multiplier effect compared to any other industry in Ireland (Phelan and O'Connell, 2011). Its economic effect on local scale is also increasingly recognized which supports rural development and livelihoods (DAFM, 2015).

The objective of this study are characterisation of the available agricultural waste biomass and development a supply chain management model and solve the model.

Materials and Methods

The project will innovatively incorporate Geographic Information Systems, Operations Research and Life Cycle Assessment methodologies. This approach will provide new insights on the environmental sustainability of emerging valorisation pathways and will allow optimization of the use of bioresources in Ireland. The project will increase the competitiveness of Irish bio-based businesses by presenting

strategies for transforming waste into high value, low carbon products, and will contribute to transition towards a green economy while enhancing the environment at a global scale through reduction of carbon emissions.

Life Cycle Assessment (LCA)

LCA (Life cycle assessment) is a powerful tool which assesses sustainability and also can be applied to analyze the environmental effects of biomass-to-energy systems over the whole life cycle; from biomass production, processing, and transportation, to combustion (Jungbluth, 2012). Recently, studies consider not only economic aspects but also the carbon footprint when planning activities within the supply chain. Nevertheless, no studies currently exist linking LCA with spatial optimisation methods for the supply chain of agricultural waste and its potential valorisation paths.

Geographic Information Systems (GIS)

GIS is generally a computational tool to manage detailed and large scale geographical data. Combination of land suitability evaluation and multi attribute decision analysis tools have been used for the aim of land planning in recent studies. Also, GIS is applied for finding the best location of candidate plants, storage, and preprocessing sites along with the land characteristics of croplands. Moreover, a novel multi-objective integrated model will be proposed to simultaneously minimize the total cost of supply chain and maximize the efficiency waste management (Rahemi, 2020).

Supply Chain Planning

Harland (1995) defines supply chain management as managing business activities and relationships (1) internally within an organization, (2) with immediate suppliers, (3) with first and second-tier suppliers and customers along the supply chain, and (4) with the entire supply chain. Scott and Westbrook (1991) and New and Payne (1995) describe supply chain management as the chain linking each element of the manufacturing and supply process from raw materials through to the end user, encompassing several organizational boundaries (Tan, 2001).

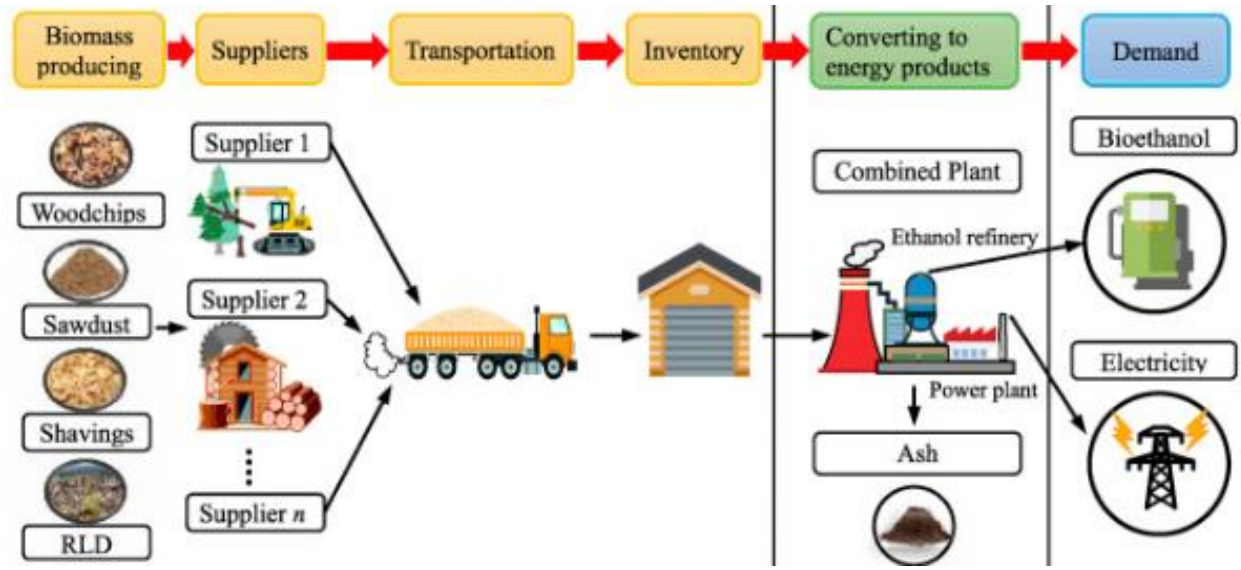

Figure 1: Biomass supply chain

Conclusion

The methodologies applied in this research will provide well-planned supply chains that reduce cost and environmental pressures. The outputs from this research will contribute to the development of biomass management strategies and guidelines, this will address the current gaps in knowledge, will pave the way towards the targets of circular economy in the agricultural sector, and unlock a sustainable resource base for the growing Irish bioeconomy. The solutions from this research will be based on requirements that are tailored for Irish scenarios. Constraints introduced by the seasonality of biological waste streams will be tackled by embracing a multi-biomass approach for better valorisation. In addition, the potential valorisation paths will be driven not only by the sustainable availability of biomass feedstock, but also by the physical-chemical characteristics of the agricultural waste.

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VALORIZATION OF FOOD WASTE IS KEY IN CIRCULAR ECONOMY

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Abstract

Industrial food waste management is one of the main challenges to overcome to ensure a sustainable environment. This calls for a need to minimise waste or use waste as a resource through the concept of valorisation of food waste to produce additional value-added products and developing new sustainable value chains to move towards establishing circular economy. This study is a quantitative analysis and characterisation of food waste arising in food industries from County Monaghan, Ireland. Alternative food waste valorisation opportunities will be proposed, followed by studying the resulting impact on the environment. The objectives of the study are; 1) collection of food waste data for Monaghan food industries, 2) identification of potential food waste valorisation processes, and 3) estimation of the resulting environmental impacts using Life Cycle Assessment (LCA) methodology.

Introduction

Climate change, increased urbanization and population growth has affected developing and developed countries in several ways. One such consequence has been for food production, as high population has high energy and goods demand, leading to increasing environmental impacts. This has pressurised the agriculture and farming systems to prevent and minimise food waste, which will impact the energy-environment nexus (Imbert 2017). Food and Agriculture Organization (FAO) of the United Nations has estimated that more than 1.3 billion tonnes of food are wasted every year (Laso *et al.* 2016). Food waste, a pollutant, arising from various stages of food value chain, significantly contributes to greenhouse gas emissions, particularly methane, when food waste reaches landfill (Dorward 2012). Therefore, utilizing waste streams to address the challenges faced by energy and agriculture sector in Ireland is key to moderating greenhouse gas (GHG) emissions. This can be done by producing bioenergy and bio-products from waste material generated during primary and secondary processing of food products, to offset the use of fossil-based products. This approach will help meet Ireland's energy target of 16% from biomass (Sustainable Energy Authority of Ireland 2017), implying a need to visualise negative-valued waste as a potential renewable stock (Garcia-Garcia *et al.* 2019).

Implementing valorisation techniques has proved to be a strong contender, as compared to the practice of landfilling or incinerating waste. Despite the increased levels of waste, the landfilling rate has dropped from 63.8% in 1995 to 25.3% in 2015 (Garcia-Garcia *et al.* 2019). For example, "the recovery of organic material by composting has grown with an average annual rate of 5.4 % from 1995 to 2015" (Imbert 2017). Valorisation practices are aimed at increasing feedstock supply to produce energy, goods and providing socio-economic and environmental benefits (Imbert 2017).

From the environmental standpoint, the sustainability of alternative food waste valorisation techniques can be evaluated using Life Cycle Assessment (LCA); an effective decision-making tool which provides evidence for the impacts of these valorisation techniques (Garcia-Garcia *et al.* 2019). This study is a quantitative analysis and characterisation of food waste arising in food industries from County Monaghan, Ireland. Alternative food waste valorisation opportunities will be proposed, followed by studying the resulting impact on the environment.

The objectives of the study are 1) collection of food waste data for Monaghan food industries, 2) identification of potential food waste valorisation processes, and 3) estimation of the resulting environmental impact using LCA methodology.

New Waste Framework in European Union (EU)

The EU directive (2008/98/EC) outlines, the policies for waste management, which is based on the concept of waste hierarchy, prioritizing reuse and recycle. Generally, incineration is the choice when dealing with biowaste. However, this reduces the opportunity to extract valuable bioproducts and bio-energy (European Commission 2014). In 2014, the EU introduced the concept of circular economy with the slogan of "take, make and dispose", to encourage circular resource management approach (European Commission 2014). The proposal is to recycle and reuse 70% of the biowaste material, thereby reducing landfill. This was to replace the linear economy, thus transitioning to a circular economy. Valorisation plays a key role in establishing circular economy in the food sector, by integrating bio-based industries and valorising the whole biomass with the application of various technologies (Blikra *et al.* 2018).

Meat Industry

Most of the waste in the meat industry is generated during slaughtering (Bujak 2015). The composition of waste is skin, blood, bones, tendons and visceral organs. The decomposition of meat waste is difficult; hence their processing is required. According to Commission Regulation (EU) No. 142/2011, the residues from the meat industry are regarded as low-risk materials. They need to be converted to safe materials prior to their transportation and storage. The directive has also mentioned the specification for the same. A survey estimates that beef and pork share about 11.4% and 7.5% of the total revenue coming from the by-products respectively (Bujak 2015; Ghosh *et al.* 2019).

Efficient use of by-products from the meat industry enhances the economy of the country. This might also result in controlling of environmental pollution. On one hand, many countries have limited the use of meat by products due to safety and hygiene issues. On the other hand, waste from the meat industry have the potential to be recycled and converted to useful products of high biological value (Ghosh *et al.* 2019). One such approach of utilising waste from the meat industry is shown in figure 1.

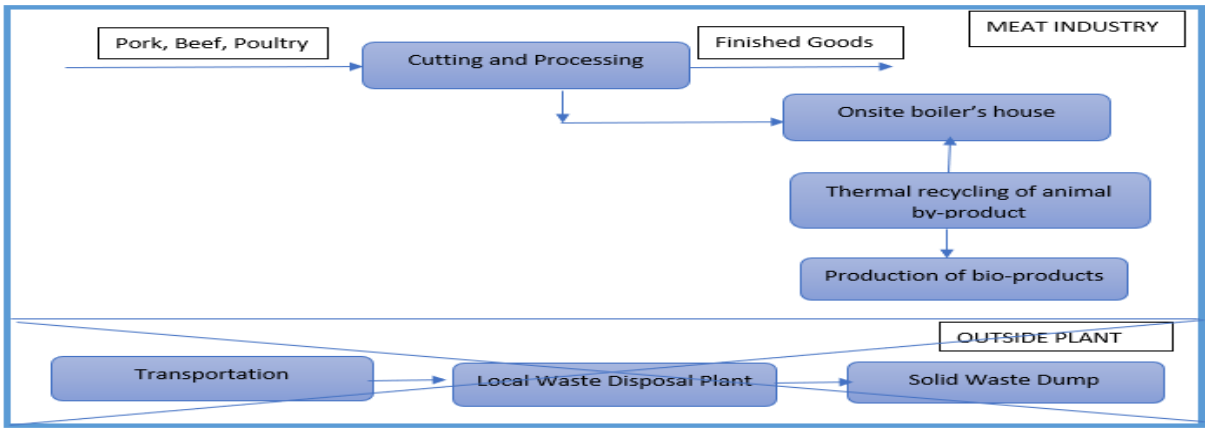

Figure 1. Suggested approach for utilising waste from the meat industry.

Fruit and Vegetable Industry

In Europe, the waste produced during the different stages of fruit and vegetable supply chain is distributed as follows: agricultural production (20%), postharvest handling and storage (5%), processing and packaging (2%), distribution (10% for fresh fruits and 2% for processed fruits) and consumption (19% for fresh fruits and 15% for processed fruits) (Verma *et al.* 2019). Thus, the high quantity of waste produced calls for the development of the biorefinery concept for valorising the non-preventable wastes. In County Monaghan, the predominant fruits and vegetable industry is that of mushrooms. This study will thus focus on waste streams generated from the mushroom industry. Mushrooms represents a 63 billion US dollar market in year 2013. The consumption of mushrooms is growing annually, resulting in sales growth (Grimm and Wösten 2018). Spent mushroom substrate (SMS) is available in huge amounts, 1 kg of fresh mushrooms results in 5 kg of spent substrate (i.e., 2

kg dry weight). Thus, making SMS a potential source for producing bio-based products, e.g. compost. It can also be used to extract enzymes for industries/bioremediation (Grimm and Wösten 2018).

Dairy Industry

Dairy industries consume significant volumes of water in food industries; the water requirement for the production of one litre of processed milk is 2-5 L of water, inclusive of cleaning and washing operations (Arvanitoyannis and Giakoundis 2006). Dairy wastewater consists of high organic content such as fats, proteins and carbohydrates. Releasing this wastewater into water-bodies leads to eutrophication. Moreover, the wastewater produced from cleaning in place (CIP), consisting of surfactants and detergents also cause toxicity to the marine life. One of the approaches to reduce wastewater is to establish pre-treatment strategies such as wetlands; a promising technique where aerobic and anaerobic digestion breaks down organic materials (Arvanitoyannis and Giakoundis 2006). In County Monaghan, a benchmarking exercise for energy consumed in the production of 1 litre of milk conducted in 2007 was 0.074 kWh (Carty 2010).

Poultry Industry

Waste produced from the poultry industry comprises of empty shells, infertile eggs, dead embryos from late hatchings, dead chickens, a viscous liquid from eggs, decaying tissue and waste water. A high protein waste with 43–71% moisture is generated from hatcheries and dried waste containing 28.8 MJ/kg of gross energy. (Glatz *et al.* 2011). Apparent metabolizable energy (AME) of the hatchery waste by-product meal is 23.9 MJ/kg and the apparent amino acid availability of the hatchery waste by-product meal is 73.5% (Glatz *et al.* 2011). This gives a huge opportunity to develop high protein feedstock, organic fertiliser or other valued products.

Methodology

The structure of this research project can be divided in four steps. At first, characterisation and quantification of waste streams arising from food industries in county Monaghan will be done. A short summary for the same is explained in table 1.

Table 1. Companies in county Monaghan, with their major food product and potential waste streams.

Major Food product	Name of the Company	Potential Waste Streams
Fresh & Packaged Mushrooms	Monaghan Mushrooms Ireland Tyholland Co., Gold Circle Mushrooms	Spent mushroom substrate, Small stubs, stalks of mushrooms after harvest, Deformed mushrooms
Beef	Liffey Meats Ltd. ABP Food Group, Mallon Sausage, Kepak, Rangeland Foods Ltd, Katie McCaghey Poultry Processing	Skin, bones, blood, gastro-intestinal tract, tendon and visceral organs, waste water containing organic and inorganic fixed Phosphorous.
Pork	Mallon Sausage, Katie McCaghey Poultry Processing	
Chicken	Katie McCaghey Poultry Processing	
Lamb	ABP Food Group, Katie McCaghey Poultry Processing	Wool, bones, horns, hooves and waste water containing Phosphorous.
Duck	Silver Hill Foods	Skin, bones, blood, beak and waste water
Egg	The Nest Box Egg Company	Shells, Infertile eggs, viscous egg liquid and waste water.
Dairy	Lakeland Dairies	Dairy Waste Water containing organic components as well as toxins from detergents and surfactants.

The next step is to develop a preliminary value chain by quantifying the waste, collecting data for different waste streams from the industries itself. This is followed by collecting and grouping the valorisation techniques based on characterisation of the wastes. Finally, the last step is to model a full life cycle assessment of valorisation technologies, to assess the environmental impact of the system.

Conclusion

The demand for energy, food, and goods has been ever increasing because of population growth, but the resources are limited. The production of food waste is approximately 1.3 billion tonnes a year (Laso *et al.* 2016). Considering the implications on food security, economic status and environmental impact, food waste needs to be tackled at every stage of food supply chain. According to United nations (UN) 2030 target of achieving sustainable development goals and European Commission 2015, for adopting the circular economy strategy contributes towards the goal of zero waste.

Overall, the bio-economy and the circular economic model represent a great opportunity for tackling the food waste issue. This is true in case of medium-high income countries where the bulk of the problem is associated with overconsumption behaviours occurring at the end of the food supply chain. However, this transition needs to be accompanied by public policies. Demand and supply side polices are crucial for pushing out emerging sectors such as the bio-economy. In recent years there has been an increased interest in the policy mix for promoting sustainability transitions. This type of approach can provide guidance to policy makers ensuring the basis for a further development of the sector.

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Maneesh Kumar Mediboyina, B.Tech, M.Tech

Project Title: Life cycle assessment of integrated biorefinery for conversion of dairy side streams to high value bio-based chemicals

Project Leaders: Nicholas Holden & Fionnuala Murphy

Abstract

Currently, dairy side streams (DSS) pose a significant challenge associated with its disposal, due its higher organic content and lack of credible disposal routes. To address the challenges, AgriChemWhey project seeks to build a world's first integrated biorefinery to transform these residues to establish sustainable bio-based products. The main purpose of the current study was to evaluate the environmental performance of the existing AgriChemWhey pilot scale biorefinery process that converts the dairy side streams (DSS) i.e., WP (Whey permeate) and DLP (Delactose permeate) to lactic acid (LA). To do this, life cycle assessment (LCA) was performed for the current system in compliance with the definition of ISO 14044:2006 involving three main phases i.e., goal and scope, life cycle inventory and life cycle impact assessment. The goal of the study was to develop LCA model based on mass flows for assessing the environmental effects of producing LA from DSS using a biorefinery approach. The functional unit was considered as 1 kg LA production from DSS. The system boundary was considered as "gate to gate" entails the feedstock (WP and DLP) reception at processing plant gate to exit of LA from the biorefinery gate. The modelling of LA production process was purely based on real time mass flow data of pilot scale trails, which was collected during a period of 12 months (January 2019 to January 2020). Moreover, the environmental impacts (Global warming potential (GWP), Acidification potential (AP), human toxicity potential (HTP) and Marine aquatic ecotoxicity potential (MAETP) were evaluated using OpenLCA as a software tool.

The LCA results indicate that among all the processes involved, acidification is the energy intensive process followed by fermentation. It was mainly due to the usage of higher quantity of sulphuric acid (H_2SO_4) which accounts to 42% of total raw materials used. Furthermore, the energy demand for H_2SO_4 production (7.12 MJ/ kg H_2SO_4) was higher than other major raw materials (3.07 MJ/ kg $Ca(OH)_2$) used in the LA production process. However, the GWP was found to be higher for fermentation than acidification, which can be attributed to the consumption of calcium hydroxide ($Ca(OH)_2$) as neutralizer in fermentation and its associated higher GWP (0.92 kg CO_2 eq/ kg $Ca(OH)_2$) than H_2SO_4 (0.208 kg CO_2 eq/ kg H_2SO_4). Though the GWP was lower for acidification, its contribution for MAETP and HTP was higher, due to the greater toxicity levels of the H_2SO_4. An interesting finding from this study was reduced impact (GWP) of yeast usage in the process. It was found that the yeast production involves the carbon credit from sugarcane as the yeast was grown in molasses generated from sugarcane industry (Ecoinvent v3.5). This study concludes that usage of yeast and H_2SO_4 makes process energy intensive but contributes less to GWP, whereas usage of $Ca(OH)_2$ has contrasting impacts on the process. Therefore, rational utilization of chemicals and exploring alternative raw materials with lower emissions would mitigate the overall emissions from the current process.

Tenzin Tashi, BE, MSc

Project Title: Process Model and Life Cycle Assessment of Irish butter and Fat-filled Milk Powder

Project Leader: Prof. Nicholas M. Holden

Abstract

Sustainable manufacturing of dairy product is of global importance. Ireland dairy processors faced immense challenges as Ireland's milk production system is a seasonal based resulting in milk composition and total milk production volume being varied throughout the year. Eventually, this caused a dairy unit processes to run inefficiently. Moreover, at dairy factory, energy and water consumption data for unit process was monitored collectively which further caused difficulty in capturing the process efficiency. Therefore, the objective of this project was to develop a unit process simulation model considering factors such as operating conditions and thermophysical properties of the milk components to bridge the data gaps and then to conduct a gate-to-gate LCA to calculate the carbon footprint for Butter and Fat-filled milk powder (FFMP). A commercial simulation software (SuperPro Designer) was used to model a butter and FFMP production process for Irish dairy plant processing an annual milk volume of about 310 million litres. A combination of locally sourced woodchip and heavy fuel oil were used as a fuel for boiler to produce steam. Evaporation and spray drying unit operation stages were the most energy intensive processes accounting for about 80 - 85 % of the total thermal energy usage. The substitution of milk fat with a vegetable fat (palm oil) with 28-30% composition in the FFMP contributed about 44 % towards the total carbon footprint. The substitution of milk fat with vegetable fat and energy consumption during spray drying unit operation were the hotspot in the FFMP manufacturing process. For butter, electricity consumption was the major contributing factor for the carbon footprint.

Life cycle assessment is a great technique to identify the hotspot in the process, however, if it is combined with the process model, It can provide a deeper insight into how the product was made and highlights the process energy improvement option. Using both models can benefit the dairy processors in making an environmentally conscious sustainable decision to reduce the carbon footprint.

Appendix 1

(Research projects in progress which have not been included in the Research Review)

Dolowy P., McDonnell K. The effect of tillage and traffic systems on soil conditions and crop performance (**PhD**). Science Foundation Ireland (SFI)

Dunne K, Holden NM, Daly K. Prediction of phosphorus sorption capacity in agricultural soils using DRIFT spectroscopy (**PhD**). Teagasc Walsh Fellowship Scheme.

Goh B.B., Holden N. Remote Sensing of Winter Wheat (**PhD**). Science Foundation Ireland (SFI)

Herron J, Moloney A, Curran T. A preliminary review of management factors affecting nitrous oxide emissions from livestock systems (**PhD**). Teagasc Walsh Fellowship Scheme.

Marajas I.R., Holden N. Proximal sensing of soil properties for nitrogen use efficiency improvement (**PhD**). Science Foundation Ireland (SFI)

Shaikh S, Zhao M, O'Donnell C. Development of PAT tools for the quantitative analysis of minerals in infant formulas (**PhD**). IRC post graduate scholarship programme .

Sparks T, McDonnell K, Murphy C. Biosensors for Green Biorefineries (**PhD**) European Commission.

Stanley S, Crickley S, Curran T. Impact of european and irish legislation on the design of dairy wastewater treatment processes (**MSc Res**). Irish Research Council Employment Based Postgraduate Scheme in collaboration with WEW Engineering Ltd.

Vinagre-Sendino J, Curran T, Crickley S. Preliminary sewage sludge inventory and compilation (**PhD**). Irish Research Council Employment Based Postgraduate Scheme in collaboration with WEW Engineering Ltd.

Zhang L, Grace P. Preliminary studies on sorption isotherms of apples and pear at 25°C (**PhD**). China Scholarship Council (CSC) and University College Dublin (UCD).

Appendix 2

Profiles of Postdoctoral Research Scholars only includes: Drs, Mariateresa Ferone, Rosanna Kleemann, Anastasia Ktenioudaki, Sindhuraj Mukherjee, Rebecca L. Whetton and Junli Xu,

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Mariateresa Ferone, MSc, PhD

Project Title: HyperMicroMacro: Multi-scale hyperspectral imaging for enhanced understanding and control of food microbiology

Project Leader: Professor Aoife Gowen, Dr. Amalia Scannell

Abstract
Recent developments in hardware have made it possible to obtain macroscopic HSI data using rapid, low cost hand-held systems which have the potential to vastly improve the food industry's ability to rapidly identify contamination along the processing chain. However, this potential is hampered by two key challenges. Firstly, there is a lack of knowledge of the underlying biochemical reactions resulting in changes in spectra of contaminated foods that occur at the macroscopic level. This makes it difficult to separate changes in the spectra due to natural senescence from those due to microbial growth. Secondly, there is no existing methodology to link microscopic, mesoscopic and macroscopic HSI of bacterial colonies.
HyperMicroMacro addresses critical gaps in our knowledge of food safety by developing new understanding of the growth and persistence of bacteria, spores and biofilms on surfaces using hyperspectral imaging at multiple spatial scales (from microscopic to macroscopic) and spectral modalities (e.g. Raman, IR and Fluorescence) combined with microbial characterization and high throughput sequencing. This approach will provide new insights on the persistence of food related microorganisms and their behaviour on foods and other surfaces.

Background, Skills & Qualifications
I have completed BSc (2011) MSc (2014) and PhD (2018) in Industrial Biotechnology at University of Naples "Federico II", Italy. My PhD thesis addressed the issue of increase the competitiveness of the microbial succinic acid production by two different strategies: 1- the utilization of low-cost, non-food-based feedstock (i.e. lignocellulosic biomass and industrial waste streams); 2- bioreactor design and optimization. During my PhD, I acquired skills and competences about microorganism cultivations (both aerobic and anaerobic), design and set up of different reactor types and operation conditions, different analytical techniques (HPLC, GC, TOC/TN, etc.) and data analysis.
Currently, I work in School of Biosystems Engineering, UCD, as a postdoctoral researcher in food microbiology under the guidance of Prof. Gowen and Dr. Scannell.

Publications
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Rosanna Kleemann, BA BAI MSc EngD

Project Title: Agri Bio Circular (ABC) Economy

Project Leader: Assistant Prof. Fionnuala Murphy

Abstract

Ireland is required to reduce GHG emissions by 30% on 2005 levels by 2030, but measures to achieve this target are expected to be insufficient. Agriculture currently accounts for 33% of Ireland's GHG emissions and is projected to increase to due to the removal of milk quotas and expanding animal herd numbers. Agri Bio Circular (ABC) Economy aims to reduce GHG emissions in Ireland by developing sustainable value chains based on cascading use of biomass to create bio-based products and generate energy. ABC Economy is focused on the valorisation of biomasses arising in two Irish counties - Monaghan and Tipperary.

ABC Economy quantifies and characterises the biomass available for valorisation arising from farming, forestry, and food production in each county. A review of valorisation technologies is then conducted with input from stakeholder workshops to ensure each solution's applicability to rural Ireland. Finally, a full supply chain sustainability analysis will be conducted to examine synergies and trade-offs between using biomass for energy generation and biobased products. This will highlight possibilities to minimise trade-offs by considering the impacts of circular economy principles and cascading systems.

Manure/litter from livestock and poultry is the most significant biomass available in each county, with ~209kt and ~873kt manure available in a best-case scenario for Monaghan and Tipperary, respectively. This is due to the high amounts of livestock and poultry in each county and their relative manure production. Crop biomass (straw and mushroom) is the next most significant amount of biomass available for valorisation with approximately 30kt and 19kt available in Monaghan and Tipperary, respectively. Spent mushroom compost and mushroom offcuts make up the bulk of biomass available in Monaghan due to the large focus on mushroom growing here. Forestry coverage in Monaghan (approx. 5% coverage) is well below the national average (11%) and has ~1kt biomass available for valorisation. This compares to Tipperary which is slightly above the national average at 12% coverage and has ~11kt forestry biomass available for valorisation. The key difference in the total biomass available lies in the focus on livestock rearing in Tipperary, compared to poultry farming in Monaghan.

ABC Economy aims to ensure agricultural, forestry, and food production biomasses are collected and utilised in a sustainable manner, i.e. sufficient quantities to be economically feasible whilst also ensuring no adverse impacts caused on the environment by its removal. A cascading system of biomass use through suitable technologies can ensure maximum value is derived from biomass whilst reducing adverse environmental impacts. With regards social sustainability, ABC Economy engages with stakeholders to develop sustainable value chains which are relevant for the local bioeconomies of Monaghan and Tipperary.

Publications

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Anastasia Ktenioudaki, BSc, MSc, PhD

Project Title: A real-time forecast decision support system for the food supply chain (FreshProof)

Project Leader: Professor Colm O'Donnell

Abstract

Reducing food waste has the potential to address current worldwide food security challenge faced by the uncertainty of meeting future food demand for an increasing population. The project focuses on an innovative systems approach to address existing food supply chain waste and shortcomings in food safety, integrity and traceability. The main objective of this project is to develop a cloud based forecast decision support system to deliver real-time food product shelf-life prediction along the farm-consumer supply chain. The experimental work took place in Florida, USA, where strawberry harvest occurs between late November to mid-March. Harvested strawberries were subjected to lab simulated shelf-life assessment including multiple temperature scenarios. Shelf-life was determined across a series of quality, nutritional and microbial parameters. Also, a hyperspectral camera was employed to explore the potential of predicting shelf-life using hyperspectral imaging technology. Arising from this work a dataset was built consisting of quality and spectral data measurements that determine the shelf- life of strawberries. Data on critical environmental conditions in the field and during processing and distribution of fresh fruit and vegetables, were collected and merged with data on fruit quality attributes, nutritional value, and shelf-life performance. Preliminary analysis of the results established a link between environmental conditions during harvest and shelf-life of strawberries as estimated by weight loss, appearance, and microbial count during eight days of storage. Increased rainfall and high temperatures during harvest led to shorter shelf-life with strawberries exposed to simulated supply chain conditions being the most negatively affected. Further analysis of the results will aim at identifying further shelf-life limiting factors and building shelf-life prediction models. It is envisaged that the results of this study will provide new insights on how fruit quality attributes are impacted along the supply chain. By integrating multiple environmental, quality, safety, and nutritional parameters of perishable food products into a single decision support tool will support smart agri-food supply and sustainability in food systems. It will enable stakeholders make informed decisions concerning required actions to prevent product, quality, and monetary losses.

Publications

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Sindhuraj Mukherjee, Ph.D.

Project Title: Automation of Agrochemical Product Development

Project Leader: Professor Aoife Gowen

Abstract

Quantification of multiple chemical components in complex agrochemical formulations is a challenging task and cannot be chromatographically separated to allow the use of standard quantitation techniques that are effective for baseline separated peaks. Currently this quantitative step is highly resource intensive and requires multiple iterative steps to prepare different combinations of the complex components together with a visual comparison of the chromatographic profile of the product being analysed with the profiles of the various synthetic blends. Simple deconvolution of chemical peaks is not easily achieved due to co-elution and is further complicated with multivariate data sets. The use of multivariate calibration models, to deal with complex multidimensional datasets (e.g. infrared, Raman, NMR and mass spectra) is seen as having excellent potential for this application.

This project will eventually combine an automated sample preparation unit together with a design of experiments (DoE) and chemometrics to prepare and evaluate the resultant chromatographic data which will allow a more automated, rapid and accurate determination of the composition of complex formulations.

Background, Skills & Qualifications

I completed my PhD at the UCD School of Biosystems and Food Engineering, specialising in the development and validation of protocols for hyperspectral imaging, specifically for studying interactions between polymeric surfaces and water. I also learnt to apply and adapt chemometric and experimental strategies to evaluate and manage the multidimensional data generated from the experiments leading to insight of molecular level processes. Before that, I received my Bachelor's and Master's degree in Biotechnology specialising in the application of hyperspectral imaging on complex food matrices for calorie intake estimation.

Publications

Mukherjee, S., Martinez-Gonzalez, J. and Gowen, A. (2019). Feasibility of attenuated total reflection-fourier transform infrared (ATR-FTIR) chemical imaging and partial least squares regression (PLSR) to predict protein adhesion on polymeric surfaces. *The Analyst*, 144(5), pp.1535-1545.

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Rebecca L. Whetton, PhD

Project Title: Crop Nutrition; limits to yield potential

Project Leader: Prof. Nicholas M. Holden

Abstract

The scientific underpinning for decision support related to nitrogen use efficiency (NUE) for winter wheat crops grown in Europe. NUE is regulated by many factors, both biotic and abiotic, many of which are understood, but their relative priority is not clearly defined.

The first stage of this work was to establish the positive and negative impacts of each interacting factor affecting NUE. This provided an increased understanding of the NUE system for each loss mechanism. Simple graphics were then made for each of the loss mechanisms, showing the positive and negative relationships aimed at model development, and a simple graphic for communication. The information is being used by computer scientists to help structure and query datasets and to develop machine learning models. The graphics are also being used to develop field guides for agronomists.

Mineralizable N is an economically important component of NUE. The laboratory tests for measuring mineralizable N are time consuming and require specific expertise. Preliminary results (1 year) show that Mid-Infrared (MIR) spectroscopy can provide accurate predictions of N mineralisation potential (0.83 R^2). Three years of data will be used to validate the approach.

N in the agricultural system is an important economic resource, however when it enters the wider environment through gaseous, liquid, and solid loss mechanisms it becomes a pollutant; We are currently working on a collaborative review paper in this area.

This project has created a better understanding of NUE, diagrams to communicate that understanding and a priority list of questions that should be asked in the field for agronomists to help farmers improve NUE. We are starting to work on a method for rapid N mineralisation detection and plan to analyse a large dataset on N management and yield results. With this project we aim to provide a novel approach to improving NUE at a commercial scale.

Publications

Conference communications

July 2020 ASABE AIM (USA): Communication of the Nitrogen Use Efficiency system using simple images and a common graphical representation

July 2020 ASABE AIM (USA): Preliminary assessment of soil N mineralization estimation using MIR spectroscopy

January 2019 Chimiométrie (France): NIR and MIR for quantifying readily mineralizable soil organic N

Junli Xu, BSc, PhD

Project Title: Spectral imaging of Biomaterials (*Biowater* project)

Project Leader: Professor Aoife Gowen

Abstract

Biomaterials' surface properties elicit diverse cellular responses in biomedical and biotechnological applications. Predicting cell behaviour on polymeric surface is an ongoing challenge due to its complexity. This work proposes a novel modelling methodology based on attenuated total reflection-Fourier transform infrared (ATR-FTIR) spectroscopy. Spectra were collected on wetted polymeric surfaces to incorporate both surface chemistry and information on water-polymer interactions. Results showed that predictive models built with spectra from wetted surfaces ('wet spectra') performed much better than models built using spectra acquired from dry surfaces ('dry spectra'), suggesting that water-polymer interaction is critically important to the prediction of subsequent cell behaviour. This project is funded by the European Research Council under the ERC Starting Grant programme and supported by Science Foundation Ireland under the SFI ERC Support Programme.

Background, Skills & Qualifications

I received my Bachler degree in Food Engineering (2014), Zhejiang University. My PhD thesis, completed in 2018, focused on the application of hyperspectral imaging on quality control of salmon fillets and development of some original algorithms to improve image analysis. My ongoing research aims to apply vibrational chemical imaging, including near-infrared imaging, Fourier transform near infrared (FTIR) imaging, dark-field microscopy combined with hyperspectral imaging (HSI), Raman imaging, to characterize the interaction between water/cell and different varieties of polymers.

Publications

Xu, J.L., Lesniak-Podsiadlo, A. and Gowen, A.A., 2020. Predictive Modelling of the In Vitro Responses of Pre-osteoblastic MC3T3-E1 Cells on Polymeric Surfaces Using Fourier Transform Infrared Spectroscopy. ACS Applied Materials & Interfaces.

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