

BIOSYSTEMS AND FOOD ENGINEERING RESEARCH REVIEW 24

UCD SCHOOL OF BIOSYSTEMS AND FOOD ENGINEERING

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FOREWORD

The Twenty Fourth Annual **Research Review** describes the ongoing research programme in the School of Biosystems and Food Engineering at University College Dublin from over 107 researchers (12 academic staff, 1 technician, 16 postdoctoral researchers and 78 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 14th March 2019**.

The six 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

<http://www.ucd.ie/eacollege/studywithus/engineering/biosystemsfood/biosystems.html>

MEngSc – Food Engineering

<http://www.ucd.ie/eacollege/studywithus/engineering/biosystemsfood/food.html>

MSc – Environmental Technology

<http://www.ucd.ie/eacollege/studywithus/engineering/biosystemsfood/environmental.html>

MSc – Sustainable Energy and Green Technologies

<http://www.ucd.ie/eacollege/studywithus/engineering/biosystemsfood/sustainable.html>

ENDA CUMMINS and TOM CURRAN 31st May 2019

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DISCRIMINATION BETWEEN FRESH AND PREVIOUSLY FROZEN POULTRY DURING AND AFTER THAWING USING HYPERSPECTRAL IMAGING

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Abstract

In an attempt to meet consumer demands for fresh meat while benefiting from increased shelf life of frozen meat, retailers may be influenced to label products thawed from frozen as fresh meat. However, freezing reduces product quality and are therefore perceived as undesirable by consumers. The objective of this study is to apply hyperspectral imaging (HSI) techniques in the near infrared region (978 - 1678 nm) to discriminate between fresh ($n = 9$) and previously frozen ($n = 9$) chicken breast fillets during and after thawing. Treatment samples were frozen for 24 h at -15°C , after which they were moved to 4°C for 7 hours. At this point, the internal temperature of previously frozen samples was $0.44^{\circ}\text{C} \pm 1.33$, indicating samples were still thawing. Following imaging, samples were stored in 4°C for 24 hours to allow for full thawing and imaged again. Partial least squares discriminant analysis (PLS-DA) models were built using combinations of the following pre-treatments: transformation to absorbance, standard normal variate (SNV), and mean centring of data. Discrimination models performed favourably while samples were still thawing. The best PLS-DA model was achieved by using data transformed to absorbance and pre-treated with SNV and mean centring, resulting in a correct classification rate of 74.43% in the training set and 80.14% in the test set. Discrimination of the two classes after thawing was poor, resulting in a correct classification rate of 58.92% in the training set and 59.11% in the test set. Poor discrimination was likely a result of increased absorbance of surface moisture due to drip loss from decreased water holding capacity of samples after freezing. Future work is needed to develop methods which could efficiently remove surface moisture either physically or from the spectral data set.

Introduction

Fresh poultry meat is highly perishable, so retailers may choose to freeze meat to prolong shelf life of products. However, freezing reduces product quality and are therefore perceived as undesirable by consumers in comparison with fresh meat. Specifically, lipid and protein oxidation increases while water holding capacity and colour decrease with each freeze-thaw cycle (Ali et al., 2015). In an attempt to meet consumer demands for fresh meat while benefiting from increased shelf life of frozen meat, retailers may be influenced to label products thawed from frozen as fresh meat. Previous studies show that between 8-15% of analysed fresh meat samples are mislabelled thawed meat (Ballin and Lametsch, 2008). As a result, authentication techniques are required to ensure correct labelling. Currently used authentication techniques include enzymatic, DNA based, spectroscopic (e.g. UV, NIR, NMR), bio-imaging (e.g. microscopy, electron microscopy), and sensory analytical methods (Ballin and Lametsch, 2008). Although current non-spectroscopic methods are capable of discriminating between fresh and thawed meat, they are time consuming, destructive, and rely on trained professionals. In contrast, hyperspectral imaging (HSI) is a time efficient and non-destructive analytical tool that can be automated for high-throughput implementation (Gowen et al., 2007). Using HSI instead of traditional spectroscopic methods can be advantageous because one system has the potential to identify thawed samples while simultaneously gathering other spatially significant information (e.g. bacteria distribution on samples). Although there have been several successful Vis-NIR in the wavelength range of 400 – 2498 nm (Liu et al., 2004) and FTIR in the wavelength range of 2500 - 20000 nm (Grunert et al., 2016) spectroscopy attempts, HSI has not yet been applied to discrimination between fresh and thawed poultry. **The objective of this study is to apply HSI in the near infrared region (978 - 1678 nm) to discriminate between fresh and previously frozen chicken breast fillets during and after thawing.**

Materials and Methods

Poultry samples

Fresh chicken breast fillets ($n = 18$) were acquired from a local supermarket. All samples were from free range, grain fed chickens, traceable to the same farm. Samples were randomly assigned to control ($n = 9$) and treatment ($n = 9$) groups. Control samples were kept at 4°C for the duration of the experiment. Treatment samples were frozen at -15°C for 24 hours, after which they were moved to 4°C . At this point, internal temperature of all samples was measured by inserting a digital thermometer probe into each sample. All samples were then imaged on the ventral side after 7 hours at 4°C , while treatment samples were still thawing (i.e. internal temperature was $0-2^{\circ}\text{C}$). Next, samples were kept at 4°C for a further 24 hours to allow for full thawing of treatment samples and imaged on the ventral side.

Hyperspectral imaging system

The HSI system used operated from 880 - 1720 nm in the near-infrared (NIR) region with a spectral resolution of 7 nm. Images were 320 rows x 580 columns x 121 bands.

Software

Hyperspectral images were obtained using the acquisition software SScanner (v1.4.5, DV Optics, Padua, Italy). All data analysis was completed using MatLab R2018b (MathWorks, Massachusetts, USA).

Data analysis

In order to reduce noise, the spectral range was reduced to 978 - 1678 nm. Greyscale images at 1503 nm were used to segment samples from background, using Otsu's method (Otsu, 1979) for automatic threshold selection to partition pixels. Next, 10% of pixels were extracted from each hyperspectral image to be used for partial least squares discriminant analysis (PLS-DA) models. The resulting subset was further split into a training and independent test set. Models were built using combinations of the following pre-treatments: transformation to absorbance, standard normal variate (SNV), and mean centring of data. Models were compared based on their correct classification (%) of the independent test set to determine the best model.

Results and Discussion

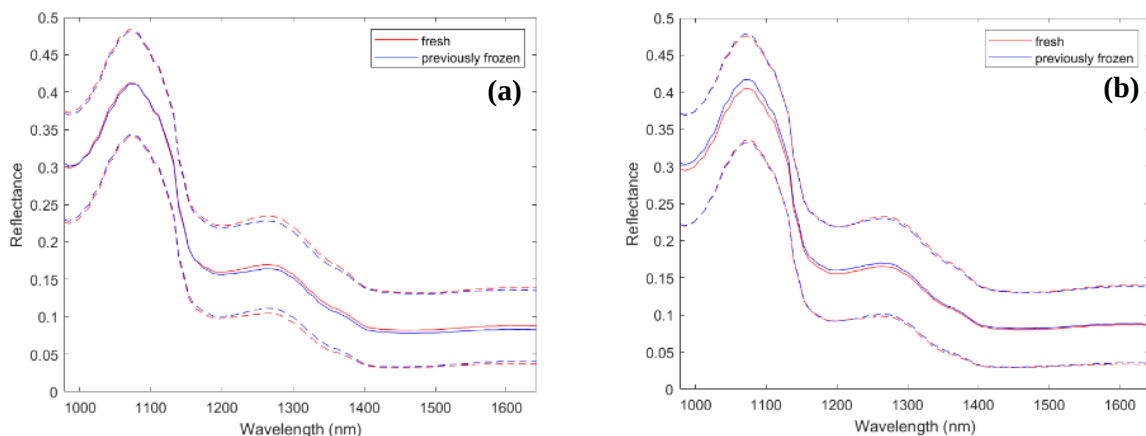


Figure 1. Mean reflectance (± 1 SD) spectra of fresh ($n = 9$) and previously frozen ($n = 9$) chicken breast fillets during (a) and after (b) thawing.

Discrimination between fresh and previously frozen chicken breast fillets was only possible while samples were still thawing. During thawing, the best PLS-DA model was achieved by using data transformed to absorbance and pre-treated with SNV and mean centring. This model used five latent variables and was capable of discriminating between pixels of fresh and previously frozen chicken breast fillets with a correct classification rate of 74.43% in the training set and 80.14% in the test set

(Table 1). The regression coefficients resulting from the PLS-DA model identified 1034 and 1132 nm as the most influential wavelengths for discrimination between classes. Change in temperature of water is expected to result in a sideways shift of the OH sensitive region between 1400 and 1500 nm (Tøgersen et al., 2003). Despite differences in temperature (Table 2), no sideways shift is observed in this region between fresh and previously frozen samples (Figure 1). Because HSI is a surface technique, this shift may not have been observed due to surface temperatures being comparable between treatment groups. As a result, it is possible that the model was able to discriminate between treatment classes based on true structural differences between samples rather than temperature. However, after a further 24 h of storage, these differences may have been overpowered by the strong absorbance of the developing surface moisture layer. Previous work has found that drip loss of poultry increases with increasing storage time, resulting in increased surface moisture of samples (Marcinkowska-Lesiak et al., 2016). No PLS-DA models were able to reliably discriminate between pixels of fresh and previously frozen chicken breast fillets after thawing. Although no model had a correct classification rate of over 60%, data transformed to absorbance and pre-treated with SNV had the highest correct classification rate of 58.92% in the training set and 59.11% in the test set (Table 1). Future work could mitigate the effects of increased drip loss with increased storage time by using different storage methods. For example, modified atmosphere packaging (MAP) with high oxygen content was found in previous work to result in the least amount of drip loss after 15 days of storage (Marcinkowska-Lesiak et al., 2016).

Previous spectroscopic work was able to discriminate between fresh and previously frozen poultry using bands in the 1400-1600 nm region (Liu et al., 2004). These distinctive bands are a result of overlapping first overtones of OH/NH stretching modes of water interacting with itself and with protein complexes, typical of meat composition (Liu et al., 2004). It is possible that these distinctive bands were not observed in the current work due to increased surface moisture of samples as a result of extended storage time. Samples used by Liu et al. (2004) were packaged 8 h post mortem and immediately placed into treatment temperatures, beginning the experiment. In contrast, samples used for this study were stored for an unknown amount of time prior to the experiment in MAP packaging. Upon being assigned a treatment, individual samples were transferred into polyethylene-linear low density (LLDPE) freezer bags. Over the duration of the experiment, drip loss likely increased with increased storage time (Marcinkowska-Lesiak et al., 2016). Rather than receiving the signals of the OH/NH stretching modes of the meat samples, the detector may have only recorded the strong absorbance of the surface moisture. However, this does not occur in all pixels (Figure 2). If the number of pixels receiving signals associated with surface moisture is different between treatment groups, this may explain why discrimination was possible only during thawing. If it is possible to extract only the spectra which show the signals of the OH/NH stretching modes, it could be possible to discriminate between fresh and previously frozen poultry despite surface moisture.

Table 1. Correct classification results (%) of PLS-DA models and number of latent variables (LVs) used on training and test sets during (7 h) and after thawing (31 h) using various pre-treatments.

Pre-treatment	During thawing (7 h)			After thawing (31 h)		
	Correct classification (%)		LVs	Correct classification (%)		LVs
	Training (n = 51656)	Test (n = 23758)		Training (n = 50250)	Test (n = 24839)	
Raw data	73.59	74.45	6	58.64	56.82	10
SNV	74.09	73.58	6	56.74	56.21	8
Mean centre	74.67	76.92	6	58.96	58.99	5
SNV + Mean centre	74.49	78.48	7	56.06	56.74	7
Absorbance	74.04	74.94	7	56.95	58.34	10
Absorbance + SNV	74.34	74.36	6	56.67	57.71	9
Absorbance + Mean centre	75.87	78.77	9	58.92	59.11	5
Absorbance + SNV + Mean centre	74.43	80.14	5	56.59	58.96	6

Table 2. Internal temperature of fresh (n = 9) and previously frozen chicken breast fillets during thawing (n = 9).

Treatment	Mean temperature (°C)	Standard deviation
Fresh	5.89	1.33
Previously frozen	0.44	1.83

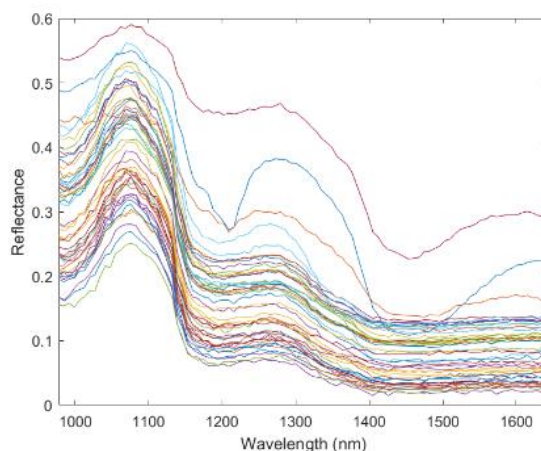


Figure 2. Reflectance of randomly selected 1 in 1000 spectra from training set (n = 50)

Conclusions

Successful discrimination between fresh and previously frozen poultry could only be predicted during thawing using HSI. However, it was not possible to successfully discriminate between fresh and previously frozen poultry after thawing, due to increased surface moisture due to drip loss of samples overpowering the signal of the sample. Future work is needed to develop methods which could efficiently remove surface moisture either physically from the sample or from the spectral data set.

Acknowledgements

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CLASSIFICATION OF DIFFERENT BRANDS OF CHEDDAR CHEESE USING HYPERSPECTRAL IMAGING

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Abstract

The present study aimed to investigate the feasibility of application of NIR-HSI to classification brands of Cheddar cheese. For the hyperspectral data, a probability based PLSDA was used to discriminate 4 brands of Cheddar cheeses. 18 PLS components were selected and the correct classification rate was 85% for both the cross-validation set and testing set. It is hoped that this study should provide a theoretical foundation on discriminating cheese products and set directions for the broader application of HSI in relevant research fields.

Introduction

Cheese manufacturers use milk from different geographic origins with various additives and specific production equipment to make Cheddar cheese resulting in a difference between qualities. However, the difference between various brands of Cheddar cheese is hard to distinguish by consumers, particularly when cheese is used as an ingredient in various foods, which enables the possibility of adulteration. Conventional classification methods mainly rely on detecting contents of specific chemicals in cheeses, such as phytosterol (Kim *et al.*, 2014) and volatile compounds (Gan *et al.*, 2016), which requires a bulk of chemical analysis and are time-consuming. Therefore, development of a rapid and non-destructive measurement tool for discriminating Cheddar cheese is needed.

Hyperspectral imaging (HSI) has great potential to be used as a non-destructive assessment tool for cheese brands classification. Near-infrared (NIR)-HSI has been widely used in dairy research, recent literatures include detecting melamine in powdery milk (Fu *et al.*, 2014; Huang *et al.*, 2016; Lim *et al.*, 2016), characterising milk powders based on different manufacturers and functional qualities (Munir *et al.*, 2018), detecting and quantifying various milk powder adulterants (Forchetti and Poppi, 2017). NIR-HSI was also applied to cheese quality evaluation in recent years. NIR-HSI coupled with PLSR was found to be suitable to predict fat content and hardness of semi-hard cheese during ripening (Darnay *et al.*, 2017). However, applications of HSI in cheese products for classification purpose are still scarce. Darnay *et al.* (2017) conducted the only research for classifying cheeses with different enzyme treatments using NIR-HSI coupled with linear and quadratic discriminant analysis (LDA and QDA) models.

The objective of this study was to classify different brands of Cheddar cheese using hyperspectral imaging.

Materials and Methods

Cheddar cheese samples: 4 brands (A, B, C, D) of plastic-sealed red Cheddar cheese were purchased from local supermarkets (Dublin, Ireland), each brand of cheese was produced in 4 batches. All cheese samples were kept refrigerated at 4 °C before analysis. Cheddar cheeses were cut into small blocks with size of $2.8 \times 2.8 \times 1.5$ cm (5 replicate blocks for each batch). The number of all samples is: 5 replicates $\times$ 4 batches $\times$ 4 brands = 80. Samples are divided into two subsets: cross-validation set and testing set. The number of samples in the cross-validation set is: 5 replicates $\times$ 3 batches $\times$ 4 brands = 60, and the number of samples in the testing set is: 5 replicates $\times$ 1 batch $\times$ 4 brands = 20. The reason for this

setting is to measure the predicting ability of models for new samples in different batches. Normally, the difference between different batches in one brand might have the biggest effect on classification accuracy.

NIR-Hyperspectral imaging systems: A laboratorial NIR-HSI system was used to acquire the hyperspectral images of cheese samples in reflectance model with 306×320 pixels. The captured spectral region of the HSI system was 950.35-1654.15 nm with a constant interval of 2.76 nm. However, the wavelength range of 1030.39-1527.19 nm was selected for further analysis because spectral data in this range have high signal-to-noise ratio. Finally, 181 reflectance data were obtained for each spectrum.

Spectral data analysis: Before PLS-DA modelling, 1st derivative Savitzky–Golay (window size: 9, polynomial order:3) method was used for spectral preprocessing. Partial least squares discriminant analysis (PLS-DA) is a supervised classification technique that bases on partial least squares regression (PLSR) (Ballabio and Consonni, 2013; Su and Sun, 2016). In the present study, a probability based PLS-DA proposed by Pérez *et al.* (2009) which integrates probability density function (PDF) and the Bayes Theorem was used for class assignment. 10-fold cross-validation is also applied to prevent over-fitting of the calibration model.

Results and Discussion

Selection of the number of PLS components is an important step in the data analysis because too few or too many components will lead to under or over-fitting of the data, respectively (Gowen et al., 2011). According to the variances of both spectra and class matrix explained by different PLS components, PLS components with the number ranging from 12 to 22 were used for modelling and further selection. For cross-validation set, the average correct classification rates over 10 times 10-fold cross-validation were calculated for each number of PLS components. The corresponding optimal models were also built after 10 times cross-validation. The frequencies of samples that appeared in the perfectly predicted test group in each fold were counted. The samples with highest 5 frequencies were culled from the cross-validation set, the rest samples were used for establishing a new model to classify testing set. The number of culled samples is 5 in order to avoid duplication with models that were already used in cross-validation (6 samples were separated as test group in each fold during cross-validation). These obsoleting samples were not outliers because they can be successfully discriminated using models built by other samples, however, models built by them cannot perfectly classify other samples because they might contain interference that would affect the classification ability of PLS-DA.

Table 1. Classification results of two sample sets using different PLS components

Number of PLS components	Correct classification rate of cross-validation set	Correct classification rate of testing set
11	67.33%	35.00%
12	69.33%	45.00%
13	77.17%	55.00%
14	79.17%	70.00%
15	81.17%	70.00%
16	82.00%	70.00%
17	80.17%	70.00%
18	85.00%	85.00%
19	86.00%	40.00%
20	84.33%	60.00%
21	85.67%	45.00%
22	85.50%	55.00%

Table 1 shows the correct classification rates for both cross-validation set and testing set. The trends of these correct rates were shown in Figure 1. With the increase of PLS components, the model explained more information about the data, therefore, the correct classification rate of cross-validation set continuously rose. The rate of testing set also rapidly increased until reached a peak with 18 PLS components. After that, the correct classification rate for the testing set dropped quickly due to the problem of overfitting. Therefore, the best number of PLS components was 18, and the correct classification rates of both two sample sets were 85%. Table 2 shows the correct classification rates for 4 brands of Cheddar cheese in testing set using 18 PLS components. For all four brands, the optimal model can classify them with relatively high correct rates (>80%).

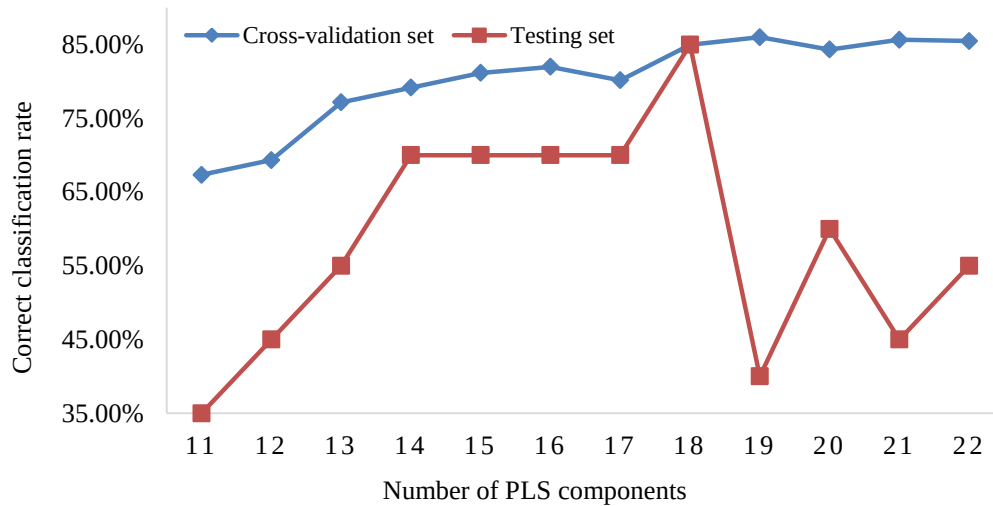


Figure 1. Change of correct classification rates with number of PLS

Table 2. Classification results of 4 brands of cheese in testing set (18 PLS components)

Brand of Cheddar cheese	Number of Samples	Correct classification rate
A	5	80%
B	5	100%
C	5	80%
D	5	80%

The only previous work about cheese classification using NIR-HSI systems was conducted by Darnay *et al.* (2017), they classified cheeses based on different enzyme treatment with correct rates of 88% and 85% by LDA and QDA, respectively. Although brands classification is a more difficult work than enzyme treatment classification due to the less difference between variables, similarly good results were still obtained in present study. The limitations of present study are: the classification ability to new brands other than current 4 brands is unknown; more preprocessing methods should be used before modelling; there is still room for improvement of classification results.

Conclusions

A robust probability based PLSDA model was established when using 18 PLS components without the problem of overfitting in this study. This work proved that NIR-HSI system has the potential to classify different brands of Cheddar cheese with a relatively high accuracy rate of 85%. Future work will focus on comparing different classification models and investigate the connection between cheese (manufacturing and nutritional) differences and feature wavelengths.

Acknowledgements

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Abstract

The purpose of this study is detect the variation of nutrients in dried milk on stainless steel 316-2B and 304-2B and aluminium using multimodal hyperspectral imaging (HSI). To achieve this goal 3 experiments were carried out: 1) in order to have different concentrations of the most influential nutrients (i.e. proteins, carbohydrates and fats) different types of dairy residues (i.e. dried whole milk, skimmed milk, protein milk, butter milk and butter) were characterized 2) the initial whole milk volume, from 0.5mL to post water washed residues and 3) the lactose concentration. The characterisation of different types of dairy residues were carried out using Raman and FTIR HSI. For the initial whole milk volume and lactose study Raman, FTIR and macro NIR HSI were used. The Raman spectra were corrected for cosmic rays using an in-house function. In the case of FTIR data, both the Near Infrared (NIR) and Mid Infrared (MIR) ranges were collected simultaneously and split into two ranges and pre-treated independently. Before re-concatenation, the spectra were normalised using the Euclidean norm. Raman and FTIR data set were both pretreated by obtaining the Savitzky-Golay derivative and using Standard Normal Variate normalisation. For the macro NIR data, the noise was removed and the spectra were transformed into pseudo absorbance and subsequently SNV was applied. The image background was removed by finding the value bigger than one and subtracting the mean silicon spectrum. Later, principal components analysis (PCA) were applied for all the studies and partial least squares-discriminant analysis (PLS-DA) for the characterisation of different types of dairy residues .

PCA on both Raman and FTIR spectroscopy, shows a good separation between the different dairy products. Despite that, observing the Raman spectra, it is easier to identify the signals of chemical groups and their effect on the loadings of PCA. In addition, PLS-DA was applied to classify each dairy product. Both spectroscopic techniques also give good results in prediction. However, Raman spectroscopy results are less precise at recognising different products. PCA on macro NIR is sensitive to volume change and it was possible to differentiate the contaminated samples from the clean surfaces. It is also possible to follow a clear trend with the decrease of the milk volume. From PCA on Raman data it is possible to discriminate the cleaned surfaces from the other samples but it is difficult to identify a trend between different volume samples. The volume variation is evident in PCA on pretreated FTIR spectra. However, the sample with just milk residues for stainless steel 316 and aluminium appear similar to the clean surfaces. In addition, applying PCA to the lactose concentration FTIR datasets it was possible to distinguish the pure lactose and milk images and some trend in the middle value. The Raman dataset in this study seems to not have relevant information. In conclusion, from characterisation of different types of dairy residues study it is clear that both FTIR and Raman spectroscopy, in combination with chemometrics approaches, are suitable to discriminate the various dairy product types. In addition, the other studies underline how the Raman and macro NIR HSI are sensitive to a volume change, whereas FTIR HSI is more suitable for the lactose study.

Selected Recent Publications

Caponigro V., Marini F., Dorrepaal R. M., Herrero-Langreo A., Scannell A., Gowen A. A. (2019). "Raman and Fourier Transform Infrared hyperspectral imaging to study dairy residues on different surfaces". *J. Spectral Imaging*, 8, a3. DOI: <https://doi.org/10.1255/jsi.2019.a3>

Project Title: Non-destructive investigation on moisture content uniformity and shrinkage rate caused by microstructure effect during microwave-vacuum drying

Project Leader: Prof. Da-Wen Sun

Abstract

Microwave-vacuum drying (MVD) are relatively time saving and efficient drying methods. Although the shrinkage between hot air drying and MVD have been compared, the shrinkage and moisture distribution between the fiber perpendicular and parallel samples, the samples with and without peel during MVD were still not investigated. Thus, this study applied hyperspectral imaging and computer vision to investigate the shrinkage and moisture distribution difference between the different ginger samples. 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 ginger sample in the reflectance model. A computer vision system was applied to acquire the images of samples during MVD. The quantitative models between the moisture content and the spectral data of the ginger slices based on diverse spectral pre-processing methods covering the raw spectra and those modified by standard normal variate (SNV) and multiplicative scatter correction (MSC) were established by partial least regression model (PLS). All the data analysis was implemented in Matlab R2016a (The MathWorks, Inc., Natick, Massachusetts, USA). The PLS models with SNV pretreatment was the optimal model to predict moisture content of ginger slices, and thus it was used to predict the moisture distribution of ginger slices. The shrinkage rate of the sample with peel were significantly higher than the sample without peel. The shrinkage rate of width and length of perpendicular samples is higher than parallel samples. In addition, the shrinkage rate of width and length in parallel samples were different. The shrinkage rate of width was higher than that of the length. In the above, the shrinkage rate and moisture distribution was different between perpendicular and parallel samples, and between samples with and without peel. The current study could provide an insight in to the moisture distribution and shrinkage difference between different cutting direction samples, and provide a direction for the improvement of drying food quality.

Selected Recent Publications

Lin, X., Xu, J.L. and Sun, D.W. (2019). 'Investigation of moisture content uniformity of microwave-vacuum dried mushroom (*Agaricus bisporus*) by NIR hyperspectral imaging', *LWT-Food Science and Technology*. <https://doi.org/10.1016/j.lwt.2019.03.034>

Ronan Dorrepaal

Project Title: The development of chemical imaging and chemometric techniques to investigate fundamental biomaterial interactions with biological systems

Project Leader: Assoc. Prof. Aoife Gowen

Abstract

A biomaterial is traditionally defined as "any substance (other than a drug) or combination of substances, synthetic or natural in origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ, or function of the body" (Galletti and Boretos 1983).

Our recent study (Dorrepaal and Gowen 2018) investigated spatial heterogeneity in magnesium oxychloride cements using hyperspectral chemical imaging (HCI). The ability to inspect cements within a mould allows for the assessment of material formation in real time in addition to factors affecting ultimate material formation. Both macro scale NIR HCI and micro scale pixel-wise Raman chemical mapping were employed to characterise the same specimens. NIR imaging is rapid, however spectra are often convoluted through the overlapping of overtone peaks, which can make interpretation difficult. Raman spectra are more easily interpretable, however Raman imaging can suffer from slower acquisition times, particularly when the signal to noise ratio is relatively poor and the spatial resolution is high. To overcome the limitations of both, Raman/NIR data fusion techniques were explored and implemented. Spectra collected using both modalities were co-registered and intra and inter-modality peak correlations were investigated while k-means cluster patterns were compared. In addition, partial least squares regression models, built using NIR spectra, predicted chemical-identifying Raman peaks with an R^2 of up to >0.98 . As macro scale imaging presented greater data collection speeds, chemical prediction maps were built using NIR HCIs.

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Selected Recent Publications

Dorrepaal, R.M., Gowen, A.A. (2018) 'Identification of Magnesium Oxychloride Cement Biomaterial Heterogeneity using Raman Chemical Mapping and NIR Hyperspectral Chemical Imaging', *Scientific Reports*, 8(13034), 1–11, available: <http://www.nature.com/articles/s41598-018-31379-5>.

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A SPATIAL INVESTIGATION INTO VTEC DISTRIBUTION IN IRELAND

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Abstract

E.coli, as one of the most prevalence bacteria colonized in the intestinal tract of humans and animals, and also remains the most frequent cause of common bacterial infection ,septicaemia and different clinical infections. Verocytotoxigenic *E. coli* is considered to have the highest diarrhoeagenic virulence. From the epidemiology side, compared with the outbreak data in other EU countries, Ireland has the highest rate of human cases of Verocytotoxigenic *E. coli* with about 15 cases of per 100,000 population. This project of using the one-health approach to survey the epidemiology assess the spatial distribution of VTEC in Ireland is also look at cross-sectoral collaborations across environment, agri-food chain, human public health and veterinary. The whole project is divided into several parts, this paper would focus mainly on the downstream parts which are drawing SNP tree using Newick format and locating metagene data of VTEC distribution in Ireland using GPS software. The whole metagene information of VTEC in Ireland can be presented after these two steps.

Instruction

Mapping tools and SNP tree can be used to show the prevalence of VTEC in Ireland and a database will be built based on the samples collected from environment food and food-producing animals in different regions. VTEC, living in the intestines of animals and humans, belongs to harmful strains of *E. coli* which are able to produce shiga toxin that can cause severe illness. The symptoms of VTEC infection include bloody diarrhea and abdominal cramps. The incubation period is about 10 days. Along the agri-food chain, lots of steps from farm to food can be considered high risk. In this project, VTEC recovered from food-producing animals, environment and food will be exploited by using whole genome sequencing. Thus the data gap regarding prevalence and types of VTEC can be filled. The whole concept of this project is so called metagenomics.

Metagenomics mainly focus on those genetic materials that are directly recovered from environmental samples. Compared with the traditional genomics cultivation, which relies on clonal cultures, methods used today take a 'shotgun' approach to detect all genes from the sample community directly from the environment which means the concept of metagenomics detection have much more potential to find out the genomic diversity and integrity. With the hidden diversity of microscopic life revealed, the investigation of unbiased information of the whole micro world could process more smoothly. In this project, samples from different ecological niches would be collected and analyzed. Thus reasonable assumptions regarding the relationship between VTEC spatial distribution and environment could be made based on metagenomics information. Among all the graphical tools, SNP tree, which visualises the results of genome sequencing, constructing distance matrix by differences of a single nucleotide, is an intuitive way to show the ties and comparisons among different subspecies of targeted microorganism.

A unique format named Newick is the way to represent the graph-theoretical trees. This format has its own grammar using commas and parentheses. Software like PARSNP could be used to visualize Newick language and then present the tree. With the increase in applications of Newick in taxonomy, more and more applicable online tools have been developed to simplify the coding procedure of Newick. Alternated choices like the Nexus file format can also be used in bioinformatics. But this method needs to cooperate with Newick in most cases.

Mapping all the spots of metagenomics of VTEC in an Irish map is the last step. Normally different spots will be measured by longitude and latitude. Varieties of software can be used at this stage. Some software are quite useful in customising mapping projects and the information can be shared real time on the internet. It's also very easy to access the backstage database to download different kinds of map. Using QGIS as an example, the drawback would be that the creating user's own database requires complicated procedures. Other online tools like Microreact and BatchGeo are very good options which requires less effort.

Methodology

Data: Samples are recovered from different channels including animal-carcass swabs, high risk agri-food chain and human faecal specimens collected by UCD, TEAGASC and HPSC, respectively. Serogroup diversity will be detected thorough the WGS method. The metadata will be transferred through the pipeline between organizations. Information like Sample type, Date of Recovery, Origin (country) should be included in the metadata.

Mapping Preparation : An online tool named Microreact, which is a tool for open data visualization and sharing for genomic epidemiology, is chosen in this stage. This software requires two kinds of files to work--The Newick format files and the data base in Excel.

To get the Newick data, we need use a tool named PARSNP. This software can analyse and compare gene sequencing in Fasta format from different serotypes. A SNP tree can be created and the tree could be saved in Newick format. Excel should contain the database created with all the results of the samples. The basic parameters include Latitude, Longitude, Year, Color and Shape. All the color has their own defining codes which can be identified by the software. The gene sequences of 31 different kinds of staphylococcus will be used.

	A	B	C	D	E	F	G	H
1	id	latitude	longitude	year	month	day	ColumnName__colo	ColumnName__shap
2	NC_010380.fna	55.3239919	-6.5259005	2018	1	1	#F4290B	square
3	NZ_AAZZ0.scf.fa	56.3239919	-5.5259005	2018	2	2	#741608	square
4	NZ_ABAE0.scf.fa	57.3239919	-4.5259005	2018	3	3	#F4290B	square
5	NC_012469.fna	58.3239919	-3.5259005	2018	4	4	#741608	square
6	NZ_ACNV0.scf.fa	59.3239919	-2.5259005	2018	5	5	#741608	square
7	NC_014251.fna	60.3239919	-1.5259005	2018	6	6	#F4290B	square
8	NZ_ACNU0.scf.fa	53.3798649	-6.6294196	2018	7	7	#B2BB2A	square
9	NC_003028.fna.ref	54.3798649	-6.6294196	2018	8	8	#B2BB2A	square
10	NZ_AAGY0.scf.fa	55.3798649	-6.6294196	2018	9	9	#F4290B	square
11	NC_011900.fna	56.3798649	-6.6294196	2018	10	10	#3C2ABB	square
12	NZ_ABFT0.scf.fa	57.3798649	-6.6294196	2019	1	11	#3C2ABB	square
13	NC_010582.fna	58.3798649	-6.6294196	2019	2	12	#F4290B	square
14	NZ_ABAF0.scf.fa	59.3798649	-6.6294196	2019	3	13	#741608	square
15	NZ_ABAA0.scf.fa	53.3831418	-6.6286417	2019	1	14	#F4290B	square
16	NC_011072.fna	55.3239919	-6.6294196	2019	2	15	#741608	circle
17	NZ_ABAC0.scf.fa	56.3239919	-6.6294196	2019	3	16	#F4290B	circle
18	NZ_ABGH0.scf.fa	57.3239919	-6.6294196	2019	1	17	#B2BB2A	circle
19	NZ_ABFS0.scf.fa	58.3239919	-6.6294196	2019	1	18	#B2BB2A	circle
20	NZ_ABAB0.scf.fa	59.3239919	-6.6283647	2019	2	19	#741608	circle
21	NZ_ABGE0.scf.fa	60.3239919	-6.5259005	2019	3	20	#741609	circle
22	NZ_ABAD0.scf.fa	53.3798649	-5.5259005	2019	1	21	#741610	circle
23	NZ_ABZC0.scf.fa	54.3798649	-4.5259005	2019	2	22	#B2BB2A	circle
24	NZ_ABZT0.scf.fa	55.3798649	-3.5259005	2019	3	23	#F4290B	circle
25	NZ_ABAG0.scf.fa	56.3798649	-2.5259005	2019	3	24	#F4290B	circle
26	NC_003098.fna	57.3798649	-1.5259005	2019	1	25	#F4290B	circle
27	NC_008533.fna	58.3798649	-1.5259005	2019	2	26	#F4290B	circle
28	NC_012468.fna	59.3798649	-6.6294196	2019	3	27	#F4290B	star
29	NC_012467.fna	57.3239919	-6.6294196	2019	1	28	#F4290B	star
30	NZ_ABGF0.scf.fa	55.3239919	-6.6214196	2019	2	29	#B2BB2A	star
31	NZ_ABGG0.scf.fa	53.3798649	-6.6294176	2019	3	30	#B2BB2A	star

Figure 1: Excel database

Thus the whole mapping result will be presented like below:

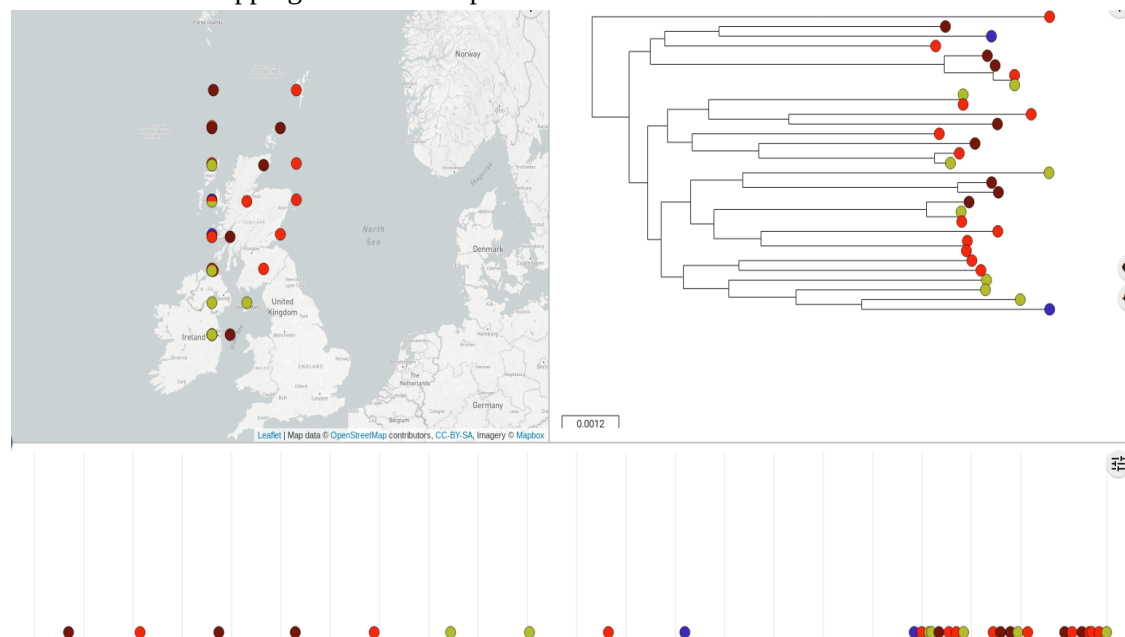


Figure 2: Mapping using Microreact

Discussion

Whole gene sequencing is a precise and convenient method to detect serotype diversity of microbes. Using this method, varieties of genes can be preserved and also detailed information like base mutations can easily be compared. Using metadata with the SNP tree of sequencing information on the side is an intuitive way to help understand the link between outbreaks and sources.

Monitoring and presenting the spread of notable pathogenic organism is critical for agri-food safety and also should be valued by government to inform policy. Micro react is a useful tool to visually present genetic data.

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

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Abstract

Marine biotoxins is a growing concern worldwide. They are naturally occurring chemicals generated by mostly harmful algae blooms (HABs). Biotoxins can easily accumulate in shellfish, leading to human intoxication after consumption of contaminated seafood products. Based on poisoning symptoms, marine biotoxins are grouped into paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), diarrhetic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), and ciguatera fish poisoning (CFP). In Ireland, the most popular marine biotoxin is diarrhetic shellfish poisoning (DSP) associated with outbreaks and harvesting area closures. This project used toxin occurrence data recorded by public authorities in Ireland with consumption data to develop the first quantitative exposure assessments for these marine biotoxins. A Monte Carlo simulation approach will be used to characterize the exposure assessment based on hazard occurrence data obtained from publicly available data sources.

Introduction

Marine biotoxins are considered a growing concern for public health. This trend not only poses a threat to wildlife but also to humans. These biotoxins are naturally occurring chemicals produced by phytoplankton, especially those harmful algal blooms (HABs). The occurrence of the blooms depends on different environmental factors. 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). Marine biotoxins can easily accumulate in seafood products. Consumption of contaminated seafood can cause human illness, symptoms vary from diarrhea, nausea, vomiting, and abdominal cramps to neurological disorders (Alexander *et al.* 2009). On the other hand, harvest area closures with prohibited harvesting activities and product recall are also triggered by the biotoxins when it exceeds the regulation limits, leading to economic loss to shellfish industries (Nicolas *et al.* 2017).

Shellfish is regarded as the primary food vectors for these human illnesses. As filter feeders, shellfish, especially oysters, mussels, and clams, can filter large quantities of water per hour. 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). Reported cases caused by ingestion of biotoxins 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), diarrhetic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), and ciguatera fish poisoning (CFP) (Gao *et al.* 2015). **The objective of this project is to establish the very first exposure assessment for marine biotoxins accumulating in Irish produced shellfish, initially targeting on DSP toxin group in mussels.**

There are numbers of marine biotoxins that are prevalent in Irish waters. The Irish Marine Institute routinely monitors for a number of HABs that are responsible for different toxin groups, including the *Pseudo-nitzschia* 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 numbers of outbreaks associated with the ingestion of DSP toxins. The dominate toxins responsible for DSP is *okadaates* (OAs). This toxin group involves okadaic acid (OA) and its derivatives the *dinophysistoxins* (DTXs), which includes DTX1, DTX2, DTX3 groups, DTX 4 and DTX5 groups. OAs are widely distributed all over the world, but are especially abundant in Europe, Japan, and South America (Valdiglesias *et al.* 2013).

Materials and Methods

Investigated location

Bantry is one of the production areas under monitored. It is located in the southwest of Cork in Ireland which is suffering from HABs explosion following with biotoxins contamination issues. Consequently, bay closure happens frequently during the peak period.



Figure 1. Shellfish production area-Bantry

Data collection and processing

This risk assessment project was achieved with toxin occurrence data provided by the Marine institute coupled with intake data generated by another co-project. The HAB Weekly Bulletin from the Marine Institute provides the information on the potential development of toxic and/or harmful phytoplankton (Figure 2.), also the level of biotoxin detected from shellfish samples (Table 1).

A Monte Carlo simulation approach is used to characterize the exposure assessment based on hazard occurrence data obtained from publicly available data sources.

Table 1. DSP level in shellfish harvested from Bantry

Harvesting site	Investigation period	Biotoxin level
Bantry outer	06/01/2014	<LOQ*
Bantry outer	08/01/2014	<LOQ*
Bantry outer	10/03/2014	0.03
Bantry outer	25/03/2014	0.02

*LOQ = Limit of Quantification

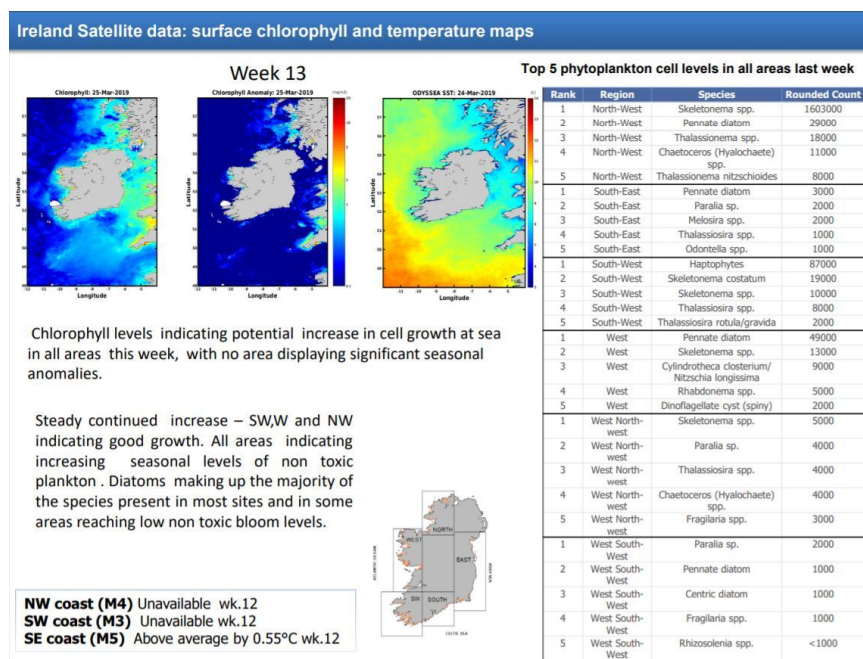


Figure 2. HAB Bulletin from the Marine institute

Future work

The next step of this project is data management. In other words, the data trend will be assessed based on the weekly HAB Bulletin from the Marine Institute.

Acknowledgement

This project is undertaken with the instruction of Joe Silk from the Marine Institute. The intake data are provided by Dr. Eileen Gibney and Sophie Govzman.

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Project Title: The comparative public and animal health risks associated with spreading Anaerobic Digestate, animal manure and slurry on land

Project Supervisor: Assoc. Prof. Enda Cummins

Abstract

Anaerobic Digestion (AD) has been identified as the cleanest green technology which can utilise farmyard manure and slurry (FYM&S) and food waste to produce heat and electricity. The digestate is a valuable co-product of this process and can be used as an organic soil conditioner. This feedstock can contain a significant number of pathogens (bacteria, fungi, viruses, parasites). AD, pasteurisation and storage can inactivate pathogens; however, complete inactivation is unlikely. Once the FYM&S and digestate are applied on land, the pathogens can transmit through air, water, soil and food. The objective of this study was to estimate the human and animal risk associated with spreading FYM&S and anaerobic digestate on land with the help of qualitative and quantitative risk assessment models. Qualitative and semi-quantitative models were used for hazard analysis. A total of 99 pathogens were scored based on their thermal resilience, ability to spread through different environmental pathways and severity of the disease. Initial concentration in farmyard manure and slurry was estimated with a Bayesian inference model. Different recipes were tested to check the fate of pathogens through AD, pasteurization (pre or post) and storage conditions. Stochastic models were studied to quantify the decay of pathogens in air, water and soil. A Gaussian air dispersion model was used to calculate the concentration of pathogens transmitted through the air. Next, an infiltration model was developed to determine the runoff volume and infiltration depth associated with specific storm events. Soil Conservation Service (SCS) model (USEPA) was used to maximise runoff and the Green-Ampt explicit model (USEPA) was used to maximise infiltration for groundwater contamination. Finally, a food model was built with a combination of a predictive and stochastic models to determine the potential number of pathogens ingested while consuming ready-to-eat salads. Hazard identification identified *Cryptosporidium parvum*, *Mycobacterium* spp., *Norovirus*, *Salmonella* spp., *Listeria monocytogenes*, *Clostridium* spp., *E. coli* (EPEC), *Yersinia enterocolitica* as the most resilient pathogens which may cause disease. The restriction period and crop growing time are important parameters which allow the pathogens to decay by desiccation, heat and UV ray from the sun. The air model found that there is a potential threat to workers during the spreading of digestate; however, after 24 hours of the spreading the risk is minimal. The water model shows that pathogens have the potential to enter groundwater and surface water. Chlorine treatment in the food packaging industry reduces the pathogen count; though, the failure to provide a low temperature in the storage and shelf life can increase the pathogen count significantly. The models developed in this study will help to assess the comparative public and animal health risks associated with spreading Anaerobic Digestate, animal manure and slurry on land.

Yingzhu Li, BE, M.EngSc.

Project Title: Risk Characterization of ENPs for Humans

Project Leader: Assoc. Prof. Enda Cummins

Abstract

Engineered nanoparticles (ENPs) have been shown to be toxic through animal tests, of which some can be extrapolated to human equivalent dose-response relationships. During this project, hazard characterization, as the first step of the risk assessment process, has been conducted. The prioritization of ENPs in the European market in terms of risk to human health reveals that the AgNP is the ENP with the highest concern. However, the corresponding behavior kinetics in natural waters under various environmental conditions is considered a black box during the risk assessing process of ENPs. Therefore, the environmental fate of AgNPs needs to be explored further to develop more accurate exposure assessments. Overall, this project aims to establish a comprehensive risk assessment of ENPs for human health. A semi-quantitative methodology is adopted for a risk ranking model. An exposure assessment of the highest ranking ENPs selected by the ranking will be established by constructing a response surface model (RSM). Environmental experiments are also designed as part of this project to identify the most critical environmental parameters influencing ENP behavior. This study highlights that, guidelines for ENP hazard characterization need to be revised and separated from traditional chemical hazard tests due to their unique physicochemical characterization of toxicity. Given the assessment of hazard and exposure potential resulting from various environmental routes, AgNP ranked the highest in terms of risks following the environmental exposure, especially from aquatic systems. The natural environment is a sink for ENPs depositing and posing a health risk to humans. Environmental experiments are expected to reveal the key influential parameters and corresponding kinetics on AgNP aquatic behavior.

COMPARISON OF HOT WATER, MICROWAVE-ASSISTED AND DEEP EUTECTIC SOLVENTS EXTRACTION OF POLYSACCHARIDES FROM *T. FUCIFORMIS* AND ITS WATER HOLDING ABILITY

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Abstract

This experiment was carried out to investigate the most efficient and eco-friendly polysaccharides extraction method of *T. fuciformis* and Polysaccharides of *T. fuciformis*, which will be extracted by using hot water, microwave-assisted, deep eutectic solvents. The highest yield level will be microwave-assisted. Deep eutectic solvents show a good and non-destructive performance in extraction as a green solvent. Water holding capacity of *T. fuciformis* Polysaccharides will be tested with casein. UV-visible spectrophotometric analysis will be applied to analyze the composition of Polysaccharides. The study will offer comparisons among *T. fuciformis* polysaccharide extraction methods and their water holding capacity with casein.

Introduction

T. fuciformis shows a low content in energy and lipid, but has a rich content in protein, and dietary fibres, which contains various minerals, trace elements and vitamins. TPS has lots of bioactivities such as enhancing immunity, decreasing blood sugar, anti-aging, anti-tumour, and anti-mutagenicity.

It is reported that most of extraction of *T. fuciformis* polysaccharides focusing on the fruiting body and mycelium. Extraction and purification is most important step for further research, like polysaccharide yield, quality, chemical structure and characterization. Hot water is the most popular method applied into extraction in *T. fuciformis*, but it is time-consuming and destructive. Microwave-assisted extraction (MAE), a relatively novel extracting approach using a microwave applicator as an energy source, has received increasing attention (Chen, Y., Zhao, L., Liu, B. and Zuo, S., 2012). MAE has many merits with shorter time, less solvent, higher extraction rate, and superior products quality at lower cost (H. Li *et al.*, 2014). Deep eutectic solvents (DES) is used as a green solvent. DES have the ability of donating and accepting protons and electrons, which confers them the ability to form hydrogen bonds, increasing therefore their dissolution capability (Zhang, Q. H *et al.*, 2012). The properties of DES, especially: low costs, and others like biopolymer dissolution ability, biodegradability, non-toxicity, polarity and recyclability make them appropriate media for polysaccharides processing (Zdanowicz, M., Wilpiszewska, K. and Szychaj, T., 2018). There isn't a study showing that the differences of polysaccharides in *T. fuciformis* among these three methods. Therefore, **the main objective of this study is to get the most efficient and eco-friendly polysaccharides extraction method of *T. fuciformis* by comparing the differences among three extraction methods: hot water, MAE and DES. Water holding capacity will be tested with casein to show the properties change.**

Materials and Methods

Materials and Chemicals

T. fuciformis was obtained from Fuzhou, Fujian Province, China. The fruit bodies have been defatted and isolated in aqua to get rid of water-soluble polysaccharides. Then it is kept and sealed at room temperature for storage. Choline chloride (AR grade), ethylene Glycol, glycerol, phenol, rhamnose, concentrated sulfuric acid, HPLC grade isopropyl alcohol (IPA), and urea were purchased from Sigma, Ireland.

Chemical Analysis

Total sugar content will be determined by phenol–sulfuric acid method using Rhamnose as standard (Dubois, M.,1956). A Unico 7200 spectrophotometer will be applied to analyze polysaccharides in the extracted solution.

Preparation of HTP

It will be boiled in distilled water for 4 h at 100 °C. After filtration to remove debris fragments, the filtrate will be concentrated in a rotary evaporator. Protein will be removed with the Sevag method (Sun, Zhang, Zhang, & Niu, 2010). Then the solution will be added into three volumes of 95% ethanol for 24h at 4 °C. The precipitate will be collected by centrifugation to get crude polysaccharides.

Preparation of MTP

The microwave-assisted extraction will be performed by applying a microwave reactor with emission frequency of 2450 MHz and maximum output power 750 W. Samples of 0.5 g of the dried powder will be extracted with 40 fold volumes of distilled water and then filtered under vacuum. The filtrate will be diluted to 100 mL for determining the polysaccharide content.

Preparation of DTP

All the three DESs will be separated to extract polysaccharides from *T. fuciformis*. Experiment I: 0.5 g dried powder will be involved separately into 10 g of DES in a beaker. The mixture will be heated at 85/95 °C for 1 h. Experiment II: 0.5 g dried powder will be heated with 10 g of DES with 10% water for 1 h. The mixtures thus attained from these two experiments will be centrifuged separately and the solid content will be washed several times by applying IPA and drying under vacuum.

Purification of polysaccharides

Four crude polysaccharides will be dissolved in deionized water, respectively. After filtrated through a filter membrane (0.45 µm), each sample will be loaded on a column of DEAE-cellulose DE 52 and then washed with gradient NaCl solution (0–1.00 mol/l). The main fraction will be got together and lyophilized for each crude polysaccharide.

Water holding capacity (WHC)

The WHC of the *T. fuciformis* will tested by a centrifugal method. Approximately 5 g *T. fuciformis* will be centrifuged at 1000g (4 °C) for 10 min. WHC will be represented by the proportion of the retained mass of *T. fuciformis* after centrifugation compared with the original mass of it. The experiments will be presented triplicate.

UV-visible spectrophotometric analysis

Each of the above-mentioned samples (0.5 mg) will be dissolved in 5 mL of distilled water. The absorbance will be determined from 190 to 800 nm, using a UV-2450 UV-visible spectrophotometer.

Statistical analysis

All analyses will be performed in triplicate. The experimental outcomes acquired will be expressed as means ± standard error. Data will be analyzed by analysis of variance ($P < 0.05$) using Origin 7.5 software (Origin Lab Corp., Northampton, MA, USA).

Results and Discussion

Yield and monosaccharide composition of HTP, MTP and DTP

Literature review : The yield of PA was 4.2% and The total yield of PA and PB is 23.1%. According to the yield and composition of PA and PB, we hypothesize that the acid treatment may extract pectic polysaccharides loosely connected to the hemicellulose, while alkali may extract pectic polysaccharides more tightly associated with the hemicelluloses (Zhang, H *et al.*,2018).

Table 1. Yields and monosaccharide compositions of PA and PB(Zhang, H *et al.*,2018).

	Yield (wt. %)	Galacturonic acid (mol %)	Neutral sugar composition (mol %)				
			Rhamnose	Glucose	Galactose	Arabinose	Xylose
PA	4.2 ± 0.7	51.8 ± 1.0	6.2 ± 0.1	—	4.1 ± 0.1	27.5 ± 0.2	10.4±0.1
PB	18.9±2.3	20.3 ± 0.9	11.7 ± 0.1	8.9	18.5± 0.2	40.6 ± 1.1	—

Expected results: In my study, the yield of HTP will be closed 13.8±0.7 mol % (Zhang, L and Wang, M., 2016), the yield of MTP will be 69.07 mol % (Y. Chen *et al.*,2012) and the yield of DTP should be more than MTP and HTP, since there is no report about the yield of DTP.

Structure characterization of HTP, MTP and DTP

Literature review : UV results show that there was a small absorption peak at 260 and 280 nm, indicating there were small amount of protein. The monosaccharide composition analysis indicated that TPS was mainly composed of rhamnose, xylose, mannose and glucose in the molar ratio of 1.13: 1.00: 4.70: 0.81 (Zhang, Y.K *et al.*,2017).

Expected results: In the UV results, it shows the compositions of HTP, MTP and DTP. Meanwhile, a small absorption peak of protein and polysaccharides of *T. fuciformis*.

Water holding capacity analysis

Literature review: TPS could improve the WHC of myofibrillar protein gels. TPS at concentrations between 0.3 to 0.5% did not improve the WHC of myofibrillar protein gel significant ($P>0.05$). However, the gel strength was enhanced significantly ($P<0.05$) with TPS ranging from 0.6% to 0.7%(Zhang, Y.K *et al.*,2017).

Expected results: In my study, the HTP, MTP and DTP will interact with casein working together as a protein gel. It is obvious that WHC of gel biopolymer will be improved and the best performance will be DTP, because DES won't cause huge changes in the molecular structure.

Conclusions

This study will demonstrate the extraction efficiency of three methods in polysaccharides of *T. fuciformis*, which shows that DES will offer a productive and eco-friendly performance. MAE will show the most high yield of polysaccharides. WHC also will be studied in this research as a basic functional property. In the future, there should be more profound study about the mechanism of WHC ability of *T. fuciformis* and any other functional properties.

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APPLICATION OF NOVEL TECHNOLOGIES FOR ESTIMATION OF BIOMOLECULES FROM SEaweEDS

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Abstract

The objective of this study was to employ ultrasound assisted extraction (UAE) for extraction of bioactives from seaweeds. Extraction of bioactive compounds i.e. total phenolic content (TPC) and total phlorotannin content (TPhC), from brown seaweed *Fucus vesiculosus* was carried out using UAE. Dried seaweed sample (2 g) was mixed with 30%, 50% and 70% ethanol solutions (20 ml) in ratio 1:10 and an ultrasound treatment (35 kHz, 130 kHz, control: No ultrasound) was given for 10 and 30 min followed by centrifugation (3,000 *g* for 15 min at 20 °C). The yield (%) was determined and the results showed that the combination: 30% ethanol for 30 min at 130 KHz, was most effective gave the maximum yield. Ultrasound was found to increase the extraction yield and it was also observed that the recovery of bioactive compounds depends largely on the solvent, extraction time and applied frequency.

Introduction

Seaweeds are rich sources of proteins, carbohydrates, polyunsaturated fatty acid and aminoacids, which possess various biological activities including antioxidant, anticancer, anti tumor and immunomodulatory (Holdt and Kraan, 2011). These biological activities are mainly attributed to the presence of phenolic compounds (e.g. phlorotannins and flavanols)(Gómez-Guzmán et al., 2018). Phlorotannins obtained from seaweeds have gained recognition for their anti-inflammatory, antidiabetic, antioxidant and anti-bacterial properties (Namvar et al., 2013) for a range of food and non-food applications.

Several extraction technologies are already being used to extract these bioactives from seaweeds and involves the use of corrosive and toxic solvents including chloroform, chlorobenzene, acetone, methanol and acetonitrile etc, depending mainly on the properties of the target compound. However, the safety risks of these solvents make it imperative to eliminate the use of these solvents or minimize their quantity used. Also, due to several other disadvantages of using conventional technologies including long duration of treatments, low extraction yields, high energy consumption and high capital investments, enhance the need of developing technologies for extraction(Tiwari, 2015). This motive to develop a sustainable process of extraction has led to more research into UAE, owing to decreased levels of solvent consumption, shorter duration of extraction and cheaper running costs(Chemat et al., 2017). UAE, is a versatile, easy to use and a low investment demanding clean and green extraction technology, for obtaining a wide range of molecules like polysaccharides, proteins, peptides, essential oils and various bioactive compounds etc and has several benefits as compared to other novel technologies (e.g., SFE, pressurized solvent extraction or ASE).

The objective of this study was to evaluate the extraction of bioactive compounds from Brown seaweed *Fucus vesiculosus* using ultrasound.

Materials and methods

Materials

Brown seaweed *Fucus vesiculosus* was purchased from Quality Sea Veg., Co. Donegal, Ireland and washed to remove any debris and epiphytes attached. The samples were further dried using an air circulating oven (55°C) for 5 days followed by grinding to 1 mm particle sized powder, using a hammer mill (Retsch SM100, GmbH, Germany). Ethanol analytical grade was obtained from Merck, Germany.

Ultrasound extraction and analysis

Powdered seaweed sample (2g) was mixed with 20 mL of 30%, 50% and 70% ethanol solution (v/v), in 50 mL containers. The sample:solvent ratio was fixed as 1:10. An ultrasound treatment of 35 kHz and 130 kHz (Figure 1) were applied using an ultrasound bath (Elma Ultrasonics, Germany) and the tests were performed in duplicate. Similar steps were followed for control samples, except giving any ultrasound treatment. The supernatants were separated and stored at 4 °C, while the residues were stored at -20 °C. Extracts obtained were analysed for Total Phenolic Content (TPC) and Total Phlorotannin Content (TPhC) using methods outlined by Rajauria et al. (2016). TPC and TPhC contents were expressed as mg GE/g and mg PhE/g respectively.

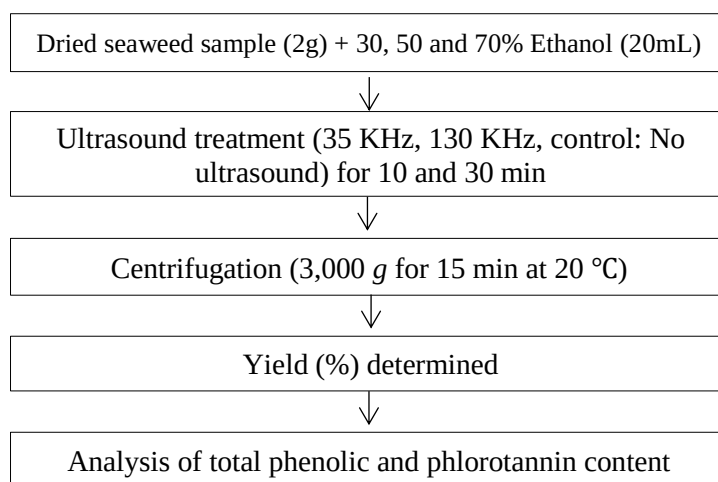


Figure 1. Experimental Flow Chart

Results and discussions

Figure 2 shows the TPC and TPhC content of various fractions obtained. It was observed that the maximum TPC yield 591.01 ± 9.26 mg GAE/g was obtained in samples extracted with 30% ethanol and an ultrasound treatment of 130 kHz for 30 min, while the minimum i.e. 316.44 ± 6.06 mg GAE/g was extracted with 70% ethanol from control samples (Figure 2c). Similarly, TPhC, a maximum yield of 478.22 ± 7.58 mg PhE/g was obtained in samples extracted with 30% ethanol and an ultrasound treatment of 130 kHz for 30 min (Figure 2e), while the least i.e. 253.58 ± 4.96 mg PhE/g was observed in the samples extracted with 70% ethanol and 30 min without any ultrasound treatment (Figure 2f). It was also noted, in both TPC and TPhC values, that samples treated with ultrasound for 30 min showed better yields as compared to 10 min, irrespective of the ultrasound frequency and strength of the solvent used. However, the changes were not similar in the control samples, which were given no ultrasound treatment.

The ultrasound treatment facilitated the extraction of both TPC and TPhC and the most effective treatment was found to be as 130 kHz for 30% ethanol for 30 min. Increased extraction yields was found to be that high ultrasonic power increases the temperature of extraction, leading to solubility of analytes in the solvent, thereby facilitating diffusion from the sample matrix to the solvent (Escalapez et al., 2011).

Conclusion

The most effective treatment for extracting polyphenols and phlorotannin was done to be 30% ethanol, 130 kHz for 30 min, as it yielded the highest total phenol and total phlorotannin content (591.01 ± 9.26 mg GAE/g and 478.22 ± 7.58 mg PhE/g respectively). Ultrasound can increase the extraction yield. Recovery of bioactive compounds depends largely on solvent, extraction time and applied frequency.

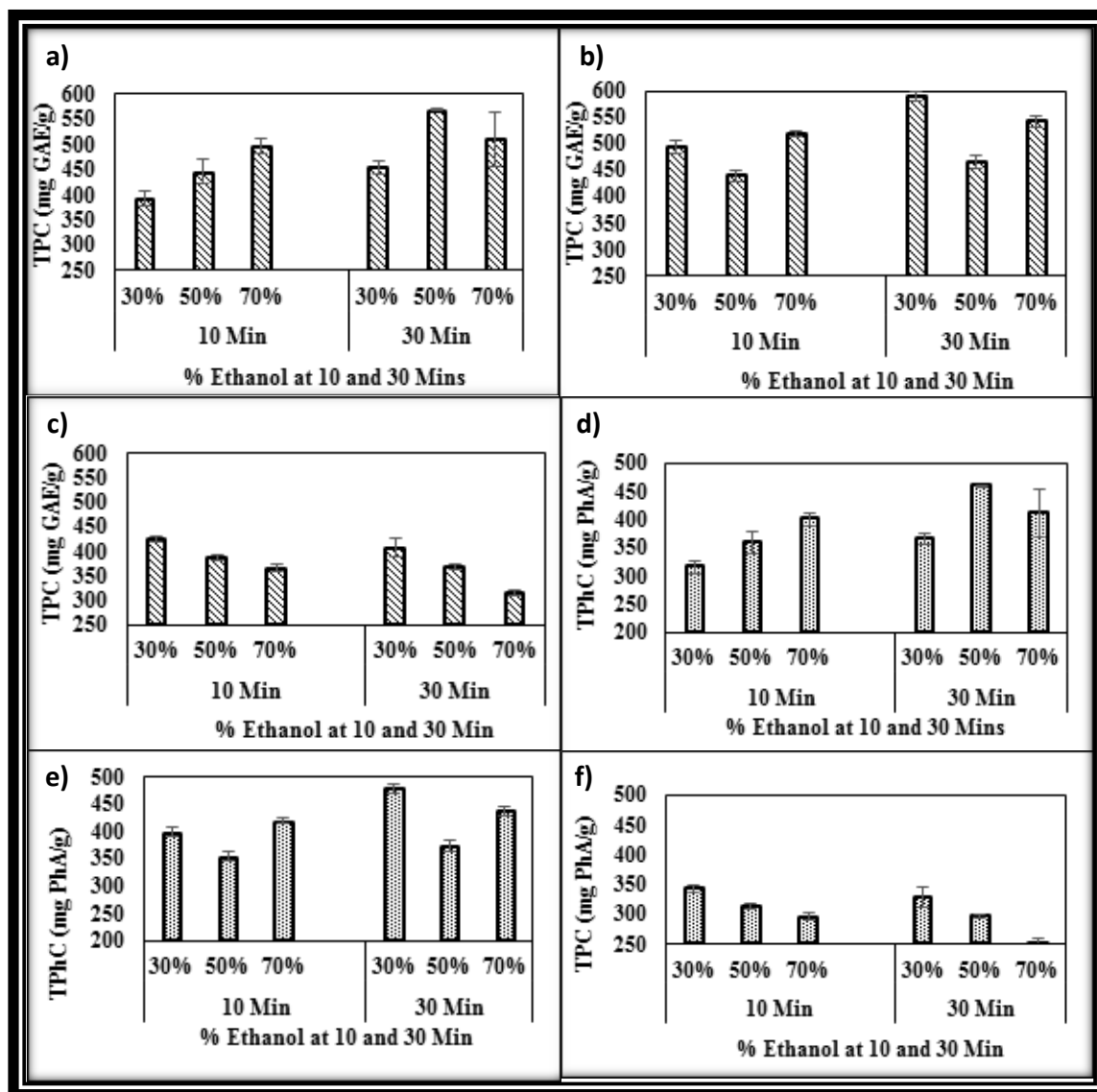


Figure 2. (a) Total phenolic content (TPC) extracted with 30 kHz (b) TPC extracted with 130 kHz (c) TPC extracted from control samples (d) Total Phlorotannin Content (TPhC) extracted with 30 kHz (e) TPhC extracted with 130 kHz (f) TPhC extracted from control samples

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Kexin Zhang

Project Title: Diagnostics of reactive species generated by cold and hot plasma

Project Leader: Prof. Brijesh Tiwari, Prof. Da-We Sun, and Dr. Ming Zhao

Abstract

Introduction: Plasma is the fourth state of matter, consisting of highly excited species. Plasma treatment has been regarded as a novel process technique and been applied to a wide range products in food industry. Plasma generated reactive species (mainly refer to reactive nitrogen and oxygen species) play an important role in microbial decontamination, toxin degradation and surface modification of packaging materials.

Objective: This study aims to detect plasma generated reactive species using both wet chemical based colorimetric method and non-destructive optical absorption spectroscopy.

Methods employed: Deionized water (25 ml) was treated using cold and hot plasma for 5min, 10min and 20min, respectively. After the treatment, the concentration levels of H_2O_2 , NO_2^- , and NO_3^- in the plasma activated water were detected using titanium oxysulfate (Sigma-Aldrich), Griess reagent (Sigma-Aldrich) and nitrate test kit (Merck), respectively. The optical absorption spectra (OAS) of plasma generated reactive species were collected using a CCS spectroscopy (CCS200, THORLABS) in the wavelength range of 350-900 nm with the illumination enhancement of a tungsten halogen lamp (QTH10/M, THORLABS). The CCS spectroscopy probe was placed vertically underneath the plasma nozzle and its position to tungsten halogen lamps was adjusted to achieve a high signal to noise ratio of the spectra. Absorption spectral data of each measurement was averaged from 50 times of scans.

Main result: Results of the chemical analysis revealed that the concentration levels of H_2O_2 , NO_2^- and NO_3^- in the activated water were increased during the treatment time. Spectral results showed that spectral shape differences are observed between the air base (control) and plasma. Absorption spectra, which were acquired after 5, 10 and 20 min plasma treatments, lay out in a pattern following the logical order of treatment time.

Conclusion sentences: In conclusion, different concentration levels of reactive species under different treatment time were found in both of the chemical references and OAS spectral data. The future work will be investigated to explore the correlations between the chemical references and OAS spectral information.

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., PhD

Project Title: Exploration of dielectric spectroscopy as a process analytical tool for fat content determination in homogenized milk

Project Leader: Prof. Colm P. O'Donnell

Abstract

This study explored the potential of dielectric spectroscopy (DS) as a process analytical tool for fat content determination in homogenized milk samples at a critical control temperature (i.e. 4 °C) during milk manufacturing and transporting. Pasteurized milk (n = 72) including whole milk, low-fat milk and skim milk was purchased in local markets. The dielectric properties of milk samples (i.e. dielectric constant ϵ' , and loss factor ϵ'') over the range of 0.2-20 GHz were measured using an Agilent 85070E high temperature open-ended coaxial-line probe kit connected to a N5230A analyser (Agilent Technologies, Santa Clara, USA) at 4 ± 1 °C. Partial least squares regression (PLSR) models and univariate linear regression models were developed for fat prediction. The PLSR model performances yielded values for the ratio of the prediction error to deviation (RPD) of 1.86-2.00 and 1.64-2.04 for fat prediction using the dielectric constant and loss factor, respectively. The RPD values between 1.5 and 2 may only distinguish between low and high values; The RPD values between 2.0 and 2.5 indicate the possibility for approximate quantitative prediction. For the results of univariate linear regression models, R^2 values of 0.54, 0.39 and 0.50, 0.31 were revealed between the dielectric constant and loss factor of each sample at 915 and 2450 MHz and fat content, respectively. In this study, dielectric spectroscopy didn't show a great potential for fat determination in homogenized milk at 4 °C. The shortcomings of daily calibration, disturbance of air-bubble, extreme sensitivity to temperature and limited detection range (only 1cm³ area around the probe) seriously restricts dielectric spectroscopy as a process analytical tool in dairy industry.

Project Title: Research on simultaneous and sequential ultrasound- and microwave-assisted methods for aqueous extraction of bioactive compounds from coffee silverskin

Project Leaders: Prof. Da-wen SUN; Prof. Brijesh K Tiwari

Coffee silverskin (CSS), as a coffee waste, has stimulated scientific interest for alternative applications due to its nutritional and functional properties. Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) has been considered efficient and economic novel extraction techniques which have been proposed to overcome various disadvantages encountered by conventional extraction methods. The combined application of the two extraction methods has showed many advantages. In this work, simultaneous ultrasound- and microwave-assisted (S-UMAE) and sequential ultrasound- and microwave-assisted aqueous extraction methods (U-MAE and M-UAE) were both applied, and the effects of different conditions were analysed for the extraction of phenolics from coffee silverskin. In addition, the combined extraction technologies were compared with their individual techniques (UAE alone and MAE alone) for the effects on the extraction yield, antioxidant capacity and contents of caffeine and some widely-known bioactive compounds from coffee silverskin.

S-UMAE achieved 25.9%, 16.7% 13.1% and 12.8% higher extraction yield than UAE, MAE, U-MAE and M-UAE, respectively. The antioxidant capacity and chlorogenic acids (CGAs) content were also enhanced significantly by S-UMAE than by the other methods. Caffeine content showed no significant ($P > 0.05$) difference between the extraction methods. Compared with U-MAE, extracts obtained by M-UAE exhibited higher antioxidant capacity (28.57% and 20.60% on DPPH and FRAP values, respectively) and 68.19% higher total content of CGAs. Three-cycle S-UMAE (20 min each cycle) under the optimised conditions achieved a similar yield of total phenolics obtained by three-cycle conventional methanol extraction (24 hours extraction each cycle). The micro-structure investigation of CSS showed the combination of UAE and MAE can be a more effective extraction technique for extraction of bioactive compounds from plant materials. This work shows the potential and compatibility of the application of combined extraction technologies on the extraction of bioactive compounds from CSS. It could be an effective option to accomplish a balance between extraction efficiency, product quality, consumption of solvent and production costs in the industry.

THE APPLICATION OF A BULK ACOUSTIC WAVE (BAW) SENSOR AS A PROCESS ANALYTICAL TECHNOLOGY (PAT) TOOL FOR MONITORING ACID-INDUCED MILK COAGULATION

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Abstract

This study evaluates the application of a bulk acoustic wave (BAW) sensor as a process analytical technology (PAT) tool for acid-induced milk coagulation kinetics as a function of different temperatures. A rotational rheometer was used as a reference method to measure viscoelastic parameters i.e. storage modulus (G') and loss tangent ($\tan \delta$), which were compared with acoustic viscosity (AV) attained from a BAW sensor. A wireless pH probe was used to monitor the pH of the milk as it decreased from 6.6 to 4.6. Three coagulation temperatures (30, 31, 32°C) were investigated during the coagulation process. Gelation starting point and maximum gel strength were the main parameters taken from the graph developed from the rheometer. To evaluate the viability and accuracy of the sensor for real-time viscosity measurement, the follow up work will include studying the effect of different GDL levels (2.5%, 3%, 3.5%) on the response received from BAW sensor as it monitors the gelation process.

Abbreviation Key: PAT = process analytical technology, BAW = bulk acoustic wave, GDL = glucono- δ -lactone, AV = acoustic viscosity, G' = storage modulus, $\tan \delta$ = loss tangent.

Introduction

Viscoelastic properties are critical indicators in dairy production especially in products such as cheese and yoghurt. They are usually used to determine the cutting time of products. If the curd is cut too early, the gel will be fragile resulting in curd and fat loss, which is vital for cheese yield and quality (Benedito *et al.*, 2002; Budelli *et al.*, 2017). Conversely, if the curd is cut too late, this can cause a firm gel and results in retarded syneresis and a product with high moisture content that requires a longer ripening time (Benedito *et al.*, 2002; Budelli *et al.*, 2017). Visual inspection carried out by experienced staff as well as off-line instrumentation are still used by cheese manufacturers to ensure the quality of the end-product. To improve the yield and quality of the product, a robust, non-destructive and real-time approach for the cutting time prediction for cheese manufacture is required.

Process analytical technology (PAT) is defined as a mechanism to design, analyse and control manufacturing processes through real-time non-destructive evaluation of critical quality attributes of products during processes and/or at intermediate stages (Panikuttira *et al.* 2018). This work used an acoustic wave sensor as a PAT tool for real-time process monitoring. The acoustic sensor used in this study is a thickness shear mode (TSM) BAW sensor, which uses an AT-cut quartz crystal with a resonant frequency of 5.3 MHz for acoustic impedance detection. This is made by placing the quartz crystal wave resonator in contact with the sample, and a change in resonant frequency obtained due to the wave damping when it is propagating through the sample. The current application of this type of sensor is viscosity measurement for products such as oil (Durdag 2008).

The objective of this study was to investigate the feasibility of using a BAW sensor as a PAT tool to monitor acid-induced milk coagulation process at different temperatures and GDL levels.

Materials and Methods

100 ml of rehydrated skim milk (protein, 3.2% w/w; fat 0.4% w/w) was prepared 14 hours prior to the test day. Three process temperatures (30, 31, 32°C) were investigated respectively, and one level of GDL (3% w/v) was chosen for the acidification experiment.

A small jacketed vessel connected to a water bath was used as a milk sample container as shown in Figure 1. A wireless pH probe is inserted into the sample and secured at the top of the heating vessel for pH monitoring from 6.6 to 4.6 during the gelation process. AV during coagulation process was obtained from the BAW sensor which was mounted at the bottom of the vessel, and was collected by the data acquisition software. The oscillation test, as a reference method, was performed on a rotational rheometer for viscoelastic parameters (G' and $\tan \delta$). These two parameters will be used along with AV for a mathematical model development.

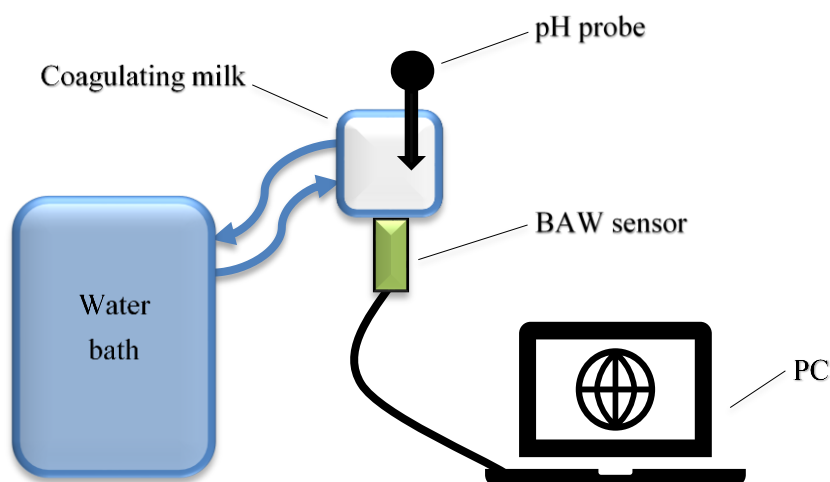


Figure 1. Experimental layout to monitor milk coagulation

Results

The results of both pH and AV profiles are shown in Figure 2. As can be observed from the graph, AV clearly increases whereas pH reduces with time.

Skim milk heated using a higher temperature reached a firmer gel in a shorter time. It is also quicker for the sample to reach pH 4.6 when heated at a higher temperature. Among the three different temperatures, 32°C was the fastest temperature to reach the same AV reading whereas 30°C was the slowest. Those results are consistent with results showed in previous study (Anema, 2008).

Figure 3 compares AV and G' readings, these two parameters clearly show the same increasing trend. Results from the BAW sensor indicate that the onset of gelling began 10 minutes prior to the reference method. This suggests that the sensor is more sensitive to changes in gel structure compared to the reference method. Additional experiments are required for a stable and repeatable measurement and model development to achieve an accurate result.

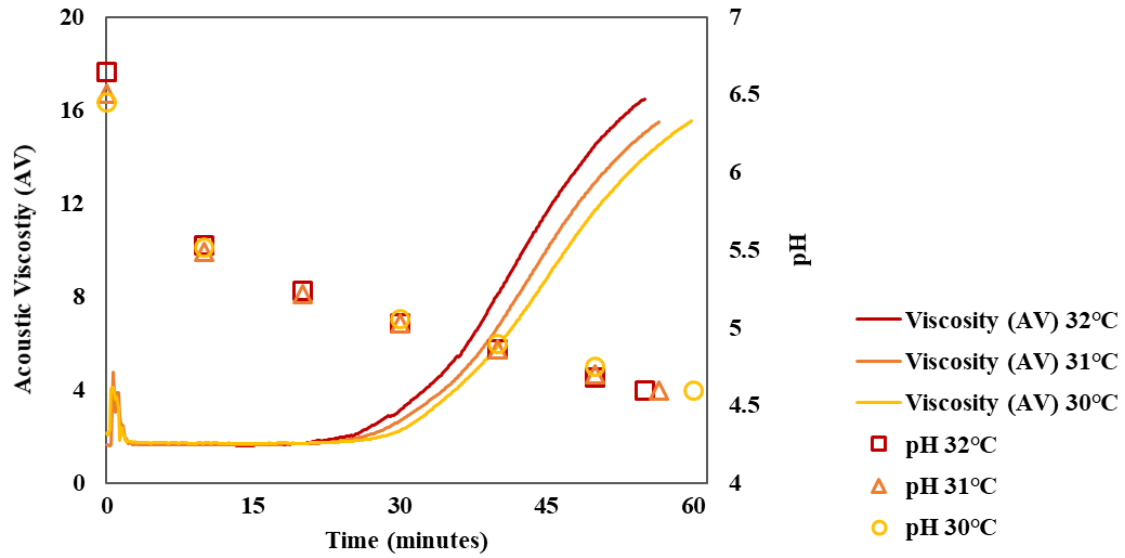


Figure 2. Acoustic viscosity (AV) and pH at 3 different coagulation temperatures (30, 31, 32°C) with time after acidulant (3% w/v GDL) addition.

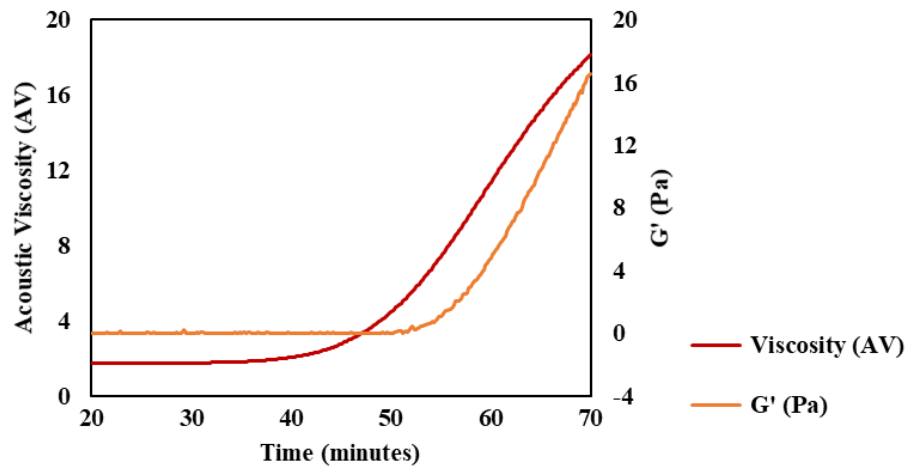


Figure 3. Comparison of acoustic viscosity (AV) with storage modulus (G') at 30°C with time after acidulant (3% w/v GDL) addition.

Conclusion

The mechanism behind acid-induced milk gelation is already well-known (Anema 2008), this work concentrated on investigating if a BAW sensor can measure AV in accordance milk a reference method, as acid-induced gelation occurs. The gelation starting point monitored by the BAW sensor was quicker compared to the off-line rheometer measurement.

The next task in this project involves (a) method optimization and (b) investigating different GDL levels as a second factor to see the influence of GDL concentration on milk coagulation process. A mathematical model (i.e. regression model) will be developed using acoustic viscosity and viscoelastic parameters (G' and $\tan \delta$) to test the sensitivity of using BAW sensor for gelation monitoring.

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Archana Bista, B.Tech, M. Tech

Project Title: Framing solutions for adoption of Process Analytical Technology (PAT) in the dairy processing factory of the future & development of PAT tools for monitoring and control of milk concentrates

Project Leader: Prof. Colm O'Donnell

Teagasc Supervisors: Dr. Norah O'Shea and Dr. John Tobin

Abstract

Viscosity is one of the main parameters that can affect the optimal running of a spray-drier and the functional properties of the final dairy powder e.g. dispersability, flowability and particle size of the powder. In particular, concentrates of a high viscosity, if not monitored can result in fouling of major processing stages involved in the production of dairy powders e.g. evaporation and spray drying. The measurement of process viscosity using inline instruments allows real time monitoring and control of concentrate flow behavior while also allowing optimisation of the total solids content pumped to the spray drier. The main objective of this project "Investigating Process Analytical Technologies (PAT) in a dairy processing plant" is to identify and investigate relevant and emerging PAT suitable for installation in Irish dairy factories. The PAT currently under investigation include Proline Promass I300 and FLOWave (inline flowmeters) for real time monitoring of dairy concentrate viscosity prior to spray drying. Promass I300 measures viscosity directly (torsional mode) and the FLOWave measures the viscosity indirectly using a surface acoustic wave.

Skim milk powder was reconstituted using reverse osmosis water at ~50 °C and stored overnight at 4 °C prior to flow measurements. Furthermore, liquid skim milk (~9% total solid (TS) content) was evaporated to 40% and 45% TS). The application of Proline Promass I300 was evaluated at laboratory (25 °C) and pilot scale (68.5 °C) using reconstituted skim milk powder, it was rehydrated from 10-40% total solids (TS) and liquid skim milk evaporated to 40% and 45% TS respectively. Similarly, FLOWave was evaluated to measure inline viscosity of reconstituted skim milk (10-36% TS) at laboratory scale (25 °C). In addition to inline viscosity measurement, offline measurements were also performed. Viscosity was measured using a rotational rheometer (reference method 300 s⁻¹), pH (pH meter), density (portable density meter) and total solids content (smart trac). A regression analysis was performed on data collected from inline instruments and offline (reference method) measurements. The goodness of fit was evaluated by adjusted R² value and standard error of prediction (SEP).

A linear positive relationship ($R^2 = 0.99$) was observed between inline viscosity measured using Promass I300 and offline viscosity measured using a rotational rheometer with a standard error of prediction of 0.42 mPa.s. For the pilot scale experiment using liquid evaporated skim milk, viscosities measured inline using Promass I300 were lower than the offline viscosity measured using a rotational rheometer (reference method 300 s⁻¹). The viscosity of the process concentrate once taken from the pipe and analyzed using the reference method, increased by 38.7% and 34.1% for 40% TS and 45% TS respectively compared to the inline viscosity from Promass I300. For FLOWave experiments, inline viscosity of skim milk concentrate (10-36% TS) was measured indirectly using FLOWave at 25 °C and a reference sample were measured offline using a rotational rheometer. An exponential negative relationship was observed ($R^2 = 0.99$) between inline and offline viscosity measurements with a standard error of prediction of 0.93 mPa.s. Hence, these studies demonstrate the application and importance of inline instruments to monitor the process viscosity of a dairy concentrate in real time. Further experiments

to evaluate the performance of these inline instruments to monitor inline viscosity of other dairy concentrate (milk protein concentrate) at higher total solids content and temperature (mimicking industrial processing conditions) would provide more information on their application.

Selected Recent Publications

Bista A, Hogan SA, O'Donnell CP, Tobin JT, O'Shea N (2019) "Evaluation and validation of an inline Coriolis flowmeter to measure viscosity during laboratory and pilot-scale food processing", *Innovative food science and emerging technologies*, 54, 211-218.

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ULTRASOUND ASSISTED PROCESSING OF THE MICROALGA *CHLORELLA VULGARIS* FOR ENHANCED PROTEIN EXTRACTION

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Abstract

The true value of microalgae as a promising ubiquitous resource containing many valuable macronutrients, micronutrients and bioactive compounds has only fully been understood in recent years. The thick cell wall of *Chlorella vulgaris* creates a barrier to these valuable components. Ultrasound (US) treatment can cause the necessary cell wall lysis to facilitate extraction of compounds from within the cell such as proteins. High power US treatments increased the protein yield from *C. vulgaris* by 10.6 % for solvent based extractions and caused significant treatment time reductions. The incorporation of an US treatment caused an increase of free amino acids by 55.6 % in enzyme assisted extractions. The results indicate that further investigations should be carried out with US as a pre-treatment to enzyme assisted extractions and more enzymes with different functioning mechanisms should be analyzed.

Introduction

Adapting food production and distribution systems to cater for the continually increasing population has long since become a global issue (Rask and Rask 2011). The rapid economic development in certain parts of the world paired with the general efforts towards (environmental) sustainability, create an unprecedented level of complexity for this challenge (Tilman *et al* 2011). One necessary step on the way to reducing the negative impact our current reliance on intensive agriculture and other exploitative food production systems have on the environment is to search for and develop alternative sources for the nutrients the human body needs to survive (Pojić *et al* 2018).

One entire group of organisms that has been largely ignored in diets the world over is algae in the form of seaweeds and microalgae. Their ability to grow in both fresh and saline water makes this aquatic plant group very versatile and almost ubiquitous. One microalga that was isolated and grown in pure culture very early on is the *Chlorella vulgaris* strain (Sydney *et al* 2014) due to its high content of valuable components such as lipids, carbohydrates, proteins, vitamins, minerals, antioxidants and pigments (Kulkarni and Nikolov 2018).

The main hurdle affecting the use of the valuable components of *C. vulgaris* is its thick cell wall (100 – 200 nm) that provides both sound mechanical and chemical protection to the cell (Sydney *et al* 2014). Thus, the key to its utilisation is the disruption of the tough cell wall. Ultrasound (US) is one of the novel non-thermal processing technologies of great interest to the food processing industry (Rastogi 2011). The effect on which most of the applications of US treatments are based is called bubble cavitation which is caused by the localised and repeated collapse of vapour bubbles (Luque-García and Luque de Castro 2003). These cavitations can lead to cell wall lysis of biological cells and thus assist the extraction of compounds from within the cell, such as proteins.

The objective of this study was to determine the effects solvent use, enzyme activity, ultrasound treatments and a combination thereof have on protein extraction from the microalga *Chlorella vulgaris* using protein content estimation, amino acid profiling and SEM imaging.

Materials and Methods

Axenic *Chlorella vulgaris* powder produced in a closed cultivation system and dried in a drum dryer (dry matter: 95.5 g/100 g) with 22.7 % protein, 14.2 % lipids, 38.7 % carbohydrates and 32.9 % fibre was supplied by Nutress B.V., Phycom, Nijkerk, The Netherlands. The *C. vulgaris* powder was stored at room temperature.

Ultrasound (US) treatments at two wave frequencies (35 kHz and 130 kHz) were applied in a Transonic Ti-H-10 Fisher Bioblock Scientific (Germany) Ultrasound Bath and high-power immersed probe treatments were applied at full power for 10 min using a UIP500hd Ultrasonic Transducer (Hielscher Ultrasound Technology, Germany).

Single solvent and sequential solvent extraction protocols were based on the method introduced by Kadam et al. (2017). The solvents H₂O and 0.4 M citric acid, HCl and NaOH (Sigma Aldrich, UK) were compared. A solid (*C. vulgaris* powder) to solvent ratio of 1:10 was applied. Control samples were placed into a temperature-controlled shaker.

Lyophilized powdered lysozyme (Sigma Aldrich, UK) and the protease AP-30L (Enzyme Supplies Ltd., UK) were used for the enzyme assisted extractions. US was applied as both a pretreatment before enzyme addition (US probe system, 10 min) and for the duration of the enzyme activity phase (US bath system). The pH of all samples was adjusted prior to enzyme addition and all samples were kept at the optimum temperature of 40°C for the duration of the active enzyme phase (1, 2, 6 and 18h). The enzymes were inactivated at 85°C prior to centrifugation.

All samples were centrifuged for 15 min at 8500 g-force. Resulting pellets were freeze dried. Protein analysis was carried out according to the Dumas method and the results calculated using the sample specific protein factor of 6.35 (Safi *et al* 2013). Amino acid profiling was carried out using High Pressure Liquid Chromatography (HPLC). SEM images of untreated and treated *C. vulgaris* cells were create using a Scanning Electron Microscope. All experiments were carried out in duplicate. The statistical methods applied to the data to test for significance comprised of a variance analysis using ANOVA.

Results and Discussion

Solvent assisted extractions

Both the results from the single solvent extraction and the NaOH/HCl sequential solvent extraction showed that NaOH extracts greater amounts of protein from *C. vulgaris* than other solvents such as HCl, citric acid and H₂O. The results from the HCl/NaOH sequential solvent extraction method shown in **Error! Reference source not found.** reveal that the level of protein recovery after the second solvent stage did not increase significantly over time for the control samples, all reaching their maxima between 29 – 32 %. The US treated samples showed a similar level of protein recovery after the first solvent stage compared to the control samples but jumped to a 10.6 % higher level than the control samples after the second solvent stage. Thus, US treatment is effective in increasing the overall protein yield and reducing the necessary treatment time of sequential solvent extractions. Safi et al. (2014) showed that treatments at pHs above 10 can increase access to cytoplasmic proteins. Proteins are also more soluble at higher pHs which suggests that the yield could be further increased by

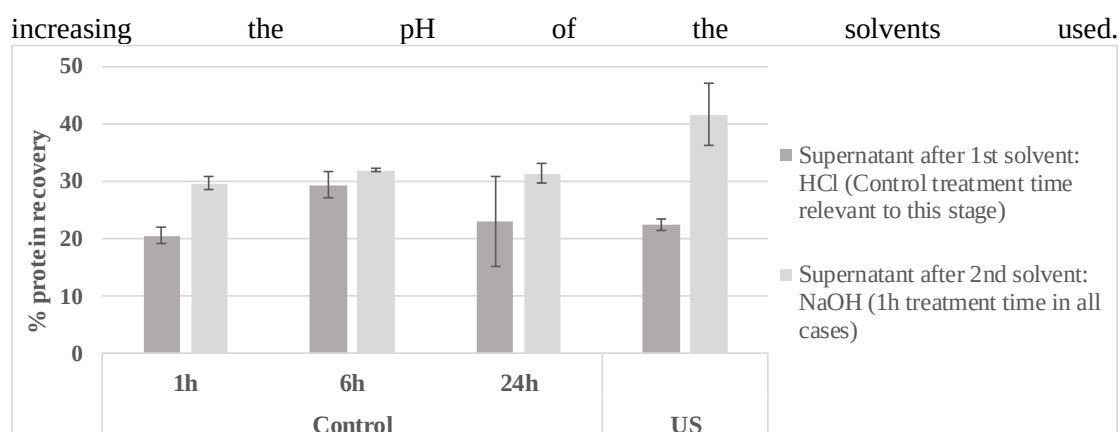


Figure 1: Effect of ultrasound probe treatment (US) on sequential solvent assisted protein extraction from *C. vulgaris* using HCl and NaOH as the first and second solvent respectively

Enzyme assisted extraction

The 35 kHz US treatment of solutions containing an active protease extracted more, in some cases twice as much, free amino acids than the treatment at a higher frequency of 130 kHz (see Figure 2), but in both cases the values are higher (22.5 and 55.6 %, respectively) than for the comparable 1h control period. The relative differences in amino acid content between the extracts were similar for all other amino acids (not shown). The 6h control period results are very similar to those of the 35 kHz US treatment which implies that US can greatly reduce the extraction time. Zhang et al. (2018), amongst others, used cellulase to extract proteins from microalgae. Further investigations could include other enzymes such as cellulase.

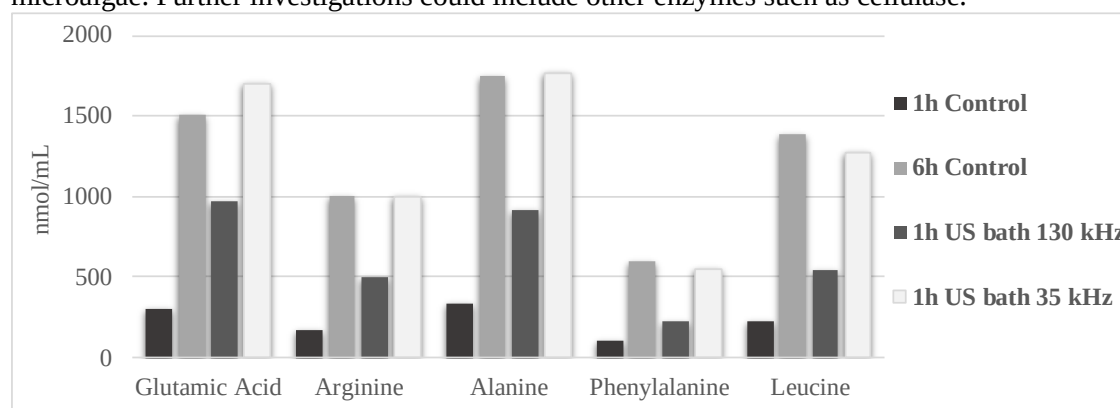


Figure 2: Effect of ultrasound bath treatments (US) on the extraction of selected amino acids during sequential solvent assisted protein extraction from *C. vulgaris* using HCl and NaOH as the first and second solvent respectively

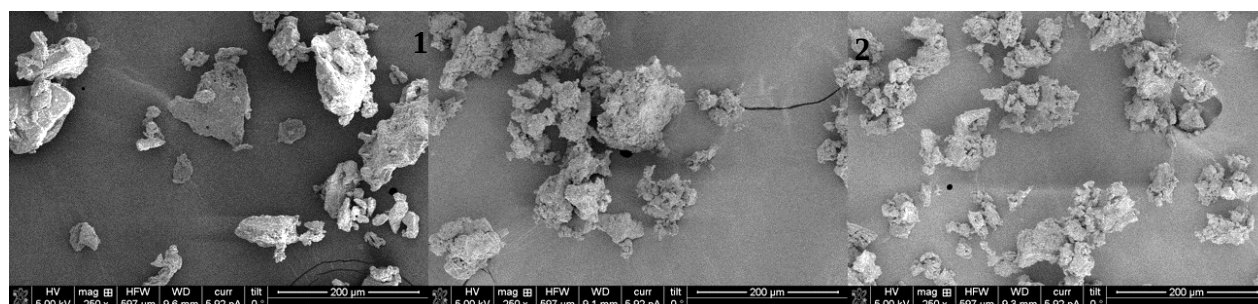


Figure 3: SEM images (magnification: 250x) of 1: Untreated *C. vulgaris* cells, 2: *C. vulgaris* cells after a 1h control treatment with protease and 3: *C. vulgaris* cells after a 1h treatment with protease in a 130 kHz Ultrasound bath

The SEM images of the *C. vulgaris* cells with and without enzymatic treatment (protease) show the effect this enzyme has on the cell wall. The surfaces of the untreated microalgae are

not as broken up and uneven as the treated ones. Image 2 and 3 are very similar, showing that this effect is not due to the US treatment. The protease AP-30L contains exo- and endopeptidase activity, hydrolyzing high molecular weight proteins into low molecular weight peptides. It is likely that this is the process affecting the changes visible in the SEM images.

Conclusions

US treatments were successful in increasing the yield (10.6 % for NaOH/HCl sequential solvent extraction) and reducing the treatment time (by 50 min) of solvent based protein extractions. US treatments increased the free amino acid content of the enzyme assisted extractions by up to 55.6 %. US as a preliminary treatment step to enzyme assisted extraction should be further investigated as this could optimise enzyme access to the cell and reduce the negative effects of temperature spikes on the heat sensitive enzymes during the US treatment. The variance in results from the two investigated enzymes and the multitude of enzymatic functioning mechanisms suggests that the number of investigated enzymes should be increased to find the one most suited to protein extraction from *C. vulgaris*.

Acknowledgements

The authors would like to thank Nutress B.V., Phycom for supplying the *Chlorella vulgaris* samples for this research project and Dr. Mahesha M. Poojary of the Department of Food Science at University of Copenhagen, Denmark for carrying out the amino acid profiling.

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NIR-HYPERSPECTRAL IMAGING OF BACTERIA ON LURIA BERTANI AGAR MEDIA

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Abstract

The application of hyperspectral imaging for the detection and identification of bacteria is a developing field with promising pragmatic applications and explicit difficulties. Two *Bacillus* strains, *B.subtilis* (BS) and *B.amyloliquifaciens* (BA) (Gram positive) and one *E.coli* (EC) (Gram negative) were cultured on 8 ml of Luria Bertani (LB) agar from 10⁻² dilutions utilizing the plate-streaking method. Six replicates for each bacterial strain and six control replicates of sterile LB agar were imaged with a NIR (880-1720 nm) push broom hyperspectral imaging system. Principal Components Analysis (PCA) was used as a first exploratory approach to observe spectral differences between the colonies of the three bacterial strains. A Partial Least Squares Discriminant Analysis model (PLS-DA) was calibrated on four of the six replicates and validated on the two remaining samples for each strain, obtaining 98 % correctly classified classification (CC) in calibration and 49% in validation. In further works, other modelling approaches will be considered, such as a sequential discrimination model, first aiming to discriminate Gram positive from Gram negative bacteria, and then to discriminate between *Bacillus* species. Colony classification instead of pixel classification can also be tested in further research.

Introduction

The microbial contamination of food or food products are of most extreme significance to food industries as it relates not exclusively to authorizing of an organization, yet in addition the wellbeing of the customers. Therefore, there is a demand of the development of such methods that leads to rapid detection of microorganisms in the food sector (He and Sun 2015). Culturing and colony counting takes a few days to identify microorganisms inferable from long incubation periods and followed by characterization which requires biochemical tests. Further, methods such as ELISA and PCR require prepared staff and constant buy of costly and reagent units (Yeni *et al.* 2014). Thus, the regular culture strategies, immunological techniques and PCR may delay the procedure of fast recognition of microorganisms in the food industry.

NIR Hyperspectral imaging consolidates NIR spectroscopy and PC vision to acquire both spatial and spectral information in one framework. Hypercubes are three-dimensional squares of information made out of two spatial and one wavelength measurement (M. ElMasry and Nakauchi 2016). Chemometrics incorporates distinctive pre-treatment strategies and displaying devices, used to break down the spectra (Cheng and Sun 2015). The spectra separated from hyperspectral images are by and large pre-treated to improve signal quality. The pre-treated spectra are then corresponded with estimated various genuine model like PLS-DA (M. ElMasry and Nakauchi 2016).

The objective of the study was discrimination of bacteria on LB agar and polystyrene petri dishes utilizing NIR Hyperspectral imaging.

Materials and Methods

Sample preparation

The following bacterial type strains were evaluated: *B. amyloliquefaciens* DSM 7, *B. subtilis* DSM 10, and *E. coli* DSM 11250. Each bacterium was grown in LB medium and incubated at 30° C in a rotary shaker at 180 rpm. The bacterial cultures were serially diluted in Ringer solution up to 10⁻² and then, each species was streaked on 8 ml of LB agar Petri plates for obtaining single colonies. Polystyrene petri dishes 100 mm diameter and 15 mm height were used for the incubation. Six replicates of each bacterium were produced. The petri plates were incubated at 30° C for 48 hours (static incubation). LB agar was chosen because it is a general growth medium containing only tryptone, yeast extract, sodium chloride and bacteriological agar. Ringers solution was used as an isotonic diluting fluid for suspending the bacterial cells. It is isotonic with bacteria and thus prevents them from being subjected to osmotic stress when they are removed from their habitual environment. All procedures were performed under aseptic conditions. After incubation, the plates were allowed to equilibrate with the ambient temperature for about one hour before imaging.

NIR Hyperspectral imaging

A pushbroom NIR (880– 1720 nm) hyperspectral imaging framework (DV Optics, Padova, Italy), was utilized to scan each of the Petri plates. A 100 % reflectance standard tile was utilized as a white reference. The polystyrene plastic lid of the petri plates was replaced with autoclaved sterile borosilicate glass lids in class II Laminar wind current hood to avoid imaging artifacts produced by the plastic. Six replicates of each bacterial species and six LB sterile agar petri dishes were imaged (24 pictures altogether). All petri dishes were placed in the same position for imaging to allow the automatic segmentation of the dishes from the background.

Data analysis

Reflectance for each image was calculated by the DV Optics system native software SScanner using a standardized white porcelain tile as white reference. Further data analysis was performed in Matlab (Version R2018b, Mathworks, USA). The spectral range was limited from 978 nm to 1600 nm to avoid spectral noise observed at the edges of the detector. The spectra for each pixel was transformed to absorbance and pre-treated by Standard Normal Variate (SNV). Masking of the region of interest for each plate was done in two steps. As a first step a single circular mask was applied to every image to segment the petri dish from the background. As a second step, regions of interest containing the bacterial colonies were manually identified. Four replicates of each bacterial strain were used as a calibration dataset. Two replicates were used for validation. PCA was applied on the spectra corresponding to the calibration dataset colonies. PLS-DA model was, further on, used to discriminate between the three bacteria. The performance of the model was assessed by the percentage of CC, calculated on the calibration and the validation dataset.

Results and Discussion

Bacterial Growth

The bacterial growth test confirmed the viability of the three bacterial cultures on 8 ml of LB agar and incubated for 48 hours at 30° Celsius (Figure 1).

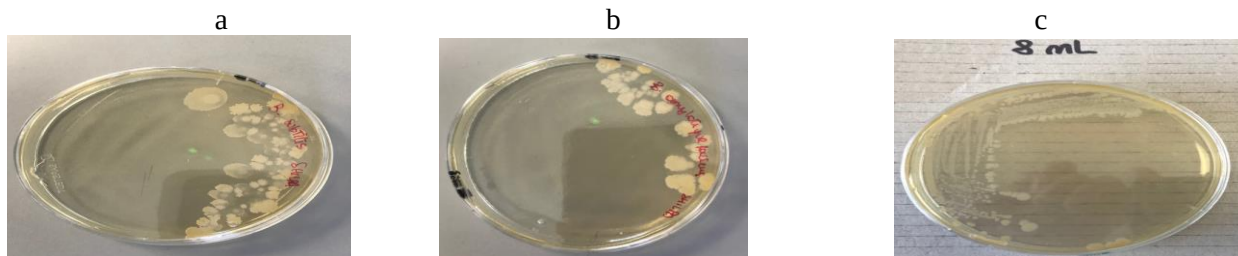


Figure 1. (a) *B. subtilis* (BS) (b) *B. amyloliquefaciens* (BA) and (c) *E. coli* (EC)

Exploratory analysis and classification of bacteria

The first two Principal Components of the PCA applied on the pre-treated absorbance spectra of the calibration dataset gathered 95% of the variance. PCA scores of the first 2 PCs, show a clear separation between EC, BA and BS. An overlap between BA and BS scores can also be observed.

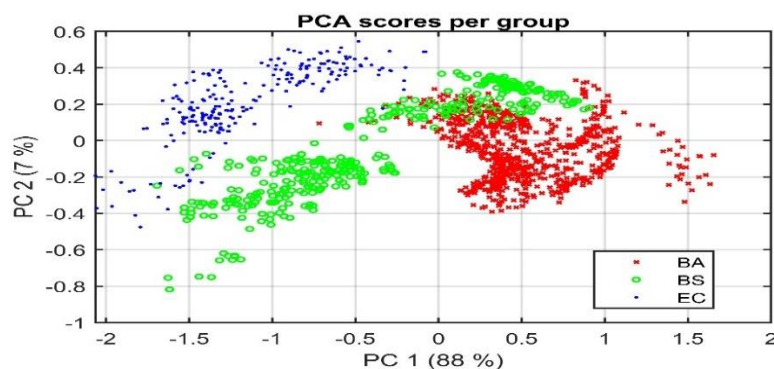


Figure 2. PCA scores of calibration dataset on PC1 and PC2. Each point corresponds to an individual pixel.

PLS-DA showed good discrimination results on the calibration dataset with a percentage of CC of 89% (Figure 3). Nevertheless, CC on validation was only 49%. As observed in the prediction map on Figure 4, better classification results were obtained for the first replicate (first column of plates) than for the second replicate. Some factors explaining this result could be the effect of different colony sizes and the similarities between BA and BS spectral profiles.

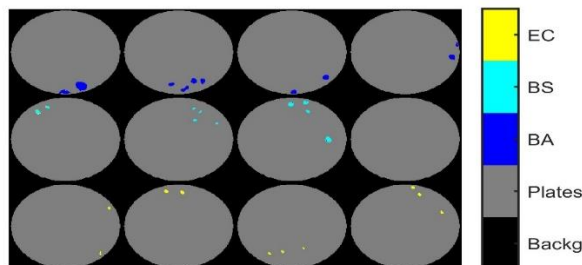


Figure 3. PLS-DA of predicted model for calibration data set, colormap scale indicates the bacteria species. First row of plates corresponds to BA, second row to BS and third row to EC. Each column corresponds to a plating replicate.

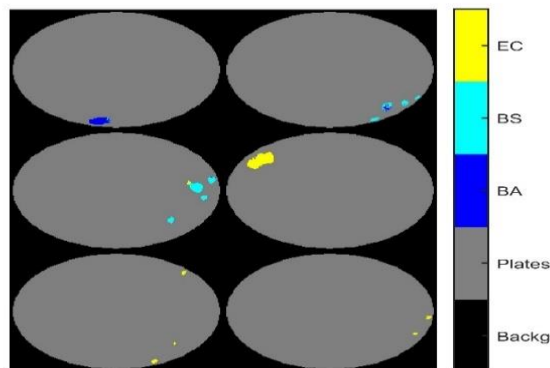


Figure 4. Predicted classification for validation data set, colormap scale indicates the bacteria species. First row of plates corresponds to BA, second row to BS and third row to EC. Each column corresponds to a plating replicate.

Conclusion

This work explores the feasibility of using NIR hyperspectral imaging for the discrimination of three bacterial species *B. amyloliquefaciens* (BA), *B. subtilis* (BS) and *E. coli* (EC), cultured on Luria Bertani (LB) media in polystyrene petri dishes. Exploratory data analysis (PCA) showed clear spectral differences between EC, BA and BS. Although discrimination results between the three strains was reasonably good in calibration (89% of correctly classified pixels) obtained by Partial Least Squares Discriminant Analysis model (PLS-DA), poor results were obtained on the validation dataset (49% of correctly classified pixels). These results suggest the need to adjust the modelling approach and extend the calibration dataset to improve the robustness of the discrimination. According to the results of the exploratory analysis, further work could explore the application of two sequential PLS-DA models: one to discriminate gram-positive from gram-negative bacteria and the second one to discriminate between BA and BS. Further experimentation is also being currently carried on in order to provide additional data to calibrate a more robust discrimination model.

Acknowledgement

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THERMAL RESISTANCE OF PATHOGENS – CRONOBACTER SAKAZAKII

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Abstract

Cronobacter sakazakii is a foodborne pathogen responsible for causing serious infections in infants and other immunocompromised groups. Despite undergoing processes to eliminate pathogens, it is found in reconstituted infant formula. One of the contributing factors to its presence is its thermal resistance at rehydration temperatures. Powdered infant formula, which caters to the most vulnerable group, is known to be the main carrier of this pathogen and hence it is necessary to investigate this pathogen. This study investigates the presence of the genomic sequence (thermal island) responsible for thermal resistance in different *Cronobacter sakazakii* strains obtained from public databases. The tool BLAST is used to compare established genomic sequences which are responsible for this trait. D values of these strains are used to confirm the genomic region to be the cause of thermal resistance in *Cronobacter sakazakii* strains. Further, the same method is applied to Irish isolates of the strain.

Introduction

Cronobacter sakazakii strains are foodborne pathogens belonging to the *Enterobacteriaceae* family. They are known to cause meningitis, necrotizing enterocolitis and sepsis (Healy *et al.* 2009). Infants, elderly and other immunocompromised groups of adults are the most vulnerable to this pathogen. These strains are found in various food products; however, they are transmitted via contaminated powdered infant formula and milk powder to the infants, who are the most affected by the *Cronobacter* strains. Despite undergoing various stresses known as “hurdle technologies” to get rid of pathogens, *Cronobacter* strains are known to survive them by developing a tolerance to the stresses (Yemis *et al.* 2012). Amongst the different traits developed by *Cronobacter sakazakii*, the most important factor for survival is thermal tolerance. Thermal inactivation is represented by decimal reduction time or the D value. It is the time taken to kill 90% of the population at a given temperature. This value is used to explain thermal tolerance.

Pasteurization is a hurdle technology which makes use of high temperatures to eliminate pathogens. Studies have identified a common marker *orfI* in the genomic sequence of *Cronobacter* strains for the presence of thermal tolerance (Gajdosova *et al.* 2011). 49 out of 73 *Cronobacter sakazakii* strains were found to have this marker (Orieskova *et al.* 2016). Strains with this marker, henceforth referred to as the thermal island, were found to have an increased survival rate as compared to the cloned mutants without the thermal island. These strains were found to survive for a longer time at 58°C with a decimal reduction time of 0.5 to 9.9 minutes (Edelson-Mammel *et al.* 2005). Previous studies have correlated the thermal tolerance of *Cronobacter sakazakii* strains to water activity, pH, the composition of the food product, previous stresses induced to these strains as well as source from where the strains have been isolated (Dancer *et al.* 2009; Arroyo *et al.* 2012). However, some studies claim that *Cronobacter* strains do not display this property and pasteurization conditions during the process are sufficient to inactivate the strains. These contradictions are due to different experimental conditions such as growth condition and isolate source (Jaradat *et al.* 2014).

The objective of this study is to identify the presence of a genomic sequence responsible for thermal tolerance in the different *Cronobacter sakazakii* strains using the BLAST tool and to identify the presence of thermal islands in Irish isolates of *Cronobacter sakazakii* strains.

Methodology

For the purpose of this study, *Cronobacter sakazakii* sequences available on public databases will be downloaded and previously established markers for the thermal island will be used to identify the same in these genomic sequences using BLAST (Figure 1). The thermal island will be compared with the previous findings of Gajdosva *et al.* (2011) and Orieskova *et al.* (2016) to determine the presence or absence of thermal resistance in the strains. D values and Z values for the strains, obtained from literature, will be used to find the D values at 72°C and to determine the verify the thermal tolerance of these strains. Further, the presence of the thermal island will be determined on Irish isolates of these strains.

Figure 1. BLAST tool layout

BLAST tool

The Basic Local Alignment Search Tool (BLAST) by National Centre of Biotechnology Information facilitates users to compare DNA sequences to established genomic sequences whose traits and functions are known. This can then be used to categorize the previously unknown DNA sequence and identify whether similar traits are present.

Results and Discussion

It is expected that the strains display the same genomic sequence for thermal tolerance, which is verified by previous studies (Gajdosova *et al.* 2011). The marker *orfI* is expected to be present in the same strains as given by literature. These strains are expected to give a higher D value as compared to strains without the thermal island. Moreover, the data of isolates obtained from hospitals as compared to those from other origins should show a higher thermal resistance than the ones obtained from other sources.

Table 1 shows the different *Cronobacter sakazakii* strains with their D_{58} values. The strains with the higher values had the *orfI* marker present. This corroborates with the assumption that there is a genomic sequence responsible for thermal resistance in *Cronobacter sakazakii* strains.

Table 1. D values for *Cronobacter sakazakii* strains (Gajdosova *et al.* 2011)

Species	Strain	Origin	D ₅₈ value (s)	Thermotolerance marker <i>orfI</i>
<i>C. sakazakii</i>	ATCC 29544	Clinical	122	+
<i>C. sakazakii</i>	LMG 2786	Clinical	111	+
<i>C. sakazakii</i>	ATCC 29004	Unknown	188	+
<i>C. sakazakii</i>	ILS 744/03	Food	126	+
<i>C. sakazakii</i>	061107/08	Food	122	+
<i>C. sakazakii</i>	091007/14	Food	102	+
<i>C. sakazakii</i>	201206/19	Food	150	+
<i>C. sakazakii</i>	201206/22	Food	129	+
<i>C. sakazakii</i>	210307/19	Food	217	+
<i>C. sakazakii</i>	ATCC BAA 894	Food	59	–
<i>C. sakazakii</i>	220108/52	Food	26	–
<i>C. sakazakii</i>	280108/V1	Environmental	28	–
<i>C. sakazakii</i>	201206/25	Food	22	–
<i>C. sakazakii</i>	120808/27	Food	30	–
<i>C. sakazakii</i>	210807/39	Food	30	–

As seen from Table 1, the ATCC 29544 has the thermal marker present. Therefore, ATCC 29544 has a flatter slope as compared to 220108 as the genomic sequence contributes to heat resistance. The isolates used for the studies have different environmental conditions which attribute to the differences in D value. Therefore, the same needs to be accounted for.

Conclusions

The presence of the thermal island (represented by the genomic marker *orfI*) in *Cronobacter sakazakii* strains was related to their thermal resistance. The higher D values of those strains confirmed the same. However, the presence of the marker does not give information about the thermal properties of the individual strains and therefore, further study of the same is required. This information will be applied to Irish isolates of *Cronobacter sakazakii* strains to determine the thermal resistance developed by them and take the necessary steps to eliminate any potential threat to neonates.

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ADULTERATION DETECTION OF WHISKEY USING UV-VIS SPECTROSCOPY

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Abstract

Whiskey is a distilled product that is very popular in the world. It is usually made from sprouted grains such as barley, wheat, and rye. Because whiskey is very popular, it is also considered a distilled alcoholic beverage that is prone to adulteration. The most common form of adulteration is by inclusion or dilution, such as a mixture of water and alcohol, industrial alcohol, edible alcohol or food colouring. UV-VIS spectrophotometer detection can effectively identify adulterated whiskey samples, which can be mainly analysed by a stoichiometry method.

Introduction

Whiskey was originally a distilled alcoholic beverage that was to be fermented in wooden barrels for at least three years (Wiśniewska *et al.*, 2017). In order to make profits quickly, some merchants in the market will mixed in harmful substances. This may cause nausea, dizziness, blindness, kidney failure and even death. The adulteration of food is essentially a behaviour that deceives consumers, but because whisky is a high-concentration alcoholic beverage, it is often considered an object of easy food adulteration. During the brewing process, most of the flavour is derived from the fermentation of the mash in the germinated grain. Only water and plain caramel (for aesthetics) are considered reasonable additions that can be added to distilled alcoholic beverages (Wiśniewska *et al.*, 2015). Everything else is considered an adulterated object. Based on the hazards and risks that adulterated whiskey can bring, researching related technologies for adulteration detection can help suppress many dangerous and illegal benefits.

UV-VIS is an ultraviolet-visible absorption spectrum that belongs to the electromagnetic spectrum, which are all due to the transition of valence electrons. It generally refers to the absorbance or reflectance spectrum of the UV-visible region. The wavelength range is about 190nm-750nm. It can be used to analyse the composition, content, and structure of the substance (Cantarelli *et al.*, 2015). The UV-Vis spectrum has its own spectral properties, which are assessed by comparing the spectral properties of the product sample with established baselines. There are many adulterated frauds in the alcoholic beverage industry, so there is a need for adulterated detection technology that is inexpensive and has no secondary damage. Spectroscopy is a relatively inexpensive, simple technique for qualitative analysis of liquid samples. After obtaining spectrally relevant data, principal component analysis (PCA) and chemometric analysis can be performed to help identify and judge the meaning of the analytical results. In general, UV-Vis spectroscopy is a non-destructive, reagent-free component analysis method that is considered a cheap and easy-to-use technique for adulterated detection of alcoholic beverages.

The objective of this study was to distinguish high quality of whiskey from cheaper commercial grade or blend or adulterated whiskey with added water or ethanol using UV-VIS spectroscopy and analyzing the data using chemometric techniques like PCA and PLSR.

Materials and Methods

In this study whiskey samples were analysed using UV-Vis spectrophotometers. First of all, different whisky brands and brewing methods can greatly affect its quality. The first step was to choose whiskeys (cheap, medium-priced, and expensive) that vary in price and may vary in composition. The detection instrument used, UV-visible spectrophotometer, which is available in the UCD Biosystems and Food Engineering school laboratory.



Figure 1. (A) UV-Vis spectrophotometers; (B) Different brands of whiskey are POWERS, JAMESON, LAMBAY, TEELING (from left to right)

Principle

Ultraviolet-visible spectrophotometers essentially work by π - or n-electron (non-bonded) molecules that absorb light in the UV or visible range to excite these electrons into higher anti-bond molecular orbitals (Pontes *et al.*, 2006).

Determination of quality indices

In the whiskey test, set a solution of alcohol and water is set as the baseline (40% alcohol and 60% water), because the alcohol content of many different brands of whiskey on the market is about 40%. As a study of adulteration testing, adding different proportions of water to whiskey samples (such as adding 5%-30% water).

Data analysis

In order to obtain data that is helpful for research, it can be guided to some extent by data prediction. In the course of the experiment, samples were analysed in twice to ensure the reference value of the experimental data. Some advanced ideas can be very helpful for the experiment. For example, whisky is usually a caramel colour liquid. It is reasonable to expect that the sample should be diluted when using an ultraviolet-visible spectrophotometer, using water as a baseline. The solution is mixed with alcohol as a diluent.

Results and Discussion

Prediction of absorption curve

By studying some of the existing literature, it is generally known that significant differences in absorption spectra can be noted at about 205 nm (Martins *et al.*, 2017). The Martins *et al.*'s literature examined different brands of whiskey using an ultraviolet-visible spectrophotometer. The results show that a 12-year brand has a higher absorbance than an 8-year brand, but regardless of the brand, their absorbance performance trends are roughly the same.

Currently available results

At present, the experimental research carried out in this paper only carries out the selection of the brand and the preliminary determination of the sample, and one of the samples is tested after water mixing. As shown in Figure 2, for the pure sample of the four samples, it can be seen that the absorption curves and absorption peaks of different brands of whiskey are very different.

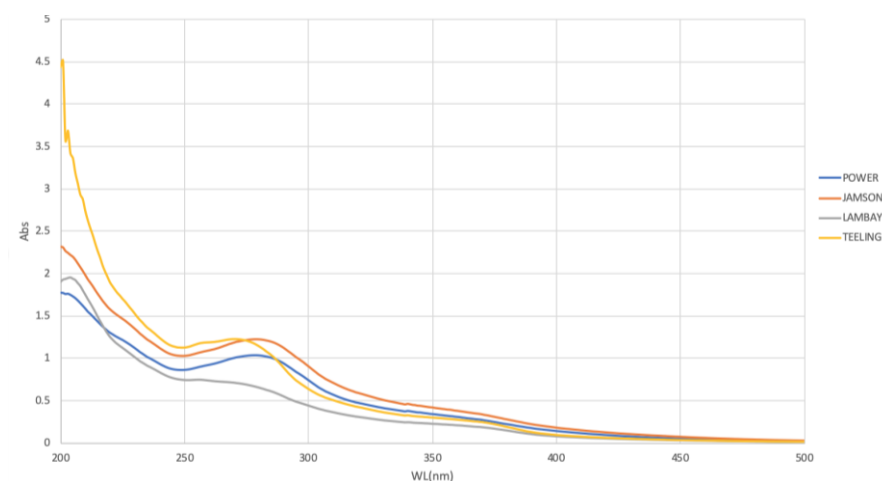


Figure 2. UV-Vis spectra of whiskies samples (Sample 1 is POWERS, Sample 2 is JAMESON, Sample 3 is LAMBAY, Sample 4 is TEELING)

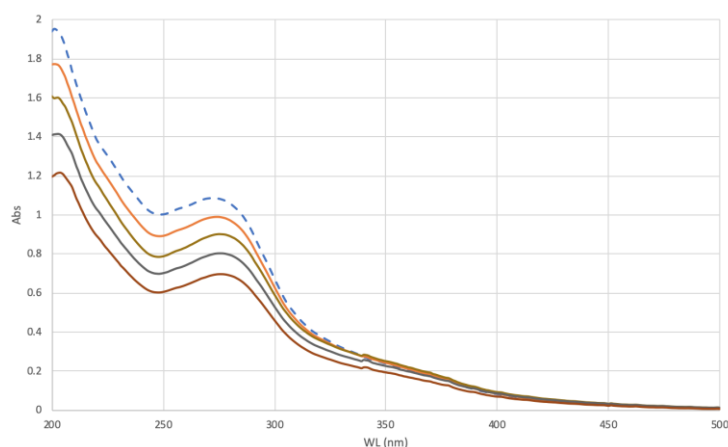


Figure 3. POWERS whiskey dilution with water

Figure 3 shows POWERS whiskey dilution with water. The top line is pure whiskey sample, and other lines are followed by whiskey samples with 5% to 30% water added (from up to down). It can be seen that the greater the proportion of water added, the lower the absorbance, the relatively flat the absorption peak, and the overall trend of decreasing.

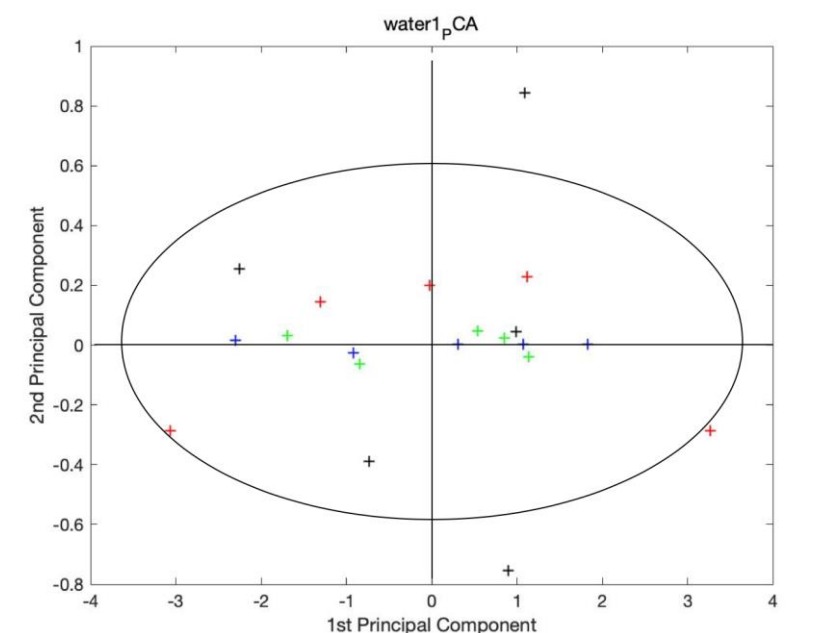


Figure 4. PCA score plot of whiskey dilution with water

Figure 4. shows the water adulterated samples. The variables are evenly distributed in PC1 and PC2. PC1 and PC2 together can explain 97% of X-variances. After using MATLAB, using the ellipse tool, I found that only three data are outside the ellipse. However, the cluster of data is scattered, the distribution is relatively fused, only one cluster is linear, but another cluster is particularly scattered, so it cannot give a very reliable analysis.

Conclusions

Ultraviolet-visible spectroscopy is a good way to detect the composition of whiskey, and the use of a three-sample test can ensure data availability and results. However, because this research experiment is very limited in terms of brand popularity and number of samples, it is possible to develop simulation tests or use a larger number of samples to obtain reliable data in future research. However, it can still be stated that the ultraviolet-visible spectroscopic technique is a technique for safely, conveniently, quickly and effectively detecting the adulteration of whiskey.

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RISK ASSESSMENT OF MARINE TOXINS

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Abstract

Shellfish poisoning caused by marine toxins has been a hot topic for researchers, causing environmental pollution and economic losses. The increase in the occurrence, frequency and geographical distribution of blooms may increase human exposure to these toxins and cause public health problems. The objective of this study was to conduct a dietary risk assessment of marine toxins produced in Ireland and provide an overview of human exposure to marine toxins by consumers and susceptible populations.

Introduction

Marine toxins are various chemical compounds mainly produced by phytoplankton and they are widely present in high-salt ocean environments (Krahl, 2009; Mulvenna *et al.*, 2012). It has numerous properties with a diverse chemical structure and small molecular weight, as well as high biological activity and unique mechanism of action. Many governmental and non-governmental agencies have developed an interest in it. It is estimated that approximately 2% of phytoplankton species have potential toxigenic capacity among all known phytoplankton species (Krahl, 2009). During the proliferation of algal population, the dense concentration of cells will form to cause visible blooms, called 'red tide'. The reason for forming of other invisible blooms is that they can proliferate well below the surface and some algae are colorless (Daguer *et al.*, 2018). All the visible and invisible blooms are generally known as Harmful algal blooms (HABs).

HABs are becoming a common event with increasing occurrence in Ireland and worldwide. As a serious ecological disaster on a global scale, HABs may cause mass economic losses, and will also cause a serious of marine ecology and food safety problems. There are several negative impacts on the environment, such as damage to the gills of fish, oxygen depletion of the water column and contamination of shellfish (James *et al.*, 2010).

Marine toxins are not directly absorbed by humans but accumulated along the food chain, which ultimately has adverse effects on humans (Daguer *et al.*, 2018). Biotoxins can be transmitted between organisms, typically filter-feeding bivalve molluscs and herbivorous finfish. Toxins are initially produced naturally by phytoplankton and distributed throughout the ocean environment. Some bivalve molluscs, including mussels, clams, scallops, and oysters are contaminated with toxins because they graze on algae and the toxins concentrated efficiently in the organism. Secondary consumers include marine mammals, birds, fish, etc., which get food from primary consumers, so the toxins will be transferred to the secondary consumers (Oyaneder *et al.*, 2017). Human beings are both secondary consumers and tertiary consumers and toxins thus are passed on to humans (James *et al.*, 2010). There are four main biotoxins groups: Amnesic shellfish poisoning (ASP), Paralytic shellfish poisoning (PSP), Diarrhetic shellfish poisoning (DSP), Azaspiracids shellfish poisoning (AZP). Different toxins have their own regulatory limits and if the dose exceeds the limits, it will cause harmful effects on consumers ranging from nausea to death (Tong *et al.*, 2018).

The objective of this study was to conduct a dietary risk assessment of marine toxins produced in Ireland and provide an overview of exposure to marine toxins by consumers and susceptible populations.

Materials and Methods

Data collection

The data required includes weekly closure level for each toxin, distribution map, and latest relevant legislation and it is collected from the database of the website of Marine Institute (Marine Institute, 2014).

Data analysis

Data analysis will include the marine toxins detected in the ocean and the risk assessment. The method to analyze the risk assessment should follow the standard human health risk assessment approach, which divided into four steps:

(1) Hazard identification: qualitatively determine whether the chemical compounds or agent have the ability to harm human health. (2) Dose-response assessment: qualitative examine the dose required to generate appreciable detectable adverse health effects in animals and humans. (3) Exposure assessment: determine the route, frequency, duration and extent to which humans will be exposed to toxins through ingestion, inhalation and dermal contact and the nature of exposed individual and populations. (4) Risk characterization: integrate the information of hazard presence, dose-response and exposure assessment and analyze the possibility of the level of hazard that can produce clinical effects.

Results and Discussion

The monitoring sites cover the entire sea area of Ireland, with a large proportion of sampling points in the south and southwest. In the analysis of the trend of DSP toxins in the different geographic distribution in the period of one year, the South which is prone to problems in history has been selected and studied. *Mytilus edulis* was chosen as the research object because the mussel farm is located in the south and it is one of the most common species of toxins.

The shellfish toxicity data provided by Marine Institute includes the location of monitoring sites, monitoring time, biological species, toxin types, and monitoring results. The figure below is the location of monitoring points and corresponding trend graphs. The abscissa of the trend graph is in month, which is convenient for observing the sudden burst of the DSP toxins.



Figure 1. The location of site one (51°46'19.0"N 9°48'43.0"W).

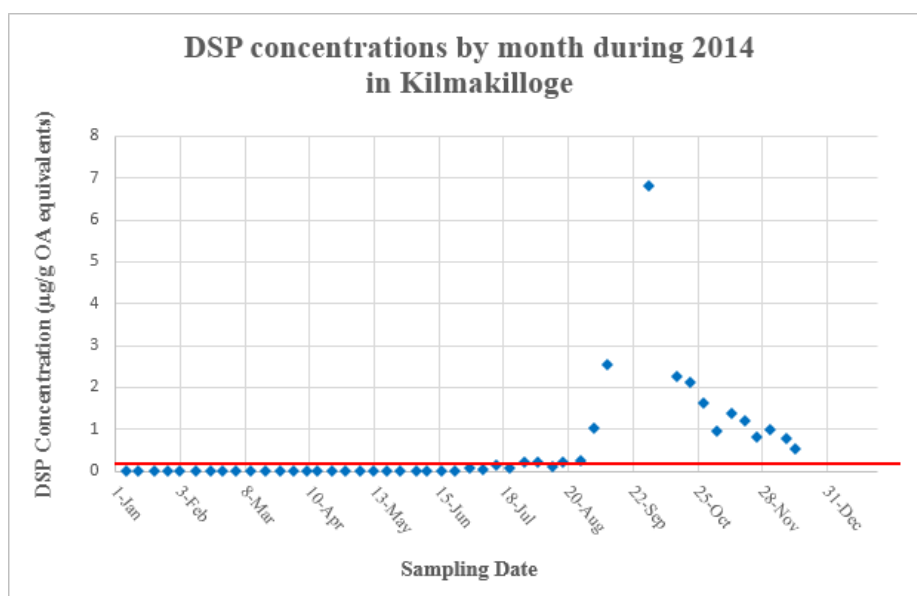


Figure 1. The DSP toxin concentration trend of site one.

As shown on the figure, the red threshold line represents the legal limit above which production areas were closed ($0.16 \mu\text{g/g}$ expressed as OA equivalents). As can be seen from the diagram, in Kilmakilloge, the toxins in *Mytilus edulis* have been in a relatively stable state from January to July, and the value is less than the limit of detection. The concentration of toxins increased tremendously from August to October, reaching a maximum of $6.82 \mu\text{g/g}$ on October 1. After that, although there is a clear downward trend, it is still in a state of fluctuation that can be detected.

This toxin is characterized by sudden and large outbreaks with little or no warning, so it must be highly vigilant for fluctuations in its level of fluctuations and the presence of potentially pathogenic species. In general, good weather and sea conditions may increase the likelihood of early seasonal jumps in levels of DSP.

Conclusions

In this study, the increased level of toxins was affected by the temperature and nutrient of the water and rocky strata, and it is shown as seasonal trend using a distribution map and the annual DSP concentration figures. DSP tends to occur more frequently in summer and the duration can last over three months. Areas with zero detection levels also need attention because there is still the probability of a sudden outbreak. The research effort, such as the development of the method of toxin control, the test of detection technology and risk assessment of human health, also needs to be worked on.

Acknowledgements

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IMPACTS OF STORAGE CONDITIONS ON BARLEY QUALITY

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Abstract

Barley grains are one of the most important raw materials that go into the brewing process. During the storage period between harvesting and malting, these grains due to an increase in temperature and moisture content undergo some changes resulting in a deterioration in quality. This study aims to understand what happens during this storage period. Data from strategically positioned sensors in the storage bin are used to assess the effects of grain location in storage and establish a correlation between storage parameters and germination potential. Preliminary results show that the location of barley grains within storage bin influences its moisture content and temperature. Grains close to storage bin walls were found to be cooler with the exception of sensor 56 while grain close to the top on both sides of the bin had a higher moisture content. This study serves as a stepping stone to preventing barley quality deterioration during the storage period and possibly proffering of quality improvement methods.

Introduction

The goal of every organization is to deliver goods and services of consistent quality as it makes the brand feel more dependable, builds consumer trust and is also a marketing tool on its own. The same goes for brewing companies, one of the goals is to provide products with consistent sensory properties to the consumers. Among the numerous factors that affect the achievement of this goal is the quality of raw materials. To achieve consistency in product quality, raw materials of consistent quality are required.

Malt is one of the major ingredients used to manufacture beer and therefore the quality of the malt is of paramount importance. Malt is produced by the controlled germination of barley grains (*Hordeum vulgare*), which is initiated by steeping barley grains in water, followed by germination and kilning periods (Woonton *et al.* 2005a). This process is known as malting and the objective of this process is to convert raw grains into malt by the production of a number of enzymes within the grain which is further utilized during brewing. To ensure this is achieved, barley must be able to germinate rapidly and uniformly.

Dormancy can interfere with the rapid and uniform germination of barley, thereby reducing the resultant malt quality (Woonton *et al.* 2005b). Post-harvest storage is a well-practised means of overcoming dormancy of malting barley but it is expensive and can be troublesome. The respiratory and metabolic processes in cereal grains continue during storage. Thus, the physical and biochemical changes occur on grains (Iconomou *et al.* 2006). Some moisture change in grains is usual under normal storage conditions. However, if the humidity and temperature are not controlled in the environment, then the negative conditions such as mould, germination, decay, rancidity may occur (Sharma *et al.* 2007). The variability of malt components during its storage depends mainly on temperature and water activity (moisture content). Both of these factors should be as low as to preserve the high quality of malt (Francakova *et al.* 2012).

The objective of this study was to look at the influence of location on temperature and moisture content of barley grains and also to establish a relationship between storage parameters (temperature, moisture content & storage time) and germination potential.

Materials and Methods

Data collection

Horizontal reinforced concrete grain storage facility was fitted with sensors 1m apart vertically and 6m apart horizontally as shown in figure 1 below. These sensors collect temperature and relative humidity data, the relative humidity data is used to provide an indicative moisture content. Irish barley harvested in July 2018 was stored in this storage facility and temperature and moisture content data were collected.

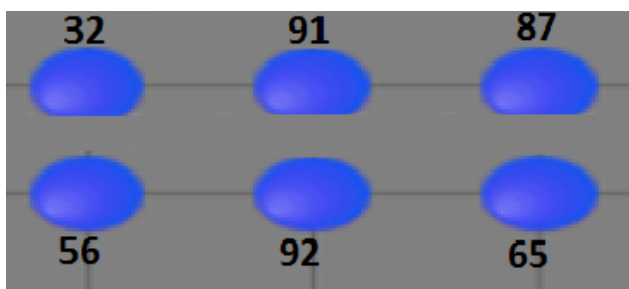


Figure 1. Diagrammatical representation of sensor positions with corresponding sensor numbers

Germination test

Barley samples were taken from each sensor position every three months and their germination potential was tested. The 4 mL and 8 mL germinative test on all samples was carried out using a modification of the European Brewery Convention methods 3.6.2 and 3.7 as in (Krajcovic *et al.* 2016).

Data analysis

Microsoft Excel was used to carry out a correlation and regression analysis between the three storage parameters (temperature, moisture content, storage time) and the response variable (germination potential). The average temperature and moisture content for each corresponding storage time period was used in the analysis.

Results, Expected Results and Discussion

Influence of location on temperature and moisture content

Plots of temperature and moisture content variation between the start date of data collection (15 September 2018) and 31 December 2018 is shown below (figure 1). The barley grains at the centre of the storage facility were generally warmer than those close to storage facility walls with the exception of sensor 56. The cooler temperature of barley grains close to storage bin walls was majorly an influence of the outside temperature.

Barley grains at the centre of storage facility had a lower moisture content as compared to grains close to the bin walls (seen in figure 2). This trend was a result of a temperature gradient within the storage bin. In the warmer regions, there is an increase in the partial pressure of water vapour while in the warmer regions, there is a decrease in the partial pressure of water vapour as a result of an increase and a decrease in temperature respectively. As a result, water vapour tends to migrate from warm regions to cool regions and in order to attain an equilibrium status with the surrounding air, grains in the warmer regions lose moisture while in the cooler regions gain moisture. Air density difference was also considered as one of the reasons for the trend.

A general drop in temperature and moisture content was noticed before day 40. This could have been a result of aeration or an outdoor weather condition. An anomaly was observed in sensor 65 readings after day 70, which could be due to condensation, sensor malfunction or barely a representation of the outdoor weather conditions.

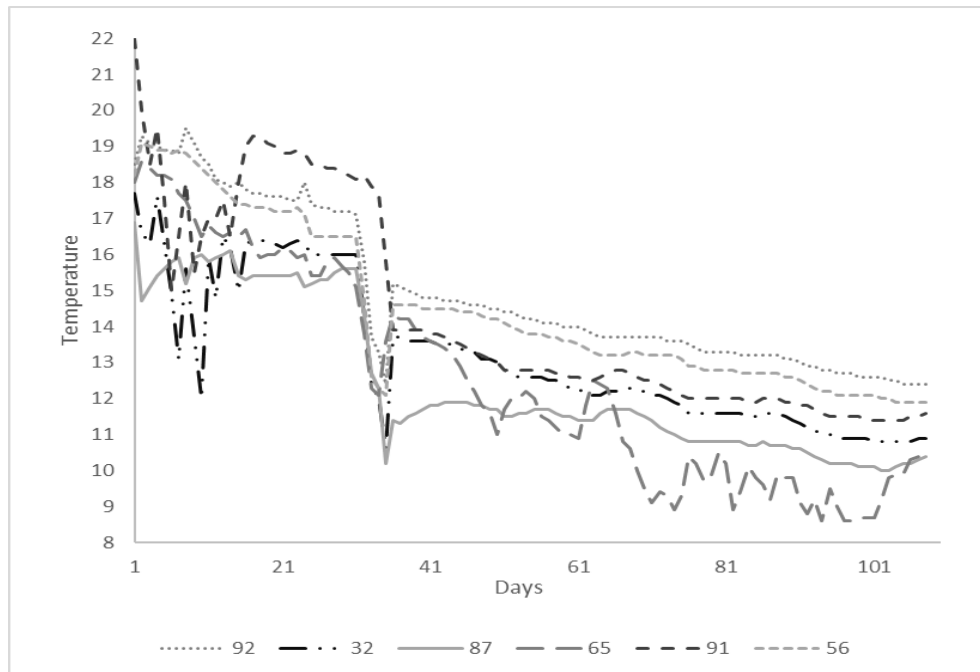


Figure 2: Temperature variation in storage bin

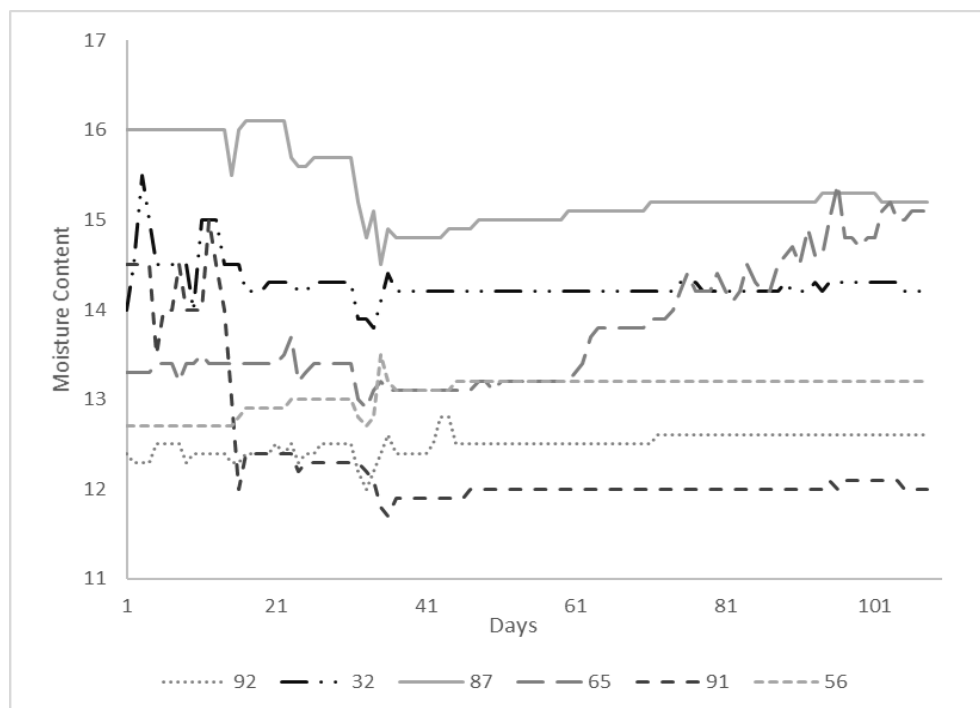


Figure 3: Moisture content variation in storage bin

Relationship between storage parameters and germination

Germination data was still being worked on and yet to be available but review of literature showed that for the best germination results, barley grains must be maintained at or below a moisture content and temperature of 14% and 14°C respectively.

Conclusion

The data presented indicates location of barley grains in storage bin has an impact on its temperature and moisture content. The grains at the centre of storage bin were found to be warmer than those on either side. External temperature also influenced temperature on sides of grains of storage bin. Moisture migration due to temperature gradient impacted moisture content of grains at different locations in storage bin. This is of practical importance to maltsters and grain storage personnel seeking to understand what happens during grain storage in prevention of grain quality deterioration.

Acknowledgements

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ADULTERATION DETECTION IN GIN USING UV-VIS AND NIR SPECTROSCOPY

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Abstract

Gin is a widely consumed and commercially important alcoholic beverage that has been associated with issues of fraudulent practice. In this study, NIR and UV-VIS spectroscopy associated with chemometric methods is used, for detection of adulterant in different gin brands. Three gin samples are used and diluted with three common adulterants like water, ethanol, and a cheap brand gin. Spectral data of both adulterated and non-adulterated samples will be obtained using spectroscopic technique and the characterization of brands will be accomplished by chemometric methods based on PCA and SIMCA.

Introduction

Gin is a spirit-based alcohol where the predominant flavour is derived from juniper berries. It is an extremely popular spirit in various countries like United Kingdom, France and Germany for exportation to the rest of the world. The United States has proven to be the most important import country in the Gin market. Gin is a complex mixture of diverse substances like water (distilled, demineralized, softened or permuted which should be capable for human consumption), neutral alcohol of agricultural origin (cooking, mashing, fermentation and distillation) and added botanicals (juniper berries, coriander seed, angelica root, sweet and bitter orange peel and licorice root) (Riu-Aumatell *et al.* 2016). It is a colourless beverage containing at least 37.5% alcohol and is usually consumed by mixing with tonic water, ice and lemon or other beverages (Riu-Aumatell *et al.* 2016).

Gin is a highly consumed liquor however; it has been associated with issues of adulteration and misbranding. Other alcoholic beverages like whisky, vodka, etc are also highly adulterated but their price in market is low, resulting in high consumption rate. Presently, food fraud cases have been increasing, making the authenticity of the food and drinks an issue of vital consideration. Brand falsification is also the major issue in alcoholic beverages occurring mostly in illegal factories, bars or restaurants (Cantarelli *et al.* 2015). The occurrence of these malpractices is to maximize the profit of the counterfeit. Furthermore, addition of adulterant to the branded spirit is another common fraudulent practice. This fraudulent behaviour have become a serious health issue for the consumers buying counterfeit spirits (Cantarelli *et al.* 2015). Therefore, it is of prime importance to develop a reliable analytic tool to help control this fraudulent risk (Markechová *et al.* 2014).

UV-VISIBLE (wavelength range 190-750nm) and NIR (wavelength range 700-2500nm) are spectroscopic techniques that provide information regarding the chemical bonds in functional groups of both volatile and non-volatile spirits (Li *et al.* 2014). They are simple, cost effective and non-destructive techniques used to verify the authenticity and discrimination of commercial brands (Nascimento *et al.* 2011). The spectral data obtained from spectroscopic results is further subjected to the chemometric analysis (PCA and SIMCA) which helps to classify the spectral scores in multi-dimensional space. Hence, coupling chemometric analysis with spectrometric techniques plays a vital role in the achievement of fraudulent screening in alcoholic beverages. In this study, a rapid and simple method for authentication of three gin brands from different origin is adopted based on spectroscopic and chemometric techniques (Pontes *et al.* 2006).

The objective of this study is to investigate UV-VISIBLE and NIR spectroscopy in combination with chemometric analysis to detect adulteration in three different gin brands.

Materials and Methods

Four different gin samples (cheap and premium) were analysed in this study and samples were purchased from local alcohol supermarkets. The brand name and the alcohol content of each gin samples are listed in Table 1. UV-VIS and NIR spectroscopy equipment in the UCD School of Biosystems and Food Engineering laboratory is used to detect the adulterant in the samples and other materials like deionised water, ethanol, pipettes, quartz cell cuvette are the important materials to be used in this study. Three test sets will be carried out based on the adulterant use: First, deionised water will be used as one of the adulterants in diluting the three gin brands (Thin, MOR and Bombay) to evaluate the dilution samples (adulterant/gin in volume: 0, 1, 2, 5, 10, 20, 30 and 40%). Secondly, pure ethanol will be used to analyse the dilution of the gin samples (adulterant/gin in volume: 0, 1, 2, 5, 10, 20, 30 and 40%). Third, to determine the effect of adding cheap gin brand (Hampstead) to the other three gin samples (adulterant/gin in volume: 0, 1, 2, 5, 10, 20, 30 and 40%). These tests will be analysed in triplicate sets to verify efficiency. Multivariate signal connection (MSC) is used to pre-treat the obtained spectral data to reduce the undesirable noise. Once the spectral peaks are obtained, the unscrambler X software (v10.4, CAMO software AS, Oslo, Norway) will be applied to enhance the Chemometric models.

Table 1. Brand name and alcohol content of gin samples

Brand Name	Alcohol (v/v) (%)
Thin gin (Irish Dry Gin)	40
Hampstead (London Dry Gin)	40
Bombay Sapphire (London Dry Gin)	40
MOR (Handcrafted Irish Gin)	40

Results

Non-diluted gin samples

Figure 1 represents the spectral peaks for four non-diluted gin samples (based on the averaged value of triplicate measurements) using UV-VIS spectroscopy from the wavelength 200 to 500nm. It is clear from the graph that the Thin Gin (Irish Dry Gin) has the highest absorbance and Bombay Sapphire (London Dry Gin) has the lowest absorbance when compared to the other gin samples.

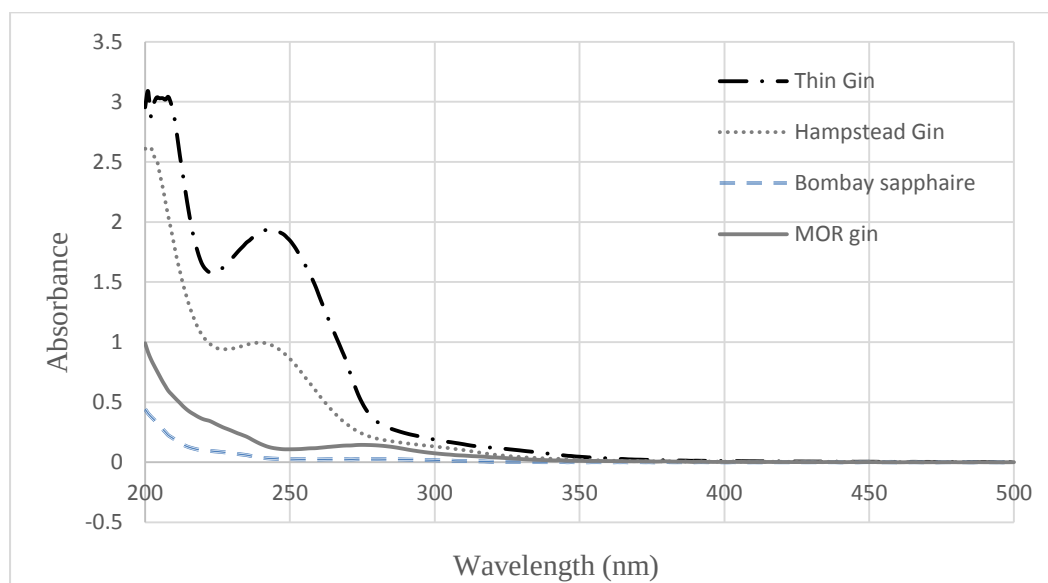


Figure 1. Spectral peaks of non-diluted gin samples using UV-VIS spectroscopy.

Thin gin diluted with water

Figure.2 represents the spectral peaks for Thin Gin (Irish Dry Gin) diluted with deionised water (adulterant/gin in volume: 0, 5, 15 and 30%) using UV-VIS spectroscopy from the wavelength 200 to 500nm. As we discussed earlier Thin Gin (Irish Dry Gin) has the highest absorbance rate, but when the pure gin is diluted with added adulterant (deionised water) the absorbance rate tends to reduce, and it is clear from the graph that increasing the adulterant tends to decrease the absorbance rate hence the quality.

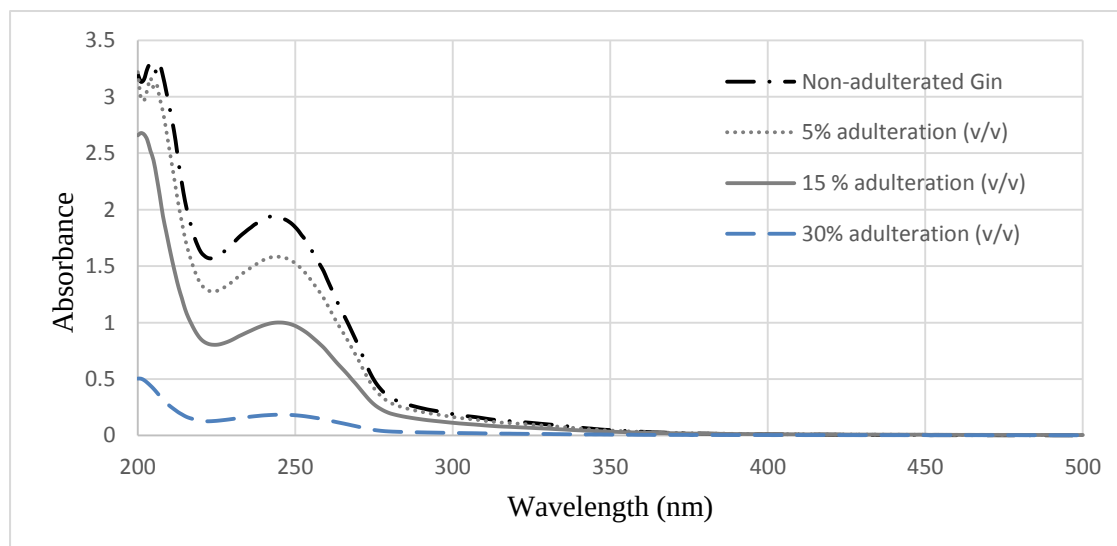


Figure 2. Spectral peaks of Thin Gin diluted with deionised water using UV-VIS spectroscopy.

Results and Discussion

UV-VIS spectroscopy

From the above obtained results, the classification of gin brands with added adulterant is hardly achievable using only the spectral data obtained from different spectroscopic techniques. Thus, chemometric analysis (PCA and SIMCA) combined with spectrometric technique is a good way to accomplish a fast data acquisition which further helps to carry out the data treatment accurately with low cost (Pontes *et al.* 2006).

The study on chemometric models provided by (Nascimento *et al.* 2011) shows that the PC1 and PC2 score plot is the best way to differentiate the non-adulterated and adulterated samples of any alcoholic beverages. The results from the above study were successful, thus chemometric methods combined with UV-VIS spectroscopy is one of the efficient techniques to be implemented for the current study on Gin.

NIR spectroscopy

The study provided by Pontes *et al.* (2006) mainly focuses on spectra of the 69 analysed samples of alcoholic beverages (whisky, brandy, rum and vodka) by using NIR spectroscopy. The spectral peaks obtained for each beverage presented very similar peaks, thus PCA and SIMCA were used to characterize each group.

The expected result can be very similar to the chemometric model score plot obtained for vodka samples analysis because of the colourless property. After modelling, it was observed that two principle components (PC1 and PC2) were enough to characterize the alcohol samples. PC1 involves the differentiation of whisky and brandy to that of rum and vodka which means that without this component the boundaries of two groups will be blurred. PC2, indicates the proximity between the two groups (Pontes *et al.* 2006).

Two groups of alcohol beverages were tested by SIMCA using the PCA data, to verify the prediction ability of each alcohol samples. Thus, at the laboratory level, where the alcohol samples were adulterated with water, ethanol and methanol showed 100% of correct prediction at the confidence level of 95% (Pontes *et al.* 2006). The expected result will replicate to those above mentioned chemometric methods in combination with both spectroscopic techniques (UV-VIS and NIR).

Conclusion

The study has proposed a methodology to tackle the problem of adulteration. This is done by classifying and authenticating the adulteration in gin samples using UV-VIS and NIR spectroscopy along with chemometric methods including PCA and SIMCA. The expected results will be obtained by collecting data from three gin samples using spectroscopic techniques. On further, analysing the result in Unscrambler X software, the quality of the samples will be determined rendering them safe for human consumption.

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VALORIZAION 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.

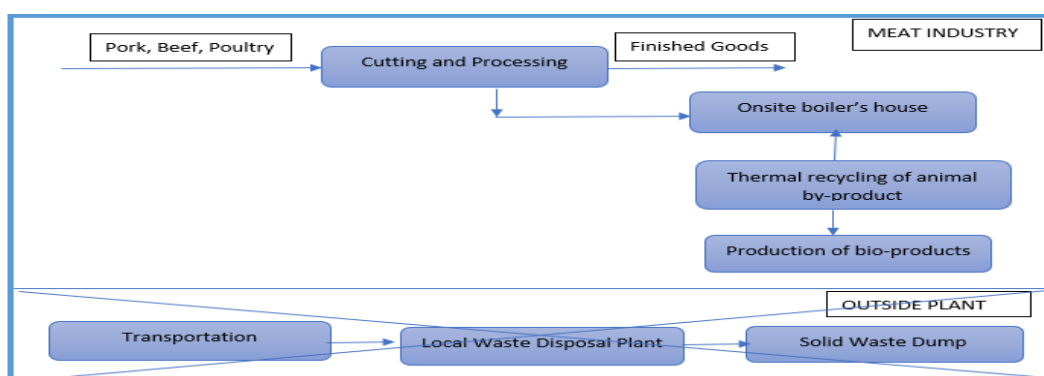


Figure 1. Suggested approach for utilising waste from the meat industry.

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 high quality bio- based product

such as compost or biofuel. It can also be used to extract enzymes for industries and 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 and 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 policies 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 effective guidance to policy makers ensuring the basis for a further development of the sector.

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NIR HYPERSPECTRAL IMAGING IN VISUALIZING MOISTURE DISTRIBUTION OF APPLE SLICES DURING HOT AIR OVEN DRYING

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Abstract

NIR Hyperspectral imaging system is a robust and innovative technique which has proven to be an effective tool to detect moisture distribution in the sample. This is an accurate way of analysis which helps in providing superior quality food. Hyperspectral imaging is the combination of spectral and spatial information. Apples will be washed, peeled and sliced into infinite slabs of thickness 2,4 and 6 mm and 45-55mm diameter using a stainless-steel food slicer. A total 30 samples of the three mentioned thickness will then go for dehydration. Drying will be carried out in hot-air oven at 70°C and moisture content will be checked every 30 min which will be recorded until the final moisture content reaches 22%. The dehydrated apple slices will be subjected to hyperspectral imaging system to visualize moisture distribution throughout the samples.

Introduction

Drying or dehydration is a familiar thermal technique highly used for preservation of agro-based food product. The drying process takes place in various modes such as conduction, convection, radiation or a combination. The process of the drying is assessed with respect to its efficiency in eliminating the moisture to certain desired level as well as minimizing the reduction of the quality aspects of the agro-based product. Hence, drying uniformity is a prominent factor in examining the dehydration method and the finished product (Y. Sun, 2017). Hot-air drying is a classic example of convective dehydration method. This technique is generally used for dehydrating various agricultural produce. Typically, in hot-air drying, the air from the surrounding environment is electrically heated and forced over the dehydrating material. Firstly, the heat is carried to the surface of the sample by convection and then to the centre by conduction (Y. Sun, 2017).

Hyperspectral imaging is an innovative and effective quality inspection system. It is non-thermal and non-destructive technology which fulfils the consumers demand for superior food quality. This novel technique comes with the advantage of its aptitude to integrate both spectroscopy and traditional imaging technique. Hence, it is a combination of spectral and spatial distribution. It makes direct evaluation of different components as well as locating the spatial distribution of these components across the test sample (Y. Sun, 2017). This method is simple, accurate and requires a limited level of sample preparation. Hyperspectral imaging is carried out in three different modes namely reflectance, transmittance and interactance.

The objective of the study was to investigate the potential of hyperspectral imaging technique in visualizing the moisture distribution of apple slices during hot air drying.

Material and Methods

Sample Preparation

The apples (Variety: GALA, produce of: Germany) will be procured from the local supermarket. The fresh apples to be used in this study will be procured from the local supermarket. Initial to dehydration the apples will be washed, peeled and sliced into infinite slabs of thickness 2,4 and 6 mm and 45-55mm diameter using a stainless-steel food slicer (Meisami-asl , 2010). A total 30 samples of the three mentioned thickness will then go for dehydration. Drying will be carried out in hot-air oven at 70°C and moisture content will be checked every 30 min which will be recorded until final

moisture content reaches 22% as given in UN Standards for dehydration of apple slices (UNECE Standard DDP-16,1998). The moisture content will be measured according to AOAC method.

Hyperspectral Imaging System

The hyperspectral images of apple slices will be secured by using a line-scan hyperspectral reflectance imaging system. Hyperspectral imaging is three dimensional. This system consists of a high-performance CCD camera (Xeva 992, Xenics Infrared Solutions, Leuven, Belgium) , a spectrograph (ImSpector N17E, Specim, Spectral Imaging Ltd., Oulu, Finland) linked with C-mounted lens (S31-f/2.0, Specim, Spectral Imaging Ltd., Oulu, Finland), an illuminating unit (500 W halogen lamps (JP245V-500WC, Ushio Inc., Tokyo, Japan) and a computer equipped with image acquisition software (SpectraSENS, Gilden Photonics Ltd., Glasgow, UK) (Elmasry, 2012).

Image Acquisition and Calibration

The images will be acquired by the CCD camera. The camera is a two-dimensional detector which simultaneously gather the spectral and spatial information. The spectrograph is the crucial part of the system which is intended to develop a spectrum for each point on the scanned line. An accurate calibration is needed to guarantee the dependability of the extracted data (Pu and Sun, 2015). The reflectance needs calibration as the spectral information collected from the CCD camera carries the intensity of detector signals and not the real reflectance values. The extracted data will be pre-processed mathematically to assimilate impact on spectra which will improve the calibration model. Pre-processing is required to identify the region of interest and extracting spectral features (Gowen, 2007).

Data Analysis

The extracted data is tremendous in quantity which requires a combination of multivariate matrices and visualization tool. The data in this study will be analysed by using MATLAB. The data analysis method will incorporate mathematical technique which will evaluate multiple variables concurrently. The reflectance data obtained will be simulated.

Optimal Wavelength Selection

Data analysis will be followed by the selection of optimum wavelength. The best subset of wavelength is required to find the moisture distribution in dried apple slices. The optimal wavelength is selected because they are equally or more efficient than the full set of wavelengths. The wavelength carrying most spectral data will be selected. Optimal wavelengths give the physical and chemical data of the tested sample (Pu and Sun, 2015).

As the sample will travel through different stages from image acquisition to data analysis, it will conclude with an illustration of the chemical composition of the sample in the visual form; also called chemical imaging which will reflect the moisture distribution in case of this study.

Expected Results and Discussions

Drying Kinetics

As reported in Amjad; (2017), the rate of dehydration depends on thickness of the slices. The moisture content reduces logarithmically with time at given drying conditions. The statistical analysis shows that drying time significantly affects the temperature and slice thickness. Similar drying kinetics are expected in the present study.

Spectrum of Apple Slices

In the paper presented by Amjad, 2017, the spectral reflectance curve of slices represents effectiveness of reflecting radiant energy. The samples of higher moisture content demonstrate minimum variation in reflectance while the sample with low moisture content shows maximum variation in reflectance. This indicates that the higher moisture content sample has greater absorption of light at given wavelengths. The present study is expected to illustrate related spectrum behaviour.

PLS Model and Moisture Prediction Maps

PLS models are robust method used to illustrate fundamental relationships. The prediction of moisture distribution in the slices will be investigated using PLS model as reported in Amjad; (2017). The PLS models are optimal and will be used to establish moisture prediction maps in this study.

Conclusion

In this study, NIR hyperspectral reflectance imaging system will be applied to gain hyperspectral images of apple slices during hot-air drying process. Moisture content will be measured by AOAC method. The spectral data hence obtained will represent reflectance values at certain wavelengths. PLS model will give accurate moisture distribution in the apple slices.

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ANTIMICROBIAL USAGE IN FOOD AND AGRICULTURE

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Abstract

Antimicrobial usage in food animals plays a major role in emerging human health issues. The use of antimicrobials is inevitable as they are used to inactivate or inhibit the growth of microorganisms in food animals. The residues of the antibiotics could also be present in the animal's tissues. Therefore, when humans consume animal derived food products (such as the meat, egg or milk), there is a chance of transfer of these antibiotics into human bodies. This can lead to many health concerns in humans, including the development of antibiotic resistance, hypersensitivity reactions, toxicity, teratogenicity and even carcinogenicity. From the literature reviewed, it is reported that the most commonly used antibiotics in animals are the tetracyclines (oxytetracycline OTC, tetracycline TTC, chlorotetracycline CTC, doxycycline DOC) followed by fluoroquinolones and penicillin. This study is focusing on human exposure to these antibiotics in humans using Monte Carlo stimulation methods. This paper presents a framework model for the development of this risk assessment.

Introduction

Antimicrobials are substances that are used to kill microorganisms or to inhibit their growth. They are commonly used in food derived animals for disease treatment, prevention, control, growth promotion or to improve feed conversion efficiency (Marshall and Levy, 2011). The commercial production of antimicrobials and its application after the late 1940s in food derived animals resulted in the effective treatment of infections, which were earlier considered to be untreatable (Saini *et al.* 2012). Unfortunately, the introduction of antimicrobials gradually resulted in the emergence of antimicrobial resistance (AMR).

The increased level of AMR can have a negative influence on the production of livestock by either affecting productivity of the farm or by increasing the cost for disease treatment. Antimicrobial use appears highest for chicken production (138 doses/1000 animal-day) followed by swine and dairy cattle (Cuong *et al.* 2018).

The high-level usage of the antibiotics thus raises the possibility that residues would remain in the edible tissues of the livestock which is meant for human consumption. This residue may cause a health threat to humans. Therefore, internationally recognized organizations like the World Health Organization (WHO), and the Food and Agriculture Organization (FAO/WHO 1988) have set maximum residue limit (MRL's) of the antimicrobial's agents (Salama *et al.* 2011).

The method used in this study to assess potential human exposure to antimicrobials is through Monte Carlo stimulation methods. It is a method for iteratively evaluating a deterministic model using sets of random numbers as inputs. This method is used when the model is complex, non-linear or involves more than just a couple of uncertain parameters. Figure 1 represents a flow diagram representation for the various pathways. The flow diagram indicates the transfer of antimicrobials from one source to another.

The objective of this study is to assess antimicrobial usage in animal husbandry (bovine, ovine, avian, swine) and to assess potential transfer of these antimicrobials into the food products (meat, milk and egg) and finally to assess potential human exposure.

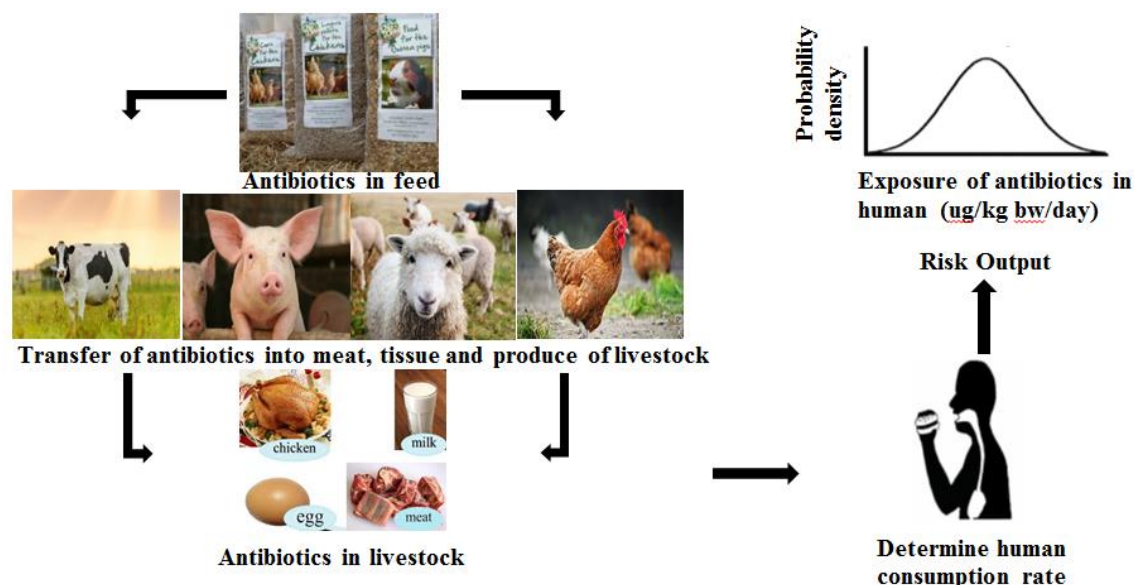


Figure 1: Flow diagram for the potential transfer pathways of antibiotics

Materials and Methods

The antimicrobials are given to the animals either by the injection administration or through the feed. Through the bio-transfer a certain amount of the antibiotics would be transferred from animals into food products such as the meat, egg and milk. EU regulations have specified the maximum residue limit (MRL) for various antibiotics. According to the EU regulations the MRL for the ampicillin in all food producing species are 50 µg/kg (muscle, fat, kidney) and 4 µg/kg for the milk. While the MRL for the tetracycline in all food producing species are 600 µg/kg (kidney), 100 µg/kg (muscle and milk) and 200 µg/kg (eggs).

Injection of higher levels of antimicrobials into animals is done mainly to prevent the disease and to promote the growth. As a result, the bio-transfer of antimicrobials into the animal tissue would be greater. This can result in human's exposure when they consume these products. The exposure level in humans is found by multiplying the level of antibiotics in the food products such as the milk, egg, or meat by the rate of consumption. The quantitative risk assessment model is developed through an excel sheet.

$$\text{Human exposure} = R_f \times C_f$$

Where:

R_f = antimicrobial residues in food products (milk, meat, egg).

C_f = Consumption of food product (milk, meat, egg) by humans.

After assessing the exposure level, the hazard characterization stage involved in the food chain is investigated. Following the exposure of humans to the antimicrobials through the food, there is the possibility of getting serious health issues such as allergies, antibiotic resistance, hypersensitivity reactions, toxicity, teratogenicity and even carcinogenicity.

The flow diagram (Fig 2) represents the framework model that has developed for the risk assessment on the human exposure to antimicrobials due to the usage of antimicrobials in the animal husbandry.

The various stages involved in the transfer of the antimicrobials from the animals to the humans is shown the framework.

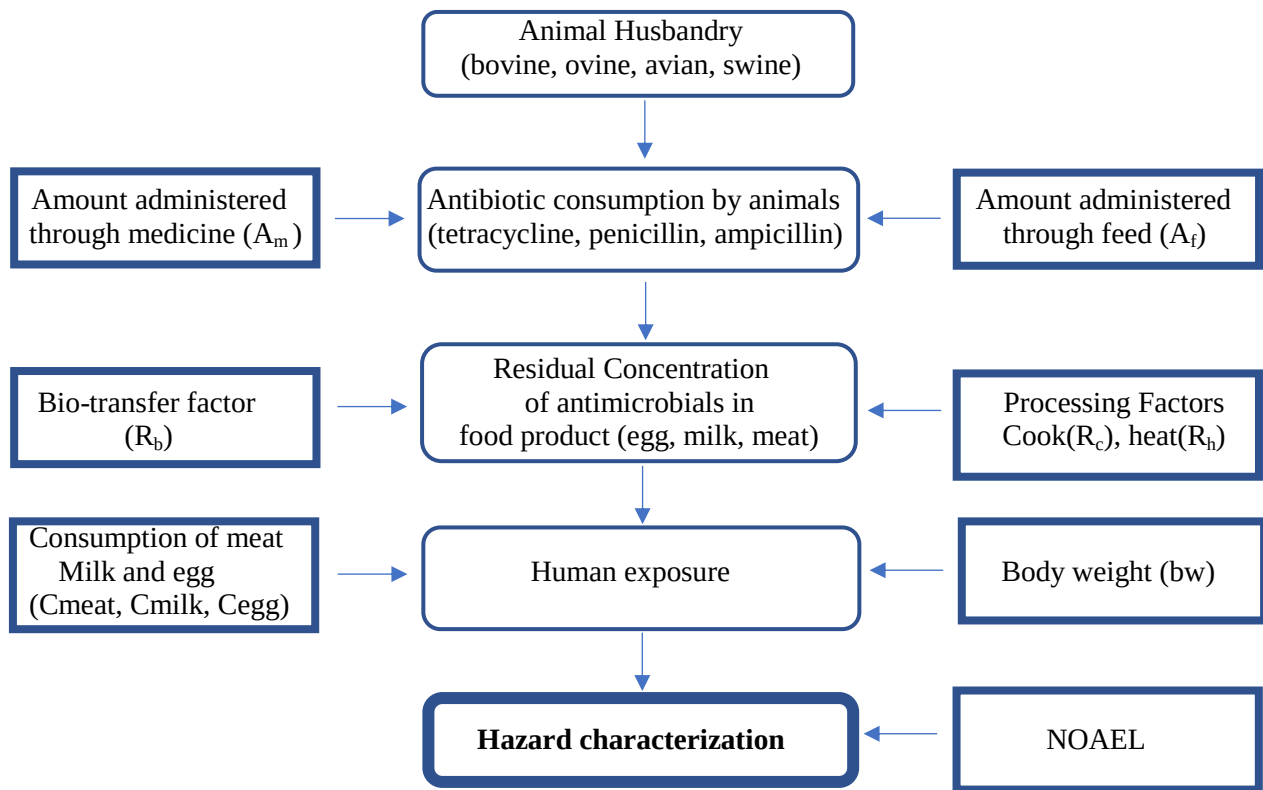


Figure 2: Framework to assess the quantitative transfer of antibiotics from the food animals to humans

Results and Discussion

A framework model for the development of this risk assessment has been developed. The future work for this project involves the collection of more information regarding the inputs in each stage of the framework from various literature reviews. After collecting all the required data's, these are then incorporated into the Excel sheet to develop a Model Carlo stimulation model using the RASP software tool (Cummins, 2019). The model will assess the risk assessment of human exposure to antimicrobials by consuming meat, milk and eggs. Based on the acceptable daily intake value and the exposure of humans to these antimicrobials, the risk involved can be found.

Conclusion

The usage of the antimicrobials on animal husbandry has a lot of advantages but when it is over used this can create serious impacts on both animals and humans. Therefore, the usage of the antimicrobials should be done based on the EU Codex Alimentarius. The transfer of the antimicrobials may take place in the food chain, from animals to the humans. Humans may get exposed to these antimicrobials when they consume the products of animal origin (such as milk, meat and egg). If the level of the antimicrobials is higher than the acceptable level, it may have a negative impact on human health. Now a day's people have become more concerned about their health. Therefore, they became more careful about the food they consume. Therefore, the use of the antimicrobials in the animals should always be as per the EU regulations of the Codex Alimentarius.

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EVALUATION OF BIOPLASTICS FORMULATED FROM FOOD WASTE USING NIR SPECTROSCOPY IMAGING

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Abstract

Plastic pollution can affect land, water and oceans negatively and also cause human health degradation and the food chain. Most plastics are derived from petroleum or natural gas, which are diminishing day by day. Manufacturing and developing bioplastics can be a sustainable solution to the problem. Initially, land grown crops were used to prepare bioplastics, as it is not a sustainable option and counters the Life cycle assessment of Starch based bioplastics. The real challenge is to synthesize new materials from food waste and not from land grown crops. This study will focus on upcycling banana peels, that contributes largely to the food waste generation. The characteristics of the bioplastics will be evaluated by determining the tensile strength, water resistivity, mechanical and thermal properties, rate of biodegradability. Near Infrared hyperspectral imaging is a new approach that identifies plastic by several groups. The applicability is effective due to its simple instrumentation and ability to detect spectra fast and without pre-process sample preparation. The NIR-HSI data will be acquired using the push-broom system in the wavelength range of 950-1700 nm.

Keywords: *Bioplastics, Banana peel, NIR, food waste, biodegradable, plastic, starch-based*

Introduction

Plastics is a class of organic carbon chain polymers, is widely used in the daily life due to its exceptional properties and pursuance over other materials like metal and wood, having advantages - light weight, low price, high strength, user-friendliness (Álvarez-Chávez *et al.* 2012; Zhang *et al.* 2017). These significant properties have made plastic a very influential form of polymer, which is a high molecular weight thermoplastic that can be molded into objects, films or filaments, derived from petroleum as a by-product. As plastics are non-biodegradable, or their rate of decomposition is as long as a decade and derived from non-renewable resources. To overcome the disadvantages, application of the green chemistry, synthesis of biodegradable plastics is a sustainable approach to the environmental crisis. The next concern is the broad range of environmental impacts, such as soil erosions, deforestation, water and air pollution along with greenhouse gas emissions during the process of food production, storage and transportation and waste management accompanied with the generation of food waste (Schanes *et al.* 2018). Though, starch-based bioplastics are sustainable and completely biodegradable, come along with drawbacks like long term instability due to water absorption, ageing caused by retrogradation and poor mechanical properties. To overcome the drawbacks, glycerol is added as a plasticizer to improve shelf-life and elasticity of the end product (Ismail *et al.* 2016). Characterization and evaluation of plastic properties will be conducted on various samples namely, the biodegradable synthetic plastic which will behave as the control, banana peel bioplastic, potato starch-based plastic and banana peel and corn starch-based bioplastic at different concentrations. Therefore, the study aims to investigate the tensile, mechanical and biodegradable properties along with evaluation of the bioplastic films in terms of thermal properties and functional group. Load test is to characterize the strength of the film whereas the water absorption test will evaluate its ability to intake water that enhances the biodegradability, which is evaluated by the 5 days soil burial test (Sultan and Johari 2017).

The objective of the study is to investigate the properties of bioplastic synthesized from banana peel starch using NIR hyperspectral imaging. The results obtained will be compared with those obtained for potato-starch based bioplastics, as well as other biodegradable synthetic plastics.

Materials and Methods

The research will be conducted as follows and is based on the literature review of development of bioplastics from banana peel starch and potato starch (Ismail *et al.* 2016; Sultan and Johari 2017).

Materials

Bananas from supermarket, analytical grade hydrochloric acid (36% v/v) [Sigma-Aldrich CAS 7647-01-0], glycerol (99.5% v/v) [Sigma-Aldrich CAS 56-81-5], sodium hydroxide (0.5M) [Supleco CAS 1310-73-2], 1% corn starch, acetic acid solution [Sigma-Aldrich CAS 64-19-7] were purchased from Dublin, Ireland.

Instrumentation

The instrument used was Near Infrared hyperspectral imaging – push-broom spectral scanner, Data acquisition software SScanner (DV Optics Ltd.) working in the wavelength region of 880-1720 nm.

Extraction of starch from the banana peel

Peel will be separated from the banana using stainless steel knife and cut into small pieces. The small pieces will then be placed in 5-6% acetic acid solution before boiling. Banana peels to be boiled in distilled water in 800 mL beaker for 30 minutes. Water will be decanted off and dried for 30 minutes. Pureed the dried peels using a hand blender to form a fluid paste, after which paste will be filtered out to separate the starch from the banana peel.

Preparation of the bioplastic film

25 mL of banana peel starch is to be placed in 50 mL beaker to which 3 mL of 0.5M HCl has to be added and mixed using a glass rod. Add 2 mL of glycerol to the mixture and thoroughly mix using a glass rod. The mixture has to be poured into a petri-dish and will be placed in the hot air oven at 60°C for 30 minutes.

Preparation of the bioplastic film in addition with corn starch

25mL of banana peel starch placed in 50 mL beaker to which 3 mL of 0.5M HCl is to be added and mixed using a glass rod. Add 2 mL of glycerol to the mixture and thoroughly mix using a glass rod. 3 ml of 1% corn starch will be added as a co-biopolymer and stir the mixture again. 3 mL of 0.5M NaOH is to be added to the blend, which will be poured into a petri-dish and placed in the hot-air oven at 60°C for 30 minutes.

Load test

A Bioplastic film is to be cut into 2 cm x 6 cm size. Film hooked onto the retort stand will be placed 3.5cm apart. A spring balance to be hooked onto the middle of the film and add weight load until sample breaks apart. 3 such repeats will be performed and recorded to obtain an average value. Tensile strength will be calculated using the following formula:

$$\text{Tensile strength} = \text{Weight load}(N)/\text{Area of cross section of biofilm}(m^2)$$

Water absorption test

A bioplastic film is to be cut into 1cm x 2cm size. The initial weight will be recorded. Place the film in 60 mL water at room temperature for 24 hours. The film will be taken out of water and wiped clean and the final weight will be recorded. The amount of water uptake will be calculated using the formula:

$$\text{Water absorption \%} = [(Final\ wt.\ (g) - Initial\ wt.\ (g))/Initial\ wt.\ (g)] \times 100$$

Biodegradability test

5 days soil burial test will be carried out. The bioplastic film is to be cut into 1 cm x 2 cm size. The film is to be buried in the soil, soil microorganisms will feed on it, which will result into weight loss of the bioplastic film. Amount of biodegradation will be calculated as:

$$\text{Soil degradation \%} = [(Final\ wt.\ (g) - Initial\ wt.\ (g)) / Initial\ wt.\ (g)] \times 100$$

NIR hyperspectral imaging

NIR spectroscopy equipment at the School of Biosystems and Food Engineering (UCD) laboratory will be used to process the samples. All the samples will be transported by a moving conveyor belt with adjustable speed and will be compared with the standards. The apparatus is used for obtaining NIR reflectance spectra with the wavelength region from 950 to 1700 nm every 7 nm. A diffused light cylinder source with tungsten lamps provides the required energy for the sensing unit. The NIR-HSI is controlled by a PC unit equipped with Spectral Scanner software. This technique is usually used to determine the water structure of polymers. For better interpretation of the spectra, multivariate analysis will be used to characterize the chemical bonds and vibrations in the films in terms of hydrogen bonding (Xu *et al.* 2018).

Data analysis

The selection of the wavelength will be carried out using MatlabR2018a (The Math Works, Inc. USA) in combination with method of principal component analysis (PCA) after pre-treatment process.

Expected Results and Discussion

The experiment will result in formation of bioplastic film synthesized by the starch from the banana peel. As the experimentation has not yet commenced, therefore the following expected results are best described based on the references to the current literature.

Load test

On determining the tensile strength of the sample, which will be compared with the tensile strength of the standard biodegradable synthetic plastics. According to the literature, the banana peel and corn starch bioplastic have the highest tensile strength due to cross linking chains in the amylose molecule of the starch (Sultan and Johari 2017).

Water Absorption test

This test determines the water resistance of the film which is a required characteristic to provide the properties of a conventional plastic. The absorption test of the film will be carried out for 24 hours and according to the literature review, the film with the corn starch is expected to have the highest water intake estimated at around 108.98% concentration (Sultan and Johari 2017). The potato starch-based bioplastic is estimated to have around 32.35% and the water intake of the banana peel starch-based bioplastic is to be determined yet. Presence of glycerol in the film, creates a tendency to absorb water as it is hydrophilic low molecular carbohydrates, but depends on the number of hydroxyl groups present and the molecular weight of glycerol (Sultan and Johari 2017).

Biodegradability test

According to the literature, the film is expected to have weight losses due to degradation process and feeding of soil microorganisms. It is expected to absorb moisture from the soil, may swell and become soft. After the burial test, it is expected to diminish in size, tend to become crisp and fragile (Imam *et al.* 2005). This is said to be a result due to degradation of the starch molecules in the film. The darkening of the sample is expected to be a sign of onset of decay (Manimaran *et al.* 2016).

NIR hyperspectral imaging

On conducting NIR-HSI, it is expected to provide information on the hydration level and distribution of water in the bioplastic films and these results can be linked to the above tests that will be performed through multivariate data analysis.

Conclusion

The bioplastic films using banana peels and corn starch is to be formulated. The 4 samples namely conventional biodegradable synthetic plastic (standard), banana peel starch-based bioplastic, potato starch-based bioplastic and banana peel and corn starch-based bioplastic is to be compared and their respective characteristics will be studied, and an overall scoring will determine the bioplastic with best characteristics. This research can have a potential application in the food packaging industry if found to be compatible with various food products.

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GENOME ANALYSIS OF PATHOGENS FOR RESISTANCE TO SANITATION PRODUCTS

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Abstract

Listeria monocytogenes is a common foodborne pathogen with a mortality rate of 20-40%, which is defined by the World Health Organization as one of the four major foodborne pathogens globally. In the context of global environmental health and food safety concerns, the use of sanitation products is increasing in several environments including in health care, veterinary, and food product development. As the selection pressure of sanitisers increases, the resistance of pathogenic microorganisms continues to increase. The formation of biofilms is one of the important causes of microbial resistance to sanitisers, and biofilms in nature are often found in the form of multiple microorganisms. In the biofilm, *Listeria monocytogenes* and commensal bacteria form biofilms, which help bacteria survive in the anti-drug stress environment.

Introduction

In recent years, food safety has become a public health concern of the world. Foodborne pathogens are the leading cause of foodborne diseases and cause serious harm to human health. They are serious risks to food safety. *Listeria monocytogenes* (LM) is a common foodborne pathogen, and WHO listed it as one of the four major foodborne pathogens in the 1990s. *Listeria monocytogenes* is a zoonotic disease that is widespread in nature and can exist in a variety of foods (Farbor 1991). It can develop from fever, gastroenteritis to severe invasive diseases (listeriosis), leading to sepsis, encephalitis, endocarditis, meningitis and other syndromes (Charlier *et al.*, 2017). *Listeria monocytogenes* belongs to the genus *Listeria*. It is a Gram-negative short rod with no spores. The growth environment is aerobic and facultative anaerobic, which can grow and survive in extreme environments. It has a growth temperature of -1.5°C to 50°C, a pH of 4.3- 9.6, high salt tolerance, and can withstand freezing and drying (Doyle *et al.*, 2001; Gardan *et al.*, 2003). After the 1980s, *Listeria* monocytogenetic food poisoning in Europe and the United States showed an upward trend. In addition to contaminating animal foods such as milk and meat products, the bacteria can also be found in vegetable foods.

The objective of this study was to analyze the gene sequence contributing to sanitizer resistance and mechanism of action and control the growth of the *Listeria monocytogenes* for reducing risks to the environment and humans.

Vitas *et al.* (2004) tested 293 raw meat products in Spain with a contamination rate of 34.9% for *Listeria monocytogenes* and 36.1% for raw poultry products. For dairy products, the *Listeria* contamination rate was found to be 6.8% in 340 raw milk samples from Spain. The detection rate of *Listeria monocytogenes* in 100 pieces of smoked salmon in Spain is 28%. In addition to animal foods, the presence of *Listeria monocytogenes* in soils and animal manure as a fertilizer allows plants such as vegetables to be contaminated with *Listeria monocytogenes* in the field. The contamination rate of *Listeria monocytogenes* in Danish vegetable products is 12.1%-34% (Nørrung *et al.*, 1999). The biofilm refers to a micro-organism adsorbed on the surface of an inert object, which secretes a polysaccharide matrix, fibrin, lipoprotein, and extracellular polymer (EPS) such as DNA, which are adhered to each other and aggregated and formed into a multi-organized structure. It is a special growth state in which microbes are adapted to the stress environment to form a

favourable environment. Biofilms are ubiquitous and can be formed on a variety of surfaces. More than 90% of microorganisms in nature are in the form of biofilms.

Materials and Methods

Identification of bacteria strains

The genomes of the *Listeria monocytogenes* strains were downloaded from NCBI (www.ncbi.nlm.nih.gov).

Data analysis

A number of studies have reported on biofilm formation. Pan et al. (2006) measured biofilm cell viability and biofilm resistance to sanitizer using an automatic plate reader on an agar plate, the survival rate is equal to No/Ni , where Ni is CFU/ml after treatment with sanitizer and No is the initial count of CFU/ml before treatment. The final factors that result in different data are: (i) two different biofilm matrices, stainless steel and Teflon; (ii) Two treatments under the SFP model, one for the experimental group treated with the sanitizer and the blank control group without the sanitary treatment. From the previous researches, the active efflux pump is the main mechanism for tolerance to sanitisers, which is inherent (Aase, 2000). Dutta et al. (2013) have demonstrated that in BAC-tolerant *Listeria monocytogenes* from various sources, the *bcrABC* box is present in 98.6% of isolates. The most suitable method for determining the MIC of antibacterial drugs is to observe the growth of pathogen after incubation for a certain period. The MIC is determined to inhibit the growth of pathogens with a drug-concentrated agar plate. With the residue of the sanitiser, the resistance of the pathogen gradually increases. Genetically moving elements also play an important role in the transmission of resistance genes in *Listeria monocytogenes*. In isolates carrying *bcrABC*, Dutta et al. (2013) have proposed that chromosomal transmission and subsequent integration and other resistance genes are mediated through plasmids containing transposons.

Results and Discussion

Biofilm inactivation of Listeria monocytogenes by sanitiser (BC) under SFP system

The test of Pan et al. (2006) showed that the degree of deactivation on the surface of stainless steel is usually higher than the degree of deactivation on Teflon. In the first week, the biofilm was clearly inactivated. In the next two weeks, the cell concentration did not change much, indicating a progressive increase in biofilm resistance. The resulting resistance mechanisms mainly include: the physical hindrance of extracellular polymers in the biofilm can effectively reduce the intra-membrane strains. The concentration of the bacteriostatic drug is also the blocking effect, so that the microorganisms in the membrane have enough time to open and express the corresponding drug resistance gene (Mah and O'toole, 2001).

The analysis of bcrABC gene's resistance to BC

Sequence analysis revealed that the *bcrABC* resistance gene cassette is part of a composite transposon. After deletion of *bcrB* gene or *bcrC* gene, the MIC of both mutants decreased to 10 µg/mL, indicating that the efflux pump *bcrBC* protein mediates the resistance of LM strain to BC. Therefore, it is speculated that the constitutive overexpression of the *bcrBC* gene is fatal to cells. The strain H7550 was exposed to a sublethal concentration of BC (like 10 µg/mL), and the transcription level of the *bcrABC* resistance gene cassette was significantly increased. However, when the mass concentration of BC solution was increased by twice or 4 times, the transcription level of the *bcrABC* resistance gene cassette was basically unchanged.

Expected work

Due to the coexistence mechanism of *Listeria monocytogenes*, the dominant commensal bacteria coexisting with it should be found out. For example, the superior commensal bacteria were isolated from the food processing equipment, and the dominant commensal bacteria and LM coexisted to form a biofilm. It provides a new theoretical basis for effective control of food safety issues arising from LM as a potential source of contamination in food products and processing, and better removal of residual LM biofilms. The effect of these dominant commensal bacteria on the regulation of the monocytogenes of the *Listeria monocytogenes*, and the effect of the coincidence, remains to be further explored.

Conclusions

In order to study the tolerance of *Listeria monocytogenes* to disinfectants, the BC sensitivity test showed that the ability of *Listeria monocytogenes* to tolerate benzalkonium chloride in the food environment under sanitation products environment is constantly increasing. Biofilm formation is the main reason for the important role of microbial pathogenicity and drug resistance. The structural characteristics and dynamic mechanism of mixed biofilms in micro-ecological systems are mainly derived from the internal inductive system communication between different species interaction. *bcrABC* can be transmitted in *Listeria monocytogenes* strains, and most resistant strains contain *bcrABC*. In addition, it is also another resistance determinant of *Listeria monocytogenes* (Katharios-Lanwermeier *et al.*, 2012).

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HYPERSENSPECTRAL IMAGING TO MEASURE THE MOSTURE CONTENT OF KIWI SLICES USING HOT-AIR DRYING

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Abstract

Hyperspectral imaging is a rapid and non-destructive detection technique for quality analysis such as moisture content, which is operated by simultaneously offering spectral data. The purpose of this study was to demonstrate the feasibility of hyperspectral imaging in measuring moisture content of kiwifruit under hot-air drying process. The data processing and analysis were based on Matlab 2015a. Calibration model was based on partial least square regression (PLSR) to establish the relationship between spectral data and moisture distribution.

Introduction

Kiwifruit is considered as “the king of the fruits” given the high contents of Vitamin C and polyphenol compounds with antioxidant activity (Zhou *et al.* 2018). Due to its multi-nutritional value, many studies have demonstrated kiwifruit’s beneficial effect on human health such as cancer prevention. Moreover, the moisture content (MC) of kiwifruit was found ranging from 80% to 86% (wet basis) (Cangi *et al.* 2011). Therefore, kiwifruit has a very short shelf-life and is highly perishable after harvest.

In order to overcome the problem of the short-life of kiwifruit, drying has become one of the commonest preservation alternatives to increase storage stability. There are various drying techniques for food, such as microwave vacuum drying, freeze drying, hot-air drying as well as radio frequency-vacuum drying. Among of these, hot-air drying is a simple and common method for fruits and vegetables drying. During the hot-air drying process, the heated dried air is forced to flow through the samples and thermal energy is transmitted to the surface of samples by convection and then transferred to the interior by heat conduction (Chin *et al.* 2015). In addition, by reducing water content, the concentrations of various ingredients increase, giving the dried kiwifruit other flavors, shapes and textures.

With increasingly demand for fruit quality, assessment of quality attributes has becoming a big concern. In order to meet the requirement and quality assurance, sophisticated analytical procedures for quality control have been carried out. Compared with traditional methods, hyperspectral imaging (HSI) techniques is a potential analytical tool with following advantages: fast operation speed, non-destructive analysis, without prior sample preparation and synchronous assessment. Using HSI methods, the quality attributes such as moisture content in the samples can be visualized during the drying process. In recent year, HSI has been researched for apple, banana and mango (Pu and Sun 2016; Nguyen-Do-Trong *et al.* 2018). However, the information on using HSI for evaluating kiwifruit MC during hot-air drying processes is limited.

The objective of the study was to investigate the potential and feasibility of hyperspectral imaging techniques for measurement of moisture content of kiwifruit during hot-air drying process.

Materials and methods

Sample Preparation

Fresh kiwifruits (variety: kiwi Hayward, *Actinidia Deliciosa Planch*, Greece) were purchased from the local supermarket Tesco. Similar ripeness and size (diameters = 35-45 mm, length=50-60 mm) were selected. Then the fruits were stored in a refrigerator at 4°C until testing, and the fruits were peeled and cut into slices with diameter 35-45 mm and three thickness: 2, 4, 6 mm for initial dehydration of kiwi. Ten samples for each thickness were prepared, and then the weight was recorded. The drying procedure was carried out in a hot-air drier at 60°C. Every hour, the kiwi was taken out of dryer to check the weight until the moisture content of kiwifruit samples decreasing to constant weight. The weight and diameter were measured and are shown in Table 1.

Table 1. Weight and diameter measurement

Thickness (mm)	2	4	6
No. of kiwi slices	10	10	10
Diameter (mm)	35-45	35-45	35-45
Weight (g)	2.7±0.2	5.5±0.5	9.0±1.0

Moisture content

Using hot-air dryer to determine the moisture content (MC) of each slice at 105°C until a constant weight. The MCs are calculated by the following equation:

$$W = \frac{W_0 - W_c}{W_c},$$

Where W_0 is the original weight, W_c is the slices constant drying weight.

Hyperspectral Imaging System

The moisture content of kiwifruit was visualized by using a HSI system (Figure 1) and the detail of the setup was described in the previous study (Lin *et al.* 2019). The system consists of a CCD camera (Canon PowerShot A75, Canon, USA), a spectrometer, a zoom lens (value at $f = 4.5$, speed at 1/10), a sample holder, and four lamps (Kaiser Fototechnik, 126 Buchen, Germany). Hyperspectral image acquisition program was used to synchronize the movement of the samples.

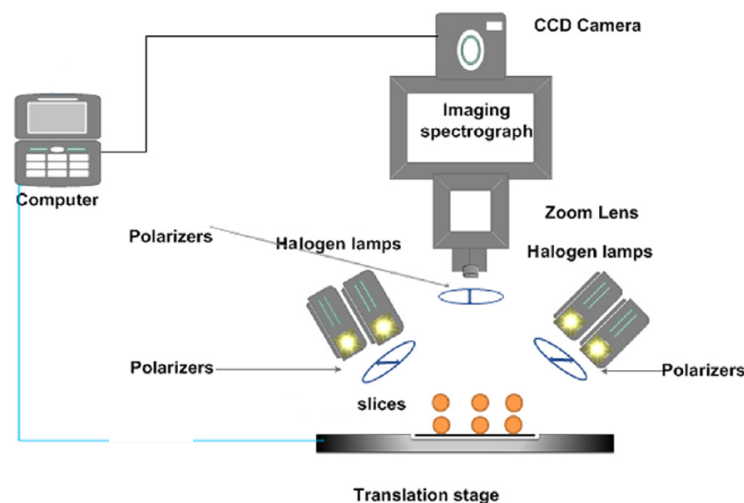


Figure 1. hyperspectral reflectance imaging system (Nguyen-Do-Trong *et al.* 2018)

Image acquisition and data analysis

When the translation stage was operated, the kiwi slices were progressively conveyed through the field of detector and the surfaces of kiwi slices were successively scanned. The white and black references were applied to remove the influence of darkness from camera. Imaging and spectra processing were conducted by Matlab software 2015a. In order to obtain reliable and robust prediction model, standard normal variate (SNV) and Savitzky-Golay (SG) were applied in pre-treatment of spectral data to remove background information and reduce noises. A large amount of spectral data extracted from hyperspectral imaging needed the establishment of multivariate analysis of correlated spectral data and moisture. Partial least squared regression, a reliable multivariate calibration method, was applied to relate spectral data and reference values (Qu *et al.* 2017). After calculating the calibration equation, it is necessary to validate its predictive performance for samples. Root mean square error (RMSE) and coefficient of determination (R^2) are significant criterion to evaluate model's performance. The values of RMSE should be low enough to get acceptable calibration equations (Pu and Sun 2015).

Results and Discussions

Mathematical modeling of drying Kinetics

The dynamic models of kiwifruit drying were conducted at a temperature of 60°C. R^2 , RMSE and χ^2 are statistical parameters for the dynamic model (Mahjoorian *et al.* 2017). Slice thickness had a significant effect on drying time and the moisture ratio was significantly affected by drying time and thickness.

Modelling and prediction of moisture content

The study establishing a PLSR model based on spectra data and visualized MC in dehydrated kiwifruit. The value of R^2 should be close to 1, meaning a perfect linear relationship between predicted and reference values (Sun *et al.* 2017).

Selection of optimal wavelength

The selection of wavelength plays an important role in multispectral imaging systems, which could simplify large amounts of spectral data. In this study, the wavelengths were selected by means of the corresponding regression coefficient obtained from the PLSR model, and then the moisture content prediction model was constructed according to the selected wavelength. (Sun *et al.* 2017).

Conclusion

In the present study, hyperspectral imaging techniques demonstrated the feasibility in measuring moisture content of kiwifruit under hot-air drying process. Moisture content was measured by conventional methods. Based on original spectral data set, PLSR models acquired accurate prediction maps of moisture content in kiwi slices. Optimum wavelengths were also chosen to simplify the spectral data.

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INVESTIGATION OF PENETRATION DEPTH OF NIR LIGHT IN FOOD PACKAGING

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Abstract

As a non-destructive measurement technology, near-infrared (NIR) hyperspectral imaging technology has become more and more mature in the research of food packaging plastics, and it has been possible to classify different plastics. In this study, three commonly used food packaging plastics, including PE, PVC and PVDC, were selected for research. The experimental results will be obtained by testing 270 samples with a spectral frequency in the range of 4000-7000 cm^{-1} . In addition, the spectrum of polystyrene is selected as the reference spectrum in this study. All experimental data will be processed by MATLAB for data analysis. This study is mainly aimed at the optical characterization of plastic film samples to explore the feasibility of quantifying the penetration depth of NIR hyperspectral imaging light on packaging plastics, so as to further explore the thickness of food plastic packaging in the thickness range will not affect the non-destructive testing results of food.

Introduction

Compared with traditional chemical procedures, instrumental methods, sensory analysis and screening methods, near-infrared reflectance (NIR) spectroscopy is a more sensitive, fast and non-destructive analytical technique, which sample preparation is simple and can be evaluated simultaneously (Fraser *et al.*, 2003). According to last surveys, NIR spectroscopy has been successfully applied to the determination of substances in food safety, such as protein and fat content in meat and sugar content in fruits (Fraser *et al.*, 2003; Prieto *et al.*, 2009). In addition, NIR can be used to distinguish foods that are not detectable by the senses (Porep *et al.*, 2015). Therefore, in the food production chain, if NIR can penetrate the plastic packaging of the finished product to carry out non-destructive quality inspection of the food, which not only can guarantee the quality and safety of the food, but also can minimize the commercial cost (Lammertyn *et al.*, 2000). In fact, this study is to determine the maximum NIR penetration depth of food packaging plastics, which is related to how to choose the optimum thickness packaging to achieve quality assurance without compromising quality testing results.

According to others research, NIR spectroscopy has relationship with the composition, thickness and the process of plastic. It is well known that NIR can penetrate to a depth from mm to cm (Prieto *et al.*, 2009). Some studies have shown that the penetration of NIR radiation is related to wavelength, which varies with the type of plastic. The penetration depth of NIR varies from 2-3 mm at 900-1900 nm (5263 cm^{-1} -11111 cm^{-1}) to 4 mm at 700-900 nm (11111 cm^{-1} -114285 cm^{-1}) in some apple thickness studies (Lammertyn *et al.*, 2000).

Food packaging film is a plastic film that is commonly used to seal food in containers, to block moisture and to prevent direct contact between air and food, keeping food fresh for a long period of time. General plastic film is about 0.0005 inches (12.7 microns) thick, and most household brand plastic film is between 8 to 10 microns thick (Zheng *et al.*, 2018). The main purpose of the current international research is to quantify the thickness of NIR radiation penetrating samples. Then to study the penetration depth of NIR radiation at different wavelengths.

The primary objective of this study is to compare the NIR penetration depth of several common plastic packaging, including PE, PVC and PVDC, to ensure that the impact of packaging on the test results is minimized when non-destructively testing food quality.

Materials and Methods

Materials

First, choose from 3 different brands of PE, PVC and PVDC food packaging film and take a 5mm (n = 5) diameter plastic film plug from them. Then, these samples will be cut to different thicknesses of 1 mm to 5 mm, which thickness of each plastic film slice is measured three times with a caliper and averaged. Repeat the experiment three to five times for each kind of packaging film (Padalkar *et al.*, 2015).

Table 1. Data table sample

		Classification (%)																										
Species		PVC									PE									PVC								
Brands		Tesco			Lidl			Spar			Tesco			Lidl			Spar			Tesco			Lidl			Spar		
Sample		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Depth (mm)	1																											
	2																											
	3																											
	4																											
	5																											

Instrument

As figure 1 shows (CAMLIN, 2019), the push-broom hyperspectral imaging (HSI) system is a highly integrated optoelectronic system used to obtain high spectral lines, which is based on Gigabit Ethernet InGaAs cameras and imaging spectrometers for extending near-infrared spectroscopy systems. This system uses an imaging spectrometer and camera to record a spectral image (two-dimensional image) in which the first dimension has a spatial map and the second dimension is the spectral axis. HSI systems are built from spectral sensors, scanning mechanisms, software and signal processing. These components are typically used to acquire and analyze hyperspectral data sets and then centrally extract data.



Figure 1. Push-broom HIS system (Gowen, 2019)

Methods

NIR fiber optic probe data collection

NIR spectra will be obtained using a 3 mm diameter silica glass NIR fiber optic reflective probe (Art Photonics, Berlin, Germany) coupled to push-broom HSI system (Padalkar *et al.*, 2015). The spectra of plastic samples of different thicknesses will be collected in contact mode, some of which placed a polystyrene plate with a spectral resolution of 16 cm⁻¹ below, and the other part did not (Huang *et al.*, 2016). In this study, the background spectrum is collected from the mirrored surface. Results included 270 co-added scans in the frequency range of 4000-7000 cm⁻¹.

Meanwhile, the reference spectrum will be collected from a polystyrene plate, which thickness is 0.54 mm, to identify a target peak (Padalkar *et al.*, 2015). During the experiment (Padalkar *et al.*, 2015), polystyrene will be placed on the mirrored surface and sample will be placed on the polystyrene. When sample is less than 1 mm, data will be collected in the form of transreflective. As the thickness of sample increases, diffuse reflection will become dominant in the spectrum.

Data analysis

Using MATLAB 2018 to process NIR spectra. Spectra of packaging films in different thicknesses will be analysed to understand the effect of thickness increase on the NIR spectrum. For data analysis, the NIR spectral range is divided into two regions: 4000-5100 cm⁻¹ and 5100-7000 cm⁻¹ (Padalkar *et al.*, 2015). Polystyrene peaks will be identified and evaluated to determine penetration depth in different regions. The spectra about samples with and without polystyrene plates will be compared to determine the penetration depth of the NIR.

The spectra will be first visually compared to see if a polystyrene peak is visible in the original sample spectrum when the polystyrene plate is placed underneath sample. In addition, second derivative spectra will be used to improve the evaluation of the presence of polystyrene in the spectrum of food packaging plastics.

Results and Discussion

No results have yet been obtained. The following is the expected experimental results.

The NIR spectrum of the packaging film with varying thicknesses

Comparing the spectra of plastic films of different thicknesses, the effect of increasing the thickness on the spectrum will be obtained. It is expected that as the thickness increases, not only the peak is changing, but the data acquisition mode also changes. When the thickness is less than 1 mm, the data is collected in a transreflective mode while the radiation penetrates the sample and is reflected back from the mirror (Zomeño *et al.*, 2012). However, as the thickness increases, the data is primarily in the form of diffuse reflection (Porep *et al.*, 2015). Therefore, when the data collection method changes, the maximum penetration thickness of different food packaging plastic films can be found.

Comparison of original and second-order derivatives of NIR spectra of food packaging films of different thicknesses with polystyrene underneath

If the polystyrene peak is clearly visible in all areas of the NIR spectrum, this indicates that the NIR penetrates the sample.

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DEVELOPMENT OF A FEASIBILITY PLAN TO CONVERT A SURFBOARD MANUFACTURING PLANT INTO A SUB-ZERO FACILITY WITH RESPECT TO CARBON FOOTPRINT OF THE PRODUCTS AND ENERGY FOOTPRINT OF THE PROCESS

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Abstract

The sport of surfing has been in existence since the 1700s wherein the sailor Captain James Cook recorded seeing Polynesian natives enjoying the sport, floating in the sea atop wooden planks made from Balsa wood. Over the past 230 years the sport has grown in popularity, especially since the 1970s. Rising demand has seen the manufacture of the surfboard vessel go from solid wood plank to high density Polyurethane(PU) foam, coated with Unsaturated Polyester Resin. A rough estimate of the number of surfboards manufactured today stands at 400,000, with manufacturing facilities located all over the world. The carbon footprint of the process has, until very recently, been overlooked. However, the industry has seen substantial developments in the last 8 to 10 years with regard to the raw material involved. This research review suggests that a large reduction in the carbon and energy footprint of the facility is possible, but reaching sub-zero levels of footprint may be unfeasible given the present advancement in raw materials required.

Introduction

The objective of this study is to determine the feasibility of converting a surfboard manufacturing factory into a sub-zero production facility with respect to carbon footprint of the product and energy consumption of the process.

Surfboards have been commonly constructed using concrete pressure moulded Polyurethane(PU) foam and encased with a mixture of Unsaturated Polyester Resin(UPR) and cloth weave (Beck, 2017). The foam is cut, or planed, down to its required dimensions and then encased in UPR/cloth weave for structural integrity and to seal the foam from water interference. Once the resin is dry, plastic moulds are inserted into the underside of the board, allowing for the attachment of the fins. Finally, the surfboard is then sanded down to a gloss smooth finish. As will be shown, the entire manufacturing process leads to a significant amount of waste and dust.

Technology Advancements:

In recent times, more advanced methods of manufacture have seen two types of technologies becoming more mainstream

1. Expanded Polystyrene Foam (EPS) encased with Marine-specific Epoxy Resin
2. Algae-based PU foam, encased with Polyester Resin.

1. The main advantage of EPS foam and Epoxy Resin lies in the recyclability and low carbon content of the materials. Whilst PU foam, made from Polyols extracted from crude oil, is not recyclable, EPS foam is 100% recyclable, it can be ground down and re-used as packaging and coffee cups. The foam is made from styrene, a liquid hydrocarbon. It comes in the form of tiny spheres glued together, and the foam itself is 95% air. When it is broken down, 25% of the tiny spheres can be re-used in a new block of foam. A rough value for the carbon footprint of this foam can be found in the figure below.

Marine-Specific Epoxy resin, compared to Unsaturated Polyester Resin, has a 40% bio-content and it emits substantially less volatile organic compounds. The figure below quantifies the reduction in carbon footprint that Epoxy provides, compared to UPR.

2. Algae-based PU foam is becoming more mainstream every year, since it's creation in 2011 and this can be used to reduce the carbon footprint of products (ArcticFoam 2015). Many eco-friendly manufacturers use Epoxy resin to encase the foam, further reducing the carbon footprint. A representation of the extent of impact an individual PU/UPR surfboard has on the local environment can be shown through the Life Cycle Analysis performed on behalf of Firewire Surfboards. The figure below illustrates the emissions from the PU/UPR surfboard, and compares it with the that of EPS/Epoxy/Wood shell surfboards.

In a similar study, The Surfboard Cradle-to-Grave (Schultz, 2009), the author calculated the emissions for both types of raw materials through the database Economic Input-Output Life Cycle Assessment (EIO-LCA) (University 2019) showed that the major contributing factors to the production process are raw materials, manufacturing energy and waste from the process. Surprisingly, the carbon emissions from transport were low, compared to the raw materials. It was estimated from a report by Pure Strategies that between 0.9 and 2.22kg of CO₂ are emitted from transport of materials from Asia to California and then from West Coast of America to East.

It has been estimated that the number of surfboards manufactured globally is 400,000 (Pitta, 2003). This is a substantial number, considering each surfboard emits a minimum of 33.5kg CO₂, overall equating to 13,400 MT CO₂ e. It can be estimated that at least 50% of all surfboards are made using the more toxic approach (PU/UPR) and 50% the lesser approach. This equates to 16220 MT CO₂ e (9,520 MT CO₂ + 6,700 MT CO₂ e). However, a report written in 2015 detailed that the sale of Algae-based PU foam had risen to 85,000 products sold, which is a substantial market share, and could reduce footprint. (Hepler, 2015)

Materials and Methods

To perform the simulations required for the feasibility of a zero carbon and energy emissions factory, a facility in Clare has been chosen as a template. This is the largest surfboard manufacturing factory in Ireland and is also typical of an average manufacturing plant due to that fact that it employs two separate types of materials in the production process, performed by two different types of craftspeople. One construction technique involves PU/UPR materials, whilst the other technique involves EPS/Epoxy.

To ascertain the material and energy requirements for functionality of the factory an audit was performed, with the permissions of the owners. A range of topics were examined covering the production process, transport of goods, materials disposal and air emissions.

It is the intention of this thesis to employ GaBi v 3 software to calculate the carbon footprint of materials and manufacturing energy of the process. It is also the intention to employ Screenview 4.0.1 to assess the air pollution and possible mitigation therein

Results and Discussion

At the current stage in this thesis it is difficult to predict what kind of results to expect from the simulations, however it is expected that the outcomes will be able to address the following key points:

- From the audit performed preliminary figures for the energy requirements will be quantifiable, and proposals for alternative sources of sustainable energy that could meet the demand will be assessed, and the costs and industrial regulations can be considered.
- In terms of thermal efficiency, alternative carbon neutral materials can be assessed, and considered
- In terms of raw materials used, alternative carbon reducing foams can be proposed, the cost of which should be similar to existing technologies.
- A calculation of waste and reduction thereof can be estimated, for both production processes, but the mitigation of each is to be seen.
- In the event that simulations show that a low carbon footprint can be achieved, it is feasible to propose the purchase of carbon credits from established carbon sequestration farms to further lower the overall footprint. (Clark, 2011)

Conclusion

Based on the evidence from existing literature, a reduction in the carbon footprint of the raw materials is achievable. By using recyclable EPS foam, eco-friendly Epoxy resin and Algae-based PU foam, the production process can be made more environmentally friendly. In addition, by using energy efficient appliances and renewable energy sources, the energy footprint of the process can be substantially reduced. Making these changes within this factory is feasible. However, the feasibility of a sub-zero manufacturing facility with respect to carbon and energy footprint is unlikely without the use of carbon credits, due to the technology advancements of raw materials at this point in time. The fact that there is a growing community of scientists and manufacturers actively working to reduce the environmental burden of the production process does bring hope for the future, thereby allowing the possibility of such a burden-free facility to exist.

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TECHNOLOGICAL POTENTIAL FOR BIOMASS TO BIOFUELS PRODUCTION AND STRATEGIES TO IMPROVE SUSTAINABILITY IN IRELAND'S TRANSITION TO THE CIRCULAR BIO-ECONOMY

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Abstract

This study is a part of Agri Bio Circular Economy, a project funded by the Sustainable Energy Association of Ireland which will help Ireland transform into a Circular Bio-Economy as well as achieve EU renewable targets. The project focuses on two counties in Ireland where the potential for new biomass to biofuel value chains will be identified in line with the circular economy principle and cascading of biomass concept. The environmental impacts associated in the upstream production process will be assessed using life cycle analysis methodology. The results will provide a strategy for Ireland to achieve the sustainable regional bio economy.

Introduction

Under the Kyoto Protocol, the EU has committed to reducing GHG emissions (UNFFC 1998). The Renewable Energy Directive (RED) is the most important legislation in the European Union (EU) and Ireland that influences renewable energy growth. The RED sets two compulsory targets for Ireland's renewable energy to be met by 2020. The first is termed as overall renewable energy share (RES) which is at least 16% of Ireland's gross final energy consumption should be from renewable energy sources. The second is focused on transport sector and defined as RES-T which states that minimum 10% of energy consumed in road and train transport should come from renewable energy sources. Further, apart from the compulsory targets, two more are set, one is for electricity referred as RES-E which is 40% and second is for heat referred as RES-H which is 12% (Dennehy *et al.* 2010).

Biofuels are defined as primarily produced liquid, gas and solid fuels from biomass. A variety of fuels can be produced from biomass such as Biogas, Bioethanol, Biodiesel, Biomethane, Hydrogen. Biofuels have emerged as one of the most strategically important sustainable sources of fuel and are considered a significant way further in reducing greenhouse gas emissions, improving air quality and biodegradability. For environmental and economic sustainability, renewable and carbon-neutral biofuels are needed.(Nigam and Singh 2011).

Until 2009, the majority of the liquid biofuels were imported in Ireland than produced indigenously (Gusciute *et al.* 2015). Since 2010, suppliers of oil products are required to mix biofuels with the fossil fuel they sell as road transport fuels in Ireland. This scheme is known as the Biofuels Obligation Scheme (BOS) and is administered by the National Oil Reserves Agency (NORA). Fuel suppliers are issued certificates for each litre of mixed biofuels that meet the minimum sustainability requirements set out in the RED and in the Directive on indirect land-use change (ILUC) (Dennehy *et al.* 2010). Due to state afforestation programs and government support for bioenergy crop production, the biomass resource base in Ireland is expanding (Gusciute *et al.* 2015).

The aim of this study is to assess the technical potential of production of biofuels using the circular economy approach and associated impacts in a holistic life cycle analysis manner improving the sustainability of biofuels

Methodology

Circular Economy

A circular economy aims to increase the share of renewable or recyclable resources and reduce the economy's consumption of raw materials and energy while at the same time protecting the environment by reducing emissions and minimizing material losses. Systemic approaches, including eco-design, sharing, reuse, repair, refurbishment and recycling of existing products and materials, can play an important role in maintaining the usefulness and value of products, components and materials (European Environmental Agency 2018).

Through the circular economy pathway new sustainable value chains will be assessed by cascading biomass for production of biofuels, where product, material and resource value shall be maintained for as long as possible and where waste generation is minimized. In this study, the Butterfly model will be the central focus where each biofuel production value chain will be discussed.

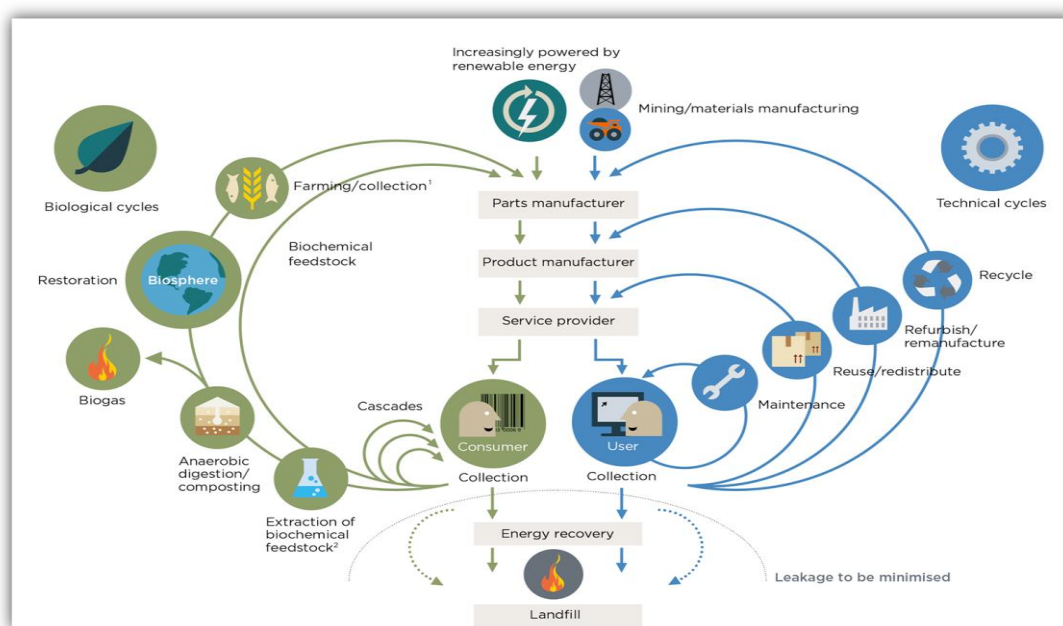


Figure 1. The Butterfly model, Source - ('Circular Economy System Diagram' 2019)

In the butterfly model (figure 1), there are two cycles; biological which comprises of ecosystem materials, and technical which consists finite stocks such as precious metals and fossil fuels. This model will help to reduce the value losses by using the value cascading principle.

Production of Biofuels

Biofuels can be classified as primary and secondary biofuels into two categories. The primary biofuels are produced directly from woody or cellulosic plant material burning and from dry animal waste. Secondary biofuels can be divided into three generations, each generated indirectly from plant and animal material. The first generation of biofuels is ethanol derived from starch-rich food crops or biodiesel derived from animal waste fats such as cooking grease. Bioethanol from non-food cellulosic biomass and biodiesel from oil-rich plant seeds such as soybean or jatropha is the second generation. The third generation biofuels produced from cyanobacterial, microalgae and other microbes, are the most promising approach to meeting global energy demands (Rodionova *et al.* 2017).

The EU has introduced sustainability criteria for biofuel production related GHG emissions, which could have a significant impact on future sustainable biofuel types. Biofuels must

Table 1. GHG emissions in Ireland associated with the production of indigenous biofuels

	Total GHG Emissions (kg CO ₂ -eq/GJ)	% Reduction in GHG Emissions Versus Fossil Fuels
Biodiesel		
Rapeseed ¹	62.16	29
Tallow ²	40	54
Recovered vegetable oil ²	27.11	69
Bioethanol		
Wheat, barley, sugar beet ³	69	28
Biomethane		
Wheat, barley, sugar beet ³	64	27
Grass ⁴	69.4	21

achieve a minimum reduction of 35 percent in GHG emissions compared to fossil fuels from 2013 to 2017. Recent figures mentioned in table no 1. Summarizes GHG emissions from Ireland's indigenous biofuels production, only residual biodiesel meets this minimum reduction. The targeted reduction will increase to 50% in 2017, which can be met by both residue biodiesels. However, the target reaches 60% beyond 2017, which can only be met by RVO biodiesel. Biodiesel from oil seed rape, bioethanol, and biomethane

from wheat, barley, and sugar beet, and grass biomethane, all fail to meet even the minimum criteria for sustainability. This shows the improvements needed to increase the sustainability of these biofuels in current biomass production and processing methods(Gusciute *et al.* 2015).

In this study, biofuels considered will be Bioethanol, Biodiesel, Tallow, Green Biomethane.

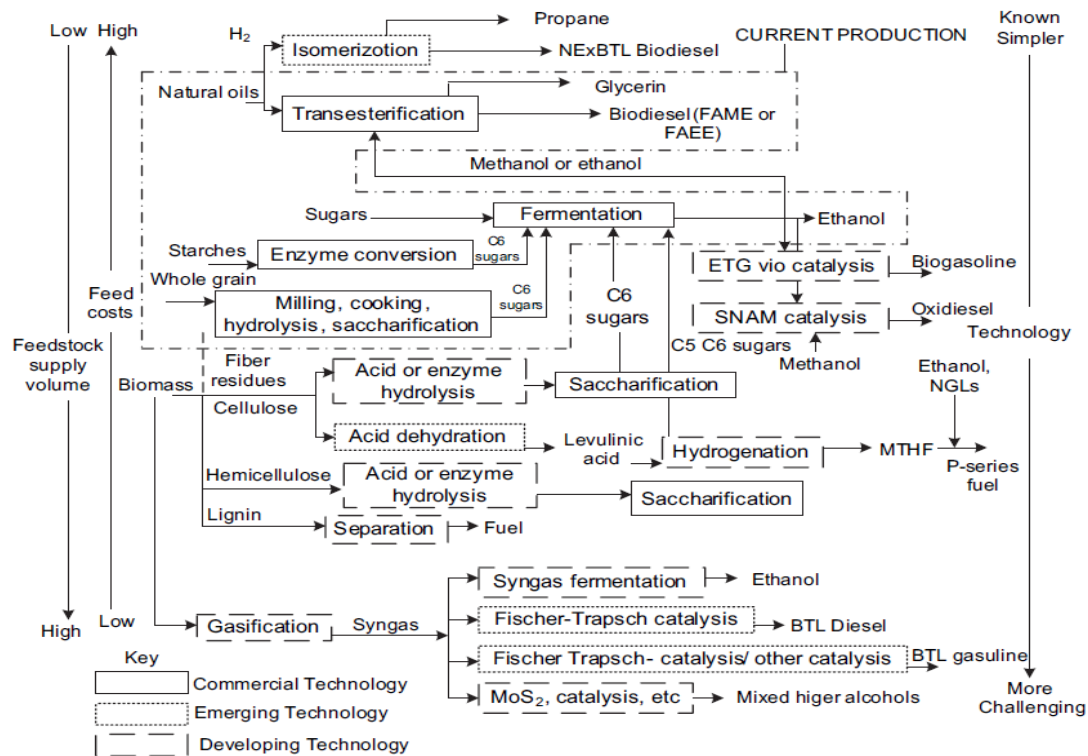


Figure 2. Diverse technological routes for the production of biofuels, Source - (Nigam and Singh 2011)

Life Cycle Analysis

Environmental Life Cycle Assessment (LCA) is an established methodology for evaluating product environmental impacts and has been widely applied in Ireland to energy systems, agricultural products and foods. Incorporation of this holistic life cycle analysis approach in this study will help identifying environmental indicators and burdening hotspots in the biofuels production system and value chains which will enhance the economic and environmental sustainability deliver maximum value by cascading biomass to biofuels. GABI

software will be used to perform the overall modelling to calculate the impacts (Council and Council 2017).

Expected Outcomes

At the end of the study, the expected results will highlight strategies to increase the sustainability of biofuel production and related impacts. The circular economy approach will be helpful to develop and to ensure the viability and potential uptake of these novel value chains which will help Ireland towards bio-economy and achieve the EU targets.

Conclusion

The overall increasing market of biofuels worldwide states that biofuels are globally accepted, and advanced technological advancement should be undertaken so that it can be large asset to replace the fossil fuels in all sectors like energy, transport, heat. Following the circular economy pathway can be more promising to minimize burdens on the ecosystem and increase cascading principle and accelerate the transition to a bio based circular economy in Ireland.

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TECHNICAL AND ECONOMIC ANALYSIS OF ENERGY STORAGE SYSTEMS

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Abstract

With the current global energy crises and global warming, there is an increasing need for the deployment of renewable energy systems. The economic viability of these renewable energy systems is crucial for development. The issue of intermittency hinders the economic viability. Energy storage systems provide a solution to this intermittency. This research will analyse the technical and economic considerations in relation to the deployment of energy storage systems to support renewable energy systems that are intermittent. The results are intended to aid in the development of renewable energy systems within Ireland in the future. The payback period, net present value, and cost of electricity will be considered along with the potential of price arbitrage in the Irish energy market.

Introduction

Global climate change and the global energy crisis are two major issues facing society. The burning of fossil fuels to generate electricity is a significant cause of both aforementioned issues. Ireland has made a commitment to meet the renewable energy targets set by the European Union with a 40% share of electricity to be from renewable sources by the year 2020 (SEAI 2019). Therefore, the development of renewable energy systems is essential. Unfortunately, the intermittency associated with renewable energy systems means that they are unreliable and, in most cases, must be supported by electricity produced from fossil fuels. Energy storage systems provide a solution to this issue. Energy storage systems allow excess electricity produced to be stored during times of excess supply, and the stored energy can subsequently be used during times of excess demand. Wind energy is the renewable energy system to be considered in this research due to the potential of wind resources in the Irish context. Ireland has one of the best wind resources available in the World and as such wind energy will continue to be developed into the future. Renewable energy is of significant environmental importance, as well as providing “a sustainable, economic opportunity for Ireland, both in terms of providing a secure, indigenous, source of energy, and as an export in the longer term” (SEAI 2019).

There are a number of energy storage systems types available, including battery storage, pumped-hydro storage, hydrogen storage, compressed air energy storage and flywheels. The focus of this research will be on pumped-hydro storage, battery storage and hydrogen storage. Pumped-hydro energy storage is a large scale option, where water is pumped from a lower reservoir to a higher reservoir during times of excess supply. The water is then released down to the lower reservoir through a turbine to generate electricity when required. The rationale behind this decision is due to pumped-hydro being a well-established mature technology with an example in Turlough Hill, Co. Wicklow. The high potential of battery storage as there is an instantaneous supply of electricity and hydrogen storage as an option due to the significant environmental potential of hydrogen as an energy carrier. The process of electrolysis is used to split water into hydrogen and oxygen. The hydrogen can be extracted and stored in tanks to be used at a later date to generate electricity or to be used in transportation. The potential of price arbitrage is an interesting concept to attract investment in energy storage systems. Price arbitrage is the purchasing of electricity during hours of low demand when electricity prices are low, such as during the night, and selling this electricity during peak hours when electricity prices are high. This provides an opportunity for potential investors to make a return on the money they invest which is fundamentally how investors are attracted to developments.

The objective of this research is to identify the most feasible energy storage system to support wind energy from an economic perspective in an Irish context.

Methodology

In order to be able to assess the viability of the different energy storage systems it will be necessary to undertake a review of the current policy regarding renewable energy. The focus will be on EU policy and Irish policy. This research will use the HOMER software package to assess the economic viability of the different renewable energy storage system–energy storage system configurations to be considered. HOMER (Hybrid Optimisation of Multiple Energy Resources) is a software package that allows comparisons to be made between multiple different configurations of energy types and storage types. The software allows an array of data to be input and calculates the cost of each system configuration to aid in the design of the optimal system. HOMER software is appropriate for this research to allow a comparison of each different energy storage systems to be made. In order to assess the potential of price arbitrage, Irish electricity markets will be studied to identify the optimal periods to purchase and sell the electricity.

Literature Overview

Energy Storage Technologies

The research will be based on supporting the intermittency of a wind farm. The energy storage system technologies focused on in this research are pumped-hydro, battery storage and hydrogen storage. “Energy storage systems at an improper size would result in no-reasonable installation, operation and maintenance costs” (Xia *et al.* 2018). Therefore, conducting a technical and economic analysis of the different storage options is necessary. Utilising the HOMER software, a variety of different sizes of each energy storage system will be analysed to distinguish the most viable. Hybrid systems will be considered also to determine whether a mix of energy storage systems would be more economically viable. There are several different battery options to utilise. “Lithium- ion, zinc–bromine, lead–acid, and sodium–nickel chloride are examples of the batteries that have been significantly developed recently” (Balali *et al.* 2017). A series of different battery types will be assessed to identify the best in the context of this research.

Economics

As outlined above the associated payback period, net present value and cost of electricity will be considered in this research. Other research has considered the economics associated with energy storage systems. Atherton *et al.* (2017), found that “the Lithium-Ion and Redox energy storage system types are the only economically viable options” and that “the Lithium-Ion energy storage system type is found to deliver the fastest payback time”. This is based on research in South Australia. Kaldellis *et al.* (2009) undertook a techno-economic analysis of different energy storage systems for Aegean island autonomous networks and found “the minimum life cycle electricity generation cost is expected for flow batteries and pumped-hydro storage (i.e. 0.095€/kWh)”. In the study it was concluded “it is the Na–S batteries that may be thought as suitable for very small island cases, while pumped-hydro storage comprise the optimum solution for big size islands” (Kaldellis *et al.* 2009). This would suggest for the Irish context battery storage would not be the best option due to difficulties associated with scale up.

Kotowicz *et al.* (2017) researched energy storage systems with distributed hydrogen production. As part of the research an economic analysis was performed. The “economic analyses pointed to the advantage of systems with higher value of the degree of storage”. Therefore, the viability of hydrogen as a storage medium would work best at a larger scale. Olateju *et al.* (2016) undertook a techno-economic analysis of a large scale wind-hydrogen system. In the study “the development of a 563 MW integrated wind-hydrogen model with energy storage is proposed”. In this study it was found “the wind turbine capital cost has a considerable impact on the hydrogen cost estimates” (Olateju *et al.* 2016). Therefore, it would be feasible to integrate a hydrogen production system into existing wind farms.

Results and Discussion

As this research is ongoing the expected results are outlined. The outcome that is expected from this research is that at present pumped-hydro energy storage is the most viable from an economic perspective. This is despite the requirement for large amounts of infrastructure and a significant water demand. “The electrical energy systems (EES) technologies of pumped hydro storage (PHS) and compressed air energy storage (CAES) sustain limited future potential in Germany due to the lack of suitable spacious locations or underground formations” (Kyriakopoulos and Arabatzis 2016). It is expected that battery storage will be a promising technology but will be too large per unit of energy that is stored. There are also concerns over the end of life disposal of batteries, whether they can be recycled or will pose another environmental issue or significant economic cost for disposal. Hydrogen energy is expected to be too costly at present due to storage and transportation costs as there is currently limited infrastructure in place to support hydrogen in the economy. There are also concerns over the safety of hydrogen as it is a volatile gas. It is important to identify the main reasons for hydrogen storage being too expensive and ways in which these costs can be reduced to increase the viability of hydrogen as a storage option. The interest in hydrogen is on the basis that the energy generated from hydrogen can be regarded as carbon neutral if the electricity used in the electrolysis process comes from a renewable energy system. By incorporating hydrogen storage with a renewable energy system such as a wind farm it will be possible to provide electricity without releasing any greenhouse gases into the atmosphere.

Conclusion

It is becoming increasingly important to integrate more renewable energy systems into the electricity grid to reduce global warming in the future. Therefore, ways to provide stability to the supply of these intermittent technologies is required. Energy storage systems provide a solution to the issues of intermittency. The development of these systems is reliant on the availability of funding, which is reliant on the economic viability associated with these systems. The research aim is to provide sufficient insight into the viability of these systems to potential investors and whether these systems are viable in the long term. These aims will be addressed by providing information on the net present value, the potential payback period of project as well as the potential of price arbitrage.

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A STRATEGIC ROADMAP FOR DEVELOPMENT OF HYDROGEN INFRASTRUCTURE (PRODUCTION, DISTRIBUTION AND APPLICATION) IN IRELAND

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Abstract:

Due to environmentally disruptive nature of fossil fuels, renewable alternative energy sources are receiving more attention. The increased global warming caused by fossil fuel combustion has led to intense research into improved low emission energy choices. Hydrogen is a clean fuel candidate, as it produces just water as a by-product during combustion. A variety of renewable and non-renewable sources can generate hydrogen. The hydrogen economy some say is an inevitable energy system scenario for the future in which the available (preferably renewable) energy can generate electricity that can be stored or transported using hydrogen and meet all the energy requirements of human civilisation. The transition to a hydrogen economy may have already begun. This paper reviews hydrogen production, storage, distribution and utilization technologies. The expected results of this paper will be a strategy for the hydrogen economy transition in Ireland.

Introduction:

The main challenge facing the modern world is the use of fossil fuels, as a result of their concomitant use for daily life. An alternative combustible which can replace non-renewable fossil fuels is therefore essential (Planton *et al.* 2008). Replacing fossil fuel with hydrogen for ultimate use could meet technical, environmental and cost challenges (Vijayavenkataraman *et al.* 2012). Hydrogen is the clean fuel of the future and is one way of storing energy and transporting it. Hydrogen fuel can be produced from a variety of sources; for example, water and natural gas are abundant sources of hydrogen. The cheapest way of producing hydrogen is to react steam on white-hot coal, but this produces enormous quantities of carbon monoxide, reducing interest of this method (Global Relations Forum 2013). A suitable substitute should therefore be developed for producing high volumes of hydrogen. Methane is the cheapest source of hydrogen in the modern world producing smaller amounts of carbon oxides (H. SHIGA 2002). Hydrogen can also be produced from renewable sources, referred to as green hydrogen. This fundamental change in the global energy system can lead to substantial improvements in energy systems and can help decarbonize the energy mix, reducing the impact of climate change. A number of studies examined the prospect and strategies possible to transition to the "hydrogen economy".

The objective of this work is to identify best possible scenarios to enhance a sustainable transition towards a hydrogen economy, in terms of economic and environmental sustainability considerations which can help Ireland to be one of the sustainable, low carbon economies in the Europe.

Production

Hydrogen can be produced from a variety of sources and methods as shown in figure 1. This study reviews these methods briefly representing the cost of technologies, cost of hydrogen produced, efficiencies and advantages-disadvantages of each technology along with storage of hydrogen energy (as shown in table 2), supply chain and applications. The following table shows various compared parameters:

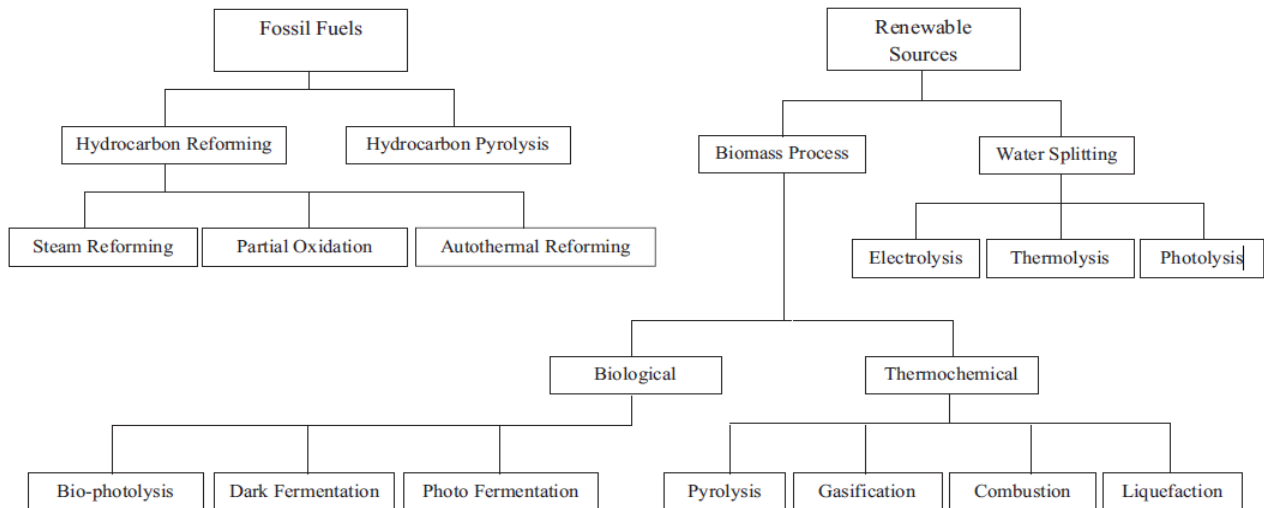


Figure 1: Hydrogen production methods (Nikolaidis and Poullikkas 2017)

Table 1: Cost of hydrogen production through different processes (Nikolaidis and Poullikkas 2017)

Process	Feedstock	Capital Cost M\$	H ₂ Cost \$/Kg	H ₂ Cost €/kg	Efficiency %
SMR with CCS	Natural Gas	226.4	2.27	2.22-2.56	60-85
SMR without CCS	Natural Gas	180.7	2.08	< 2	60-85
CG with CCS	Coal	545.6	1.63		80 (Ju and Lee 2017)
CG without CCS	Coal	435.9	1.34		
ATR (CH ₄) with CCS	Natural Gas	183.8 ^a	1.48		60-75
Methane Pyrolysis	Natural Gas	-	1.59-1.70		
Biogas Pyrolysis	Woody Biomass	53.4 ^b	1.25-2.20	2-3	35-50
Biogas Gasification	Woody Biomass	149.3 ^c	1.77-2.05	2-3	47-56 (Gnanapragasam and Rosen 2017)
Direct Bio-photolysis	Water + Algae	50 \$/m ²	2.13		10
Solar PV Electrolysis	Water	12-54.5	5.78-23.27	4-6	40-60
Wind Electrolysis	Water	504.8-499.6 ^d	5.89-6.03	4-6	40-60
Nuclear Thermolysis	Water	39.6-2107.6 ^e	2.17-2.63		20-45
Solar Thermolysis	Water	5.7-16 ^f	7.98-8.40		20-45

(As the costs depend on the size of the plant and quantity produced, average range is provided as per respective references).

(FCH JU_Report, 2017) for the Hydrogen costs in €/kg

^a 600MW hydrogen plant with capital cost of 306.35 \$/kW_{H₂}

^b 72.9 ton/day plant capacity with capital costs of 53.4 M\$

^c plant capacity of 72.9 ton/day with capital cost of 149.3 M\$

^d 504.8 M\$ is coproduction of hydrogen with electricity

^e 2107.6 M\$ cost considers 583 ton/day.

Storage

Storing hydrogen is a complex task where cost for storing hydrogen depends on the quantity of hydrogen; as underground hydrogen storage is most economical in case of bulk quantity; it isn't feasible for modest quantities. Using abandoned natural gas wells is the cheapest alternative, followed by solution salt mining and hard rock mining (Global CCS Institute 2018). The table 2 shows methods of hydrogen storage.

Table 2: Hydrogen storage methods and costs (Yu Wang, Julia Kowal, Matthias Leuthold 2012)

Method	Volume considered	Pressure (bar)	Cost (€/kg)
Salt Cavity	500,000 m ³ (for 12 ton) ^a	60-180	5.56 (2079.44)
Compressed gas	12 ton 3330 m ³	45	374.74
Pipe container	12 ton 3330 m ³	45	507.07
Pipeline	12 ton 3330 m ³	45	1059.74
Cryo liquid	12 ton	> 50	83.40

^a if considered storing 12 ton hydrogen in salt cavity, it will cost 2079.44 €/kg (salt cavity only economical feasible at bulk quantity i.e. above 150,000 m³).

Distribution

The supply chain in this study is discussed, considering the central plant for hydrogen production with the design capacity of 150,000 kg/day. The cost associated with supply and dispensing are associated with 1000kg/day hydrogen.

Table 3: Distribution of Hydrogen cost comparison (Simbeck and Chang 2002)

Feedstock	Liquid tanker (\$/Kg)	Gas tube trailer (\$/Kg)	Pipeline (\$/Kg)
Natural gas	3.66	4.39	5.00
Coal	4.51	5.18	5.62
Biomass	4.98	5.77	6.29
Water	7.62	8.39	9.13

Expected outcome

This study has its emphases on the transition from a fossil-fuel based economy to mitigate GHG emissions with major focus on a hydrogen economy. To enhance this transition there is need to initiate the set-up of hydrogen infrastructure (i.e. production, storage, distribution and application) in Ireland. This study aims to provide the best possible scenarios to initiate this infrastructure by comparing the production, distribution and storage methods for hydrogen, based on economic and environmental sustainability considerations. Furthermore, the role and potential of hydrogen to meet the renewable energy targets set by the government will be discussed. As the research is on-going, the cost data will be represented in euro for better compatibility to utilise this work.

Conclusion

Hydrogen is one of the most attractive sustainable fuel sources which has potential to replace fossil fuels as it has wide application area; electricity generation, fuel for transport, heating, fertiliser, various industrial uses. Thus, this study will provide a roadmap to establish hydrogen economy in the Ireland stating environmental, economic and societal benefits.

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A FEASIBILITY STUDY OF OPTIONS TO REDUCE PLASTIC CONTAMINATION OF MARINE ENVIRONMENTS

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Abstract

Currently there is a significant amount of plastics in the ocean globally, and this is on an upward trajectory. Efforts to mitigate the influx of plastics to marine environments have not yet been successful, with the estimated amount of marine plastic to increase by 2025 as approximately 8 million metric tonnes of plastic enters the ocean annually. This thesis aims to assess the feasibility of marine plastic recovery and prevention. Three solutions will be assessed under economic, societal and technical aspects to determine their feasibility in solving the marine plastic problem. The three solutions to be examined in detail are; waste management infrastructure improvement in developing countries; societal transition towards sustainable consumer behaviour through the removal of single use plastics; and repurposing recovered marine plastics through different methods of recycling.

Introduction

Large volumes of plastics are produced annually, and due to their short use phase, durable composition and low recycling rates, a significant amount of plastics enter oceans globally (Lebreton *et al.* 2017). The dispersal, durability and mobility of plastics makes it extremely difficult to monitor and establish governance over (Dauvergne 2018). Between 60-90% of marine litter is plastic, with over 9 million metric tonnes of plastic entering oceans in 2015 (Jambeck *et al.* 2015; Dauvergne 2018). Marine plastic can be separated into two categories; macro plastics ($\geq 5\text{mm}$) and micro plastics ($< 5\text{mm}$) (Lohr *et al.* 2017). Micro plastics can be further categorized into primary and secondary microplastics (Dauvergne 2018). Primary microplastics are already under 5mm when entering oceans, where as secondary microplastics are formed through the degradation and fragmentation of macro plastics (Nor and Obbard 2014). These micro plastics have been found in numerous food and drink items, however the severity of their impacts on human health is relatively unknown as this is a recent discovery and limited research has been conducted (Ribeiro *et al.* 2018). Marine plastics can be found globally, from Arctic and Antarctic sea ice to coastal locations around the world and areas of sea as deep as the Mariana trench (Jambeck *et al.* 2015).

Due to the globalization of the plastics industry, increased production coupled with poor waste management, and the land sources of marine plastic being so vast, it is difficult to establish governance over the issue (Jambeck *et al.* 2015; Dauvergne 2018). Limited improvements are being made when quantified against the magnitude of the problem, and government and non-government organisations struggle to gain control over the growing issue.

The objective of this study is to assess the feasibility of potential solutions to the marine plastic problem by focusing on mitigation at the source of plastic production, consumption and disposal.

Theoretical Methods

Literature Review

This thesis will examine the current state of the marine plastic problem, including the current recovery technologies, mitigation schemes and global policies surrounding the issue. Through this analysis,

potential feasible solutions can be determined. The three areas of the marine plastic problem that are being examined are waste management in developing countries, repurposing of recovered marine plastics through recycling, and transitioning society towards more sustainable consumer habits through the removal of single use plastics.

Case Study

This thesis will assess the economic, societal and technical feasibility of transitioning a society towards sustainable consumer behaviours through the removal of single use plastics. UCD campus will be examined in this context, considering how this plastic removal could be implemented in all the campus shops, restaurants and cafes. The use of biodegradable plastics will be considered instead, coupled with an exemplary waste management scheme to compost and dispose of these biodegradable plastics.

Interviews

In July of 2018, the Dun Laoghaire - Rathdown county council begun a movement to make their town the first single-use plastic free town in Ireland. Interviews with members of this initiative will be conducted to examine how they are implementing these changes in society and to identify the issues they are facing so far with the project. This will assist with the feasibility study on how to make UCD single use plastic free, as numerous shops in the Dun Laoghaire - Rathdown area have already made the transition to become plastic free.

Literature Overview and Expected Results

Since this thesis is in the early stages of completion, the proposed solutions will be further developed and the following section contains an overview of each solution in context with each problem.

Waste Management Infrastructure

To determine how large volumes of plastic enters the ocean, it is important to identify the land-based pathways and the quantities of marine plastic based on their origin locations (Jambeck *et al.* 2015). Plastic concentrations show a direct correlation with human population densities (Lebreton *et al.* 2017). Population size and the waste management infrastructure of a specific region are the main factors determining how waste enters the oceans from these regions (Jambeck *et al.* 2015). Developing countries have under developed waste management infrastructure, and therefore these countries have high volumes of mismanaged waste entering land-based waterways and eventually the oceans (Jambeck *et al.* 2015).

The largest river catchments contributing to the marine plastic problem are located in Asia; this coupled with Asia's rapid economic development means future mitigation schemes and waste management infrastructure needs to be implemented to mitigate future risks of increased plastic influxes into the ocean (Lebreton *et al.* 2017). The large volumes of plastics found in the North Pacific Ocean suggest that this is the location where plastics from Asian countries accumulate (Lebreton *et al.* 2017). This is unsurprising considering Asian countries are the largest producers of plastic globally, with China accounting for 28% of all global production in 2015 (Dauvergne 2018). With large volumes of plastic being produced in these countries, and inadequate waste management infrastructure it is not surprising that the influx rates of these mismanaged plastic waste into oceans is occurring at an alarming magnitude.

Circulate Capital is an investment management firm that focuses on stopping plastic flow into the world's oceans by financing innovation, companies, and infrastructure dedicated to this cause, along with developing the circular economy (Circulate Capital 2018). The Circulate Capital project called The Incubator Network partners with The Ocean Conservancy aims to improve waste management infrastructure in developing countries (Circulate Capital 2018). This is a new initiative to increase the progression of solving the ocean plastics problem (Circulate Capital 2018). The Incubator Network partner with existing incubator programs to build waste management systems and recycling innovators in India and Indonesia to increase the quality and quantity of regional waste management

and recycling companies working to prevent plastics entering the ocean (Circulate Capital 2018). As an organisation geared towards solving the marine plastic problem, they aim to bring together the political, economic, financial and social components needed to solve the issue of marine plastics (Circulate Capital 2018). It is mandatory at this stage that different companies and government bodies work in collaboration to overcome this environmental hazard. Along with the Incubation Network project, there are numerous non-government organisations trying to improve the marine plastics problem through mitigating the amount of mismanaged waste, and subsequently plastic entering oceans. These include, but are not limited to; the G7, the Honolulu strategy and the Global Partnership on Marine Litter (Lohr *et al.* 2017).

With global peak waste to be reached in 2100, it is mandatory that waste management infrastructure in developing countries be improved drastically to target the marine plastic problem at the site of land plastic disposal. These improvements can be achieved through a combination of government policy improvements concerning waste disposal and non-government organisations focused on addressing the marine plastic problem at the source. Potential solutions combining policies and waste management in these regions will be further assessed in this thesis to determine feasible solution/solutions for these countries in order to minimise plastic waste entering oceans and develop a more circular economy for these countries.

Recovery Solutions

Currently there are numerous recovery movements to capture marine plastic and repurpose this plastic through recycling, mainly by chemical and energy recovery (Iniguez *et al.* 2017). Majority of these recovery movements occur at coastal locations and are limited to beach and coastal clean ups. The Ocean Cleanup project is currently the only project of its magnitude working at physically removing marine plastic from the ocean at the site of the Pacific Garbage Patch (Ocean Cleanup 2019). Once this plastic has been recovered it can be recycled as polyolefin waste, which can be converted into clean fuels and other valuable products such as naphtha and polymers (Iniguez *et al.* 2017). The economic and technical feasibility of large scale valorisation of the recovered marine plastic waste to these products of value will be considered, also accounting for the degradation of the plastic at sea.

Reduction of Single Use Plastic

The global governance of plastic is failing to get a handle on the marine plastic pollution problem, as the amount of plastic that is set to enter the ocean by 2025 will potentially be double the amount already in oceans in 2010 (Dauvergne 2018). International policies are uncoordinated, there is resistance from the plastic production industry to abide by government legislation, and weaknesses exist in re-enforcement of legislations (González Carman *et al.* 2015). This is coupled with important factors such as increased production, global consumption, and growing international trade (Dauvergne 2018). The market for plastics has become increasingly dominant since its emergence in 1930, with the largest sector for plastic use in society being packaging of products with comprises approximately 40% of all manufactured plastics with consumer items accounting for another 25% (Jambeck *et al.* 2015; Dauvergne 2018).

The difficulty governing the environmental repercussions from the plastics industry arises from both the versatility of plastic products and the rapidly growing market for plastics (Dauvergne 2018). The current knowledge of the marine plastic problem provides the basis for effective action, however there is a lack of efficient policies and initiatives establishing control over the problem (Lohr *et al.* 2017). One of the solutions of the marine plastic problem lies within transitioning towards more sustainable ways of production and consumption in society (Lohr *et al.* 2017). Transitioning society away from plastic use completely will be difficult, but an alternative is replacing single use plastics with biodegradable plastics. This allows society to gradually transition towards a circular economy, creating a plastic substitute for consumers to purchase. This solution will be examined through a feasibility study of how to make UCD campus single use plastic free. The on-campus shops, restaurants, and cafes will be the focus of this study. UCD has over 30,000 students and a fast population turnover rate; if UCD became single use plastic free it would be creating a population that is constantly growing and moving into the work place with sustainable consumer behaviour habits.

Similar single use plastic free movements are occurring in communities around the world. To solve the marine plastic problem, a multitude of solutions will need to be established including; state and federal legislation, hard and soft laws, along with consumer and manufacturer responsibility for the nature of product used and its correct disposal through implementing a circular economy perspective (Schuyler *et al.* 2018).

Conclusion

Further research needs to be conducted concerning the feasibility of the suggested solutions and how they can be implemented. Solutions to the marine plastic problem are contextual and combine to form the pieces needed to solve this marine plastic jigsaw puzzle. Short term solutions involve the improvement of waste management infrastructure, along with marine plastic recovery and recycling. Long term solutions to the marine plastic problem involve societal progression towards a circular economy, with more sustainable consumerism and a significant reduction in plastic use.

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IoT (INTERNET OF THINGS) SOLUTION FOR SEWER BLOCKAGE DETECTION

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Abstract

Sewer blockage problems are widespread these days many major countries like the US, UK are dealing with so-called ‘fatbergs. Major flooding incidents in the UK and other countries are associated with the sewer blockages. These sewer blockages usually occur due to deposition of fat, oil and grease (FOG) waste along with other materials such as sanitary items such as wet wipes. There are many technologies available in the market for sewer blockage detection, but it is still challenging to find the exact location of the blockage. Internet of Things (IoT) is a revolutionary technology which connects many objects in a network and makes them work to achieve a common goal. Using IoT, it is possible to create a system which can detect the possibility of blockages in the sewers and provide a warning before it happens.

Introduction

Background

Fat Oil and Grease (FOG) is a byproduct from multifamily housings and Food Service Establishments (FSEs) such as restaurants, meat processing factories, residential buildings (Wallace *et al.* 2017). These FOGs react with other sanitary products such as wet wipes, condoms, nappies in the sewers and create a concrete-like insoluble solid material which blocks the pipeline and causes sanitary sewer overflows (SSOs). Sewer overflows can cause severe environmental and health impacts (EPA, 2004). According to several studies (He *et al.* 2013; Hao *et al.* 2017), about 40 to 50 % of SSO-related incidents occur in United States (US) due to deposition of FOGs in sewer lines. In the United Kingdom (UK), about 300,000 sewer blockages occur every year, and 75% are caused by FOGs. The cost of maintenance and removal of FOG blockages in the UK was around £15-50 million (Mills 2010; Williams *et al.* 2012).

This congregated mass of fat, oil and grease in sewers is also known as a ‘fatberg’. The term ‘fatberg’ was initially coined by media when the first fatberg found in Kingston upon the Thames in 2013. In the year 2015, a 10-tonne fatberg was found in Chelsea, west London and in the same year, the Oxford Dictionary officially added the term ‘fatberg’ into their collection (Ratcliffe 2015; Adams 2018). Fatbergs featured heavily in the media when the largest ever fatberg was found in Whitechapel, East London - it was 130 tons in weight (equal to two Airbus 318 aircraft or 19 African elephants) and 240 meters in length (equal to London’s Tower Bridge). The removal cost of the fatberg and repair of underground sewer network was estimated around £400,000 (Moore-Bridger 2017; Adams 2018).

FOGs can be prevented from entering the sewer line by using Grease Interceptors (GI) or Grease Traps (Sager 1996). These GIs can be installed in food service establishments (FSEs), meat and food processing plants and multi-housing societies to recover fat, oil and grease content and reduce the risk of fatberg formation in sewers. A FOG prevention program was launched in Dublin in 2008 by Dublin City Council (DCC), which has been largely successful and reduction in blockages due to fatbergs was observed (Wallace *et al.* 2017).

The objective of this research is to find and develop a cheaper IOT solution for sewer blockage detection.

Context of work

In the UK and Ireland, most of the sewer inspections are carried out by using CCTV method. To eliminate sewer overflows it is necessary to keep an up to date information of sewer conditions.

Recent developments in optical technology made it possible to include 2D and 3D scanning technologies such as Digisaver[®], Panoramo[®] & Spherix[®] with CCTV method to improve the visible inspection and structural of sewer walls (Chae *et al.* 2008). Sensing methods such as acoustic sensing method, pipeline breakage sensing method were introduced to detect structural damages in the sewer system. Acoustic sensing method uses sound waves to detect blockages and damages in pipelines. Similarly, pipeline breakage sensing system uses multiple pressure sensors to measure water pressure at different locations and identify breakage location in the pipeline (Ziska 1990; Kurisu *et al.* 1998). Many computational models have been developed to predict the sewer blockages, but these models are not very accurate due to insufficient data availability. Development of better alternate methods is necessary to create an accurate and real-time data for finding the exact location of blockages in sewers; the accurate data will also help us to improve mathematical modellings used in the predictive analysis.

This can be achieved by using the Internet of Things (IoT) based solutions. The concept of IoT is that, it connects many objects such as sensors, actuators, phones, computers, Radio Frequency Identification (RFIDs) using unique addressing schemes and works together to achieve a common goal (Atzori *et al.* 2010). UCD (University College Dublin) conducting this research in collaboration with the Science Foundation Ireland funded Connect Centre and their Pervasive Nation project which is the testbed for Ireland's 'Internet of Things' (IoT).

Methodology

Components & Design

The concept of the project is by continuous monitoring of different parameters (temperature, humidity, water level & pressure) in sewers; it is possible to identify a potential blockage before it occurs. Components of the project are a sensor, a gateway device, router, a server and admin computer with a user interface. Figure 1 represents the layout of the project.

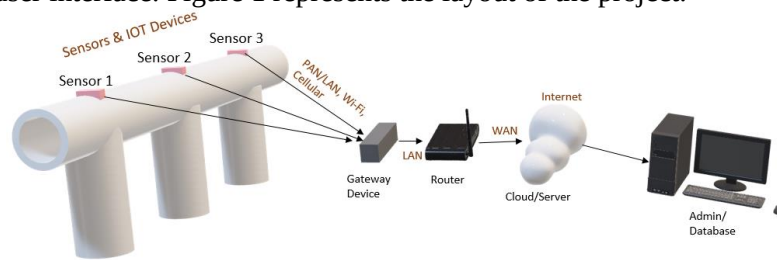


Figure 1: Project components

Sensors

To monitor various parameters, different IOT sensors are required. Multiple Industrial IoT (IIOT) sensors such as temperature sensor, ultrasonic sensor, gas sensor, humidity sensor, pressure sensor & level sensor will be connected to a Multi-circuit board with power supply controller. A power supply controller provides a specific amount of power required for each sensor. These sensors will be compacted in a sensor board with wireless capability. Table 1 presents the different sensors and their specifications, which will be used in the project.

Gateway device & protocols

An IoT gateway device aggregates and processes data from multiple sensors before sending it to the admin's system. There are many IoT protocols available such as Bluetooth, Zigbee, Z-wave, 6LowPan, Thread, WIFI, Cellular, NFC (Near Field Communication) and LoRaWAN. Selection of a protocol is based on IOT application factors such as range, data requirement, battery life and the communication speed (DesignSpark 2019). For this project WIFI protocol will be used, it targets WANs (Wide-Area Networks) and provides secure bi-directional communication and suitable with IIOT applications.

Table 1: List of Sensors

Name of the sensor	Company	Operating range	Resolution	Operating Voltage	References
Ultrasonic	Maxbotix	5cm – 500cm	5 mm	2.7V to 5.5V	(Maxbotix 2018)
Temperature and Humidity	Sensirion	-	-	2.7V to 5.5V	(Sensirion 2018)
Pressure	Measurement Specialties	0 to 14 bar	1/0.6/0.4/0.3/0.2 mbar	2.7V to 3.3V	(Specialities 2019)
Laser Sensor	Garmin	1cm to 40 m (131ft)	+/- 1cm	2.7V to 5.5V	(Garmin 2019)

Design simulation

The circuit for the multisensory device will be tested by using simulation software such as Microsoft Azure IoT (Microsoft 2019) and National Instrument's LabView-2018 (NI 2019). There are several simulation software packages available in the market, but these three software were chosen based on user interface and availability.

Experimental testing

The next phase of the project after the simulation is the construction of a physical model. This model will be installed and tested in UCD campus sewers.

Results and discussion

Previous study

In a previous experiment (Curran 2018), the 'Kotahi Level Monitor sensor' and 'Sagemcom Siconia PN1 sensor' for monitoring humidity, temperature and pressure were installed in UCD sewers. They concluded that using real-time data of different parameters available from IoT sensors, it is possible to pinpoint the exact location of sewer blockages and eliminate them before a blockage occurs. They also concluded that the efficiency and accuracy of the results could be improved by using a more robust and wider range of IoT sensors.

Simulation results from this study will be used to build a sensor device which will be installed in the UCD campus. The sensor device will produce different output results such as temperature, water level, humidity and gas levels, which will be studied to determine the blockage condition in the sewer.

Conclusion

The result from the past study shows that it is possible to build an advance warning system using IoT. In this study, more options for range and sensors will be examined. An IoT device simulation will help to determine the number of sensors and devices in the system, expected results and challenges in the physical world.

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MICROGENERATION OF ELECTRICITY USING SOLAR ENERGY

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Abstract

The electricity generation using solar energy is one of the sustainable forms of renewable energy, however the uptake of solar PV system remains very low in Ireland. The aim of this study is to determine the pathway for the deployment of PV systems for microgeneration under Irish climatic conditions at a location based in Dublin. This was accomplished by estimating the electricity load requirement of each residential building, designing a community based PV installation project and carrying out power flow analysis on the electricity network model of the grid for the proposed PV system. Results indicate the life cycle GHG emissions from solar PV is significantly lower compared to that of the national grid and potential to improve sustainability of the community by self-generation, consumption and feeding the excess electricity to the grid.

Introduction

Ireland is significantly dependent of fossil fuel imports and has limited indigenous fossil energy resources. In 2014 fossil fuels (coal, natural gas, oil and peat) accounted for 91.4% of the primary energy demand for electricity and generation of heat. The burning of fossil fuels for the generation of energy is the dominant contributor to greenhouse gas emissions (GHG) equating to 63.3% of total national GHG emissions in 2012 (Murphy and McDonnell 2017). In line with European Union, 2009/28/EC Renewable Energy Directive (RED) Ireland is committed to decrease GHG emissions and advance in developing alternative energy sources to find reduce the national dependence on fossil fuels. Under this RED, Ireland's overall renewable energy target of 16% is driving the urgency to deploy indigenous renewable sources of energy. The National Renewable Energy Action Plan (NREAP) outlines the target of 40% electricity use from renewables by the year 2020 (Murphy and McDonnell 2017).

In 2017 the Sustainable Energy Authority of Ireland (SEAI) estimates the overall renewable energy supply was 10.6% and Ireland is 26th out of the EU-28 for progress towards overall 2020 renewable energy target. In 2017 62% of renewable energy was renewable electricity, overall renewable energy has displaced 1.8 Mt of fossil fuel consumption and avoided 4.2 MtCO₂ of GHG emissions in 2017 out of which 80% of CO₂ emissions reduction were from generation of electricity (SEAI 2019). The major share of renewable energy includes wind, hydro and biomass however, the share of power generation from solar remains very low around 49 PV micro-generation grid connected installations at the end of the year 2012. The SEAI highlights Ireland is not on track to meet 2020 renewable energy targets and has estimated that for each percentage point shortfall in meeting these targets has an implication of €100 million to €150 million. **The objective of this study was to assess the potential of harnessing the solar PV microgeneration of community based projects into the grid in Ireland and to explore a crowd funding mechanism for community ownership of solar PV microgeneration projects in Ireland.**

Materials and Methods

System Description

The proposed solar PV microgeneration community project consists of 68 residential buildings located at Belfield, Dublin. The solar irradiance data is collected from the nearest

weather station at Dublin airport at 963 kWh/m². The PV panels are mounted on the roof-top of each building with collector facing south direction with an tilt angle of 30°. Each PV solar panels considered for use in this system are the Hanwha Q cells¹ Q peak G4.1 300 Rev4 monocrystalline modules with dimensions of 1670 × 1000 × 32 mm, linking to a surface area of 1.67 m² with an efficiency of 18%. Annual average solar irradiation received by these modules is 1074 kWh/m². The roof area available for mounting of PV panels is 10.042 m² (Murphy and McDonnell 2017). PV system details are listed in Table 1.

The total solar PV installed effect of each building is calculated using equation

$${}^2W_{pi} = A \times r \quad \text{-----} \quad (1)$$

Where, Wpi = Total solar PV installed effect of each building in kW

A = Total roof area in m²

r = solar panel efficiency in %

The number of panels installed in each building is calculated using equation

$${}^2N_p = W_{pi}/W_p \quad \text{-----} \quad (2)$$

Where, Np = Number of panels installed in each building

Wpi = Total solar PV installed effect of each building in kW

Wp = Nominal power rating of the panel in kW

The annual peak output of the PV system of each building is calculated using the equation

$${}^2E_p = A \times r \times H \times C \quad \text{-----} \quad (3)$$

Where, Ep = Annual peak output of the PV system in kWh/year

H = Annual average irradiation on tilted panels in kWh/m²

C = Coefficient for losses (range between 0.9 to 0.5)

²Losses details depend on site, technology and sizing of the system includes Inverter losses (6 to 15%), Temperature losses (5 to 15%), DC cable losses (1 to 3%), AC cable losses (1 to 3%), Shading (0 to 40%), weak irradiation (3 to 7%), Losses due to dust, snow (0 to 2%), degradation of modules (0.5 to 1%), other losses (1 to 2%).

The Performance ratio of the PV system is calculated using equation

$${}^2PR = (E_p/W_{pi}/H) \times 100 \quad \text{-----} \quad (4)$$

Where, PR = Performance ratio of the PV system in %

Table 1. Details of the PV system

Data for each building	Unit	Quantity
Area of the roof area (A)	m ²	10.042
Panel efficiency (r)	%	18
Installed effect (Wpi)	kW	1.8
Nominal power of panel (Wp)	kW	0.3
Number of panels (Np)	piece	6
Annual average irradiation (H)	kWh/m ²	1074
Coefficient for losses (C)	factor	0.8
Annual peak power output (Ep)	kWh/year	1553
Performance ratio (PR)	%	~ 80
Lifetime expectancy	years	30

¹Hanwha Q Cells manufacturing facilities in China, Malaysia and South Korea.

²photovoltaic-software.com/principle-resources.

Electricity loads

With approval from each building owner, electricity demand data can be collected to build the detailed annual load characteristics with average maximum hourly electricity use kWh or Figure 1 shows the example of monthly electricity use in relation to the maximum hourly electricity use kWh/h for a typical household with low annual usage of 3100 kWh (La and Ryan 2017).

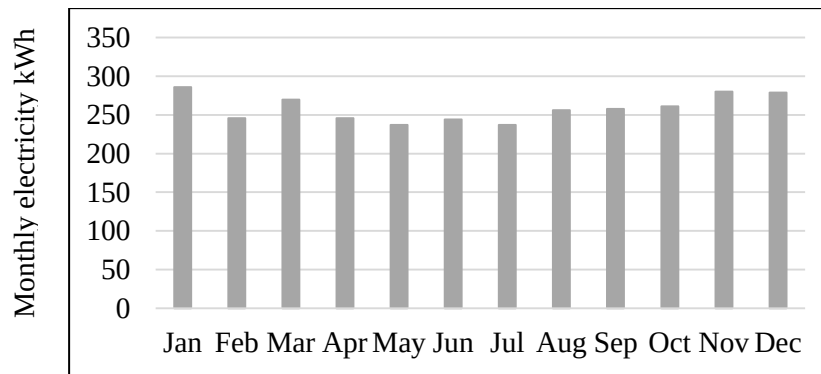


Figure 1. Annual building electricity demand kWh.

Solar PV electricity generation

The system was modelled using PV×SOL software (pvsol-online.valentin-software.com). The monthly solar PV electricity generation is shown in Figure 2.

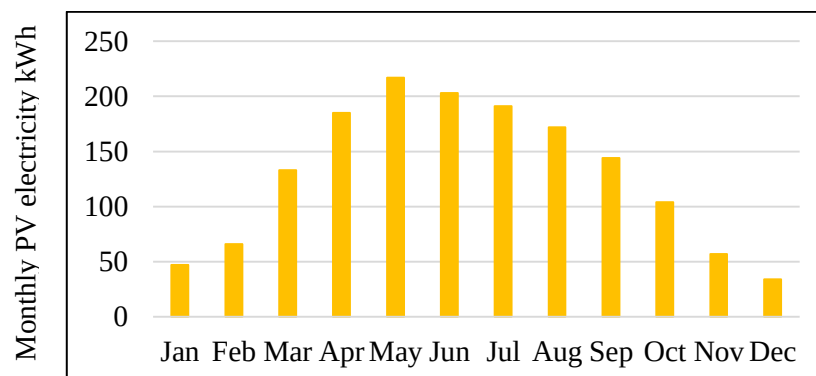


Figure 2. Annual PV electricity generation kWh.

Electricity network model

The electricity network model is build based on a real MV and LV power transmission and distribution network supplying a surrounding town and rural area. The pertinent data has been provided by ESNB. The network model consists of 38 kV primary substation with 2 x 5MVA, 38/10 kV transformers, 10kV feeder has a total circuit route length of 40km with mix of overhead lines and underground cables, the distribution substation with 1 x 630 kVA, 10/0.400 kV transformer is located at a distance of 5.9 km from the primary substation, LV network includes 06 low voltage underground cable feeders, each cable feeder of size 185 mm² cross sectional area conductor connect to around 11 buildings via street pillars equating the total to 68 residential buildings (Ellis and Breathnach 2017).

Results and Discussion

A comparison between Figure 1 and 2 indicates the low annual match between use of electricity and available PV electricity in Ireland. Figure 3 shows the expected annual electricity – with PV generation for self-consumption (653 kWh) & for grid feed-in (900 kWh) and demand on grid (2448 kWh).

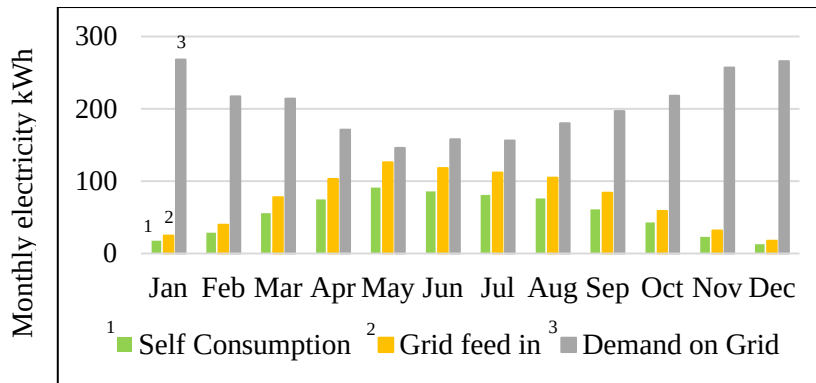


Figure 3. Annual electricity – PV for self-consumption, grid feed-in and demand on grid

Prediction of annual CO₂ emission reduction

Life cycle GHG emissions from solar PV electricity production (69 g CO₂-eq per kWh⁻¹) in Ireland is approximately 6.5 times lower than the GHG emissions from electricity production on the national grid (457 g CO₂-eq per kWh⁻¹) (Murphy and McDonnell 2017).

Prediction of annual savings in electricity/money

Savings in electricity and money by each residential building is equated to annual PV electricity that are directly self-consumed and by electricity fed to the grid at the prevailing rate of feed in tariff.

Prediction of annual losses reduction from power grid

The power flow study of the primary substation, MV network, distribution substation and LV network during the winter maximum load reading estimates the technical losses to be 106kW for entire 68 residential buildings (Ellis and Breathnach 2017).

Prediction of annual indigenous fossil resource or import displaced.

The annual displacement of coal, natural gas, oil resource is estimated by equating the annual solar PV electricity production (kWh) and electricity losses with the factor 3.2704×10^{-07} ktoe for coal, 0.00303 ktoe for natural gas and 2.24×10^{-07} ktoe for oil.

Conclusions

Annual reduction in CO₂ emissions, electricity consumption from grid, electricity losses and displacement of fossil fuel resource is predicted using above methods. This study showed that solar electricity generation will yield significant GHG emission savings compared to the national grid of Ireland and will result in further greening of national grids. The economic payback time of solar PV systems is associated with extending of renewable energy feed in tariff (REFIT) which is critical for the future uptake of PV in Ireland.

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UNDERSTANDING SOLAR ENERGY CHARITY TO ADVANCE GEO POLITICAL DYNAMICS

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Abstract

The growth of renewable energy and its implementation in the power sector has already come so far than any of other energy resource which also includes fossil fuels. Globally, there is a new trend of transformation of energy which is a kind of shifting from fossil fuels to any source which can be replaced naturally in certain time period. The concept of this research is to understand how a renewable energy in this case solar can be used as a charity of trade purpose between developing and developed nations. This transformation of energy can bring out global development in a sustainable and legitimate manner. Moreover, the study be an exploratory review deriving its threads of geopolitical energy trade through documents from the government, scientific papers and articles. Significant portion of this study will utilize secondary research which involved interviews with influential and experienced dignitaries of the field. This paper presents the whole phenomenon of energy charity and its transformation to outlines the initiative based on sustainable energy development.

Introduction

Today, there are 1.4 billion individuals around the globe that need access to power, some 85% of them in provincial territories. Without extra devoted approaches, by 2030 the quantity of individuals drops, however just to 1.2 billion but still it is beneficial. Some 15% of the total populace still need to get to, source their energy from renewable energy their geographical location possesses. Most of them living in Sub-Saharan Africa (Solangi et al 2011). Also, these nations hold enough potential to create an adequate measure of sunlight based energy that can be transported to different nations in return of assets they need. Nonetheless, planning an effective solar oriented collecting framework to understand the potential advantages of energy reaping requires an analysis of significant number of components. For instance, solar-based energy supply is exceedingly time changing and may not generally be adequate to control the installed framework. Gathering segments, for example, solar based boards, and energy stockpiling components, such as, batteries or ultracapacitors, have diverse voltage-current attributes which influence energy use and capacity choices (Raghunathan et al 2005). Thus, a system to exchange energy generated with one nation then delivered to the next would require an abundant measure of energy collecting plants that can capture and move sun-powered energy into power. Government officials are always belittling the genuine capability of solar energy (Commoner 1980).

The study aims to conduct an in-depth literature review of existing research done in the field of energy policy in India and conduct in-depth interviews to further explore the possibilities of energy transfer on the qualitative forefront. The research will be based on feasibility study. Moreover, the primary data will be collected through in-depth expert interviews and will be further strengthened by fieldwork in developing nations particularly India.

The objective of this study is to understand whether solar energy can be used as a renewable energy tool for energy charity, where the solar energy-rich developing countries can transfer the energy to developed countries and improve the geopolitical relations, which would further advance the development of developing nations.

Materials and Method

The study started with the aim of understanding how energy charity with respect to solar energy can impact the scene of geopolitics between developing and developed nations. Over a period, the research narrowed down to the regional geopolitics and the solar energy charity with respect to the villages situated near the major solar energy producing plants. In order to make the study structured, a set of five research questions were developed which further helped in defining the research objective and methodology of the study. The research questions are as follows:

1. What is the current status of solar energy consumption in the villages of India?
2. What is the overall proportion of solar energy consumption in different sectors majorly industry and households in different zones of India?
3. Who all are the major actors (stakeholders) who define the policies and programs with respect to solar energy production and consumption?
4. Are villagers willing to accept solar energy as the only source of energy for their personal and agricultural needs?
5. What is the overall awareness of villagers with respect to solar energy in a developing nation like India?

A glimpse of answers from the research questions came from already existing literature however, the concrete picture was derived from the ground experience.

In order to understand the current state of development with respect to solar energy consumption, acceptance and creation, the length and breadth of a developing nation India needed to be studied. The research majorly derives its validation from exploratory research which focused a particular objective of understanding the potential lying in solar energy. To derive a right sample for the research, India was divided into four zones namely North, East, West and South. Further, one state from each zone was selected based on the work done in the field of solar energy. Ten villages were considered for the study to understand the acceptance and feasibility of solar energy creation and consumption with respect to the operations of Government and local NGOs working on solar energy. The sample can be understood as follows:

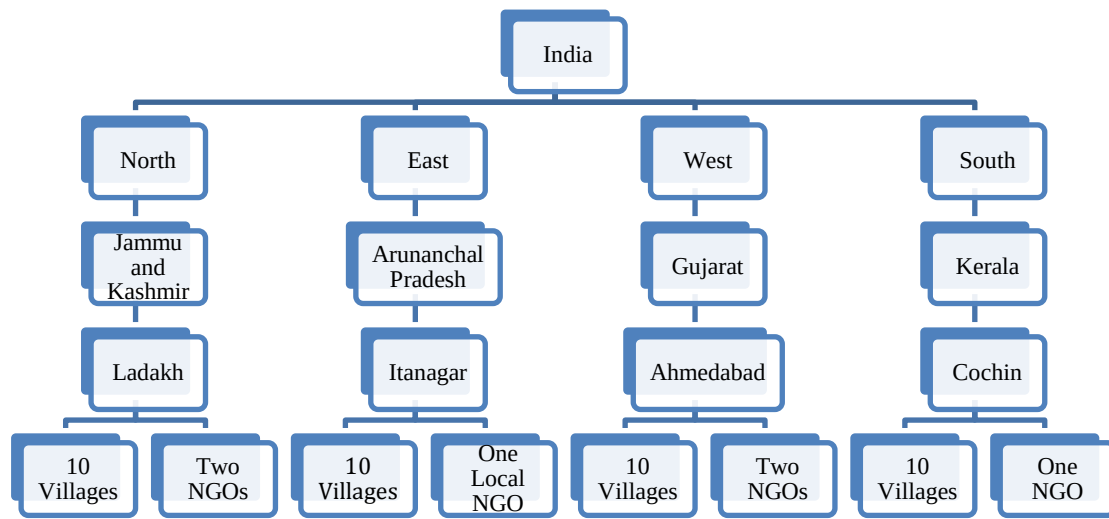


Figure 1. India divided in four zones with their respective areas.

Results and Discussion

The interviews yielded an advanced understanding of solar energy mechanisms. It helped in understanding how it can yield a strong thread of advancing geopolitical relations between developing and developed nations. Unless there is a method to transport the energy gathered within with one nation or to facilitate the transfer of that energy to the next region through links either hung on utility posts, covered in the ground or generally submerged in the ocean, sunlight based energy would require the transportation and utilization of huge stockpiling batteries to give control. Such a capacity medium would not be financially viable or feasible on a small scale.

Power Networks in different nations can be interconnected and consequently purchased and sold from one another when a request requires. However, that requires extensive scale circulation to be set up over built up. Small chance that you are simply undertaking to transfer capacity to nearby site for it to utilize a small-scale display, certainly it's a more financially viable to purchase and execute either a convenient or structured framework. While one is creating their own capacity locally and not getting profit by a sector which has a wealth of daylight introduction, they are likewise not being forced to again consider an agreement which can be a risky journey for them which they are improbably ready to manage.

The exchange of energy to a remote nation is potentially possible on the grounds that the European national power framework lines are associated by mean of the synchronous lattice of Continental Europe. Once the energy supplier delivers in the matrix there's no real way to perceive the source, you simply consent to a Power Purchase Arrangement (PPA) or present a buy request on the energy showcase and that is it, the physical piece of the exchange will be adjusted by the Transmission Systems Operator (TSO).

Conclusions

The study conducted to date considered the insights received from interviewing the professionals and scholars from the field. The interview analysis presented that the transfer of renewable energy like solar energy can improve the relations and development agenda between developed and developing nations. Moreover, India being a hub of diverse terrains also holds the potential of generating energy in deserts and transferring the same to foreign countries. However, a strong potential and viability of such Energy Transfer and Charity projects is unexplored and requires a great deal of scholar research to understand the relative impact.

Additionally, India is an untapped market for renewable energy especially solar energy. The potential of Indian renewable energy production is underutilized due to poor infrastructure and lack of public policy. However, India has initiated a tremendous growth phenomenon in transforming energy sector with renewable energy production. There is a scope of foreign investments in the field of renewable energy and the same being transferred to foreign countries. A concept of Energy exchange can be established where a regulating body would ensure the trade of energy as a currency and presentation of the same in the Gross Domestic Product of every nation. Here the agenda of globalization and achievement of sustainable development goals will take place through energy trade and charity. Moreover, the countries who possess geographical advantage of solar energy will hold the veto power where they will be the regulating authority of the same. The same concept can be implemented to other energy sector however, solar energy can be transformed and utilized in various ways as compared to other energy.

Acknowledgements

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ASSESSMENT OF WIND POWER INTEGRATION TO SOLAR PHOTOVOLTAIC MINI-GRID.

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Abstract

Access to electricity predominantly enables improvement in socio-economic development and economic growth in poor societies. Renewable energy smart grid technologies solicit deliverance of real and sustainable decentralized energy solutions for remote and rural communities. This paper aims to investigate the rationale to integrate wind turbine generators to the existing 75-kilowatt (kW) solar photovoltaic with the storage of 370-kilowatt-hour (kWh), the backup diesel generator of 20 kW with 400 liters of diesel storage to the off-grid rural community. The power distribution intended for 70 household stands, the maximum power supply is 55.7 kW that is 300 kWh/day. The power demand per stand is 1.3 kW equated to 7 kWh/day. Hybrid Optimization Model for Electric Renewable Pro (HOMER) grid design software to simulate optimal system configuration and scalability of wind power integration to hybrid solar photovoltaic. The work on this paper presents the technical aspects and risks associated with the inclusion of a wind power component to solar mini-grids, data analysis and the expected performance of the proposed system will be presented. The simulation results envisage finding out how realistic to implement wind energy system integration and the advancement of renewable energy technologies to substantiate the deployment of mini-grids.

Introduction

The South African constitution authenticates the electricity as the basic right under the municipal services in section 73 of the Municipal Systems Act. One of the South African Government objectives is to provide access to electricity to all of its citizens. Geographical constraints, low-density populations and high costs for grid extension hinder the provision of electricity to rural and remote communities. The hybrid wind-solar photovoltaic mini-grid renewable energy system assessed in this paper aimed at electrifying rural and remote areas that are off the electricity grid. Integration of wind turbine generators to the ground-mounted hybrid solar photovoltaic system with the diesel generator and batteries storage is investigated to deliver sustainably and decentralized power generation. Renewable energy sources offer a viable alternative to the provision of power in rural areas, and the seasonal variations of wind and solar resources are complementary to each other (Lal *et al.* 2011).

Application of mini-grids in South Africa is not a new concept, barriers to implementing smart grids include institutional capacity, policy formulation, lack of mini-grid precedents and social cohesion. Previous studies concluded that it is not feasible to deliver sustainable mini-grids in South Africa based on the challenges of competing with low-cost grid electricity are not so prominent ((SP) 2003; Power 2003; Azimoh *et al.* 2016). The lifetime cost of electricity grid extension in rural areas is lower than installing off-grid renewable energy solutions (Yadoo and Cruickshank 2012). Furthermore, implemented mini-grid at Lucingweni in South Africa present the challenge of inadequate power supply (spatial) to match the demand potential and opportunities (Szewczuk 2013).

This study investigates the feasibility of implementing hybrid wind-solar mini-grid in rural remote areas, by analyzing the simulation and modeling of wind power generators. Combined assessment of renewable energy sources with the input from battery storage, and diesel generator to equate to the demand load of the community. Optimization of renewable energy technologies and decentralized energy distribution has the potential to meet the rural energy demand load potential. The assessment will present a hybrid system design, power quality, and scalability of wind power generators to ensure the stability of the system in any working condition.

The objective of this study was to investigate the technical aspects and risks associated with the inclusion of a wind power component to solar mini-grids.

Material and Methods

The proposed hybrid renewable energy system consists of wind power generator integrated to the existing energy system consisting of solar photovoltaic battery storage, diesel generator (backup unit), and the inverter as depicted in figure 1 below. Light Detection and Ranging (LiDAR) for wind resource assessment will be used to collect physical wind measurements for six months. The wind data collected will be correlated with the Fort Beaufort monthly meteorological data, and Wind Atlas for South Africa. The viability of hybrid wind-solar mini-grid energy system provides a reliable energy supply compared to the separate use of energy systems for the off-grid rural remote areas. Diesel generator backup systems used to cope with the intermittency of solar and wind energy supply.

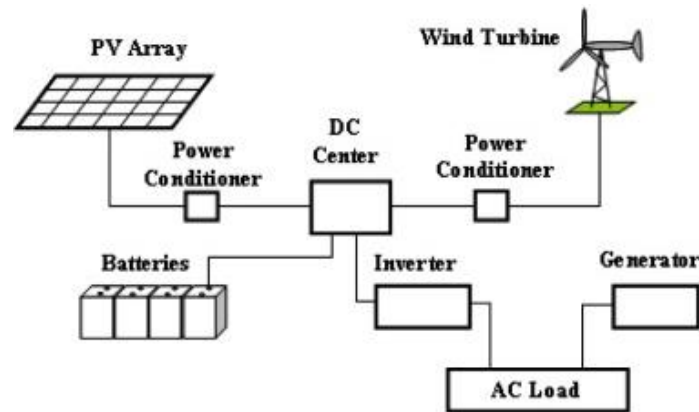


Figure 1. General schematic diagram of the hybrid system (Lal *et al.* 2011).

Location of the study area

Upper Blinkwater is a small rural village located at the Raymond Mhlaba Local Municipality, in the Province of the Eastern Cape, South Africa, located in a higher plateau (height res. 900 m above sea level) at 32° 34.7' south and 26° 33.5' east. The village is not grid-connected. However, there is no prospect of electrifying the village for the next coming five to ten years. The rural village consists of 53 households, a school and a church, and a separate cluster of 7 standalone houses, approximately 23km north-west of Fort Beaufort in the Eastern Cape, South Africa. The rough terrain, low electricity demand, low population density, high-cost grid extension, and remote locality of the village hinders the electrification of the village (Szewczuk 2013).

Measurements

Preliminary wind assessment at 50 meters above ground level is about 6 meters per second at the site. The wind speed and direction will be measured for six months.

Wind power integration assessment

Mini-grid code

Integrated energy planning for wind turbine generator to simulate and model the mini-grid is investigated using the HOMER Pro grid design software. The intermittent wind power generation will be analyzed. The relevant factors such as optimization and sensitivity analyses of various conditions on the risk and technical aspect will be determined. Furthermore, HOMER Pro will be used to assess the feasibility of utilizing renewable energy sources to electrify remote rural areas.

HOMER Micro-grid modeling

Simulation

HOMER Pro software simulates based on the system design with various energy component or equipment combination. However, the simulation is carried out using 1-hour intervals, during which all of the parameters (load, input and output power from the components, etc.) remain constant (Bernal-Agustín and Dufo-López 2009). For this study, the wind speed variance and energization will be simulated to determine the best feasible system configuration, which can adequately serve the

electric demand. Additionally, the HOMER simulation results depict graphics with detail and precision.

Optimization

Subsequently to simulation, optimization of wind component to determine and review the holistic system approach of hybrid renewable energy system configuration with the lowest total net present cost.

Sensitivity analysis

The analysis will determine how changes in the input variable affect the performance of the system and the relative ranking of different systems.

Results and discussions

The envisaged and proposed hybrid solar–wind power generation system consists of PV array, wind turbine, diesel generator, battery bank, converter, and other auxiliary components as depicted in figure 2 below.

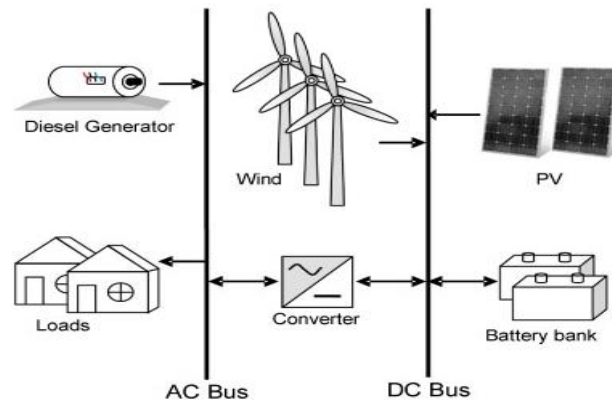


Figure 2. HOMER schematic diagram of solar- wind hybrid system (Ramli *et al.* 2018).

HOMER Pro grid software design performs hundreds or thousands of hourly simulations (to ensure best possible matching of demand and supply) and offers a list of feasible schemes ranked based on the NPC (net present cost) (Lal *et al.* 2011). The simulated results will ensure the power generator provides enough power to meet the demand load profile. Furthermore, the results will characterize the electrical energy production, annual electrical load served, excess electricity, renewable energy fraction, capacity shortage and unmet load. The battery bank and the diesel generator will cope with the intermittent wind and solar power. The autonomous operation of mini-grids needs to be considered and mini-grid operation has a far-reaching impact on the existing safety, control, protection, and dispatch practices and strategies of electrical energy, yet mini-grid operation has neither been fully understood nor investigated (Katiraei *et al.* 2005).

Conclusions

The study will analyze and improve integration of wind and solar renewable energy generation and parity with energy demand forecasting. Previous studies illustrate the deliverance of sustainable and meaningful energy to remote and rural communities utilizing renewable energy technologies. Creating reliance and replication of mini-grids to other un-electrified rural communities. Implementation of mini-grid will certainly influence the decision-makers on the energy policy development to include mini-grids, and thereby creating economic opportunities and to stimulate economic growth.

Acknowledgments

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A FEASIBILITY STUDY OF THE AGROCYCLE MARKETPLACE – SECONDARY & QUALITATIVE RESEARCH

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Abstract

AgroCycle Marketplace is the result of a Horizon 2020 project, AgroCycle. It is an online trading platform which facilitates the free flow of waste across the European agri-food industry and beyond, thus reducing waste through industrial symbiosis. The hypothesis is that the AgroCycle Marketplace Platform, by targeting the agri-food industry, can be economically sustainable. The objective of this study was to unearth potential customers' views, preferences, needs and wants regarding the AgroCycle Marketplace offering via qualitative empirical research; and secondary research of current trends, policies and legislation. Preliminary results indicate that policy makers, industry leaders and ultimately, potential customers, find that there is a real and pressing need for the product.

Introduction

The global scientific community strongly believe that the 1°C increase in the world's temperature, compared to the pre industrialisation period, has principally been caused by the emission of Greenhouse Gases, (GHG), for which mankind is responsible (Intergovernmental Panel on Climate Change 2018). It has been found that agriculture, forestry and land use change are responsible for 30.9% of GHG emissions (Swaminathan and Kesavan 2012). Studies have found that the percentage of world food waste is approximately 33% (Gustavsson *et al.* 2011). With such high levels of waste associated with the production and consumption of food, the solution is obvious. The agri-food industry can have a prodigious and direct impact on global warming by simply reducing food waste.

Today, inadequate food security is an acute problem with 100 million children under the age of twelve being underweight; and 3.1 million children under the age of five dying from hunger annually (McGuire 2015; United Nations 2019). The agri-food industry must act so as to create a more sustainable and just world.

As the European Union's resources are becoming scarce and its per capita material consumption rates are above global averages, it has been actively incorporating Circular Economy (CE) policies and procedures since 2011 (European Commission 2011). Also in 2011, the European Union (EU) initiated a move to consolidate its research, innovation and resources under one umbrella strategic framework, Horizon 2020. Its objective is to secure Europe's global competitiveness by nurturing avant-garde technologies, processes, practices and methodologies, products and services (European Commission 2019).

AgroCycle was a Horizon 2020 project whose objective was to make the agri-food industry more sustainable by the recycling and valorisation of waste streams. One of the AgroCycle tasks was to develop AgroCycle Marketplace, an online trading platform which would facilitate the intricate free flow of waste across the different components of the European agri-food industry and beyond, thus rendering it dynamic, and ultimately, reducing waste through industrial symbiosis (AgroCycle 2019a; AgroCycle 2019b). The next step, which was outside the scope of the AgroCycle project, is to commercialise the AgroCycle Marketplace.

The objective of this study was to unearth potential customers' views, preferences, needs and wants regarding the AgroCycle Marketplace offering via qualitative empirical research; and secondary research of current trends, tendencies, policies and legislation.

Materials and Methods

Regarding the theoretical perspective within which the study will be grounded, the disciplinary orientation of this study is business administration. The study will conduct secondary research which will consider a broad range of literature including concepts, models and theories from scientific journals, business journals, legislation and policy journals. Websites from reputable sources of information like the EU and the United Nations (UN) will also be considered. The problem statement, or feasibility statement, “the AgroCycle Marketplace Platform, by targeting the agri-food industry, can be economically sustainable”, is defined within this framework. The purpose of the study, in turn, “to unearth potential customers’ views, preferences, needs and wants regarding the AgroCycle Marketplace offering” is established within the problem statement (Merriam and Tisdell 2016).

The literature review was conducted with a view to carrying out secondary research which would serve to both: 1) Achieve the purpose of the study by identifying and analysing macro level trends, tendencies, policies and legislation which shape micro level views, preferences, needs and wants; 2) Help shape and define the empirical research.

If the aim of research is to understand how a community or individuals within it perceive a particular issue, then qualitative methods are often appropriate (Baruch 1999). The objective of this research is to unearth potential customers’ views, preferences, needs and wants regarding the AgroCycle Marketplace. So, qualitative research, rather than quantitative research, would be the optimal strategy. At this point in time, AgroCycle Marketplace is not aware of the critical factors, (from the potential customer’s perspective), which will be decisive in the proliferation, or non-proliferation, of online platform users. Any quantitative research that it would design would be based upon criteria that it would be obliged to assume, which would be a perilous strategy. AgroCycle Marketplace cannot quantify phenomena of which it is not aware. It is obliged to use qualitative research so as to discover what the potential customer values most, thus, the key point to success.

Qualitative research comprises a combination of interpretive and material practices that visualises the world, converting it into a range of representations such as photographs, recordings, interviews, and field notes. Researchers investigate real world settings, analysing and interpreting phenomena in an attempt to describe the meanings people attribute to them (Lincoln and Denzin 2005).

There are five principal qualitative approaches: 1) Narrative research; 2) Case study; 3) Grounded theory; 4) Ethnographic research; 5) Phenomenology (Creswell 2013). Phenomenology research strives to illustrate what people who share the same experience have in common, thus converting individual experiences into a representation of a group experience (Van Manen 2016). The researcher amasses data from a number of individuals and establishes an overarching experience from a group perspective (Moustakas 1994). The research question is to unearth views, preferences, needs and wants of a specific group, the agri-food industry participants, and so, phenomenology research will be utilised.

With regard to the sample size, the authors have decided that, so as to maximise the richness and variety of the data, as many interviews as the time constraints will permit will be considered. Interviewees will be selected randomly from, but not limited to, the following events: 1) Irish National Ploughing Championships 2018; 2) ICT-Biochain's Digital Innovation Hub Launch 2019; 4) Agri Innovation Summit 2019; 5) UK AD and World Biogas Expo 2019; 6) Res Urbis Stakeholder Meeting. Potential concerns related to procedures, data analysis, ethical considerations, trustworthiness, potential research bias and limitations will be identified and dealt with using recognised, world class industry standards, norms and procedures.

Results

The secondary research has identified that in order for the AgroCycle Marketplace to be a success, it must attract a critical mass of users (Chesney and Lawson 2015). AgroCycle Marketplace's target markets are: 1) Suppliers of waste; 2) and Potential "Value-isers" of waste. As there is so much waste created right across the agri-food industry, there is no shortage of suppliers. So, the question "whether the demand will be sufficient, or not?", is crucial. In order for the demand to be satisfactory, there has to be enough viable means of valorising waste. What is of the utmost importance is that these waste valorisation means can lead to profitable, stand-alone business units, without the aid of government financial subsidies. The alternative being that they are not sustainable, and the foundations under which the CE is built, simply crumble.

This paper has reviewed state of the art technologies for valorising waste and finds that the future looks promising. For example, aqueous biphasic systems made up of Carbohydrates and cholinium-derived bistriflimide ionic liquids were studied with a view to extract carbohydrates and antioxidants from agri-food waste (Neves *et al.* 2019). There are attempts to produce hydroxymethylfurfural from agri-food waste and to assess the catalytic efficiency of tetravalent and trivalent metals (Yu *et al.* 2017). Despite some challenges, it was found that the elevated fat, protein and sugar substances found in most agri-food waste streams can be successfully commercialised via enzymatic valorisation (Andler and Goddard 2018). Nonetheless, there are a limited number of sustainable "waste valorisation business models" in existence today. It has been found however, that Anaerobic Digestion, (AD), is a means of valorising waste that has been used since ancient times and has proliferated across the globe, particularly during the twentieth century (He 2010). It has been proposed that AD can be the hub in the EU's, and consequently the world's, drive towards a CE (Fagerström *et al.* 2019). This leads us to the hypothesis of the study: "the AgroCycle Marketplace Platform, by targeting the agri-food industry, can be economically sustainable". As sustainable business models related to agri-food waste valorisation technologies are still in the development stage, the question "can the AgroCycle Marketplace establish its foundations upon the AD industry?" begs itself. From a strategic point of view, it may make sense to focus AgroCycle Marketplace's source of revenue on the AD industry in the short to medium term. However, as other valorisation techniques may become more prominent in the medium to long term, this study will not be solely limited to the AD industry. As of yet, the secondary research is in progress. The final report will address issues such as truth value, transferability, triangulation, dependability, conformability, subjectivity and replicability. Ultimately, considering that qualitative inquiry can lead to multiple understandings, the report will strive to document the truth considering our present knowledge (Marshall and Rossman 2015).

Discussion

The AgroCycle Team did make contact with potential customers. However, a requirement to carry out market research was identified as the audience, (the partners, owners and stakeholders of the AgroCycle Project), do not know if the AgroCycle Marketplace would be a commercial success; and consequently, if they should invest in it. The unique contribution that this study will provide are potential customers' views, preferences, needs and wants regarding the AgroCycle Marketplace offering. However, the conclusiveness of qualitative research has been questioned (Sale *et al.* 2002); and so, the results of this study may have to be complemented by further quantitative research.

Conclusions

AgroCycle Marketplace, a Horizon 2020 project, is an online trading platform which facilitates the free flow of waste and can reduce waste through industrial symbiosis. The objective of this study is to unearth potential customers' views, preferences, needs and wants regarding the AgroCycle Marketplace offering via qualitative empirical research; and secondary research. Preliminary results are positive. However, the results of this study may have to be complemented by further quantitative research.

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FEASIBILITY STUDY OF ENERGY EFFICIENCY SOLUTIONS IN EXISTING PUBLIC LIGHTING SYSTEMS IN IRELAND

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Abstract

The energy efficiency targets for Ireland are crucial and very much essential. Implementing cost effective and energy efficient proven technologies like LED retrofitting and Central Management System in Ireland's public lighting system will be beneficial to the government to achieve the national targets for reducing energy consumption along with positive economic and financial returns. Both the technologies can have proven benefits of about 55% savings in cost as well as energy in Ireland's existing public lighting system.

Introduction

The Government of Ireland has designated 'Energy Efficiency' as fundamental and integral share as well as one of the main pillars of Ireland's modern energy policy (Ireland. Department of Communications, Climate Action and Environment, 2009; Department of Communications, Climate Action and Environment, 2019). A national target of 20% energy efficiency by 2020 is envisaged by Government of Ireland in its first 'National Energy Efficiency Action Plan (NEEAP)' as per requirement of Article 24 of EU Energy Efficiency Directive (Department of Communications, Climate Action and Environment, 2019). Also, higher target of 33% energy efficiency by 2020 has been set for public sector in the country so as to implicate a national contribution and to recognize that the government must take a lead role in achieving these bold and essential national targets (Ireland. Department of Communications, Climate Action and Environment, 2009; Department of Communications, Climate Action and Environment, 2019).

In 2017, the Government produced Ireland's 4th NEEAP which stipulated a comprehensive overview on the progress made towards the above set targets. Based on this report, the public sector target is estimated to equate to 3,910 GWh annual energy savings by 2020 (Ireland. Department of Communications, Climate Action and Environment, 2017). As of 2016, public sector has achieved 20% (2,336 GWh) energy efficiency improvement on business as usual while 31 local authorities have reported almost 21% (298 GWh) energy efficiency improvement together (SEAI, 2017a; Ahern, B. *et al.*, 2019). These 31 local authorities account for more than 15% (1418 GWh) of total public sector energy consumption (SEAI, 2017a). Out of which 472 GWh primary electricity is consumed by public lighting system to operate approximately half a million street lights all over the country (Ahern, B. *et al.*, 2019). The public lighting system is one of the important sub-sectors where range of energy efficiency measures can be implemented to achieve Ireland's energy efficiency targets in the public sector as these lights consume approximately 50% of the entire electricity consumption and about 33% of the total energy consumption of all local authorities (SEAI, 2017a).

The objective of this study is to analyse the techno-economic feasibility of different energy efficiency solutions in existing public lighting systems in Ireland.

Materials and Methods

Existing scenario

The inventory of 31 local authorities' public lighting system comprises of 486,627 street lights (as of 2017) which includes about 33% Low Pressure Sodium Lights (SOX), 58% High

Pressure Sodium Lights (SON) while only 9% energy efficient LED Lights (Ahern, B. *et al.*, 2019). The Irish Government is spending more than €56 million in public expenditure every year for the operation and maintenance of these luminaries so as to operate public lighting system smoothly (Ahern, B. *et al.*, 2019). This paper will focus on assessing the saving potential in energy as well as money for the two major energy efficiency strategies which is expected to have a greater positive impact. The techno economic assessment is based on the business case and cost benefit analysis report as prepared by Road Management Office (Ahern, B. *et al.*, 2019). The overall saving potential is calculated on overall public lighting system assuming that all the 31 local authorities implement these solutions together with all funding available.

LED Retrofitting

Light emitting diode (LED) is the most proven energy efficient technology currently being implemented worldwide in artificial lighting system. Simply retrofitting of conventional lighting system with LED luminaries can achieve savings of 50-70% in energy as well as cost of electricity consumption. LED's have an estimated life of about 100,000 hours which equals more than 20 years in operation (Ahern, B. *et al.*, 2019)('LED Drivers with 100,000 Hour Measured Lifespans' 2012). LED luminaries have gained much popularity in being an energy efficient alternative for conventional public lights like SOX and SON as its increased colour rendering index proves to be beneficial in increased safety on streets. Its maintenance costs are significantly low due to low requirement of maintenance activity (Ahern, B. *et al.*, 2019). Considering the best technology available in market, LED retrofitting has a very high potential in achieving maximum energy savings in all the local authorities of Ireland. Few of the local authorities have implemented small scale LED retrofitting projects, but there is a need for the Irish Government to look upon a larger scaled or country wide retrofitting project. By replacing remaining 442,831 public lights of SOX/SON type with at least 50% efficient LED lamps, country's public lighting department can become significantly more energy efficient. For carrying out cost analysis and evaluating the payback period, following parameters are incorporated as mentioned in Table 1.

Table 1. Parameters for cost analysis of LED retrofitting

Sr. No.	Parameter	Value	Source
1.	Cost of LED Luminaire with bracket	€ 447 each	(Ahern, B. <i>et al.</i> , 2019)
2.	Life of Luminaire Driver	12 years	(Ahern, B. <i>et al.</i> , 2019)
3.	Cost of Driver replacement	€ 50 each	(Ahern, B. <i>et al.</i> , 2019)
4.	LED retrofitting period	2 years	Assumed
5.	No. of lights replaced with LED in 1 st year	221,416	Assumed
6.	No. of lights replaced with LED in 2 nd year	221,415	Assumed
7.	Cost of implementing project, procurement process and infrastructure upgrade	€ 43 per light	Estimated (Ahern, B. <i>et al.</i> 2019)

Central Management System (CMS) and Smart Metering

About 90% of the public lighting system in Ireland is presently unmetered ie. the energy consumption is calculated from lamp wattages and fixed yearly operation of 4,150 hours using pre-decided unmetered lighting profiles. This method has many unrealised losses in local authorities' energy expenses. Implementation of Smart Metering and Central Management System (CMS) technologies in addition to LED retrofitting can assure further improvement in energy savings in Ireland. Smart metering will benefit the whole system in recording actual energy consumption, whereas with CMS the switching on/off and dimming patterns can be remotely set and operated along with saving energy. As no actual energy consumption is measured, the energy savings and cost benefits from smart metering solution can be evaluated by further technical and financial analyses on existing methodology of the local authorities for accounting and payment processing. Of all the public lights, there is a potential of setting up CMS in 50% of these lights which are present in less traffic areas or empty rural streets. CMS

are online systems and numerous patterns can be defined for on or off of individual street lights and/or to reduce the intensity of lamps during different operation timings. To analyse efficiency of such a system in Ireland, two different dimming profiles (25% on Pattern 1 & 25% on Pattern 2) are considered as shown in Figure 1. The switch on/off times will directly depend on actual dusk and dawn timings throughout the year, but the overall operating hours (4,150 hrs) is considered to be similar to existing for baseline analyses of energy savings.

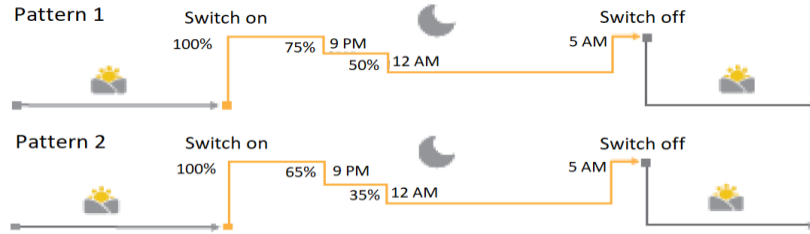


Figure 1. Dimming Profiles for Street Lights (Ahern, B. *et al.*, 2019).

The CMS is programmed with the operation pattern 1 of 25% of total street lights (Post LED scenario) in which the intensity of street lights is decreased to 75% at 9 pm and further reduced 50% at 12 am until 5 am. For another 25% of total street lights, the pattern 2 is defined in which the intensity of street light is decreased to 65% at 9 pm and further reduced to 35% at 12 am until 5 am. This pattern can be remotely modified by authorised representatives so as to create variability in the system as per required situation. For carrying out cost analysis and evaluating the payback period, following parameters are incorporated as mentioned in Table 2.

Table 2. Parameters for cost analysis of LED retrofitting

Sr.	Parameter	Value	Source
1.	Cost of CMS including maintenance	€ 50 per light	(Ahern, B. <i>et al.</i> , 2019)
2.	Cost of CMS communication yearly	€ 3 per light per year	(Ahern, B. <i>et al.</i> , 2019)
3.	Street Light operational hours yearly	4,150 hrs	Similar to existing scenario

For the economic analysis of the energy efficiency solutions, following parameters are taken into considerations: Inflation rate of 1.9% pa. on maintenance cost of non-LED lights (€ 22 per light per year) and LED lights (€ 10 per light per year), 2% yearly increase in electricity cost of € 0.139 per kWh presently. For the large-scale implementation, the economies of scale are not taken into consideration in the present study.

Results

With implementation of LED retrofitting and CMS with two dimming profiles, all over the country, following results can be expected or achieved as illustrated in Table 3 and Table 4.

Table 3. Post LED Retrofitting energy savings expected

Parameters	Value	Source
Existing actual energy consumption	227 GWh	Calculated
Existing primary energy consumption	472 GWh	Using primary energy factor of 2.08 (SEAI, 2017b)
Post LED + CMS actual energy consumption	101 GWh	Calculated
Post LED + CMS primary energy consumption	210 GWh	Calculated
Savings in actual energy consumption	126 GWh	Calculated
Savings in primary energy consumption	262 GWh	

Table 4. Post LED Retrofitting cost savings expected

Parameters	Value	Source
Existing annual expenditure (Capital cost + Electricity cost + Maintenance Cost)	€ 44m	Calculated (Incremental with respective escalation)
Post LED + CMS annual expenditure	€ 20m	Calculated (Incremental with respective escalation)
Overall savings in annual expenditure	€ 24m	Calculated
Investment cost (LED Cost + Infrastructure upgrade cost + Project implementation cost)	€ 217m	Calculated
Payback period	< 9.5 years	

Conclusions

Overall with largescale implementation of these two energy efficiency solutions in public lighting system of Ireland will provide a benefit of more than 55% energy efficiency in primary energy consumption. This also impacts the savings of Government funds in long term with overall annual savings of about € 24 million. The payback period of these solutions is estimated to be less than 9.5 years. These expected savings can be further improved by strategic and efficient business model by considering economies of scale, competitive tendering and procurement and higher efficient products.

Acknowledgements

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MAPPING AND CHARACTERIZING BIOMASS RESOURCES FOR SUSTAINABLE VALUE CHAIN DEVELOPMENT

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Abstract

Sustainable value chain development is essential for the circular bioeconomy in Ireland. Maximizing the values of biomass supply chains; with the production of energy and bio-based products and maximizing the lifecycle of materials. A characterization of the biomass resources in the regions of Monaghan and Tipperary will be useful in determining which technologies (biorefineries) should be developed. Geographic Information Systems is a tool which will present data and information on the biomass streams in Tipperary and Monaghan. Securing supply chains from these sources to help develop a functional circular market is the goal. Government incentives and collaboration with existing companies in the agricultural and forestry industry may be required.

Introduction

The circular bioeconomy in Ireland aims to produce renewable biological resources and convert these feedstocks into bio-based products and bio-energy. These feedstocks are generated from supply chains such as agriculture, forestry, fisheries, food and residual waste industries. When planning the construction of biorefineries, the feedstock supply chain of the biomass in the given region must be accounted for. The two regions this study focuses on are Monaghan and Tipperary; agri-food is a huge industry in both these regions. Closing nutrient loops during cultivation of food and bioresources, maintaining the value of products for as long as possible while mitigating environmental damage is in line with the circular economy ideal set out by the European Commission (Commission 2018).

This project aims to analyze and quantify the production of biomass in Monaghan and Tipperary, describing their current waste treatment methods and their uses. To evaluate sustainable value chain development, the following objectives must be completed;

- Feedstock Assessment
- Market Potential Assessment
- Sustainability Assessment
- Technology Potential

Sustainable value chains in these two regions come with many benefits for both environmental and economic purposes; job creation, ecological damage mitigation and raw material acquisition. Agri-food production is a pillar in Irish society and the Irish economy. The main sectors in the agri-food biomass sector can be characterized by livestock manure, cereal straw, fruit pomace, vegetable, pomace, leaves, peels, oil, fruit, seeds. Currently agricultural-waste streams in these two regions are under-utilized for the purpose of animal feed, energy recovery and bio-fertilizer (Agrocycle 2019). Essentially the aim of this study was to research the potential to set up sustainable bio-based value chains. The possible value chains include; bioenergy, biochemicals and other biomaterials. At a time where there is uncertainty regarding the rural economy, sustainable value chains in the agri-food sector can benefit rural growth (Murphy *et al.* 2016). Stakeholders involved in this study include; farmers, public authorities (county councils) and companies from industries including the agri-food sector.

The objective of this study is to map and characterize the major biomass value chains in Monaghan and Tipperary, specifically agricultural and forestry waste.

Materials and Methods

Feedstock Assessment

Feedstock is the key factor in determining the bioresource availability in the two regions and ultimately will determine which technologies will be feasible. The feedstock assessment is the first step in the biomass supply chain, different studies have presented different results in terms of feedstock estimates, however it is widely understood from several bioenergy studies that the discrepancies which influence bioenergy potential include; system boundaries, biomass resource types, use of heterogeneity of datasets and scenario assumptions (Batidzirai 2013).

Market Potential Assessment

The market potential will depend on the technological potential and the comparisons between biomass and other energy sources such as fossil fuels. Demand driven cost supply analysis are necessary for the market potential assessment (Batidzirai 2013). ‘A farm to gate’ cost analysis will be conducted for this study which will include a comparison of energy prices and energy carriers. Competing feed, fuel and fertilizer sources on the market have been investigated (Batidzirai *et al.* 2016).

Technology Potential

Technology in the biomass industry is in its early development and constantly updating and advancing. The possible technologies to be implemented in the two regions include anaerobic digestion and gasification and will depend on the feedstock assessment and the market potential assessment.

Sources used to characterize bioresource availability in the two regions

Agrocycle is particularly useful for determining physicochemical characteristics of the waste streams produced in the agri-food industry and how to make the best use of them (Agrocycle 2019). The SEAI Bioenergy forecasts provide information by (TJ) forecasts of biomass across Ireland for the future 15 years (SEAI 2015). Other sources include; SEAI Bioenergy supply in Ireland 2015 – 2025, EPA statistics, County Council data and Coillte.

Characterizing Biomass for Energy Potential

The characterization of biomass in this study is ultimately to investigate its potential to be converted to energy and bio-based products. Analysis for biomass energy characteristics include: higher heating value (HHV), lower heating value (LHV), volatile matter, ash yield (Agrocycle 2019). Physical properties will be defined by weight (Wt), volume (Vol) and moisture content (MC).

GIS

Using geographical information systems (GIS) data, a characterization of the biomass streams in each region will be presented, along with the processes which generate the biomass, including cultivation, harvesting, animal by-products and many more. GIS is useful to visually present information in a map format and display the relationships between regions and the biomass generated, trends in agricultural activity and supply chains. The specific GIS software used for this study is ArcGIS software.

Agri Bio Circular Economy (ABC Economy)

ABC Economy is a project lead by Dr Fionnuala Murphy, engaging with stakeholders; project partner Cre, and project collaborators Tipperary Country Council and Monaghan County Council.

Data Analysis

The analysis for this study involved literature research (Andre Brosowski 2013), examining existing reviews, various studies on a global scale, continental scale and national scale. The potentials of this study include: an understanding of the (TJ) of biomass feedstock, the suitable technology to be implemented such as anaerobic digestion, gasification, incineration. The area potential in both Tipperary

and Monaghan will depend on factors including; protected areas, crop land, urban land, marginal or low quality land, planning and legislation (Dornburg *et al.* 2010)

Results and Discussion

Theoretical Resource Assessment

For estimating manures produced by cattle, pigs and poultry, projected livestock number are combined with the estimates of quantity of manure produced each day and the proportion of animal waste managed by liquid slurry systems is considered (SEAI 2015). The feedstock production potential is theoretical and based on agricultural production levels, the residue production and chemical characteristics (moisture content, calorific values), covering the regions of Tipperary and Monaghan. The biomass resources will cover agri-waste and forestry biomass. Moisture content, heating value and energy density will be determined by mass and energy yield. The technical biomass energy potential prediction is based on the food and feed production in the regions and the biophysical conditions including soil, water and climate (Batidzirai 2013).

Suitable Technology

The theoretical resource Assessment has determined that the technology which should be implemented in the two regions include; anaerobic digestion, gasification and combustion.

Conclusion

Establishing a sustainable biomass resource feedstock supply is essential for the circular economy ideal to prosper in Ireland. The feedstock assessment in the two regions of Monaghan and Tipperary has provided important data on the biomass supply chains in both cases, which will be useful in determining the best technology, infrastructure and value chains to be developed in these two regions.

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STUDY OF ENERGY EFFICIENT MEASURES IN BUILDINGS AND EVALUATING THE FEASIBILITY FOR THE IMPLEMENTATION OF RENEWABLE ENERGY

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Abstract

This study is carried out for analyzing thin-film solar plant as an energy efficiency measure in Agriculture building in University College Dublin. This technology can prove to be beneficial in such old structured buildings to become more efficient and contribute to achieving renewable energy targets. A 50 kW thin film solar plant installed on the rooftop of Ag building can save more than 3% by reducing energy costs by EUR 9,000. Further savings can be evaluated by integrating small scale wind turbines.

Introduction

The 2030 climate and energy framework stated by Europe includes EU-wide targets and policy objectives for the period from 2021 to 2030 (European Commission 2019). The European Union had set the 2020 targets under the Directive 2009/28/EC which are revised upwards in 2018. The key targets for 2030 are wide spread in three areas affirming firstly cutting down the Greenhouse gas emissions by at least 40%, secondly by increasing no less than 32% share for renewable energy and the last which states at least 32.5% improvement in energy efficiency (European Commission 2019). Ireland is committed to produce from renewable sources at least 16% of all energy consumed by 2020 (Department of Communications, Climate Action, and Environment, 2019). As per the current scenario globally, the target to have 40% of electricity consumed from renewable energy sources is one of the most demanding and most likely will be revised upwards.

University College Dublin has the Energy unit dedicated with the determination of conserving energy, reducing costs and achieving sustainable energy sources (UCD Estate Services 2019). The unit is playing its part in the global effort against climate change by means of the efficient consumption of energy and expanding the amount of energy obtained from low-carbon or renewable generation. UCD recognizes this potential and has invested in a renewable biomass boiler, solar PV and solar thermal panel on campus buildings (UCD Estate Services 2019). There are a few buildings on campus which are quite old structurally and have relatively low energy saving and efficiency measures compared to the other building structures on the campus. UCD agriculture and food science centre is one of those old structure built in the 1980s and needs to improve the energy efficiency of the building and build up a renewable generation system for the building.

Solar energy is the most abundant and infinite source of energy and there has been substantial attention in developing efficient technologies to convert solar energy into electricity or thermal energy since the energy crisis in the 1970s (Settino et al. 2018). Numerous solar photovoltaic technologies comprising a wafer, thin film and organic, have been studied to accomplish dependability, cost- efficiency and high efficiency with huge success (Lee and Ebong 2017).

The objective of this study is to determine the feasibility of energy efficient measures in the agriculture building of the UCD agriculture and food science centre located in University College Dublin and optimization with renewable energy like solar and wind.

Materials and Methods

Thin Film Solar Cell Technology

A thin-film solar cell is a second-generation solar cell, they are favourable because of their minimum material usage and rising efficiencies. This paper has included the potential of each technology in a commercial setting and its reliability in Ag Building is equally explored in this paper, the evolution of technology is discussed in both aspects technical and economical settings, and market share and reliability are equally explored. A thin-film solar panel is made up of one or more thin layers of photovoltaic materials that are laid onto a substrate like glass, plastic or metal. They have a benefit over the traditional solar panel. They are lightweight because of their construction where the panels are sandwiched between glass without a frame (Solar-estimate 2019). A thin film solar panel has a lesser impact on the environment since they use less silicon. Amorphous silicon (α -Si), Copper Indium Gallium Selenide (CIGS), and Cadmium Telluride (CdTe) are the three most commonly used thin film solar cells. These three technologies can be merged into Building Integrated Photovoltaics (BIPV). It is utilized in BIPV as PV glazing material that can be laminated on windows (Solar-estimate 2019). In Table 1, Commercial modules of Thin films and their efficiencies are shown escalating and prominent (Lee and Ebong 2017).

Table 1. Chart of commercial module efficiencies (Lee and Ebong 2017).

TFS cell type	Champion Research Module	Efficiency Percentage		
CdTe	CX3–85 - Calyxo		8.5	
a-Si	Sharp Thin Film Module a-Si/micro-Si		9.5	
a-Si	MICROMORPH™ G5 - TEL Solar		12.2	
CIGS	SP3S–250 - SoloPower		12.7	
CIGS	SL2 CIGS Thin-Film Module - Solibro		13.3	
CIGS	SF170-S CIS Module - Solar Frontier		13.8	
CdTe	FS–4112 First Solar Series 4™ PV module		14.0	
CIGS	TS–165-C2- TSMC Solar		15.2	
CIGS	M-GE101E092 - Manz		16	
CdTe	TSMC Solar		16.5	
CdTe	First Solar		18.6	

Methodology

For this study, a walk-through survey was carried out to examine the potential for Ag building. The mandatory data was collected and evaluated from the UCD Estate Services and ESB Active Energy Manager Portal regarding the details of the Ag building like the area and layout of the building, energy consumption-management and efficiency of the Ag building (ESB 2018). At the same time, factors such as- Solar radiation and daylight times, policies, legislation, economic fund, and current energy efficiency measures have also been analysed and is incorporated to create a viable data set for analysis to be carried out on.

Optimization Models

Optimization models will be developed using energy system modelling software like HOMER PRO Renewable Energy and PVSyst V6.78. In this case, a modified energy system model will be created using Microsoft Excel from a mixture of the data acquired from the software considered in addition to the relevant information gathered externally. A further study needs to be carried out using HOMER for evaluating the consistent electrical system. This can be incorporated with the Solar PV system to develop a model that highlights the optimal energy system solution from an economic point of view along with its feasibility.

Model approach and potential

Based on the studies and research, two solutions for energy efficient measures in Ag building with the integration of renewable energy source can be implemented:

1. Thin Film Solar Cell Technology: Thin film Solar cell panels on the rooftop and Flexible thin films mounted on the concrete structures on the outer sides of the agriculture building
2. Small Scale Wind Turbine: On the roof, small-scale wind turbines can be installed to obtain greener energy.

Application in agriculture building of the UCD agriculture and food science centre

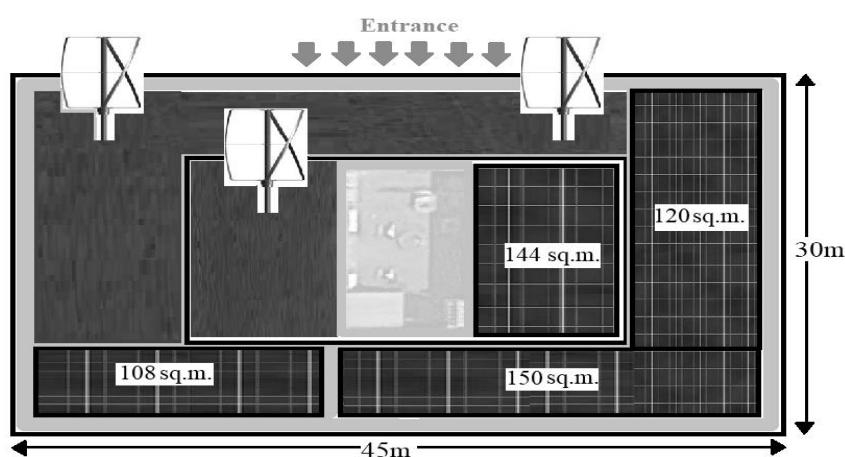


Figure 1. Top view layout of roof-top of agriculture building.

Here is the top view layout of roof-top of agriculture building to illustrate the solar technology and installation along with wind turbines. Based on the preliminary survey and data collected, it was examined that the total roof area is 822 m². and upon evaluating, around 522 m. of an area of efficient utilization for thin-film solar plant was observed. Whereas, some of the other space on the roof-top can be used for installing wind turbines. A Solar plant can be installed having a capacity of 50 kW with the total panel area of 300 m². From this installation, 40 GWh will be the annual energy generated from the plant and Ag building can have annual cost savings of about EUR 9,000 considering only the 60% roof area for the Solar technology. Along with this, if flexible thin films and wind turbines are incorporated in this green energy generation than Ag building can have an optimal benefit on environmental aspects as well as in an economical way.

Economic Feasibility

Subsequently, another study needs to be carried out for assessing economic feasibility based on the overall results. This will be achieved by a characteristic approach to evaluating the viability of energy projects on economic perspectives. Net Present Value of the project will be examined as it basically calculates the project's future cash flows compared to the initial investment. Positive values will approximate the economic viability of the project owing to the profit gained. Furthermore, the payback period will be planned and will be evaluated to manage extensive payback period as mostly the lengthier the payback period the bigger risk to investors. Relative analyses will be carried out so that it can highlight what makes solar PV economically viable in an educational institution with old structures and provide a basis for further research into measures to ensure economic viability in the future for existing buildings.

Results

Expected Results

The project is still in the information accumulation phase and so it is known what the precise results will be. Although, upon evaluation of one system in this study, there are expected

results which are positive for a part. By installing a Solar plant having a capacity of 50 kW, we can generate annual energy of 40 GWh and can save annually about EUR 9,000 from an evaluation done for Solar technology. Along with this, the energy proficiency can be further amplified by using 3 quantities of 5KW Wind Turbine on the rooftop for greener energy generation and economic advantages.

Conclusions

In concluding, the thin film solar plant of 50 kW is the potential energy efficient solution which can be implemented in the Agriculture building located in University College Dublin to decrease its overall carbon footprint. Also optimizing this micro energy generation can be done by integrating small scale wind turbines. Further technical study in this will conclude, by thorough and precise analysis of energy efficient measures and incorporating it with solar and wind energy, to find ways to attain the best possible outcomes for an economic and environmentally suitable energy system. Currently, it is expected that external factors such as those deliberated in the expected results will be the deciding factor in this analysis based on literature and comparisons to other countries where solar PV has a large market share of energy production.

Acknowledgments

The authors would like to thank the building services of UCD as well as the UCD Estate services for providing necessary details regarding the campus buildings. The authors would also like to acknowledge ESB Cylon Active Energy, Ireland for their statistical data of the energy consumption and generation.

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TECHNO-ECONOMIC ASSESSMENT OF STRATEGIES TO DECARBONIZE MONEYPPOINT POWER STATION

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Abstract

With climate change becoming an ever-more pressing issue and global legislation enforcing stricter emissions control, countries are facing a growing need to decarbonize their electricity generation. For many countries, coal still represents a large fraction of power generation, despite coal being one of the ‘dirtiest’ fuels for electricity generation. This study will explore the feasibility of three methods for decarbonizing coal power plants, using Moneypoint Power Plant as a case study: conversion to biomass feedstock; retrofitting carbon capture and storage (CCS) technology; and implementation of both methods. This study will ideally form a basis for future investigations into retrofitting coal power plants with decarbonizing technology.

Introduction

Despite the growth of the renewable energy sector in recent years, global dependence on fossil fuels like coal will likely continue for the next several decades (Davies *et al.* 2017). Coal power plants are established technologies with long lifetimes—up to 40 years—so policies to decarbonize electricity generation must deal with these ‘dirty’ power plants in addition to implementing technologies such as wind, solar, and nuclear. Some strategies to clean up coal power plants are highlighted in the table below from Davies *et al.* (2017):

Table 1: Examples of ‘clean coal’ technologies (Davies *et al.* 2017)

Technology	Description
Advanced Pulverized-Coal Combustion	Increase temperature and pressure via steam cycle regeneration to improve efficiency
Integrated Gasification Combined Cycle	Gasify coal pre-combustion to produce cleaner-burning synthetic gas
Oxy-Fuel Combustion	Add oxygen to combustion process to improve efficiency (higher temperature and pressure)
Pre-Drying of Lignite	Dry lignite (brown coal) via air drying or fluidized bed dryers to improve efficiency
Biomass Co-Firing	Substitute biomass for coal for cleaner feedstock without mechanical changes to the power plant
Post-Combustion CCS	Capture CO ₂ from flue gas via chemical or physical methods, then store or use the captured CO ₂

Most of the above methods are not suitable for retrofitting, and only mitigate emissions. However, the IPCC states that the world needs to achieve negative carbon emissions to keep global warming below 2°C (Consoli 2019). The two methods with the potential to achieve zero, then negative, emissions are: conversion to biomass feedstock and post-combustion CCS. Biomass feedstock has the potential to be carbon neutral and, in combination with CCS, has the potential to achieve negative emissions (Drax Group 2019).

The objective of this study is to investigate the economic and technical feasibility of various retrofitting schemes for the decarbonization of coal power plants via feedstock conversion and carbon capture technologies.

Materials and Methods

Decarbonization Options

The ideal retrofitting option from an environmental standpoint is biomass energy with carbon capture and storage (BECCS); this would necessitate converting a coal power station to biomass feedstock, then installing CCS technology to handle the flue gas from biomass incineration (Consoli 2019). This option offers the potential for negative carbon emissions if the biomass feedstock is produced sustainably and becomes a ‘carbon neutral’ fuel (Consoli 2019). However, this is also a significant change that will likely need to take place in phases over a longer period of time. The other two options this study will consider are: retrofitting Moneypoint with CCS technology without changing operations otherwise; and converting Moneypoint to biomass feedstock without CCS technology.

Potential biomass feedstock includes energy crops, agricultural/forestry residues, and other wastes (SEAI 2019). These biomass sources are often pre-processed into pellets before being burned as fuel. In Ireland, the most likely sources of biomass are wood residues (i.e. woodchips and wood pellets). Irish biomass from forest and wood industry by-products already complies with EU sustainability criteria, and wood processing sites are common in Ireland (SEAI 2019). However, energy crops and agricultural wastes are other feasible options as well.

The most commonly deployed carbon capture system is chemical absorption or scrubbing, often using amine-based solvents such as monoethanolamine (MEA) (Wang *et al.* 2017). The power plant flue gas is sent into a counterflow absorption column, where the flue gas flows upwards and the solvent flows downwards, absorbing CO₂ as the two phases interact; this system can extract a CO₂ stream with up to 99% purity (Wang *et al.* 2017). The rich-loading solvent stream is then heated to regenerate the solvent and separate the CO₂ for transport to either storage (often geological) or further use (Xue *et al.* 2017).

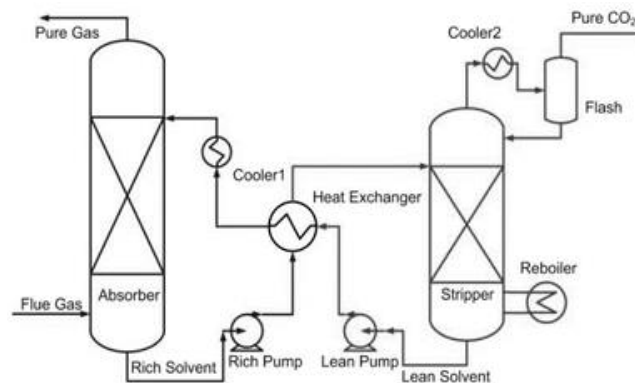


Figure 1: Schematic of CO₂ capture process using MEA (Wang *et al.* 2017; Xue *et al.* 2017)

The biggest issues with a CCS system is the amount of energy needed in the stripping column to regenerate the solvent (Wang *et al.* 2017). This energy use will lower the overall power plant efficiency and increase the cost of the produced electricity (Al-Qayim *et al.* 2015)

Economic Feasibility

For a retrofitting operation to move forward, the project must demonstrate economic feasibility. This study will assess the economic viability of the three different options using payback period, levelized cost of electricity (LCOE) and cost of CO₂ avoided (Al-Qayim *et al.* 2015).

The formula for LCOE, assuming a constant amount of net electricity produced and sold each year, is as below in Eq. 1 (Rubin 2012):

$$LCOE \left(\frac{\$}{MWh} \right) = \frac{(TCR)(FCF) + FOM}{(MW)(CF)(8766)} + VOM + (HR)(FC) \quad (\text{Eq. 1})$$

where

TCR = total capital requirement in the base year of analysis (\$)
 FCF = fixed charge factor (constant frac.)
 FOM = fixed O&M costs (\$/yr)
 MW = net power output of the plant (constant MW)
 CF = capacity factor of plant (constant frac.)
 VOM = variable O&M excluding fuel cost (\$/MWh)
 HR = net power plant heat rate (MJ/MWh)
 FC = fuel cost per unit energy (\$/MJ)

For this study, FCF will be calculated using Eq. 2 (Rubin *et al.* 2013):

$$FCF = \frac{r(1+r)^t}{(1+r)^t - 1} \quad (\text{Eq. 2})$$

where

r = interest rate/discount rate
 t = economic life of the plant

The cost of CO_2 avoided is the cost associated with keeping a unit of CO_2 emissions out of the atmosphere, and is a comparison between a retrofitted plant and the current Moneypoint configuration. This cost will be calculated as below (Rubin *et al.* 2013):

$$\text{Cost of } CO_2 \text{ avoided} \left(\frac{\$}{tCO_2} \right) = \frac{(LCOE)_{retrofit} - (LCOE)_{ref}}{(tCO_2/MWh)_{ref} - (tCO_2/MWh)_{retrofit}} \quad (\text{Eq. 3})$$

For economic feasibility, the payback period and LCOE cannot be too high, and the cost of CO_2 avoided should be as low as possible.

Technical Feasibility

Other technical considerations this study will consider are feedstock availability and the engineering changes required to successfully implement these retrofitting schemes. The preference is for domestic, abundant feedstock sources. Importing feedstock is not only detrimental for energy security, but also generates extraneous environmental burdens. Choosing a limited feedstock will incur high costs and energy insecurity. In addition, this study will consider physical demands of retrofitting Moneypoint. These demands might include changing turbine designs, introducing biomass feeding mechanisms, increasing land use for a CCS unit, connecting a CCS unit to both CO_2 transportation pipelines and flue gas lines, etc.

Another key criterion for this study is the ability of the three options to reduce the carbon emissions of Moneypoint in a sustainable way. For this reason, the annual CO_2 emissions of each retrofit option will be compared to the reference emissions of an un-changed Moneypoint operating at the same capacity, to ensure that a significant change in CO_2 is achieved compared to the reference plant.

Results and Discussion

Based on initial research, the feasibility of CCS and biomass retrofitting is expected to depend partially on the availability of profitable CO_2 sinks and inexpensive, sustainable feedstock (Drax Group 2019). The high costs associated with amine solvent regeneration mean that CCS units have high operation costs; moreover, the energy consumed by the regeneration process will decrease the efficiency of the overall power plant (Al-Qayim *et al.* 2015). Both issues will increase the final cost of the electricity generated by the power plant. To offset this increase in cost and accelerate payback of the capital expenditures of the retrofit, a CCS project should try to derive value from its captured CO_2 stream. Existing commercial CCS deployments in power plants use the captured CO_2 in a variety of sectors, from enhanced oil recovery to the fizzy drink industry; these additional revenue streams help make the CCS retrofitting projects economically viable (Drax Group 2019; NRG Energy 2019).

Biomass feedstocks have a lower energy density and less-developed supply chain compared to fossil fuels (Consoli 2019). For a baseload power supply, reliable and cheap fuel sources are essential; these

considerations will be key in successfully changing Moneypoint's feedstock from coal to biomass (Davies and Madden 2017). The more cheap, domestic biomass feedstock Ireland can supply without relying on foreign imports, the more Irish energy security will benefit. A retrofitting project will likely need to address both of the highlighted concerns—valorising the CO₂ stream and ensuring a secure biomass supply—to achieve economic and technical feasibility.

Conclusions

Further research into the economic and technical aspects of each of the retrofitting options is needed. This paper defines the parameters that will be used to quantitatively assess the feasibility of each option, and lays the groundwork for a process to evaluate the suitability of any coal power plant for biomass or CCS retrofitting. Transitioning Moneypoint to a power plant using biomass as a feedstock and/or using CCS technology is expected to reduce emissions associated with power generation in Ireland, and potentially increase Ireland's energy security if biomass can be domestically sourced. However, the realities of implementing such a system need to be thoroughly evaluated to avoid implementing a project that is economically or technically infeasible.

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THE EFFICIENCY OF SOLAR WATER HEATING IN IRELAND

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Abstract

The efficiency of two specific designs of solar water heating systems was investigated under temperate oceanic climatic conditions in the low irradiance region of Ireland. Design parameters and climatic conditions are applied into simulation formulas in order to obtain estimations of the annual average energy yield. Calculations were carried out for two separate solar collector designs: A parabolic trough collector design and a solar plane collector design. Simulations of the performance for each of these designs was carried out and results are presented. The results were compared, and the efficiency and sustainability of each design were calculated. The results obtained demonstrated that the through technology has the potential to be more efficient than solar plane collector technology.

Introduction

Over half the world's consumption of energy can be attributed to heating applications, an amount that is as high as 129 exajoules (129×10^{18} joules) (3.583×10^7 MWh). Over 75% of this energy used for heating, is obtained through the use and combustion of fossil fuels resulting in almost 33% of global CO₂ emissions (Eisentraut & Brown 2014). Analysing the environmental impacts of these heating systems is, therefore, of great importance as it can help us build more sustainable and environmentally friendly systems. Conti *et al* (2016) have predicted in an international energy report that world energy demand is set to increase significantly throughout the next number of decades and by as much as 48% by 2040. A significant hotspot for this energy consumption has long been heating systems and in particular, residential heating systems. Energy consumption within the residential sector of the EU (European Union) maintains an average annual increase of 0.9%, not only this but in 2016 it accounted for 10% of the total GHG's (Greenhouse Gas) emitted worldwide (EEA 2016). The EU has adopted a new 2020 energy policy package in direct response to this global rise in energy consumption (EC 2008). The main objectives of this package were; Improve energy efficiency by 20%, reduce GHG emissions by 20%, increase renewable usage to cover 20% of EU energy consumption by 2020 and have at least 10% of vehicle fuel comprised of biofuel by 2020 (Tulus *et al* 2019). Solar thermal heating systems are an innovative technology which could substantially reduce emissions produced from heating systems and help meet these ambitious goals set out by the EU. It is predicted that if solar thermal systems are utilized effectively and efficiently in Europe, by 2030 they have the potential to cover half of the heat demand in the continent (Endale 2019). This prediction demonstrates the potential for solar thermal technologies, even in areas with average to low irradiance such as Europe. Pinel *et al* (2011) have also reported that installations of solar thermal systems within the residential sector could effectively cover the heat demand in many countries worldwide. These installations could, therefore, go a long way to reducing the 10% of global GHG's emitted from the residential sector.

Of all the solar thermal technologies, solar water heating is the most environmentally friendly and economically viable system which harnesses the unlimited supply of energy from the sun (Shukla *et al* 2013). The most common solar water heating system utilized today is a solar plane collector system and although this system has proved effective, the parabolic solar trough design which this paper will look at in detail has the potential for even more impressive results.

The objective of this study was to calculate the efficiency of a parabolic solar trough water heating system when utilized in Ireland and compare it to the efficiency of a solar plane collector system.

Materials and methods

Predicting the annual energy saving potential of Solar Water Heating systems is essential to analysing their efficiency and economic feasibility. This energy output achieved from a solar water heating system is dependent upon several factors such as climatic conditions, storage tank volumes, design and optimal sizing of components. All of these factors will have to be included when modelling the design of the solar water heating system if accurate results are to be obtained.

The solar water heating system which this report will be studying in detail is a parabolic solar trough system. Similar to a CSP (concentrated solar power) system, a Parabolic Solar Trough system utilizes mirrored surfaces which are curved into a parabola shape to allow incoming solar energy to be directed towards a centre receiver tube which extends the length of the system, see (Fig. 1). Cold water is pumped

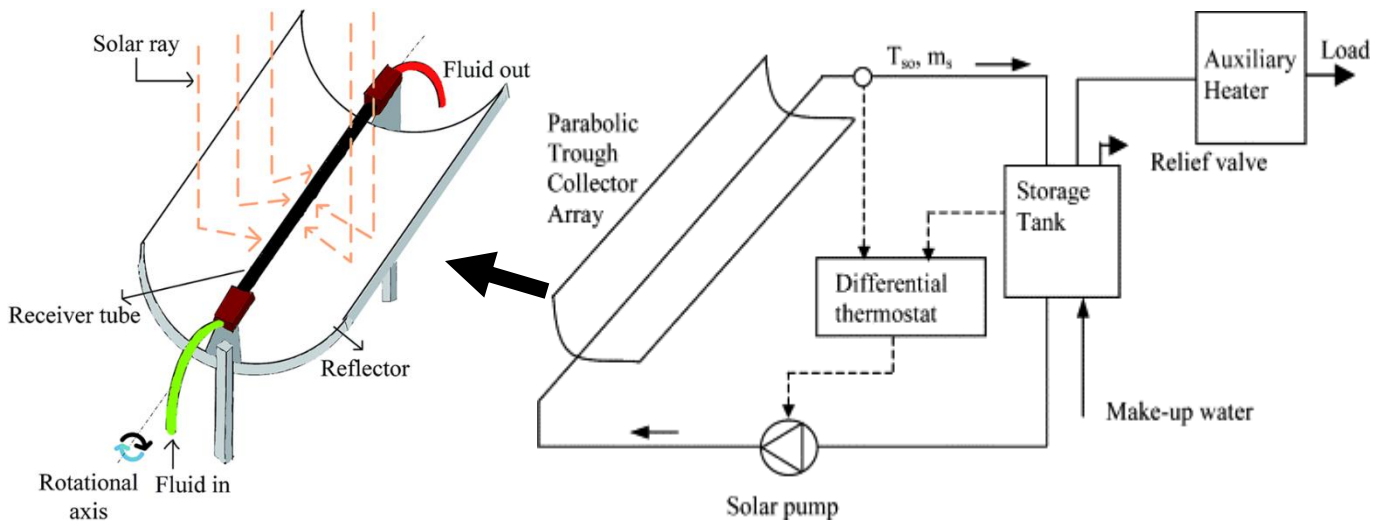


Figure 1. Diagram illustrating the typical design of a parabolic solar through system Source: (Islam et al 2015), (Kalogirou 2002).

through the receiver tube at one end of the trough system, this water is then heated as it passes through the tube due to the concentrated solar energy and exits the tube at the other end of the system where it is stored in a storage tank. This heated water may then be used in a household or public amenity such as a swimming pool (Islam *et al* 2015). A tracking system may also be added to the system, which can substantially improve energy output. (Fig.1) Illustrates a typical design of a parabolic solar through system. The system comprises of a circulating pump, parabolic trough collectors, storage tank and a thermal relief valve. The relief valve is designed to relive energy when water temperatures within the storage tank exceed 100°C (Kalogirou 2002). A parabolic trough collector has the potential to generate large amounts of electricity and can prove highly beneficial for heating applications such as water heating (Kalogirou 2002). The efficiency and power delivery of this system depend on a number of factors as mentioned above; the design plays a very important role in achieving an efficient system. Receiver absorptivity, mirror reflectivity, flow rate, and incident angle are all details which will need to be calculated and modelled within a software programme in order to obtain feasible and usable data (Reddy 2012).

Irradiance values

Solar Irradiance is a determination of the level of solar power which reaches a select location, in this case, Ireland and is a crucial component to consider when modelling the efficiency of a solar thermal system. Irradiance values are mathematically represented by watts per metre squared or W/m^2 . Irradiance varies dramatically depending on the location on earth and with the seasons as they are directly affected by climatic conditions. The yearly solar irradiation in Dublin, Ireland is calculated to be in the range of 1000 W/m^2 and this is the irradiance value which will be inputted into the model (<http://contemporaryenergy.co.uk>) (<http://www.greenrhinoenergy.com>). It is also important to note that this irradiance value is similar to other cities that have successfully implemented solar energy and heating systems including several projects in northern Germany.

Modelling the system

Sizing of components within the design of a solar system is an important and difficult task to get right. This includes difficult data components to predict, such as irradiance values and climatic conditions and predictable data components such as collector characteristics. This section will determine how all data acquired is formulated within a model so that sufficient data may be obtained, this will be done so by using the modelling system TRNSYS (transient simulation program) (TRNSYS 1996). TRNSYS is a quasi-steady simulation model. The program comprises of numerous subroutines that are utilized to model subsystem components. TRNSYS has the ability to connect all these components in any way required to complete the simulation, it does so through utilizing differential equations. Therefore, through the use of TRNSYS, the difficult task of completing a simulation for a solar energy system comes down to identifying what particular components are required and how they can be mathematically represented (Kalogirou 2002).

Results

The optimal overall design and optimization of components were calculated for a parabolic solar trough solar water heating system in Ireland, in order to obtain accurate estimations on system efficiency and overall energy output. The results of this study indicate that the utilization of a parabolic solar trough solar water heating system in Ireland can achieve greater water temperatures and a higher energy output than a conventional flat plate solar collector (Krueger *et al* 2000). This result is believed to be greatly influenced through the use of the tracking system which allows for the parabolic trough to be inclined towards the sun at all times to allow for maximum solar energy absorbance. Results have indicated that the flow rate of the water within the system increases as the size of the receiver increases. However, if the receiver size is increased this results in reduced efficiency of heat gain (Islam *et al* 2015). A case study which carried out simulations on the performance of different solar water heating systems also demonstrated that the trough technology is more efficient than the plane collector technology, this is especially more apparent at high fluid temperatures of $60^\circ - 75^\circ\text{C}$ (Krueger *et al* 2000). The study region also has a direct solar irradiation of 1080 W/m^2 very similar to that of Ireland. These results show that Ireland has the energy capacity to efficiently utilize these systems.

Conclusion

The results of this study demonstrate that at lower temperature ranges the parabolic solar trough design is more efficient and economically viable than flat plate solar collectors. Therefore, the use of these systems in residential buildings or public amenities for district heating could prove to be environmentally and economically sustainable. This is extremely important in a sector which has shown to consume vast amounts of energy and contribute a high percentage of GHG emissions to global levels. There is,

however, one downfall with the parabolic solar trough design and most solar water and thermal heating systems which is the high investment costs. Although, these costs are substantial the application of a parabolic solar water heating system in Ireland should be closely investigated and considered for future construction projects in Ireland.

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A COMPARATIVE ANALYSIS OF THE ENVIRONMENTAL IMPACT ASSESSMENTS OF WIND FARMS

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Abstract

The conversion of wind power into different forms of useful energy is hardly a novel concept. The potential of wind energy has been recognised for the past 3,000 years as a source of inexpensive, renewable power. Despite being a source of clean, environmentally friendly energy, wind farms face a high level of opposition, the bulk of which occurring on a local level. While a number of different externalities have been identified, a lack of communication between wind farm developers and the local communities in an area seems to be at the heart of the issue. This lack of engagement has resulted in a level of distrust forming. However, studies show that attitudes towards wind farm development become increasingly positive through early community engagement, with developers freely providing information on each stage of development publicly and providing different forms of monetary compensation for local communities and individuals.

Introduction

The progression of human culture is linked with the development of new energy sources. The shift from wind and solar powered technologies to fossil fuel technologies took place over the last two centuries, with coal coming to prominence in the 19th century, oil in the 20th century and now natural gas (Hall *et al.* 2004). In 2013, it was estimated that the world consumed 13,583 million tonnes of oil (Zainol *et al.* 2017). While fossil fuel reserves are currently increasing, our heavy dependency and their finite nature make fossil fuel use unsustainable (Sorrell *et al.* 2010; Abas *et al.* 2015). Moreover, there is an extensive range of environmental impacts associated with the extraction and combustion of fossil fuels (Ellabban *et al.* 2014). Renewable energy technologies provide sources of energy that are continuously replenished by nature, turning these forms of naturally occurring energy into usable forms of energy such as electricity, heat and fuel. It is estimated that renewable energy sources have the potential to generate over 3,000 times the current global energy demands, highlighting their importance as a modern source of fuel and energy (Ellabban *et al.* 2014).

Of the available renewable energy technologies, wind energy is the only proven and mature technique for the generation of electricity that is at present commercially promising. Wind can be an effective source of power generation that has significant potential to close the gap of the world's energy demands. Wind energy is a renewable source of clean free energy that does not produce toxic gases during power generation and occupies relatively little land area (Kumar *et al.* 2016). Wind power converts wind energy via the use of wind turbines into a useful form of energy such as electricity and mechanical energy (Leung and Yang 2012). Wind turbines are generally grouped together into wind power plants or wind farms, typically in the size of 5 to 300 MW (Ellabban *et al.* 2014). Globally, wind energy is responsible for the generation of 539 GW of energy in 2017 alone. While hailed as a relatively benign source of energy which offers a host of benefits to local community's post construction, wind farms meet a high level of opposition at a local level. This level of resistance has resulted in the development of wind farms becoming increasingly more difficult (Warren *et al.* 2005).

The objective of this study is to compare and contrast objections to wind farms and identify the best practice for developers aiming to achieve planning approval.

Materials and Method

Data on wind farms, their development, environmental issues, and objections were collected. Data was collected using online databases such as Google Scholar and the University College Dublin One Search search engine (which incorporates a large number of different literature sources, including scientific journals, books, reports, etc.). Data was searched for online by inputting different relevant terms including keywords such as; “Wind Energy”, “Wind Power”, “Wind Turbine”, “Environmental Issues of Wind Turbines”, “Wind Farm Development”, “Wind Farm Objections”, “Not In My Backyard Syndrome”, etc. and their possible synonyms into database search engines.

Data collected was evaluated for further reading, taking into account the relevance of; the title of the literature, date, source, number of citations, abstract and any ethical issues possibly relating to the literature such as plagiarism, transparency of the methodology and results, bias, etc. Where possible, data was collected from scientific journals no older than 10 years old.

Results and Discussion

Wind farm objections:

While accepted at an international level due to their potential as a source of renewable energy, the development of wind farms is controversial in many countries across the world (Warren *et al.* 2005). While there are a significant number of barriers to the development of wind farms, the heart of the controversy seems to be opposition at a local level. This form of opposition appears to be shared across many different countries and not unique to one. Studies have shown this form of localised negative opposition occurs for a diverse number of reasons ranging from landscape impairment, biodiversity loss, noise pollution, shadow flicker and deterioration in property prices (Warren *et al.* 2005; Ladenburg 2009; Jensen *et al.* 2015; van Rensburg *et al.* 2015). The most common type of objection to the development of wind farms are those relating to human welfare. A study carried out by Rensburg *et al.* in 2015 cited the most common reason for planning refusal to be the possible impacts wind turbines will have on the natural landscape accounting for 17% of refusals. This is closely followed by conflicts that local communities have with the strategic development plan proposed by the developer accounting for 12% of refusals in Ireland, proximity to dwellings at 5%, public safety at 2% and adverse effects on tourism at 1% (van Rensburg *et al.* 2015). A separate study carried out by Warren *et al.* in 2011 found that opposition to wind farms partly occurs due to the exaggerated perceptions of the possible impacts of living close to a wind farm, with a desire for wind farms to be out of sight and therefore out of mind (Warren *et al.* 2005). Interestingly however, many studies argue that these reasons are too simplistic to characterise the opposition to wind farms, with many studies also indicating that there is a high level of distrust between wind farm developers and local communities (Warren *et al.* 2005; van Rensburg *et al.* 2015; Brennan and Van Rensburg 2016). In a study carried out by Brennan and Van Rensburg, 66% of individuals who completed a survey stated that they did not believe a wind farm developer would cooperate with the local community, refusing to provide information around the development or financial support (Brennan and Van Rensburg 2016).

Best Practice for Wind Farm Developers

Creating a strong and trusting relationship between wind farm developers and local populations as early as possible is of utmost importance for the approval of a wind farm development proposal. As stated above, a high level of distrust exists between local communities and wind farm developers, with communities often not satisfied with the strategic development plan laid out by developers (Warren *et al.* 2005; DCCAE 2016; van Rensburg *et al.* 2017). Communication and engagement between developers and the local community is essential, especially at the commencement of the

development process to gain an understanding of different stakeholder's views for the development and for them to be considered in the projects final design (Warren *et al.* 2005; Jones and Richard Eiser 2010; DCCAE 2016). To achieve this, a nominated community liaison person should be appointed as a point of contact for local residents to communicate with developers. In addition to the provision of clear and transparent information about the project and any milestones achieved (Jones and Richard Eiser 2010; DCCAE 2016; van Rensburg *et al.* 2017).

The community liaison and developers should engage with the community throughout each stage of the development and at a minimum create a dedicated website, regular newsletters and outreach programmes (DCCAE 2016; van Rensburg *et al.* 2017). Additionally, a strategic development plan for the project and community should be created and approved by key community members (Brennan and Van Rensburg 2016). Interestingly, attitudes on the development of wind farms tend to become more positive over time, with individuals who have a negative attitude towards wind farms becoming more accepting over time. This can further strengthen the attitudes of those who support the construction of wind farms (Warren *et al.* 2005; Jones and Richard Eiser 2010; Brennan and Van Rensburg 2016). In addition to providing transparent information to local communities, a host of benefits can be availed of by local communities and residents post construction (van Rensburg *et al.* 2015; Brennan and Van Rensburg 2016; DCCAE 2016). These benefits can come in a number of different forms such as employment, the creation of community funds and discount in electricity costs for local residents (Warren *et al.* 2005; Jones and Richard Eiser 2010; DCCAE 2016). Studies on resident's willingness to accept wind farms in their locality indicate that the majority of community members are willing to make monetary trade-offs to permit the progression of wind farm developments in their locality (Ladenburg 2009; Jones and Richard Eiser 2010; Brennan and Van Rensburg 2016). While the level of monetary compensation varies from development to development, depending on the height, number and set back distance of the wind turbines, one study found individuals generally require between €319.70 and €437.53 in compensation per annum to accept the construction of wind farms in their locality (Brennan and Van Rensburg 2016). Monetary compensation can come in a number of different forms such as community funds, monetary payments or benefits in kind such as discounted electricity (DCCAE 2016; van Rensburg *et al.* 2017).

Conclusion

Wind energy is a renewable source of clean, free energy that is accessible worldwide. Despite this and being able to provide a host of benefits to the local communities and residents situated close by, wind farms face a high level of opposition, especially from local communities. This opposition can occur for a number of different reasons; however, it would seem that there is a level of distrust experienced by local communities towards wind farm developers due to lack of communication and engagement between wind farm developers and the local communities. To combat this, it is essential for developers to set up a source of communication with local communities to address their concerns and wants relating to the development. Additionally, monetary compensation should be provided to local communities and residents for allowing the development of a wind farm in the locality, with most people attitudes on wind farms becoming increasingly positive post construction.

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ALLEVIATION OF SUBSTRATE INTERFERENCE IN FTIR SPECTRA DURING MICROPLASTICS DETECTION

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Abstract

Plastic pollution is a growing global environmental problem. Microplastics (MPs) are pieces of plastic <5 mm in diameter and are classified as primary and secondary MPs based on their origins. A standardized protocol for the sampling, separation and detection of MPs has not yet been established. Fourier transform infrared (FTIR) is a reliable technique for the detection of plastic polymers. Transmission mode is suitable for clear materials however a substrate is required to hold MPs in place. Principle component analysis (PCA) after Standard Normal Variate (SNV) pre-treatment demonstrates good performance for differentiating between plastic polymer and the substrate. Minimizing the spectral interference of such a substrate will allow for the application of this technique to identify MPs in field samples, potentially contributing to the development of a standardized protocol for their identification and quantification.

Introduction

MPs are defined as pieces of plastic that are < 5 mm in diameter or along their longest edge in the case of fibers (Dris *et al.* 2017). They are classified into primary and secondary MPs, based on their origins. Primary MPs are particles that are intentionally engineered to be small such as microbeads found in cosmetics. Secondary MPs are broken fragments from larger plastic products (e.g. plastic bottles, fishing equipment, other plastic waste). Plastics can be broken down in various ways, such as wave action in the sea or UV light induced degradation (Sharma and Chatterjee 2017). MPs have been found in table salt, beer, tap water, bottled water, organic fertilizers and marine organisms (Auta *et al.* 2017; Dris *et al.* 2017; Prata 2018; Schymanski *et al.* 2018).

Since MPs are ubiquitous, a detection method is necessary. FTIR has been utilized to analyse MP samples. The plastic polymers present in MP samples can be identified rapidly by comparing the resulting spectra with spectra of known polymers from spectral libraries or by using literature. Two modes are possible in FTIR; reflectance and transmittance modes. Reflectance errors can occur in reflectance mode due to the irregularity in the shapes of MP. This is a disadvantage because the spectra can be distorted. When working in transmittance mode, IR light must go through the sample, therefore a substrate through which IR light can penetrate is necessary. If MPs are too thick then the IR light will not penetrate (Bergmann *et al.* 2015).

PCA reduces data dimensionality and has been applied to spectral data in the past as a pre-processing step (Wold *et al.* 1987). The data matrix is broken down into two different contributing factors; the score matrix which implies the association between the samples and the loading matrix which implies the “load” explaining the variance in each principle component (PC). By observing the PCA scores plot, similarities between samples can be detected. The more grouping together the more similarities in spectral behaviour exist (Serranti *et al.* 2018). SNV pre-processing centres and scales each spectrum by its standard deviation (Bi *et al.* 2016).

The objective of this study is to minimise the spectral interference caused by the substrate when detecting MPs using FTIR.

Materials and methods

FTIR (Nicolet iN10 Infrared Microscope) was used to discriminate between materials. Four plastic polymers: Polycarbonate (PC), polyethylene (PE), polytetrafluoroethylene (PTFE) and polyvinyl chloride (PVC) were scanned singularly with no substrate present. They were then cut up into small pieces in order to simulate MPs and placed on a substrate. A metal mesh of pore size 45 μm from The Mesh Company (Warrington) Ltd. was used as the substrate for two reasons; firstly, the pores allow measurements to be taken in transmission mode and secondly it holds the MP pieces in place with no need for an adhesive. Both PCA and SNV pre-processing were conducted on MATLAB.

Results and discussion

The mean spectra for the mesh, PC, PVC, PE and PTFE are shown in figure 1 above. In $\frac{3}{4}$ cases the signal including the mesh is lower than the reference polymer. The opposite is found for PE where the signal increases with the addition of the mesh. In the future more polymers will be analysed in order to investigate this phenomenon. Figure 2 shows the mean spectra after SNV pre-processing. The SNV pre-processing minimises the interference caused by the mesh and appears to be a promising tool to use.

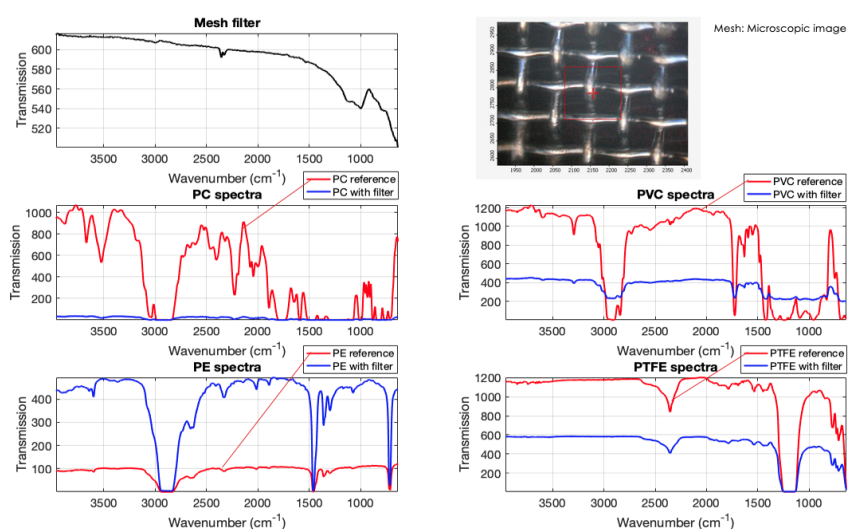


Figure 1. Mean spectra for mesh, PC, PVC, PE and PTFE

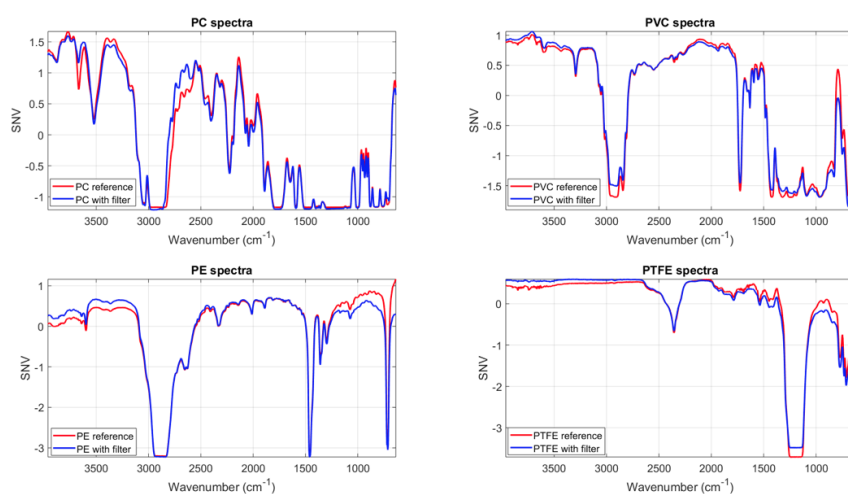


Figure 2. Mean spectra of PC, PVC and PTFE after SNV pre-processing

Figure 3 shows an intensity image of PE taken on the mesh at 700 cm^{-1} . In comparison with the light image on the left a clear distinction between polymer and mesh cannot be observed.

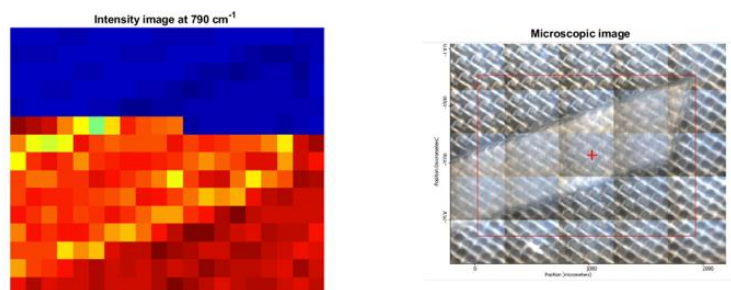


Figure 3. Intensity image of PE taken at 700 cm^{-1} with aperture size of $100\text{ }\mu\text{m} \times 100\text{ }\mu\text{m}$ and step size of $100\text{ }\mu\text{m}$ (on left), and light image of PE (on right)

PCA was carried out on the image as shown in Figure 4. However, distinction between polymer and mesh cannot be achieved based on the first three score images.

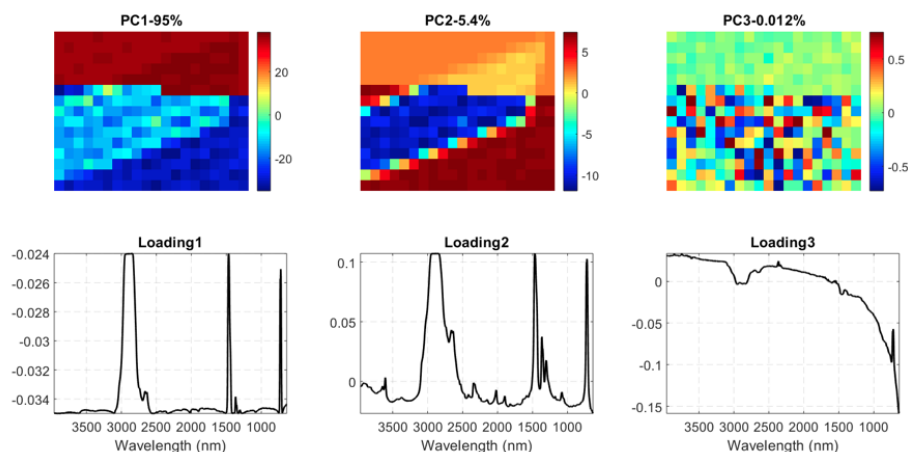


Figure 4. Image after PCA pre-processing

Results of performing SNV prior to PCA are shown in figure 5 above. As shown, polymer pixels are highlighted in blue in PC1 score image while mesh pixels are in red, indicating a good separation between polymer and mesh.

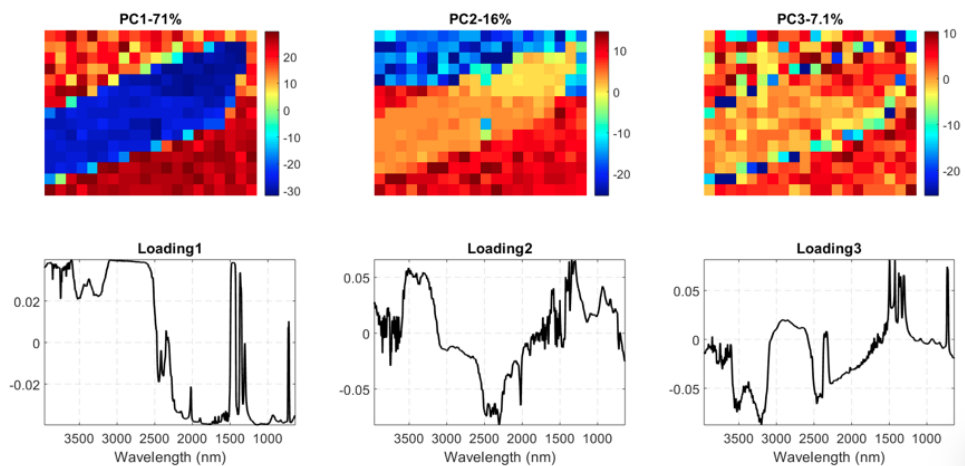


Figure 5. Image after SNV followed by PCA

Conclusions

The substrate used was suitable for working in transmission mode due to its 45 µm pore size. This allowed IR light to pass through the sample and the pore in order to give a good spectrum. Another benefit of using this mesh was its ability to hold the MPs stable on it without the use of adhesives which could interfere with the readings. SNV pre-processing seems to be an auspicious tool to use in order to reduce spectral interference caused by the substrate. Applying SNV followed by PCA to images facilitates a clearer separation between polymer and substrate than applying PCA alone. In conclusion, PCA combined with SNV pre-processing appears to be a promising approach to alleviate substrate interference for MPs detection.

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MODELLING AMMONIA CONCENTRATION IN A PIG FINISHING HOUSE

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Abstract

There are a number of EU directives which aim to protect sensitive habitats and species from pollutants such as atmospheric ammonia. Extensive, long-term monitoring of NH₃ emissions is expensive, requiring the use of equipment such as Photoacoustic or Cavity Ringdown sensors. Pig farms are recognised as hotspots for NH₃ emissions and can contribute to high localised NH₃ concentrations. This study aimed to develop a preliminary statistical model capable of accurately determining ammonia concentrations in a pig finishing house using simple, easily measured parameters previously collected by the AmmoniaN2K project. This model was capable of estimating ammonia concentration (in ppm) in the monitored pig finishing house. This paper suggests further development of this model, improving its accuracy and application to other intensive hotspot sources.

Introduction

The European Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC) require that all European Union (EU) member states to identify Natura 2000 sites, and maintain the network of these designated sites as having “favourable conservation status” (Kelleghan et al. 2019). Pollution from atmospheric pollutants, specifically from atmospheric ammonia (NH₃) is a major threat to global biodiversity. The National Emissions Ceiling Directive (2016/2284/EU) requires that each member state monitor and report on a number of atmospheric pollutants, including NH₃. The pig production industry in Ireland accounts for 7% of all national NH₃ emissions (EEA 2006). Although this emission level may seem relatively minute on a national scale, these hotspots of ammonia emissions can have a much higher concentration (and thus, impact) on a local scale.

Intensive NH₃ emission monitoring of pig finishing houses was conducted by the AmmoniaN2K project between 2016 and 2018, where indoor concentrations of NH₃ were recorded. This intensive monitoring was conducted using a Los Gatos Research Ultraplortable Ammonia Analyser (UAA) which is relatively expensive, and as such is not feasible for long-term extensive monitoring. In order to accurately monitor and report NH₃ emissions from pig production facilities without entailing excessive cost, it is suggested that the data collected during AmmoniaN2K monitoring be utilised to develop a preliminary statistical model capable of predicting NH₃ concentrations, utilising other more easily measured parameters, primarily temperature, relative humidity and ventilation rate (based on carbon dioxide mass balance).

The objective of this study was to analyse data collected from a single pig finishing house to develop a simple statistical model capable of closely approximating NH₃ concentrations using only simple parameters.

Materials and Methods

Data Accumulation

This study aimed to analyse the feasibility of generating a working statistical model. Therefore, only data from one farm over a one month period was analysed. The month used was June 2016, and was

gathered from previous intensive monitoring of an intensive integrated pig farm in Co. Meath, Ireland. Monitoring in this finishing house was conducted semi-continuously. This house was monitored for an hour in sequence with two other finishing houses, and outdoor concentrations. During monitoring, Temperature (°C), ventilation rate (m³/s), ammonia concentration (ppm), and relative humidity (%) were collected at second intervals. This amounted to 713,280 data points collected for this preliminary examination.

Data Analysis

For each analysis which was carried out, ammonia concentration was assumed as the dependant variable while temperature, ventilation rate, and relative humidity were considered to be independent variables. Pearson's correlation coefficient calculations were carried out on ammonia concentration vs. each individual parameter for each individual day monitored. The resultant R-values were then used to determine if the dependant and independent variables were correlated with each other.

For the remaining analyses, the total daily data was minimised by generating daily means for each parameter. Using these means, ANOVA analyses were carried out between the dependant and independent variables. For generation of the preliminary statistical model, any variable with a P-value of 0.15 or greater was to be excluded from the model. The statistical model itself was produced using regression analysis on excel.

Results and Discussion

Pearson's Correlation Coefficient (R-values)

R-values were obtained for each set of daily data, testing the correlation between ammonia and the independent variables. The range of the R-values obtained for these independent variables was high. The highest R-value found was for ammonia vs. temperature on day fourteen ($R^2 = 0.86$). This indicates a strong correlation between ammonia vs. temperature, showing that as temperature increases, ammonia concentration decreases. This may also be influenced by ventilation rate. If ventilation rates are high, the concentration of ammonia in house may be lower.

The lowest R-value obtained was for ammonia versus ventilation rate on day three ($R^2 = 0.20$). This R-value indicated a negative correlation, although not a strong one. This was the lowest R-value obtained, and was an outlier when compared to the spread of R-values from the rest of the data analysed. Scatter plots visually representing these correlations can be seen in Figure 1.

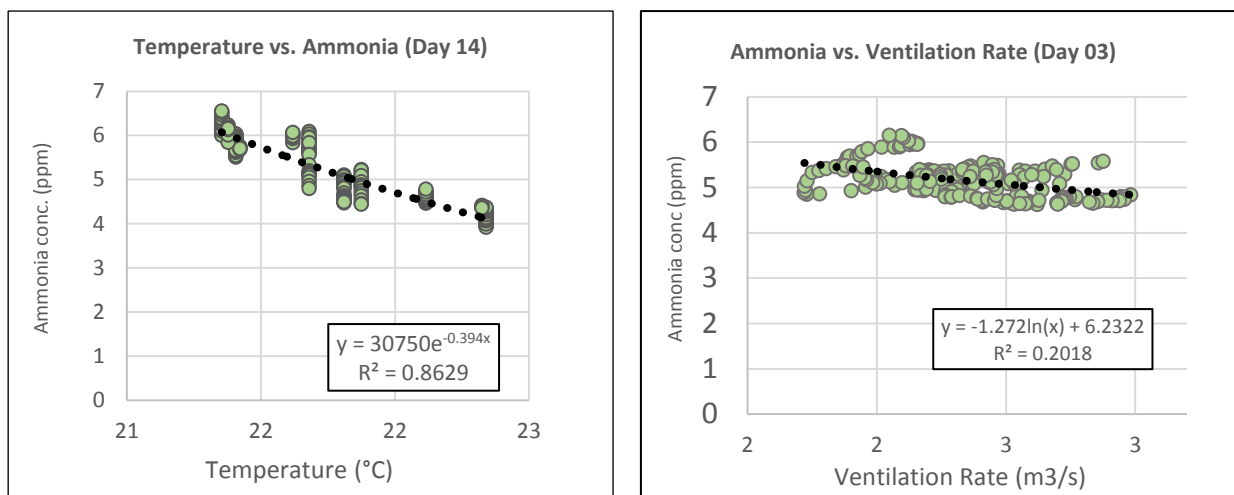


Figure 1. Scatter plots of ammonia (ppm) vs. temperature (°C) [left], and ammonia (ppm) vs. ventilation rate (m³/s) [right].

ANOVA Analysis

ANOVA analyses conducted on the daily mean for each parameter determined that all three parameters were to be used in the statistical model. Ammonia versus temperature had a P-value of 0.081, ammonia versus ventilation rate had a P-value of 0.04, and ammonia versus relative humidity had a P-value of 0.002. Each of these P-values determined that the independent variables had a statistically significant effect on ammonia concentrations that was not due to chance. These results are comparable to other studies which also state that these independent variables effect ammonia concentration in livestock houses (Rosenbaum et al. 2010, Phillipe et al. 2011).

Regression Analysis and Development of Statistical Model

Using regression analysis on excel for the dependant and independent variables, coefficients were determined as follows; temperature (-6.018), ventilation rate (0.463), and relative humidity (0.055). These coefficients were used to generate the statistical model equation which can be seen as equation one, where **T** = temperature (°C), **RH** = relative humidity (%) and **VR** = ventilation rate (m³/s).

$$NH_3 \text{ (ppm)} = 216.37 + (T) (-8.6807) + (RH) (-0.20441) + (VR) (-0.00277)$$

Equation 1. Preliminary statistical model to determine ammonia concentration (ppm)

In order to test the models capability of determining ammonia concentration, known ammonia concentration values for June 2016 and August 2016 were plotted against the models predicted ammonia concentrations for the same months. A visual representation of these plots can be seen in Figure 2. The model ammonia data closely represents the actual ammonia concentration data for each month, with the largest concentration differences being between day 11 in June (-1.8 ppm) and day 20 in August (+1.7 ppm). It was expected that the model for June would be accurate, as this was the data with which the model was produced. August's data was not used in the model, and therefore shows that the model is capable of predicting ammonia concentrations in this pig finishing house.

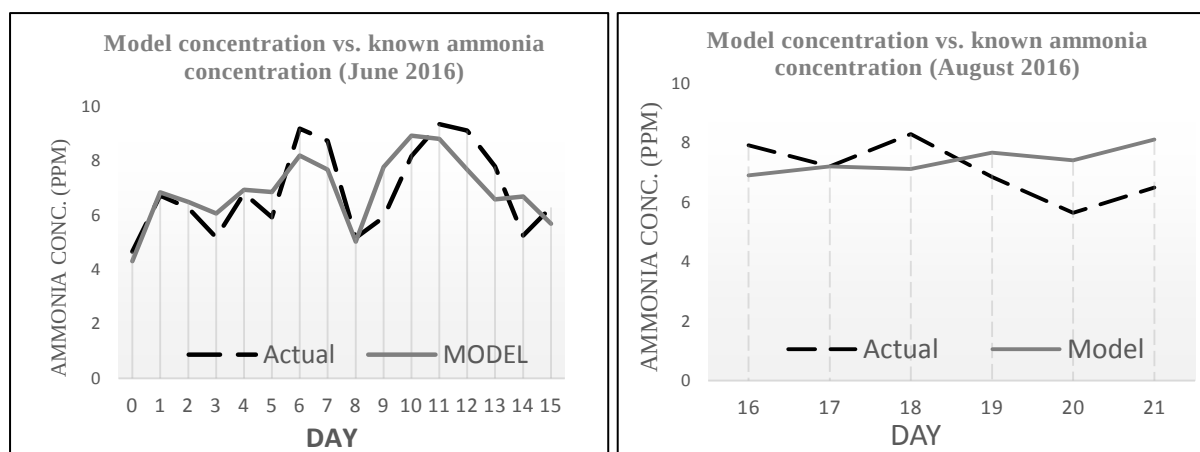


Figure 2. Ammonia concentration (ppm) from model versus actual known values in June 2016 (left) and August 2016 (right).

Conclusions

The preliminary statistical model that was generated in this study was found to be accurate. This study shows that the development of a statistical model for ammonia concentration determination in pig finishing houses may be a feasible option for long term extensive monitoring. Statistical models such as these may be functional for determining NH_3 concentration in hotspot areas, such as poultry rearing and other pig rearing facilities. This model may also be extended to reach industries such as dairy and beef, but would need to be cattle specific as emissions differ greatly from each sector. It is recommended that further analyses on the data sets collected by the AmmoinaN2K project be carried out. This would involve the analysis of over 100 million records, and would be expected to yield more confident results. This would result in a more accurate model which could be integrated into future monitoring programmes across Ireland.

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RISK ASSESSMENT OF ANTIMICROBIAL RESIDUES IN ENVIRONMENTAL SETTINGS: SOURCES, PATHWAYS AND EVENTUAL FATE

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Abstract

Antibiotic resistance in pathogenic bacteria can be caused by the presence of antimicrobial residues in natural settings. Risk assessment methodologies can be used to investigate industrial sources of antimicrobials that enter natural settings, primarily ground and surface waters, potentially contributing to the development of antimicrobial resistant bacteria. Two primary industries are investigated: healthcare and agriculture. Information from government agencies has been compiled, with the intent to construct a model generating predicted environmental concentrations for a risk ranking.

Introduction

The development of antimicrobial resistance in pathogenic bacteria is a pressing issue, leading to increased incidences of illnesses that do not respond to antibiotic treatment. Antimicrobial resistant Bacteria (ARB) causes three main issues; increased hospital stays, increasing cost of treating infections, and a restriction of surgical procedures requiring antimicrobials (Laxminarayan *et al.*, 2013). "ARBs in natural settings can act as pathogens, with recreational water users potentially contracting disease via ingestion of water" (O'Flaherty *et al.*, 2019). Environmental ARB can also function as reservoirs of resistance genes. Resistance can be transferred between bacteria via mobile genetic elements. Therefore, understanding the movement of antimicrobials from human use into natural settings is paramount in understanding how to mitigate and prioritise management strategies.

Antimicrobials lead to the development and selection of ARB when the concentration of the antimicrobial exceeds the Minimum Inhibitory Concentration (MIC). Once this concentration is exceeded, a selective pressure is exerted, favouring the proliferation of ARB. A second concentration, lower than the MIC, called the Minimum Selective Concentration (MSC), has also been proposed by several publications (Bengtsson-Palme and Larsson, 2016). Current consensus is that two sectors contribute to the majority of antimicrobial pollution into the environment; agriculture and health.

In health, antimicrobials are prescribed to treat illness in both hospital and community settings. Due to low bioavailability, antimicrobials pass through the gastrointestinal (GI) tract of the patient unchanged or in the form of active metabolites, then are egested into sewage waters. From here, they pass into surface and ground waters, creating antibiotic residues in natural systems. The over-prescription of antibiotics to treat non-bacterial illnesses, as well as patient non-compliance is also associated with the development of ARB.

In agriculture, antimicrobials are used to treat illness, and also administered to livestock at constant low doses as a growth promoter. As in the health sector, antibiotics pass through the GI tract of the organism and are egested in faeces. When this is left or used as fertiliser, antimicrobials can leach into soil and move into ground and surface waters. Agriculture is a major consumer of antimicrobials. In Ireland, 103.4 tonnes of antimicrobials were sold for veterinary use in 2016 (Department of Health, 2018).

The objective of this paper is to establish an understanding of the current state of antimicrobial pollution sources and establish an appropriate risk assessment methodology to examine it.

Materials and Methods

The process of risk assessment allows for an objective and quantitative analysis to compare several risk factors. Risk ranking is a quantitative method of comparing different risk factors, allowing for informed prioritisation of certain factors in management. In the context of antimicrobial resistance, risk assessment can be used to offer insights in two ways; firstly, a risk ranking between different industries, and secondly, a risk ranking between different antimicrobials.

A Risk Quotient (RQ) is a numerical value obtained by dividing a Predicted Environmental Concentration (PEC) value by a Predicted No Effect Concentration (PNEC) value. A PEC value is the observed or predicted concentration of an investigated chemical. The PNEC is the theoretical limit above which an inhibitory or selective effect is observed. Several methods have been developed and used in other risk assessment procedures which allow predictive modelling of antimicrobial partitioning and movement into natural systems. These models allow a PEC to be generated. Current studies into antimicrobial pollution use PNEC values only for eukaryotic species; algae, arthropods and fish. Therefore, these risk rankings do not directly represent risk of antimicrobial resistance developing or being selected for. A 2016 paper used MSC values to generate PNEC estimates for many different bacterial species, utilising the precautionary principle (Bengtsson-Palme and Larsson, 2016). The incorporation of these values, as well as PEC values generated via the model would constitute a novel approach to evaluating risk of ARB development.

Results and discussion

Several official government sources provide usage rates for different antimicrobial use in different sectors. The One Health report (2019), which synthesises data from the health and agricultural sectors states that per unit biomass, humans consume more than three times the amount animals do, stating figures of 155.6 mg/kg of estimated biomass per year in humans and 48.0 mg/kg of estimated biomass per year in animals (Department Of Health, 2018). In the health industry, the primary antimicrobials used are beta lactams, macrolides and tetracyclines.

Table 1: Antimicrobials used in combined hospitals and the community in Ireland 2017,(Adapted from ECDC, 2017)

Antimicrobial classes	Percentage of total usage
Tetracyclines	13.50%
Amphenicols	<0.1%
Beta-lactam antibacterials, penicillins	49.20%
Other beta-lactam antibacterials	6.00%
Sulfonamides and trimethoprim	4.30%
Macrolides, lincosamides and streptogramins	21.10%
Aminoglycoside antibacterials	0.50%
Quinolone antibacterials	4.30%
Combinations of antibacterials	0.00%
Other antibacterials	1.00%
Total	100%

In the agricultural industry, in both the Irish and European contexts, the primary antimicrobials administered are tetracyclines, penicillins and sulphonamides.

Table 2: Table of antimicrobial sales for veterinary uses in 30 EU countries in 2016. (Adapted from ESVAC 2017)

Antimicrobial family	Percentage of total usage
Tetracyclines	32%
Penicillins	26%
Sulphonamides	12%
Macrolides	7%
Aminoglycosides	5%
Polymyxins	5%
Other	13%
Total	100%

Conclusion

Using the above consumption data, a simulation model is being constructed to estimate levels of different antimicrobial groups being released into natural systems from different industries, with the view toward constructing a risk ranking. Previous studies in this field have used simulation models to estimate levels of antimicrobial pollution from hospitals (Harris, Cormican and Cummins, 2013). This study will attempt to use a similar rationale and expand it to apply to agricultural runoff as well.

In the construction of this model, information from the literature will be used. In particular; information from pre-existing literature regarding soil sorption rates, half-lives in water, and bioavailability of antimicrobials.

Acknowledgements

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THE NITROGEN CYCLE A MINI REVIEW

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Abstract

Nitrogen is the building block of protein and is essential for all living organisms. Nitrogen is the 5th most abundant element and makes up 78% of the earth's atmosphere. The natural nitrogen cycle is complex and although plentiful nitrogen is largely inaccessible to living organisms in its gaseous form. It must first be converted into bioavailable nitrogen through redox reactions. In this way Nitrogen can exist in many oxidative states. This mini review examines the natural nitrogen cycle and how nitrogen is made available to organisms and how anthropogenic activity has greatly influenced the nitrogen cycle.

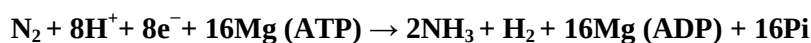
Introduction

The nitrogen cycle is composed of four main steps nitrogen fixation & ammonification, nitrification, and denitrification and can be defined as the continuous movement of nitrogen in the environment in various forms active and inactive. 78% of our atmosphere is made up of diatomic inorganic nitrogen gas (N₂). Nitrogen is essential for the growth and development of plants and animals, and allows for the production of amino acids and genetic material which ultimately form proteins. Nitrogen cycles through our biosphere but cannot be directly assimilated from the air by plants in its inorganic form and requires nitrogen fixing i.e conversion to organic ammonium and nitrate compounds. This process is called fixation and is carried out by nitrifying bacteria present in the soil. Occurring due to transformations to N₂'s oxidative state via oxidation and reduction through the donation or accepting electrons.

Objective Comprehensive Mini Review of the Natural Nitrogen Cycle

Nitrogen Fixation

Nitrogen fixation is an oxygen sensitive process that ultimately allows for the conversion of inactive N₂ into active forms of N which can be utilized by plants. Biological Nitrogen Fixation (BNF) occurs when bacteria convert atmospheric di-nitrogen into Ammonium (NH₄⁺) by utilising metalloenzymes called nitrogenases in anaerobic environments. Microorganisms including bacteria and archaea synthesize these nitrogenase enzyme complexes such as molybdenum-iron protein dinitrogenase and or vanadium iron protein dinitrogenase reductase where one molecule of H₂ is formed via the hydrolysis of 16 equivalents of ATP. This process allows for the production of nitrogenase-generated NH₄⁺ (de Bruijn, 2015). Nitrogenase can be used to break the triple covalent bond in atmospheric N₂ and ultimately leads to the production of ammonia (NH₃) which becomes ammonium NH₄⁺ when mixed with water providing a source of N that can be utilized by plants (Stein and Klotz, 2016). The process of **BNF** is described in the **equation** below



There are two types of nitrogen-fixing bacteria comprising of 'free-living (nonsymbiotic) bacteria including cyanobacteria, Anabaena and Nostoc and genera such as Azotobacter, Beijerinckia, Clostridium and mutualistic (symbiotic) bacteria which invade root hairs and form nodes in plant

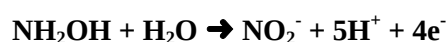
roots examples, include the relationship between *Rhizobium* & leguminous plants, *Frankia* & dicotyledonous species (actinorhizal plants); and certain *Azospirillum* species & cereal grasses (Franche et al., 2009).

Ammonification

Organic Nitrogen can also be returned to the soil via the process of ammonification. During this process detritivores (usually bacteria), examples, of which include *Pseudomonas* and *Bacillus* return nitrogen from waste or dead organisms into ammonia which can combine with water to form ammonium and return to the soil. Fungi have also been cited to exhibit high ammonification activities examples include *Acromonium*, *Alternaria* and *Penicillium*. The process of ammonification is considered an essential part in the nitrogen cycle and often determines the amount of NH_4^+ in soil and the amount of volatilized NH_3 (Huang et al., 2019).

Nitrification

During nitrification ammonium (NH_4^+) ions and ammonia (NH_3) are oxidized and converted to Nitrites (NO_2^-) and nitrates (NO_3^-) by nitrifying bacteria present in the soil. When NH_4^+ oxidizes NO_2^- , N_2O may be produced as an intermediate product lost to the atmosphere. (Gilsanz et al., 2016) The Nitrifying bacteria responsible for the nitrification process are chemotrophic bacteria that thrive at 25 – 30°C and favour alkaline pH. There are two types of nitrifying bacteria these include bacteria which convert ammonia to nitrite and include *Nitrosomonas*, *Nitrosococcus* & *Nitrospira* bacteria. These bacteria are ammonium oxidizers utilizing enzymes including ammonia monooxygenase (AMO) and hydroxylamine oxidoreductase (HAO). Ammonia monooxygenase oxidizes Ammonia to hydroxylamine using two quinone pool electrons. A transmembrane copper protein catalyses the oxidation reaction. Hydroxylamine oxidoreductase catalyses hydroxylamine resulting in the production of 4 electrons and nitrite. The quinone pool replenished with 2 electrons with the other 2 electrons creating a proton motive force through the membrane releasing nitrites



The second type of nitrifying bacteria convert nitrite to nitrate examples of these nitrite oxidizing bacteria include *Nitrobacter*, *Nitrospina*, *Nitrococcus* & *Nitrospira*. To allow this oxidation reaction to take place an iron-sulphur molybdoprotein enzyme nitrite oxidoreductase (NXR) is utilized. NXR enzyme is responsible for the electron transport chain. The mechanism allowing the conversion of nitrite to nitrate via the use of NXR is external. (Bitton, 2002)



Excess nitrates in soil, are prone to leaching and may cause pollution of waterways, via excess enrichment of nitrogen entering ground or surface waters. Which often causes overgrowth of phytoplankton leading to eutrophication. The overgrowth of phytoplankton can, in turn, deplete water oxygen levels causing hypoxia and dead zones (Paerl, 2009). Other negative impacts of excess nitrogen include water acidification, loss of biodiversity and negative human health impacts such as blue baby syndrome (Leach et al., 2016). These negative effects are often associated with human activities including the use of nitrogen fertilisers and burning of fossil fuels which result in excessive levels of bioavailable nitrogen. (Bernhard, 2010) Efforts to prevent pollution of water bodies with excess nitrates has led to much interest in nitrification inhibitors such as Dicyandiamide (DCD) which work by inhibiting NH_4^+ and NH_3 oxidation by nitrifying bacteria (Soares et al., 2012) and in recent years urease inhibitors have been explored as mitigation tools to minimise nitrogen losses via ammonia volatilization .

Anammox

Strous et al. (1999) discover and anaerobic type of ammonia oxidation known as Anammox and carried out by prokaryotic *Planctomycetes* bacteria, these bacteria oxidise ammonia using nitrite as an

electron acceptor to produce N_2 this process is thought to be an especially important nitrogen loss pathway in marine environments (Bernhard, 2010).

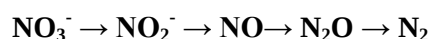


Assimilation

Bioavailable nitrogen can be assimilated by plants through their root system in the form of ammonium or nitrate. Plants prefer uptake of nitrates over ammonium as particle uptake is faster due to ammonium being positively charged and therefore, bound to the negatively charged soil particles. Soil conditions will dominate the type of nitrogen available to plants with ammonium being the principal source in acidic and anaerobic soil conditions and nitrate being the principal type in well-aerated soil conditions (Miller and Cramer, 2005). Once assimilated the majority of the nitrate absorbed is transported to the shoot of the plant here a reduction reaction occurs utilizing nitrate reductase present in the cytoplasm to produce nitrite. A further reduction reaction occurs utilizing nitrite reductase present of the enzyme glutamine synthetase (GS) to produce ammonium. The resulting ammonium or ammonium taken from the soil directly can then be assimilated into amino acids by way of the GS/glutamine-2-oxoglutarate aminotransferase (GOGAT) cycle (Xu et al., 2012).

Denitrification

Denitrification is a microbial process carried out in anaerobic conditions by heterotrophic bacteria that utilize organic carbon as an energy source to reduce to nitrate (NO_3^-) to Nitrogen gas (N_2). During this process NO_3^- acts as an electron acceptor and is reduced to NO_2^- followed by NO (Gilsanz et al., 2016). NO is toxic to cells so bacteria quickly transform it into N_2O which is a necessary intermediate in the denitrification pathway that causes nitrogen losses from the soil system and ultimately converts it back to atmospheric N_2 .



The levels of NO and N_2O produced are dependent on various factors including soil PH, O_2 Levels & levels of Nitrates present in the soil.

Denitrifying bacteria use enzymes such as nitrate oxide reductase (NOR), an essential membrane protein complex produced by the metabolic processes in denitrifying bacteria to make these N transformations possible, NOR is associated with haem/copper cytochrome oxidases and can be classified into two groups quinols (qNOR) usually present in pathogenic bacteria. Which responsible for removing NO created in there surrounding environment or cytochrome c redox type proteins (cNOR) present in many denitrifying bacteria. Classification is determined by the type of electron donor they use some examples of denitrifying bacteria include *Pseudomonas stutzeri*, *Ralstonia eutropha*, and various other proteobacteria (Hendriks et al., 2000). Which are specialized to carry out the denitrification though their ability to utilize nitrate as a final electron acceptor in order to respire anaerobically when soil O_2 is absent or in low levels (Burger and Venterea, 2011). These bacteria are classified by the end products they produce and are known as complete denitrifiers who produce N_2 or incomplete denitrifiers who produce N_2O . Certain fungi have also been cited to have the potential to produce N_2O though the use of the enzyme (P-450nor) which is part of the cytochrome P-450 family and is used to catalyse NO reduction to N_2O (Hendriks et al., 2000). Denitrification is an essential part of the nitrogen cycle and deemed advantageous as a way to remove nitrates from wastewater. It is however, often regarded as negative in regards to agricultural practices due to losses of N applied through fertilizers. This is especially the case with CAN-based fertilizers that apply nitrate directly to the soil. N_2O released into the atmosphere during Denitrification also negatively impacts the environment in various ways. N_2O stimulates Ozone (O_3) destruction contributing to global warming and climate change.

Conclusion

Nitrogen is an essential nutrient for both primary production in the food chain and biodiversity of ecosystems. The nitrogen cycle is mainly driven by microbes present in the soil and consists of four main pathways though which nitrogen is recycled throughout the biosphere including Nitrogen

Fixation, Ammonification, Nitrification, Denitrification. In 1998 a new pathway was discovered for the anaerobic oxidation of ammonia known as Anammox which is thought to play a vital role in marine nitrogen recycling. Bioavailable nitrogen may be assimilated by plants or recycled back into its gaseous form by microorganism. Anthropogenic activities such as the use of nitrogen based fertilisers and burning of fossil fuels can greatly disrupt the nitrogen cycle and cause pollution, health and economic concerns. It is likely that as the world's population continues to grow disruption of the nitrogen cycle caused by anthropogenic activities may threaten our resources and it will be necessary to employ mitigation technologies to minimise such disruptions and alterations to the global nitrogen cycle.

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REMOTE SENSING FOR WINTER WHEAT YIELD MONITORING AND PREDICTION

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Abstract

Yield mapping is an important support tool for precision agriculture management. Spatial distribution of yield is very important for farmers to understand field condition and achieve yield potential. However, yield map generated from onboard yield monitoring systems are erroneous due to sensor performance, calibration issues and limitations of the transfer function model for the combine, which can be of poor quality. This study is a preliminary examination of the use of satellite images to improve the quality of yield maps. The confidence interval of the yield prediction model is between 722.62 and 723.78 with 95% of confidence level. The model indicates that there is good evidence that REIP and Yield are related. The residuals values of the yield prediction model were defined from the values other than between 722.62 and 723.78 to identify the location of unlikely yield values. The method helps to improve the quality of the yield map to better predict the yield value even pre-harvest date.

Introduction

Crop yield is measured as sellable crop harvested (tonnes) per unit area (hectare) of cultivated land. It is an important metric because it indicates success of farming practices, allows monitoring of food security is a key input for calculating gross margin at the field scale and for predicting what might happen the following year (Fischer, 2015). Each crop has a maximum possible yield, which is called the yield potential, but each year a farmer has in mind a target yield for each field, or unit of land. The farmers can compare crop yield to target yield and yield potential to find out how well they are competing in the market. For that reason, a farmer's goal is to achieve the target yields close to yield potential for the minimum financial outlay (Haak, 2019). This should maximise gross margin. If the farmer's crop yield is greater than the target yield, it means the farmer is making more money than planned. It is essential for farmers to balance the price of growing a crop (crop husbandry) with the target yield (expected income from sale) so that they can earn as much money as possible (Lobell et al., 2009; Sadras et al., 2015). Additionally, if the crop yield has declining for consecutive years, farmers can make the decision to switch to other crops.

During the last three decades, yield measurement has evolved from coarse result of using volume or mass per wagon/trailer to calculate average yield per field, to advance onboard yield monitoring system that produce a yield map during the harvest operations (Chung et al., 2016). The creation of a yield map is key development in precision agriculture. Many farmers place high confidence and believe that yield maps can provide reliable indication of yield variation within a field (AWG Farms Inc. n.d.), which can be used to estimate the amount of nutrient removed by the crop or target properties for spray planning (Reitz and Kutzbach, 1996; Luck and Fulton, 2015). Farmers can calculate profit based on the yield information on yield map after harvest (Vellidis et al., 2017). Moreover, the yield map also helps farmers to identify sub-field management zones for more precise future management planning (Bramley and Ouzman, 2019).

The objective of this research was to evaluate the potential of producing accurate and reliable yield map using satellite radar imagery using the most successful vegetation index reported in the literature. If it proves successful a more detailed study will be undertaken, else an alternative approach will be defined.

Yield maps are being used by farmers and research organisation without full knowledge of their accuracy. Onboard yield monitoring data contains errors that will influence the final result on yield map due to: (1) forward speed variation, which has a non-linear relationship between yield and

throughput (Arslan, S. and Colvin, T.S. 2002); (2) static transfer function models that describe grain flow from cutter bar to clean grain elevator that contribute to error in ascribing a recorded value to a location in the field; (3) grain moisture sensing, which is confounded by dust and dirt; (4) location error from the Global Navigation Satellite System (GNSS); and (5) variation in cut width, which is difficult to maintain but is assumed to be constant (Fulton et al., 2018). The time when onboard yield maps become available is also suboptimal for farm management, because the farmer only has a map of the outcome once the harvest is complete, therefore it cannot contribute to planning in the yield it applies to. In order to get more value from yield maps, a greater level of map accuracy is required, especially when management decisions are based on this single piece of evidence, and a method to estimate yield earlier in the year would allow the map to be used for real-time management rather than just planning.

Materials and Methods

Study Site

The preliminary evaluation was completed using a study site located in Porton UK (Figure 1). The farm is situated at 51°8'30"N and 1°44'40"W, and an area of 14.9 hectares growing winter wheat was selected (Figure 2). A combine harvester on board yield map from 12th August 2017 was used as the ground truth data. Bearing in mind the issues noted above, this cannot be considered a gold standard dataset.

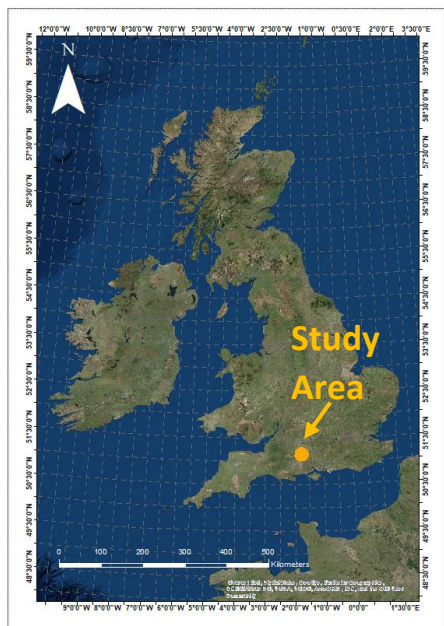


Figure 1: Location map of study area

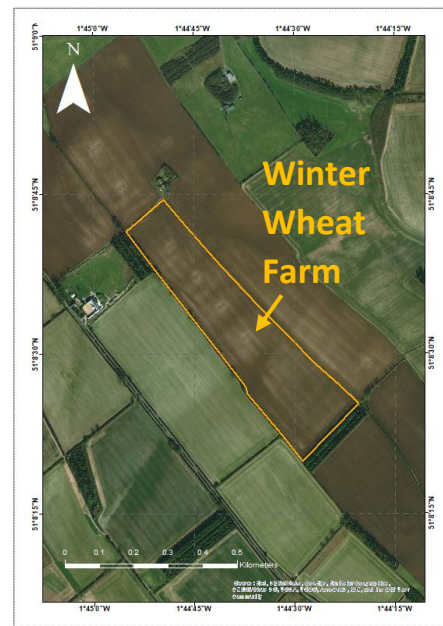


Figure 2: Location map of farm area

Satellite Imagery

Data were taken from Sentinel-2 from 22nd June 2017 as GS50, when uptake of nitrogen from soil is minimal and nitrogen in the leaves will be mobilized to contribute to grain filling (Joseph L. et al 2016). The Sentinel-2 imagery consists of 13 spectral bands with 3 different resolutions (10 m, 20 m, 60m). Bands 2 to 4 and 8 are available at 10 m resolution, bands 5, 6, 7 and 8a (typically used for vegetation characteristics) and shortwave bands 11 and 12 are at 20 m resolution and bands 1, 9 and 10 are at 60 m resolution (mainly used for atmospheric corrections) (ESA Sentinel Online 2019). The data were used to calculate the Red-Edge Inflection Point (REIP) vegetation index from four red edge and near infrared bands (ca. 670, 700, 740 and 780 nm; bands 4, 5, 6, 7), which is reported as the best performing index to describe winter wheat N concentration (Mistele et al. 2004). REIP is calculated by (eq 1) (Guyot et al. 1988):

$$REIP = 700 + 40 \left(\frac{\left(\frac{670nm+780nm}{2} \right) - 700nm}{740nm - 700nm} \right)$$

Data Analysis

Both yield map and the Sentinel-2 data were sampled to a raster image with 10 m resolution. The relationship was modelled using type II linear regression (Lieberman and Cunningham 2009) because of similar uncertainty in both datasets and because neither yield nor REIP is an independent variable, but both are assumed to be dependent on some other variable, which is unknown. There were a total of 1443 sample points extracted from the yield map and REIP map and the model was implemented using a R script. (Legendre 2008)

Results and Discussion

The result of Model II regression (Figure 3) showed neither the correlation ($R^2=0.033$) nor regression coefficient ($R=0.184$) was significant. This is expected from the data errors in the yield monitor and the time difference between observations during which unknown changes might have occurred. The 95% confidence interval is between 722.62 and 723.78 and does not include 0. It also means there is good evidence that REIP and Yield are related. Thus, for REIP values other than between 722.62 and 723.78 of the yield prediction models to be identified to locate the point with unlikely yield values for the sample location.

As the approach was not particularly successful at the sub-field scale, different time series of satellite imagery and yield maps from more fields will be used to develop a more useful yield prediction model. The better accuracy yield maps will be integrated with other geographical data such as weather, soil, and applications in one single dashboard for better farm management decision support.

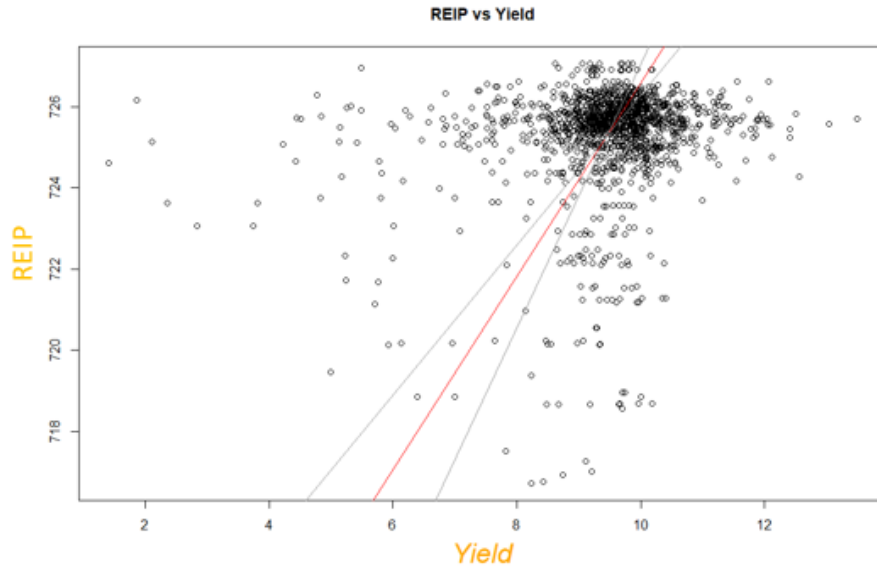


Figure 3: Model II regression of REIP vs Yield

Conclusions

Yield map is an important piece of information and support tool for management decision. Therefore, the knowledge of understanding the factors that contributes to the quality of yield map is important among the farmers and researchers. The Red-Edge Inflection Point (REIP) vegetation index implemented at sub-field scale using Sentinel-2 data was not a reliable means of estimating winter wheat yield as early as GS58.

Acknowledgements

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LIFE CYCLE ASSESSMENT OF PHYCOCYANIN PRODUCTION FROM *ARTHROSPIRA PLATENSIS* IN A CONCEPT OF BIOREFINERY

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Abstract

Arthrospira platensis is a blue-green microalga (i.e. cyanobacteria) commonly known as *Spirulina*. This species naturally synthesizes phycocyanin, a blue pigment which accounts for up to 20% of the biomass. Phycocyanin is extracted and mainly used as food colouring and supplement, and as natural pigment in cosmetics. More recently, bioactivity tests have shown its promising biological properties (e.g. antioxidative, hepatoprotective). Despite the fact that the extraction process is well-established, there is a need to improve the value chain to reduce the production costs and make the European market more competitive. In this context, the SpiralG project aims to revisit the whole phycocyanin production process. The Life Cycle Sustainability Assessment study conducted will evaluate the environmental, social, and economic impacts, and ensure a reduction of at least 10% of the carbon footprint.

Introduction

Microalgae have recently received considerable research attention for their promising biotechnological applications in the food, feed, cosmetics, nutritional, pharmaceutical, and bioenergy industries (Odjadjare *et al.*, 2017). These microorganisms are widely cultivated in open ponds or closed photobioreactors for the production of high value biomolecules such as pigments, proteins, lipids, carbohydrates, vitamins, and antioxidants (Markou *et al.*, 2013). As higher plants, microalgae are capable of photosynthesis: they use light to synthesize energy-rich organic molecules from carbon dioxide and water, and release dioxygen (Packer *et al.*, 2011). More interestingly, microalgal cultures do not compete with arable lands and show higher energy yields per area than conventional crops (Clarens *et al.*, 2011). Since they also have the ability to grow in wastewater and a high capability to fix carbon dioxide from flue gases (Singh *et al.*, 2016), microalgae are an interesting alternative feedstock for biorefineries (Chew *et al.*, 2017). *Spirulina* is an aquatic blue-green microalga which has been harvested for decades from natural lakes in African countries. The biomass has been used as a source of nutrients in traditional food (Habib, 2008). Nowadays, this well-known species is mainly cultivated in open raceway ponds for biomass production. *Spirulina* is mostly commercialised in the form of powder as food supplement for its high content in proteins and vitamins. However, this microalga is particularly interesting for the two pigments responsible for its blue-green colour: phycocyanin and chlorophyll. Since the American Food and Drug Administration (FDA) approved phycocyanin as natural blue dye in 2013, new applications were developed in the food and cosmetic industries (e.g. food colouring, edible dye in ice creams, natural dye in cosmetics etc.). More recently, studies have shown the antioxidative and hepatoprotective properties of phycocyanin and its potential use for cancer treatment (Fernandes e Silva *et al.*, 2018).

The European phycocyanin market is largely dominated by imports from the Asian market which comprises companies producing up to 20 MT of dried phycocyanin per year (Habib, 2008). Despite the well-established *Spirulina* cultivation and phycocyanin extraction processes, there is a need for improving the value chain to make the European market more competitive. In this context, the SpiralG project gathers four industrial partners to revisit the sourcing, extraction, and co-valorisation of *Spirulina* in a concept of biorefinery. The aim is to develop a demonstration plant able to produce 10 MT of phycocyanin per year and reduce the carbon footprint by 10% at least. A Life Cycle Sustainability Assessment (LCSA) will be conducted to evaluate the environmental, social, and economic impacts of the production chain. **This paper provides a description of the system studied and the methodology that will be used to implement the LCSA in the frame of the SpiralG project.**

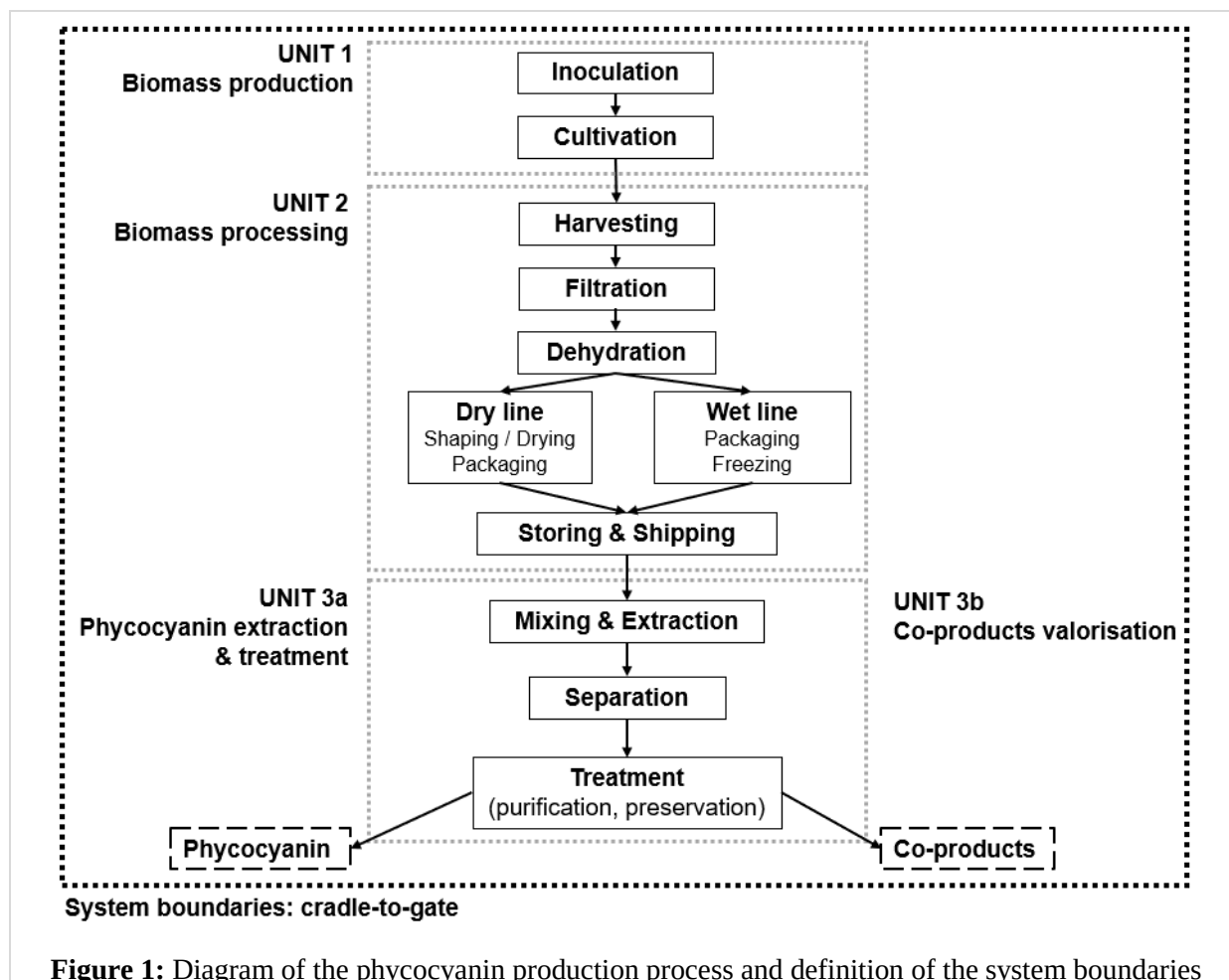
The LCSA study will assess the environmental, economic, and social impacts of phycocyanin production from *Spirulina* in a concept of biorefinery. This analysis will ensure that the revisited value chain enables a reduction of at least 10% of the carbon footprint and highlights the process stages responsible for the largest environmental impacts.

Description of the system studied

The modelled system comprises all the process stages from *Spirulina* cultivation to phycocyanin production (extraction and treatment) and co-product valorisation. The system is subdivided into three units: biomass production, biomass processing, and phycocyanin extraction and treatment. *Figure 1* shows all stages included in the system from the inoculation to the end- and co-products treatment.

The function of the system is to produce phycocyanin. The functional unit considered is 1 kilogram of dried phycocyanin extracted from wet or dried *Spirulina* biomass. Phycocyanin will be used as a natural blue dye in the food, feed, and cosmetics industries. The co-products valorisation could lead to the development of new applications or the commercialisation of new products.

The phycocyanin life cycle begins with the extraction of raw materials for biomass production (cradle) and ends with the packaging of the end- and -by-products (gate). Therefore, the LCSA analysis will be conducted on a cradle-to-gate system, according to the International Organization for Standardization (ISO) 14040 and 14044 requirements.



The system boundaries include all the process stages and will capture the full impacts of the value chain. The reduction of the production costs will be achieved by implementing automated stages with the use of new facilities and machinery, and by optimising the nutrient inputs. The reduction of the

energy consumption during the cultivation will be achieved by using photovoltaic panels and solar heating systems. Through this project, new extraction methodologies will be developed and research on the phycocyanin content enhancement of the biomass will be conducted.

The LCSA study will be based on primary data (i.e. directly collected on the production and transformation sites). Mass flows, energy flows, and environmental losses will be measured. Secondary data (i.e. based on laboratory experiments or extracted from databases) could be used to complete missing data. This LCSA analysis will be one of the first studies conducted on phycocyanin production, on a cradle-to-gate system, and based on primary data. The results will provide background information for process improvement and optimisation to achieve the goals defined in the frame of the SpiralG project.

Description of the process stages

Unit 1: Biomass production

The biomass production site is located in Sardinia (Italy). *Spirulina* is cultivated in six open raceway ponds in a greenhouse. The environmental conditions (e.g. light, temperature, pH, nutrient supply) are controlled. Each pond is inoculated with concentrated *Spirulina* from maintained cultures. Water and nutrients are regularly added to maintain an optimal growth. The biomass is continuously mixed with paddle wheels during the day. *Spirulina* growth parameters are monitored by operators and enable the establishment of the harvesting program. The ponds are cleaned once a month by removing microalgae and salty residues with water, and once a year with detergents to remove the sediments.

Unit 2: Biomass processing

The biomass processing unit consists of all the stages from biomass harvesting to packaging and shipping. These stages reduce the water content from 99% to 8% and the production of a stable biomass for phycocyanin extraction. The biomass is harvested everyday using three pumps (one for two ponds). The biomass is directed through three separate process lines. The filtration facility consists of three vibrating and filtering systems, one for each process line. The microalgae broth is separated into a concentrated paste and a clarified water stream that is pumped back to the ponds. The resulting paste is dehydrated by using three water presses (one per process line). The humidity is reduced from 99% to 75%. After dehydration, the paste moves to the dry or wet lines. In the dry line, the paste is shaped, dried, and packaged while the paste is directly packaged in the wet line. Dried bags are stored in wardrobes and wet bags are frozen. The biomass is then shipped for the next process stages.

Unit 3a: Phycocyanin extraction and treatment

The extraction of phycocyanin from *Spirulina* biomass is conducted using a continuous flow mixing and extraction system to develop a full integrated production line. The continuous extraction method replaces the two steps method using two centrifuges and allow the separation of the by-products and their concentration which reduce the shipping costs. In addition, a three-tangential filtration system will be tested to ensure the sterilisation, purification, and washing of the phycocyanin extracts. Three different drying systems (spray drying, freeze drying, and band drying) will be studied and adapted to the product quality requirements.

Unit 3b: Co-products extraction and valorisation

New extraction methods will be tested at the laboratory scale to favour the use of eco-friendly technologies such as green solvents, commercial enzymes, and ultrasounds technologies. The development of new extraction systems should improve co-product extraction yields. These co-products will be treated separately in two fractions: the proteins, peptides, and amino acid fraction, and the carbohydrate fraction. In addition, bioactivity tests will be conducted.

Conclusion

Most of the LCA studies conducted on microalgae-based products focused on bioenergy production (biofuel and biogas) and highlighted process bottlenecks. Therefore, the research interests were oriented towards high-value molecules production such as omega-3 fatty acids, pigments, or vitamins. Phycocyanin recently gained a considerable attention for its potential industrial applications. Therefore, the LCSA study conducted in the frame of the SpiralG project will be one of the first studies focusing on phycocyanin production in a concept of biorefinery and based on on-site data collection. The LCSA results will serve as a decision supporting tool for the project partners to improve the value chain and make the European phycocyanin market more competitive.

Acknowledgement

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LIFE CYCLE ASSESSMENT OF INTEGRATED BIOREFINERY FOR CONVERSION OF DAIRY SIDE STREAMS TO HIGH VALUE BIO-BASED CHEMICALS

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Abstract

The EU's post milk quota era represents a higher production of milk and milk products. Consequently, expansion of the European dairy processing activities is expected to result in an increase in generation of by-products and waste at the same time. However, dairy processors lack a reliable disposal routes to treat dairy side stream mainly whey permeate (WP) and de-lactose whey permeate (DLP). Due to the raising concerns regarding waste minimization and environmental issues, there is an increasing demand on EU milk processing industries to develop processes that are viable and sustainable to volarise industrial waste to high value products. Addressing this issue, AgriChemWhey project aims to build a first-of-a-kind integrated symbiotic industrial biorefinery to volarise over 25,000 tonnes per annum of undervalued European dairy processing side stream (WP and DLP). This paper will majorly focus on sustainability evaluation of the process for conversion of dairy waste streams (WP and DLP) to high value bio-based chemicals mainly polylactic acid (PLA) using LCA as a tool.

Introduction

Since the abolition of milk quotas in 2015, European Union (EU) farmers now have greater potential to produce milk and milk products. Moreover, due to the growing domestic consumption and export demand for EU cheese, the production is expected to reach 11.2 million tons by 2025 (FAO, 2019). This surge in cheese production is directly linked to the production of cheese whey and other side streams. Currently, the dairy processing industries faces a significant issue related to disposal of whey. As, it is considered to have the prime polluting potentials with BOD and COD values in the range of 27-60 g/L and 50-102 g/L, respectively (Prazeres *et al.*, 2012). The high level of organic load of whey is believed to be ten times higher than municipal waste water due to presence of water, lactose, protein, fats and minerals (Carvalho *et al.*, 2013). Therefore, the disposal of whey is considered problematic and often landfilled or discharged in to the local water bodies.

To reduce the waste and recover the nutrients, European dairy industry processes the whey to produce whey proteins, lactose and whey powders. The extraction of protein and lactose from whey in turn results in the by-products like whey permeate (WP) and de-lactose whey permeate (DLP) (Smith *et al.*, 2016). However, due to the presence of high lactose in the side streams of whey concentration process, WP possess almost as high as BOD of the raw whey. Even the lactose concentration process results in the DLP that ends up with significant amount of sugars and fats (Ahmed *et al.*, 2013). So, the WP and DLP represent a key challenge for the dairy industry due to a lack of reliability in current disposal routes and create a sustainability bottleneck for the expansion of milk production in the EU's "post-milk-quota era". AgriChemWhey will build a world's first integrated biorefinery to valorise these residues from dairy processing to make sustainable bio-based products such as chemicals and biopolymers (PLA) with improved sustainability profiles. Though all the AgriChemWhey technologies are feasible and implementable, to have real value in a circular bioeconomy, they must be demonstrated to be sustainable. **Therefore, the objective of this work is to evaluate the sustainability of the integrated biorefinery processes for conversion of dairy residues to bio-based products and will be explored through life cycle assessment (LCA) of all integrated process and products.**

Materials and Methods

Goal and Scope

The main goal of this study is to evaluate the environmental impacts of the integrated biorefinery process for production of PLA and other by-products from dairy side streams. The environmental impacts will be estimated following the ISO 14040/14044 standards methodology (ISO 2006a, b). The impacts will majorly cover resource depletion, land usage, greenhouse gas (GHG) emissions, fresh water eutrophication and acidification potential. OpenLCA will be used as a platform for assessing the environmental impacts.

The functional unit is defined as 1 ton of PLA produced from dairy side streams (DP and DLP). The system boundary considered is “gate to gate” comprising transportation of DP/DLP from dairy gate till exit of AgriChemWhey plant gate. The “gate to gate” approach mainly includes the upstream (Pretreatment and centrifugation) and downstream processes (Fermentation, Nano-filtration, centrifugation, vacuum filtration, distillation and concentration) involved in conversion of DP/DLP to PLA at AgriChemWhey plant (Fig. 1). The co-products obtained during the PLA production process will be valorised as a new value chain for industrial symbiosis with local industries. Thus, closing the loops to create a zero waste process making it a circular bio-economy approach.

Allocation method

According to ISO 14044 (ISO 2006b), a product should be appropriately allocated with its associated emissions and impacts by sub-dividing the process system. However, it is not possible with the PLA production system as its co-products (calcium phosphate, gypsum and bacterial biomass) shares significant unit process with PLA system. It is rare in multifunctional processes to divide into subsystems and thereby avoiding the allocation. Therefore, to avoid the allocation in such complex processes, ISO 14044 (2006b) recommends system expansion, which indicates the inclusion of avoided production of co-products (calcium phosphate, gypsum and bacterial biomass) from other systems. The co-products obtained from this process will be validated for its use in agri-food industry, particularly for fertilizer and mushroom production (gypsum and bacterial biomass) and mineral supplement (calcium phosphate).

Life cycle inventory

All the processes included in the process from dairy farm gate to AgriChemWhey biorefinery gate are clearly outlined in Fig.1. Initially, the data regarding mass, energy flows and environmental losses for modelling will be collected from the AgriChemWhey pilot plant. Additional data which is not available will be adopted from the literature and Ecoinvent database. The data collected and collated from pilot plant and literature will be used to refine the unit process models, to facilitate the inventory data for estimating the resource depletion, environmental impacts and industrial symbiosis. Various models will be developed towards the process considering the variables parameters that has significant impact on the PLA yield. There are some input parameters involved in this process study that can considerably contribute to the output, majorly to the environmental impacts and resource depletion. Thus, sensitivity analysis will be performed to evaluate the effect of variation of these input on end results.

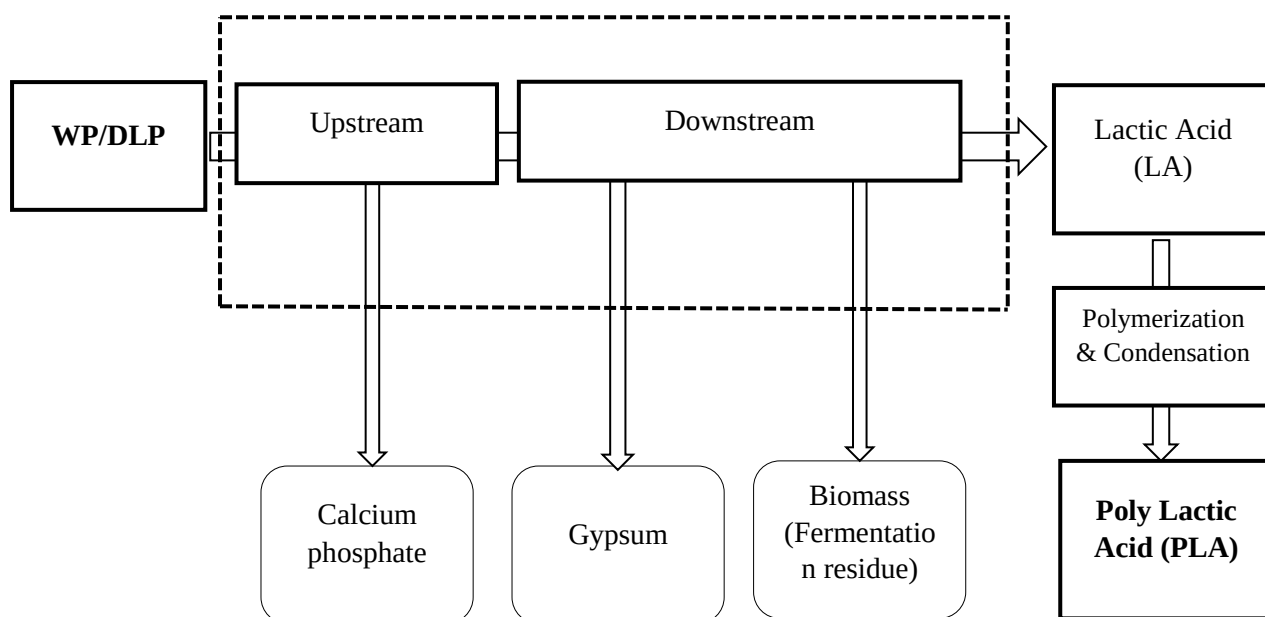


Figure 1: System boundaries and process flow steps for conversion of dairy side streams to PLA

Results and Discussion

Since the study is in the initial stages, it is anticipated that the environmental impact profile of the second-generation PLA produced from dairy waste streams would be established and compared with PLA produced from other sources, such as sucrose or corn sugar (glucose). It will also be compared with the first-generation plastic production systems (PE, PET, PP etc.) as the AgriChemWhey's PLA would replace the non-renewable plastics in milk packaging applications.

The major hotspots in the AgriChemWhey process will be identified and optimized by selecting the best modelled scenario that contributes in the lower resource depletion and reduced environmental impacts by varying the parameters that significantly affects the PLA production. It is expected that the system expansion of the process by including the avoided burden of the co-products with alternative production processes will enhance the overall environmental profile of the PLA production process.

As the co-products, specifically WP and DLP derived gypsum can replace the mined or quarried gypsum, thus significantly benefit the end users (used in agricultural sector as biofertilizer and mushroom production) both in economic and environmental perspective. It will also help in averting the excessive nutrient loss to the water stream by binding phosphates.

Conclusion:

The present study assumes to deliver a holistic, life cycle sustainability model for integrated biorefinery for conversion of dairy waste streams (WP and DLP) to PLA and other by-products. As the AgriChemWhey process represents a novel circular bio-economy approach within the dairy value chain, the life cycle sustainability results would strength the replication potential of this process

across other regions of Europe. It is also expected that the integration of life cycle results of the process with socio and techno-economic dimensions would facilitate the demonstration of bio-economy build around the system is genuinely sustainable.

Acknowledgement

The authors gratefully acknowledge funding from Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme (BBI-JU-H2020-744310).

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Tenzin Tashi, BE, MSc

Project Title: Process Model and Life Cycle Assessment of Whole Milk Powder

Project Leader: Prof. Nicholas M. Holden

Abstract

EU milk quota abolition in April 2015 led to a target of 50% increase in Ireland's milk production volume by 2020, which represented about 7.6 billion litres. This increased milk volume created both an opportunity for Irish dairy processor to increase their production capacity and challenge to produce dairy products in a sustainable manner. Therefore, the objective of this project was to develop a process model and conduct a life cycle assessment for Whole Milk Powder (WMP). A commercial SuperPro Designer process simulation software was used to model whole milk powder manufacturing process and GaBi software was used for LCA. The process model approach was chosen because the energy and water consumption data in a large multi-product dairy plant were available as an aggregated form. A process model approach can bridge the data gap encountered due to lack of high-resolution empirical data and consequently, a process model was developed for WMP production process consisting of key unit operations (i.e. separation, homogenization, evaporation and spray drying operation). The mass and energy consumption data at key unit operations were estimated based on the thermo-physical properties of the milk and heat & mass balance calculation. The energy consumption result for key unit operations were validated with the industry data.

It was found that energy consumption (i.e. steam and electricity) for spray drying unit operation represented about 70-80 % of the total energy consumed. Moreover, evaporation unit operation consumed less energy compare to spray drying operation due to using 5-stage 2-effect falling-film Mechanical Vapour Recompression (MVR) evaporator, which consumed electricity in the first effect and a small fraction of live steam in the second effect. This research project identified the energy consumption of spray drying unit operation as the hotspot, contributing major portion to WMP carbon footprint. Therefore, it is essential to reduce the energy consumption for the spray dryer unit operation in order to reduce its carbon footprint.

Jonathan Herron BAgSc

Project Title: Preliminary modelling of the environmental impact of the inclusion of white clover in perennial ryegrass swards on intensive pasture based dairy production systems

Project Leader: Dr. Thomas P. Curran

Abstract

Fertilizer N application is a key source of nitrous oxide (N_2O) emissions from grass based systems. A previous paper has highlighted first results from the whole farm modelling of nitrous oxide emissions when considering silage harvest date and fertiliser application on intensive and extensive beef production (Herron *et al.*, 2019). White clover (WC) is a common legume that fixates N from the atmosphere and releases it into the soil as plant available N through exudates in the root to companion plants. The inclusion of WC into a PRG sward thus has potential to reduce reliance on N fertilizer. The objective of this study therefore was to conduct life cycle assessments (LCA) to determine the effect of the inclusion of WC into PRG swards on the environmental impact of pasture based dairy systems. Cradle to farm gate LCA of pasture based dairy systems on three treatments obtained from the Teagasc clover experiments were conducted (i) a PRG/WC receiving 150kg of N/ha per year (CL150) (ii) a PRG/WC receiving 250kg of N/ha per year (CL250) and (iii) a PRG only sward receiving 250kg of N/ha per year (GR250).. The Moorepark Dairy Systems Model (MDSM) and the Moorepark Dairy Environmental Model were amalgamated to create a hybrid model that allows for the improvement in production system description and the calculation of environmental impacts that are more representative of the systems simulated. The hybrid model was modified with particular focus on nitrogen (N) flow in the model. Equations that calculate the quantity of forage N deriving from atmospheric fixation were added to the model. Recently developed country specific N excretion equations for each animal category were added to the model to capture N use efficiency of dairy animals. Regarding N_2O emissions, to ensure the model is representative of Irish pasture based systems recently developed country specific emission factors for fertiliser N application and excreta deposited onto pasture were added. The environmental impact categories assessed were global warming potential, non-renewable energy use, acidification potential and eutrophication potential. Environmental impacts were expressed per tonne of fat and protein corrected milk (FPCM). Preliminary results are highlighted here. The GR250 system was found to have the greatest environmental impact per kg FPCM across all impact categories. Although CL250 system was found to have the greater environmental impact when expressed on an area basis, due to the positive effect of the inclusion of WC on milk production, when expressed on a product basis CL250 was more efficient. Moreover, the substitution of synthetic N fertilizer with N derived from the atmosphere in CL150 system further reduced the environmental impact of dairy production system on both an area and product basis. This reduction in environmental impact occurs due to the reduction in total CO_2 , N_2O , NH_3 and NO_3 losses and non-renewable energy usage from the substitution of carbon intensive N fertilizer with N derived from atmospheric fixation. Moreover, the improvement in animal performance with the inclusion of WC further reduced the environmental intensity across all environmental impact categories. In conclusion, this preliminary LCA study indicated that the inclusion of WC into a PRG sward can reduce the environmental impact of intensive pasture based dairy system at a given stocking rate and farm area.

Acknowledgements

This study is funded under the Walsh Fellowship Scheme.

Recent Publications

Herron, J. *et al.* (2019) 'Whole farm modelling the effect of grass silage harvest date and nitrogen fertiliser rate on nitrous oxide emissions from grass-based suckler to beef farming systems', *Agricultural Systems*. Elsevier, 175, pp. 66–78. doi: 10.1016/J.AGSY.2019.05.013.

Juan Vinagre-Sendino, BE, M.Eng., M.Sc.

Project Title: Sustainable Sludge Management in Ireland

Project Leader: Dr. Thomas P. Curran

Abstract

It is a well-known fact that sludge contains valuable nutrients and organic substances. That is why, in Ireland, over 98% of wastewater sludge was re-used in agriculture in 2014. However, there are many constraints to land application of sludge such as metal accumulation in soil and crops or groundwater and surface runoff contamination. Moreover, in Ireland, there are closed periods for sludge spreading during the winter months due to the implementation of the Nitrates Directive and S.I. 31 of 2014. Furthermore, the expansion of the agri-food sector with the Foodwise 2025 Strategy will lead to the generation of extra sludge, thus, creating extra pressure to find sustainable strategies for sludge management. On account of all the mentioned limitations and due to the steady increase in sludge quantity which is expected to continue in the upcoming years, sludge management has become a growing environmental challenge.

The objective of this project is to compile an inventory of sludge currently applied to land in Ireland according to source in order to assess the long-term capacity of land for sludge management e.g. nutrient limits, distance from sources and economic aspects. The project will also include a multicriteria Geographical Information System (GIS) analysis.

The performance of a GIS multicriteria analysis and the assessment of the long-term capacity of land for sludge management is being carried out on a county basis. The information is being collected from relevant datasets from the EPA, the Geological Survey of Ireland, the National Park & Wildlife Service, Teagasc, the Local Authorities and the Department of Agriculture, (i.e sludge quantities, soil properties, protected areas, distance to waterbodies, groundwater vulnerability, etc). GIS tools will allow merging all information and layers into one map, thereby figuring out and depicting the most risky and sensitive zones to sludge land spreading in Ireland. This analysis will simultaneously help to spot new areas for sludge land spreading and to cope with the problem that poses the fact that the soil-holding capacity for sludge application is expected to deplete in some areas of the country within a few years. The project will finally permit establishing sustainable sludge recommendations, alternatives and strategies.

Since sludge quantities are expected to increase in the upcoming years and, so far, sludge spreading seems to have been the only feasible disposal alternative, a proper sludge inventory which helps to develop an accurate assessment of the long-term capacity of land for sludge management is required in Ireland.

The research project is still in the middle of its third year and key objectives and results were scheduled to be attained in a four-year scheme. To date the achievement of the key objectives and the development of the GIS analysis are still ongoing.

Acknowledgements

This project is funded by the Irish Research Council as part of the Employment Based Postgraduate Programme with Veolia Water Ireland as the Employment Partner. The authors would like to thank and appreciate all parties for their support.

Appendix 1

(Research projects in progress which have not been included in the Research Review)

- Achata EM**, Esquerre CA, O'Donnell CP. NIR - Hyperspectral imaging and chemometrics as a pat tool for the prediction of food powders mixing kinetics (**PhD**). FIRM as administered by the Irish Department of Agriculture, Food and the Marine.
- Charoux C**, O'Donnell CP, Tiwari B, Scannell A. Design and development of novel technologies to improve the removal of biofilms and destruction of spores. FIRM as administered by the Irish Department of Agriculture, Food and the Marine
- Dunne K**, Holden NM, Daly K. Prediction of phosphorus sorption capacity in agricultural soils using DRIFT spectroscopy (**PhD**). Teagasc Walsh Fellowship Scheme.
- Guth F**, Ward S, McDonnell KP. Disease level assessment in crop plots using RGB images and deep learning algorithms (**PhD**). Brazilian agency *Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq*.
- Hao Q**, Butler F. Occurrence of Cronobacter in a dairy powder ingredient plant (**PhD**). China Scholarship Council (CSC) and University College Dublin (UCD).
- Henihan LE**, O'Donnell C, Esquerre C, Murphy EG, O'Callaghan DJ. Comparison of front-face fluorescence spectroscopy and fourier transform infrared spectroscopy as process analytical tools in dairy ingredient and infant formula manufacture (**PhD**). Food Institutional Research Measure (FIRM) administered by the Irish Department of Agriculture, Food and the Marine.
- Li F** and Butler F. Efficacy of novel thermal and non-thermal processes to reduce spore numbers within dairy manufacturing processes (**PhD**).
- Liu R** and Holden N. Greenhouse gas emissions from homogenization for liquid milk production (**PhD**). CSC-UCD Scholarship Scheme.
- Luo J**, Esquerre C., O'Donnell C. Applying PAT tools to monitor milk coagulation in cheese manufacture (**MEngSc Res**).
- Panikuttira B** and O'Donnell C. Development of process analytical tools for food processing (**PhD**).
- 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 .
- 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.
- Zhao YM**, de Alba Ortega M, Sun DW, Tiwari B. Quality evaluation of mackerel fillets after high pressure treatment (**PhD**). China Scholarship Council (CSC) and University College Dublin (UCD).

Appendix 2

Profiles of Postdoctoral Research Scholars

Nebras Alattar, BSc,MSc, PhD Physics

Project Title: Chemical Imaging and Chemometrics to Accelerate and Improve Patient Prostate Biopsy Assessment for Cancer.

Project Leader: Associate Prof. Aoife Gowen

Abstract

Currently diagnostic and therapy methods are often limited by insufficient sensitivity, specificity and spatial resolution, depending upon staining processes to illustrate vital features of a tissue. Nowadays, Raman imaging technique is more and more often used in analysis of biological samples, including tissues and cells, with the prospect to become a potent new method of medical diagnostics. However, this chemical imaging technique has potential not just for diagnosis but for prognosis of cancer based on direct characterisation of the biochemistry of a tissue sample. The aim of this work is to combine Raman Chemical Imaging with conventional methods (immunohistochemistry) to generate highly detailed chemical images that contain imperceptible biochemical information from the prostate tissue. Raman chemical images are acquired using a Raman microscope with spatial mapping ability to provide a detailed chemical map over the surface of a sample. Three multivariate analysis (MVA) methods; Independent Component Analysis (ICA), Partial Least Squares (PLS) and K-means, are employed here to generate chemical images. Integrating the chemical images with existing digital pathology and patient medical histories have been proposed to generate predictive models of patient outcomes from pre-radical prostatectomy data.

Background, Skills & Qualifications

I obtained a BSc in Physics, in 1997, from Almustansiriyah University-Baghdad and MSc in physics, in the field of optics & lasers, in 2002 from University of Baghdad. I have joined the department of laser and optoelectronics /university of technology-Baghdad as assistant lecturer in 2005. In 2010, I have awarded a scholarship funded from the ministry of higher education-Iraq to obtain PhD degree in UCD. I obtained the PhD from school of physics/UCD in early 2015. My thesis, was centred on the development of a multifunctional microscope which has applications in spanning fluorescence imaging, Raman spectroscopy, fluorescence correlation spectroscopy, time correlated single photon counting, and Raman imaging. Following my PhD, I was awarded a post doc position funded by SFI, focusing on the development of an optical system for investigation and sensing the pathological bacteria. This experience helped me to develop an image analysis modulus, in the field of the digital pathology, in my next post-doctoral fellow role. This modulus would quantify protein expression in tumour/non-tumour areas, was generated by immunohistochemistry methodology. Currently, I am working with associate prof. Aoife Gowen in spectral imaging research group as a post doc funded by HRB.

Selected Recent Publications

Malallah, R.; Li, H.; Qi, Y.; Cassidy, D.; Muniraj, I.; **Al-Attar, N.**; Sheridan, J. T., Improving the uniformity of holographic recording using multi-layer photopolymer: Part II Experimental results. *Journal of the Optical Society of America A* **2019**.

- Malallah, R. e.; Li, H.; Qi, Y.; Cassidy, D.; Muniraj, I.; **Al-Attar, N.**; Sheridan, J. T., Improving the uniformity of holographic recording using multilayer photopolymer Part I Theoretical analysis. *Journal of the Optical Society of America A* **2019**.
- O'Connor, D.; Kelly, C. M.; Crown, J.; Russell, N.; Barron, S.; Loughman, T.; Lynch, S.; O'Grady, A.; Sheehan, K. M.; Fay, J.; Saha, A.; Dynoodt, P.; Fender, B.; Wang, C.-J. A.; O'Leary, D.; Bracken, A. P.; Rahman, A.; Gonzalez, C. A.; **Al-Attar, N.**; Gallagher, W. M., Additional prognostic value of OncoMasTR multigene prognostic signature to clinicopathological information in patients with HR-positive, HER2-negative, lymph node-negative breast cancer from the TAILORx Tissue Bank, Ireland. *Journal of Clinical Oncology* **2019**, 37 (15_suppl), 535-535.

Wenhao Chen, BSc, MSc, PhD

Project title: AGROCYCLE/VALUMICS

Project Leader: Professor Nicholas M. Holden

Abstract

The aim of **AGROCYCLE** is promoting circular economy in agriculture and food sector. The main objective of the **AGROCYCLE** project is to further develop, demonstrate and validate novel processes, practices and products for the sustainable use of agricultural waste, co-products and by-products (AWCB). The systems will be tested and evaluated from technical, environmental and socio-economic perspectives, including their impact on the sustainability of agricultural systems, thereby contributing to the creation of sustainable value chains in the farming and processing sectors. A key aspect is identifying sustainable extraction rates for wastes, as well as guidance on the optimal use of crop residues (in particular straw) for soil improvement taking into account the need to maintain soil organic matter levels. This project developed several waste valorization technologies to produce bioenergy, biomaterial and nutrient from agriculture waste. The objective of **VALUMICS** is to improve the resilience, integrity and sustainability of global food supply chains. **VALUMICS** project provides decision makers throughout food value chains with a comprehensive suite of approaches and tools that will enable them to evaluate the impact of strategic and operational policies to enhance the resilience, integrity and sustainability of food value chains for European countries. This overall objective is divided into specific aims, which are associated with the four operational phases of the project where key activities have been defined, and these are supported by efficient project management and communication strategies to achieve the overall objective.

Background, skills & Qualifications

I have completed my BSc in Nanjing Agricultural University in 2011. After that I obtained my MSc (2012) and PhD (2017) in University College Dublin, School of Biosystems and Food Engineering. During my PhD, my research focus is about LCA application in livestock systems. My PhD was funded by EU project SILF and Irish government funded project eRuminant. The objective of SILF is using information and communication technology (ICT) systems to improve production efficiency, environmental performance and animal welfare of livestock system. The focus of eRuminant is to evaluate the ecosystem service in livestock system. Currently, I work in School of Biosystems Engineering, UCD, as a postdoctoral researcher under the guidance of Prof. Nicholas M. Holden.

Recent publications

- Chen, W.**, Oldfield, T.L., Katsantonis, D., Kadoglidou, K., Wood, R. and Holden, N.M., 2019. The socio-economic impacts of introducing circular economy into Mediterranean rice production. *Journal of Cleaner Production*, 218, 273-283.
- Chen, W.** and Holden, N.M., 2018. Bridging environmental and financial cost of dairy production: A case study of Irish agricultural policy. *Science of The Total Environment*, 615, 597-607.
- Chen, W.** and Holden, N.M., 2018. Tiered life cycle sustainability assessment applied to a grazing dairy farm. *Journal of Cleaner Production*, 172, 1169-1179.
- Chen, W.** and Holden, N.M., Social life cycle assessment of average Irish dairy farm. *The International Journal of Life Cycle Assessment*, 22(9), 1459-1472.
- Chen, W.**, White, E. and Holden, N.M., 2016. The effect of lameness on the environmental performance of milk production by rotational grazing. *Journal of environmental management*, 172, 143-150.

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

Ferone M., Raganati F., Olivieri G., Salatino P., Marzocchella A., Succinic Acid Production from Hexoses and Pentoses by Fermentation of *Actinobacillus succinogenes*, Chemical Engineering Transactions, 2016, 49, 211-216

Ferone M., Raganati F., Olivieri G., Salatino P., Marzocchella A., Biosuccinic acid from lignocellulosic-based hexoses and pentoses by *Actinobacillus succinogenes*. Appl Biochem Biotechnol (2017). doi:10.1007/s12010-017-2514-4

Ferone M., Raganati F., Olivieri G., Salatino P., Marzocchella A., Continuous Succinic Acid Fermentation by *Actinobacillus Succinogenes*: Assessment of Growth and Succinic Acid Production Kinetics. Appl Biochem Biotechnol (2018). Doi: 10.1007/s12010-018-2846-8

- Ferone M.**, Raganati F., Ercole A., Olivieri G., Salatino P., Marzocchella A., Continuous succinic acid fermentation by *Actinobacillus succinogenes* in a packed bed biofilm reactor. *Biotechnol Biofuels* (2018) 11:138 <https://doi.org/10.1186/s13068-018-1143-7>
- Ferone M.**, Ercole A., Raganati F., Olivieri G., Salatino P., Marzocchella A., Efficient succinic acid production from leftover beverages by *Actinobacillus succinogenes*. *Biotechnol Progress* (2019) 2019;e2863. <https://doi.org/10.1002/btpr.2863>
- Raganati F., Procentese A., **Ferone M.**, Olivieri G., Russo M.E., Salatino P. Marzocchella A., Continuous glucose fermentation by *Clostridium acetobutylicum* – kinetics issues under acidogenesis and solventogenesis conditions. Submitted to *International Scientific Journal*.
- Ferone M.**, Olivieri G., Salatino P., Marzocchella A., Bioreactors for succinic acid production processes. *Critical Reviews in Biotechnology* (2019) DOI: 10.1080/07388551.2019.1592105
- Lu T., Marmion, M., **Ferone M.**, Wall P., Scannell A. G.M., Farm to Shelf strategies to minimize *Campylobacter* contamination in retail chicken 1: On-farm interventions. Submitted to *International Scientific Journal*.
- Lu T., Marmion, M., **Ferone M.**, Wall P., Scannell A. G.M., Farm to Shelf strategies to minimize *Campylobacter* contamination in retail chicken 2: Processing and retail storage. Submitted to *International Scientific Journal*.
- Skoog E., **Ferone M.**, Montriwat P., Mapelli V., Olsson L., ATP levels and membrane lipid composition give insights to the difference in adipic acid tolerance in *Candida viswanathii* and *Saccharomyces cerevisiae*. Submitted to *International Scientific Journal*.

Ana Herrero-Langreo, BSc, M.EngSc, PhD

Project Title: Multi-scale hyperspectral imaging for enhanced understanding and control of food microbiology (HyperMicroMacro)

Project Leader: Assoc. Prof. Aoife Gowen and Assoc. Prof. Amalia Scanell

Abstract

Ana is a senior Postdoctoral researcher in the HyperMicroMacro Project, working with Aoife Gowen in the UCD Spectral Imaging Research Group - University College Dublin. 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. The overarching aim of this project is to create the knowledge base required to develop a user-friendly hand-held device, capable of detecting and identifying microbes on a range of surfaces. We will address these questions using hyperspectral imaging (HSI) at multiple spatial scales (from microscopic to macroscopic) and spectral modalities (e.g. Raman, IR and Fluorescence) combined with microbial characterisation and high throughput sequencing (HTS). This approach will provide new insights on the persistence of food related microorganisms and their behaviour on foods and other surfaces. The knowledge developed will allow us to develop a prototype rapid detection system to improve safety and security of the food chain. Funding for this research was provided by Science Foundation Ireland (SFI) under the investigators programme Proposal ID 15/IA/2984

Background, Skills & Qualifications

She finished her PhD in non-destructive assessment of fruit quality in 2010 in Universidad Politécnica de Madrid (Spain). Since then, she has worked in the adaptation and development of multivariate data analysis methods to a wide variety of food science and agronomical applications. Some examples of her research include the adaptation of sampling methods to the calibration of spatial models in precision viticulture, (Herrero-Langreo et al., 2018); the assessment and improvement of NIR model robustness for plant breeding purposes; and the integration of spatial and spectral information for sampling (Gowen et al., 2019) and model assessment (Herrero-Langreo et al., 2019); Her current research at UCD focuses on the application of hyperspectral imaging for the investigation of microbial growth in food matrices, exploration of different spectral modalities at different scales and development of adapted chemometric approaches for developing new understanding of the growth and persistence of bacteria, spores and biofilms on surfaces. Her last publication, feature article in the prestigious journal *Analytica Chimica Acta*, proposes a methodology to first, quantitatively evaluate the spatial structure of prediction maps, and then, use this information to assess model performance. The main advantage of the approach is that is based only on the spatial characterization of prediction maps and does not require ground truth values. This approach could also be used to characterize the spatial distribution of a sample, allowing for example to quantify the aggregation of bacteria within the context of the project HyperMicroMacro.

Selected Recent Publications

Gowen A., Xu J.-L., **Herrero-Langreo A.**, Comparison of Spectral Selection Methods in the Development of Classification Models from Visible Near Infrared Hyperspectral Imaging Data, (2019) *Journal of Spectral Imaging*, 8 a4.

Herrero-Langreo A., Gorretta N., Tisseyre B., Gowen A., Xu J.-L., Chaix G., Roger J.-M., (2019). Using Spatial Information For Evaluating The Quality Of Prediction Maps From Hyperspectral Images: A Geostatistical Approach, *Analytical Chimica Acta*. In Press

Herrero-Langreo A., Tisseyre B., Roger J.M., Scholasch T., Payen S., (2018) Test of Sampling Methods to Optimize the Calibration of Vine Water Status Spatial Models. *Precision Agriculture*. 19 (2), 365-378.

Rosanna Kleemann, BA BAI, MSc, EngD

Project title: Agri Bio Circular Economy – Developing sustainable value chains from waste

Project Leader: Assistant Professor Fionnuala Murphy

Abstract

Ireland has one of the most challenging targets to meet a 20% reduction in greenhouse gas (GHG) emissions on 2005 levels by 2020. Agriculture accounts for 33% of Ireland's GHG emissions and is expected to increase due to dairy sector expansion caused by the removal of milk quotas. Agri Bio Circular Economy (ABC Economy) targets the agricultural and forestry sectors to develop bio-based products and energy generation from waste streams in a cascading system of biomass use to reduce GHG emissions. Novel value chains will be created in conjunction with farmers, food processors, and foresters in counties Monaghan and Tipperary. Workshops were held in each county to understand stakeholders' opinions on the opportunities and barriers to developing new value chains from their wastes. Using this information coupled with detailed data on feedstocks, novel value chains will be developed based on technological and market potential. ABC Economy moves beyond current research by conducting full Life Cycle Assessment (LCA) to highlight the synergies and trade-offs between using biomass for bio-based products and energy generation.

Background, Skills & Qualifications

I have strong expertise in water and waste management, sustainable development, and circular economy, through both industrial and academic roles. I gained my engineering doctorate (EngD) in Sustainability for Engineering and Energy Systems from the University of Surrey. My doctorate, based in Thames Water UK, focused on the sustainable recovery of phosphorus from wastewater. I have presented my research on various media outlets including BBC news, Sky news, Al Jazeera, and The Independent and Guardian newspapers. Currently, I work in the School of Biosystems Engineering, UCD, as a postdoctoral researcher on the Agri Bio Circular Economy (ABC Economy) project under the guidance of Assistant Prof. Fionnuala Murphy. I have a keen interest in conducting industry relevant research, maintaining links between industry and academia, and disseminating research through a variety of methods to reach a wider audience.

Recent publications

- Kleemann, R.,** Chenoweth, J., Clift, R., Morse, S., Pearce, P. & Saroj, D. (2016) Comparison of Characteristics and Phosphorus Recovery from Pyrolysis and Incineration Residues Waste Management DOI: 10.1016/j.wasman.2016.10.055
- Kleemann, R.,** Chenoweth, J., Clift, R., Morse, S., Pearce, P. & Saroj, D. (2015) Evaluation of Local and National Effects of Recovering Phosphorus at Wastewater Treatment Plants: Lessons Learned from the UK Resources, Conservation and Recycling DOI: 10.1016/j.resconrec.2015.09.007
- Shepherd, J.G., **Kleemann, R.,** Bahri-Esfahani, J., Hudek, L., Suriyagoda, L., Vandamme, E. and Van Dijk, K.C.. (2015). The Future of Phosphorus in our Hands Nutrient Cycling in Agroecosystems DOI: 10.1007/s10705-015-9742-1
- Kleemann, R.** and Morse, S. (2015) Sustainable Phosphorus Management — A Global Transdisciplinary Roadmap by Roland W. Scholz, Amit Roy, Fridolin S. Brand, Deborah T. Hellums and Andrea E. Ulrich Ecological Economics, 114, 245-246. DOI: 10.1016/j.ecolecon.2015.02.009

Anastasia Ktenioudaki, BSc, MSc, PhD

Project title: A real-time forecast decision support system for the food supply chain (FreshProof)

Project Leader: Professor Colm P. O'Donnell

Abstract

The project focuses on an innovative systems approach to address existing food supply chain waste and shortcomings in food safety, integrity and traceability. Data on critical environmental conditions in the field and during processing and distribution of fresh fruit and vegetables, will be collected and merged with data on products quality attributes, nutritional value and shelf-life performance. The project is aiming to combine both pre- and postharvest conditions in a single decision support tool, implementing prediction models to determine the remaining shelf-life and nutritional value of a product to consumer level.

Background, Qualifications and Skills

My current research is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Global Fellowship grant. I am currently hosted at the Food Quality Laboratory, University of South Florida, Tampa, USA. I obtained a PhD in Biosystems Engineering from University College Dublin in 2008, which assessed novel rheological and physical/chemical techniques for wheat quality evaluation.

Since graduating I have worked in multidisciplinary research projects as a research officer and post-doctoral researcher at Teagasc Food research Centre, Ashtown; and I had the opportunity to lead NPD and research projects in my previous role as a senior research and development scientist at Kerry Global Technology and Innovation Centre, Ireland. My research projects have mainly been in the areas of food engineering and food science focusing on the development of new quantitative and qualitative methodologies for assessing product quality, monitoring shelf-life and investigating physicochemical and nutritional properties of food and food molecular structure.

Previous studies include an MSc in Biosystems Engineering from UCD and a BSc in Agriculture from Aristotle University of Thessaloniki, Greece.

Recent Publications

- Ktenioudaki A**, O'Donnell CP, do Nascimento Nunes MC, 2019. Modelling the biochemical and sensory changes of strawberries during storage under diverse relative humidity conditions. *Postharvest Biology and Technology* 154:148-158
- McCarthy U, Uysal I., Mercier S, Badia R, **Ktenioudaki A**, O'Donnell C, 2018. Global food security – Issues, challenges and technological solutions. *Trends in Food Science and Technology*, *Trends in Food Science & Technology* 77:11-20
- O'Shea N, **Ktenioudaki A**, Smyth TP, McLoughlin P, Doran L, Auty, M. A. E., Arendt, E., Gallagher, E., 2015. Physicochemical assessment of two fruit by-products as functional ingredients: Apple and orange pomace. *Journal of Food Engineering* 153:89-95
- Ktenioudaki A**, Alvarez-Jubete L, Smyth TJ, Kilcawley K, Rai DK, Gallagher E. 2015. Application of bioprocessing techniques (sourdough fermentation and technological aids) for brewer's spent grain breads. *Food Research International* 73:107-16
- Ktenioudaki A**, Alvarez-Jubete L, Gallagher E. 2015. A Review of the Process-Induced Changes in the Phytochemical Content of Cereal Grains: The Baking Process. *Critical Reviews in Food Science and Nutrition* 55:611-9

Sindhuraj Mukherjee, Ph.D.

Project title: Automation of Agrochemical Product Development

Project Leader: Associate 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.

Recent 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),1535-1545.

Mukherjee, S., Martínez-González, J., Dowling, D. and Gowen, A. (2018). Predictive modelling of the water contact angle of surfaces using attenuated total reflection – Fourier transform infrared (ATR-FTIR) chemical imaging and partial least squares regression (PLSR). *The Analyst*, 143(15),3729-3740.

Joe Sweeney, BSc, Eng, MSc, PhD

Project title: Biosensors for Biological processes

Project Leader: Dr. Fionnuala Murphy

Abstract

My research area which is a combination of computer science and microbiology entails creating novel cost-effective monitoring and control systems for biological processes. Biosensors that were initially developed in UCD with a view to providing a robust cost effective monitoring and control system for high throughput grass silage fed AD systems, are currently being adapted to include an array of fermentation processes. A major focus of these biosensors is providing monitoring and control systems to the emerging Green Biorefinery sector. Grass being the Green biorefineries primary input substrate has meant that a monitoring and control system can be developed by adapting the biosensors that were initially developed for grass-silage fed AD.

Background, skills & Qualifications

BSc in Industrial microbiology (2007), MSc in Computer science (2012) and PhD in Biosystems Engineering (2016), (UCD). As part of my MSc in computer science I was employed as a software developer on an Enterprise Ireland funded research project where I was responsible for developing the various assembly- and C-programming-language algorithms necessary to adapt digital signal processors, to implement the “*Ultrasonic athlete tracking system*”. My PhD which was funded by the Charles Parsons Science Foundation Ireland project entailed developing novel biosensors capable of provisioning small-scale, remotely deployed anaerobic digestion systems with cost effective and robust monitoring and control systems. To bring this project to completion extensive use of both computer science and microbiology techniques were required. I am currently working as a postdoctoral researcher in the School of Biosystems Engineering (UCD) under the guidance of Dr. Fionnuala Murphy and Prof. Kevin McDonnell on the BBIJU project, SpiralG.

Recent publications

Sweeney, J., Murphy, C.D. & McDonnell, K. Towards an effective biosensor for monitoring AD leachate: a knockout E. coli mutant that cannot catabolise lactate. *Appl Microbiol Biotechnol* (2015) 99: 10209. doi:10.1007/s00253-015-6887-4

Sweeney, J.B., Murphy, C.D. & McDonnell, K. Development of a bacterial propionate-biosensor for anaerobic digestion monitoring. *Enzyme Microb. Technol.* (2017) doi: 10.1016/j.enzmictec.2017.09.011

Rebecca L. Whetton, BSc, PhD

Project title: Crop Optimisation Through Sensing, Understanding and Visualisation - Crop Nutrition, limits to yield potential

Work package Leader: Prof. Nick Holden

Abstract

The overall project is a multi and inter-disciplinary approach to investigate digital, precision agriculture and crop science. As part of the larger project, the work package aims to provide the scientific underpinning for decision support related to nutrient (mainly nitrogen) use efficiency (NUE) for winter wheat crops grown in Europe. While nitrogen supply is effectively unlimited, current technology relies on fossil energy for the creation of suitable N fertilisers. Other macro-nutrients such as phosphorus have a limited global supply, with peak-P predicted to occur between 2027 and 2033. This mean that NUE needs to be increased to remove limits from the supply side. In addition, eutrophication associated with N (limiting nutrient in oceans) and P (limiting nutrient in fresh waters) losses will be reduced with increased NUE. NUE is regulated by many factors, both biotic and abiotic, many of which are understood, but their relative priority is not clearly defined.

Background, skills and qualifications

I Completed a BSc (Hons) degree in Biological sciences: Ecology and Environmental Management at Nottingham Trent University in 2013. During which I took a year's placement at an Agro-research company. In 2018 I graduated from Cranfield University with a PhD in Multi-sensor and data fusion approaches for determining yield limiting factors, and in-situ measurements of yellow rust and fusarium head blight in cereal crops. Shortly after submitting the thesis I assisted on a remote sensing project at Rothamsted research in 2017, and then began a PostDoc later that year at UCD in the department of Biosystems Engineering. My current work is focused on improving Nitrogen use efficiency, with a main aspect of that being predictions of nitrogen mineralisation potential using Mid infrared spectroscopy.

Selected recent publications

The current work conducted in UCD is now being prepared for publication

Whetton, R.L., Hassall, K.L., Waine, T.W. and Mouazen, A.M., 2018. Hyperspectral measurements of yellow rust and fusarium head blight in cereal crops: Part 1: Laboratory study. *biosystems engineering*, 166,101-115.

Whetton, R.L., Waine, T.W. and Mouazen, A.M., 2018. Hyperspectral measurements of yellow rust and fusarium head blight in cereal crops: Part 2: On-line field measurement. *Biosystems engineering*, 167, 144-158.

Whetton, R.L., Waine, T.W. and Mouazen, A.M., 2018. Evaluating management zone maps for variable rate fungicide application and selective harvest. *Computers and Electronics in Agriculture*, 153, 202-212.

Junli Xu, BSc, PhD

Project title: Prediction of preosteoblastic cell attachment on different polymers using ATR-FTIR and Raman spectroscopy

Project Leader: Associate Professor Aoife Gowen

Abstract

Interactions between bone and biomaterials are vitally important to the success of the implants and bone tissue engineering scaffolds. Although a general understanding of biocompatibility, biofouling and degradation of biomaterials exists, the molecular mechanisms driving these processes at the interface between cell and biomaterial are still largely unknown. Water is typically the first molecule that comes into contact with biomaterials inside the human body and it plays a key role in mediating subsequent protein and cell adhesion, which ultimately determine the biocompatibility of a material. This project aims to explore the multivariate modelling in conjunction with Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) and Raman chemical imaging to investigate whether experimentally characterized surface chemistry can be used to predict surface cell adhesion. ATR-FTIR and Raman spectra were collected on dry and wetted polymeric surfaces, followed by evaluation of preosteoblastic MC3T3-E1 cell attachment. Partial Least Squares Regression (PLSR) models were built using IR spectra as the predictor variable.

Background, skills & Qualifications

I received my Bachelor 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.

Recent publications

- Xu, J. L.,** & Gowen, A. A. Spatial-spectral analysis method using texture features combined with PCA for information extraction in hyperspectral images. *Journal of Chemometrics*. 2019, e3132.
- Xu, J. L.,** et al. Development of a polarized hyperspectral imaging system for investigation of absorption and scattering properties. *Journal of Near Infrared Spectroscopy*. 2019.
- Herrero-Langreo, A, Gorretta, N, Tisseyre, B, Gowen, A.A, **Xu, J. L.,** Chaix, G, Roger, J. Using spatial information for evaluating the quality of prediction maps from hyperspectral images: A geostatistical approach. *Analytica Chimica Acta*. 2019.
- Xu, J. L.,** & Gowen, A. A. Investigation of plasticizer aggregation problem in casein based biopolymer using chemical imaging. *Talanta*. 2019, 193, 128-138.
- Lin, X., **Xu, J. L.,** & Sun, D. W. Investigation of moisture content uniformity of microwave-vacuum dried mushroom (*Agaricus bisporus*) by NIR hyperspectral imaging. *LWT*. 2019.
- Xu, J. L.,** et al. A polarized hyperspectral imaging system for in vivo detection: Multiple applications in sunflower leaf analysis. *Computers and Electronics in Agriculture*. 2019, 158, 258-270.