BIOSYSTEMS AND FOOD ENGINEERING RESEARCH REVIEW 22

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FOREWORD

The Twenty Second Annual **Research Review** describes the ongoing research programme in the School of Biosystems and Food Engineering at University College Dublin from over 98 researchers (12 academic staff, 1 technician, 11 postdoctoral researchers and 74 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 First Annual **Biosystems and Food Engineering Research Seminar** held in University College Dublin on **Tuesday 14th March 2017**.

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;
- a photographic record of postgraduate students;
- a photographic record of full-time staff; and
- links to Postgrad Research Activities with YouTube Videos

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 16th May 2017

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APPENDICES

EFFECTIVE POSTHARVEST PRESERVATION METHODS FOR MUSHROOM (*AGRICUS BISPORUS*): A BRIEF REVIEW

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Abstract

Mushroom (*Agaricus bisporus*) is a popular agri-food product that is being produced worldwide. However, the short shelf life of mushrooms is an issue limiting their commercial value. To extend the shelf life, preservation techniques for postharvest mushrooms quality are essential. This review briefly summarized a number of preservation methods for *Agaricus bisporus* mushrooms, including packaging, cooling, drying, washing, and coating.

Introduction

Agaricus bisporus mushroom are popular edible fungi worldwide for their special flavour and nutritional value, and this kind of mushrooms accounts for about 40% of total mushrooms production (Kumar et al., 2013). Due to the nature of an unprotected structure, *Agaricus bisporus* mushrooms are quite perishable and is prone to physical and microbial damage. During postharvest storage, mushrooms experience a continuous quality degradation (Ding et al., 2016). Induced by enzyme activities and microbial contamination, the colour of mushrooms shows a browning trend. A high water content and a relatively high respiration rate in mushrooms lead to serious postharvest water loss, causing mushrooms shrinkage and weight loss. The thin and porous structure makes them vulnerable to mechanical damage during transportation, handling and processing. Off-flavour and nutrient-loss also influence mushrooms postharvest quality. Consequently, the shelf-life of fresh *Agaricus bisporus* mushrooms under ambient temperature is only about 3 days (Mahajan et al., 2008). The short shelf-life is a main disadvantage for promoting their economic value in the food market. To solve this problem, some preservation methods were applied on mushrooms. Based on previous research, effective preservation methods for *Agaricus bisporus* mushrooms have been applied, including modified atmosphere packaging (MAP) (Guillaume et al., 2010), vacuum cooling (Sun, 1999), drying (Pei et al., 2013), coating (Jiang, 2013), and washing (Cliffe-Byrnes and O'Beirne, 2008).

The above-mentioned preservation methods could extend the shelf life of mushrooms to a certain stage. Generally, low O_2 concentration used in MAP postharvest storage period reduced the respiration rate of mushrooms, thus the quality loss was retarded (Guillaume et al., 2010) Vacuum cooling and drying inhibit the growth of microorganisms by reducing water activity. Chemical coatings form a protective film on the surface of mushrooms so as to avoid microbial contamination. Washing could effectively reduce mushrooms microbial loads, thus the postharvest quality loss was minimized.

The objective of the study is to briefly review different preservation methods for postharvest *Agaricus bisporus* mushrooms.

Packaging

Modified Atmosphere Packaging (MAP) is a simple and effective economical packaging method for mushrooms preservation. Guillaume et al. (2010) investigated the effect of different packaging films on products quality by packaging fresh mushrooms with stretchable polyvinylchloride (PVC) films, normal papers, and papers coated with wheat gluten solution, respectively. Results showed that only after one day of storage, dark brown blotches appeared on the stretchable film packaged mushrooms and about 30% of the mushrooms showed open veil. Due to the high respiration rate of mushrooms and low water vapour transmission rate of the non-perforated polymeric film, water accumulation occurred in the package, making products unattractive and leading to the growth of microorganism. In order to solve this problem, Mahajan et al. (2008) used mixed desiccants (bentonite, sorbitol and $CaCl_2$ were mixed in a ratio of 0.55:0.25:0.2) as a moisture absorber for packaged fresh mushrooms. It was suggested that the use of 5 g of the mixed desiccants in the 250 g mushrooms could improve mushrooms appearance compared to the mushrooms packed without absorbers.

Vacuum Cooling

Vacuum cooling is a rapid cooling method based on moisture evaporation. The porous structure and the high moisture content property of mushrooms make them suitable for vacuum cooling. Compared to mushrooms cooled by conventional methods, vacuum-cooled mushrooms have a better quality when storage at $18^{o}C$, less browning and no significant damage in hyphal structure on cap tissue was observed. As shown by Frost et al. (1989), if the storage temperature increased to $5^{o}C$, colour difference between vacuum-cooled mushrooms and mushrooms cooled by conventional methods was negligible after 102 h storage.

Weight loss is a major disadvantage in mushrooms vacuum cooling. According to Sun (1999), cooling mushrooms from 21 to $1^{o}C$ induced 3.6% of weight loss, this weight loss was higher than that in air blast cooling (2%). However, when using vacuum cooling followed by cold storage at $1^{o}C$, those mushrooms with 5 days storage had a similar total weight loss as mushrooms cooled by air blast. The result indicated that the weight loss in vacuum-cooled mushrooms is even lower than the weight loss in air blast cooled mushrooms in cold storage period. Wetting mushrooms prior to vacuum cooling is an effective way to reduce weight loss, mushrooms could absorb 6% of their fresh weight after being wetted with water for 5 minutes (Sun, 1999)

Drying

Drying is the most commonly-used food preservation method to remove free water from products. About 5% of the fresh mushrooms was preserved by dehydration (Sagar and Kumar, 2010). As water activity reduced gradually along with the removal of free water, the growth of microorganisms is inhibited during dehydration process. Therefore, shelf life of the mushrooms could be extended.

Conventional drying methods include solar drying and hot air drying. The long-time and high process temperature in these conventional drying processes lead to serious damage on sensory properties of mushrooms, such as discoloration, nutrient loss , off-flavour, bulk density reduction and rehydration capacity decrease. Microwave is an electromagnetic wave in the frequency ranged from 300 MHz to 300 GHz. Compared to solar drying and hot air drying, microwave drying could increase sensory properties of dried mushrooms (Maskan, 2000). Freeze drying could produce high quality products based on water sublimation, however, the operating cost of the system was relatively high (Sagar and Kumar, 2010). Pei et al. (2013) dehydrated mushrooms using freeze drying (FD) and freeze drying combined with microwave vacuum drying (FMVD), suggesting that both methods could effectively preserve the sensitive flavour of mushrooms. However, the FMVD method reduced drying time by 35.63% when compared to FD, with a similar quality obtained in the final products.

Washing

Commercially, mushrooms cultivation relies on composting, which means that mushrooms are likely to expose to various microorganism, thus mushrooms might have a high possibility of being contaminated. Washing treatment is essential to remove attached casing soil from the skin, therefore, mushrooms browning and microorganism growth were inhibited. Nevertheless, water-washed mushrooms are even more vulnerable compared to unwashed mushrooms due to the difference in water activity. Therefore, some antimicrobial agents were added in the washing process, which could remove casing and retard quality deterioration (Cliffe-Byrnes and O'Beirne, 2008).

Early in the 20th century, sulphite solution was used as a washing agent to remove unwanted casing particles and thus to enhance the whiteness of mushroom. However, for Irish mushroom processing, the use of sulphite has been reduced and replaced by stabilized chlorine dioxide (Brennan et al., 2000). Citric acid or hydrogen peroxide are effective washing agents for mushrooms, which could extend the shelf life up to 19 days. As it was investigated by Brennan et al. (2000), the number of pseudomonad bacteria on mushrooms treated by citric acid or hydrogen peroxide solution was reduced, compared to the water soaked slices. H_2O_2, ClO_2 and sodium D-isoascorbate monohydrate were also proved to be effective washing agents for fresh sliced mushrooms, leading to a better appearance and a lower microbial content on mushroom. From the aspect of reducing the number of pseudomonad counts, H_2O_2 treatments were superior to ClO_2. As it was suggested by Cliffe-Byrnes and O'Beirne (2008), the optimum treatment was to wash the whole mushroom with the use of 3% H_2O_2 for up to 60 s and then slice followed by spray with 4% sodium D-isoascorbate monohydrate or 1% H_2O_2.

Coating

Coating mushrooms with semi-permeable films is a promising preservation method in recent years. The coating materials with a unique colloidal characteristic could generate strong gels or insoluble polymers. By increasing the water barrier and preventing microbial contamination, the shelf life of mushrooms were extended (Jiang, 2013).

As it was reported by Eissa (2007), coating treatment with aqueous solution of 2 g chitosan/100 ml followed by packaging with polyethylene bags at 4^oC could delay discoloration and reduce enzyme activities on postharvest mushrooms. Mushrooms coated by alginate and stored at a high oxygen atmosphere were preserved to 16 days (Jiang, 2013). Kim et al. (2006) showed that with the same coating material and storage condition, the colour of coated whole mushrooms was darker than the coated sliced ones.

Conclusion

Short shelf life of *Agaricus bisporus* mushrooms could be extended by various preservation methods, such as vacuum cooling, drying, washing and coating. Those methods are based on different mechanisms. Overall, modified atmosphere packaging slows down mushrooms respiration rate so as to retard postharvest quality degradation. Vacuum cooling and drying methods effectively extend mushrooms shelf life by reducing the water activity and inhibiting the growth of microorganism. Chemical coating helps to prevent microbial contamination on the mushroom surface Washing could reduce mushroom microbial loads and diminish postharvest spoilage.

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DEVELOPMENT OF NEW TOOLS TO VISUALISE CHEMICAL IMAGING DATA

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Abstract

Modern research measurement equipment allows for both the increasingly rapid acquisition and increasingly massive storage capacity of data. However, due to the growing size of output data, human interpretation is presenting a bottleneck in research pipelines and this is particularly true in the field of chemical imaging. While tools do exist for chemical image visualisation, new custom visualisation GUIs are presented herein and may be used to further increase researchers' proficiency in chemical image exploratory analysis. The GUIs may be particularly useful when working with data from different measurement instruments and may also prove beneficial in the dissemination of chemical image information to others.

Introduction

Spectroscopy
Spectroscopy is the study of matter using electromagnetic radiation (Ball 2001). Generally spectroscopic techniques are used to investigate the light absorption/reflection spectrum for a single point of a material. The interaction of light with a given material dictates the resultant light spectrum and can provide researchers with insights into the chemical nature of a material.

Digital Imaging
Digital imaging, borrows from spectroscopy in that it measures spatially resolved light absorption/reflection information. Each pixel of a digital image generally stores one-spectral band (Black-White) or three-spectral band (Red-Green-Blue) data based on the amount light absorbed or reflected. Therefore digital imaging can be thought of as sacrificing most spectral data in favour of spatial data. For example, an image with 20 x 20 pixels (= 400 pixels) and three RGB colour bands will comprise 1200 array elements. A single point spectrum with 1200 measured spectral bands will equivalently comprise 1200 array elements, taking up identical or negligibly different computer drive space.

Chemical Imaging
Chemical imaging bridges the gap between traditional spectroscopy and digital imaging by mapping detailed spectroscopic data to digital image pixels (Dorrepaal *et al.* 2016). This leads to a new challenge. While it was previously possible for a researcher to personally investigate measured spectra, chemical imaging leads to datasets which are too large for human interpretation. Even a very small 10 x 10 pixel image has 100 spectra to review, while a 1000 x 1000 pixel image has 1,000,000 spectra. Due to the massive size of chemical image data, chemometric methods (statistics and machine learning applied to chemical data) have been adopted in the field. In addition, quick, convenient and automated methods of data visualisation have been, and continue to be, developed to great effect.

The objective of this work was the development of custom, in-house visualisation tools for efficient data exploration and information dissemination.

Materials and Methods

All visualisation tools were developed in Matlab version 2016a in combination with the Image Processing, Statistics and Machine Learning Toolbox and in-house functions.

Discussion

Snapshots of four GUI data visualisation tools are presented below. All visualisations use the same magnesium oxychloride cement sample NIR chemical image as an example. However, the same visualisation tools have been implemented with Mid-IR and Raman chemical images in several arrangements.

Visualisation 1: Image Inspection

The first visualisation is a simple point-and-click GUI. Upon initialisation, the intensity of each pixel is dictated by the maximum (or minimum, mean etc.) value of the relevant spectrum.

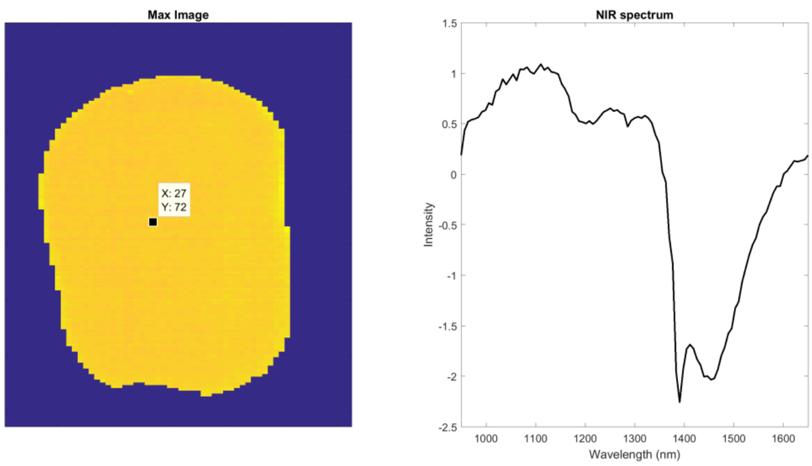

Figure 1. Visualisation 1**:** Image inspection function visualisation

Once a pixel is selected, the spectrum associated with that pixel is displayed to the right. Both the image and the spectrum may now be selected. Selecting a pixel on the image will result in the relevant spectrum plot being generated. Selecting a wave-band on the spectrum ploted will generate a colour map image showing the relative absorbance/reflectance of all pixels at the wave-band. As shown in Figure 2 inspecting different wave-bands may highlight bad pixels which indicate spectral aberrations.

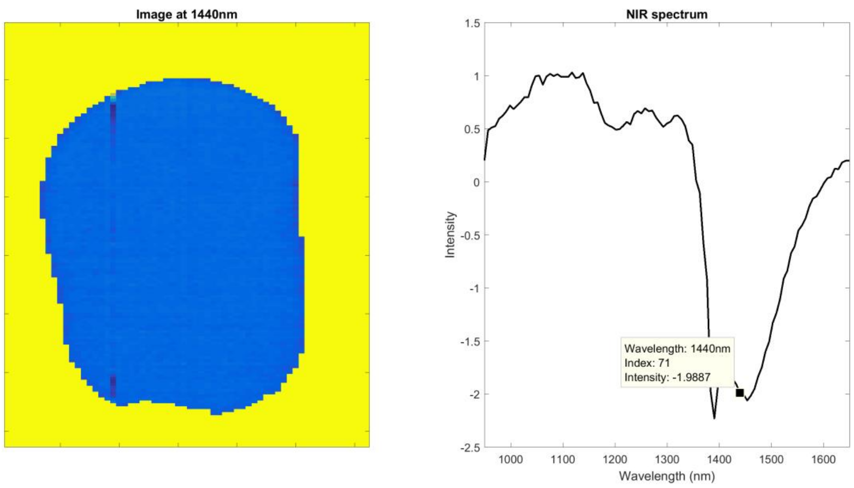

Figure 2. Visualisation 1**:** Image inspection function visualisation on selected wave-band

Visualisation 2: Red-Green-Blue (RGB) Inspection
Visualisation 2 builds upon *Visualisation 1* by allowing three wave-bands to be selected and visualised (as red, green and blue). Each colour band can be hidden if the user wishes to limit visualisation to just one or two wave-bands.

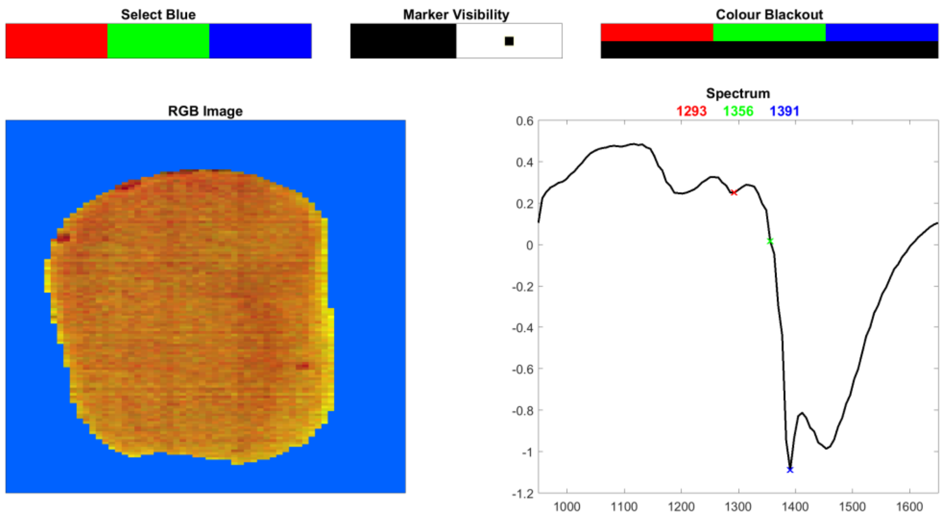

Figure 3. Visualisation 2**:** RGB image inspection function visualisation

Visualisation 3: PCA Inspection
The next visualisation relates to Principal Component Analysis (PCA). After performing PCA, the resulting PC scores and loadings are displayed in addition to the original chemical image. Within the GUI, the user can then toggle through the PC scores and loadings in tandem. The functionality of *Visualisation 1* is still available, as well as thresholding and inversion options.

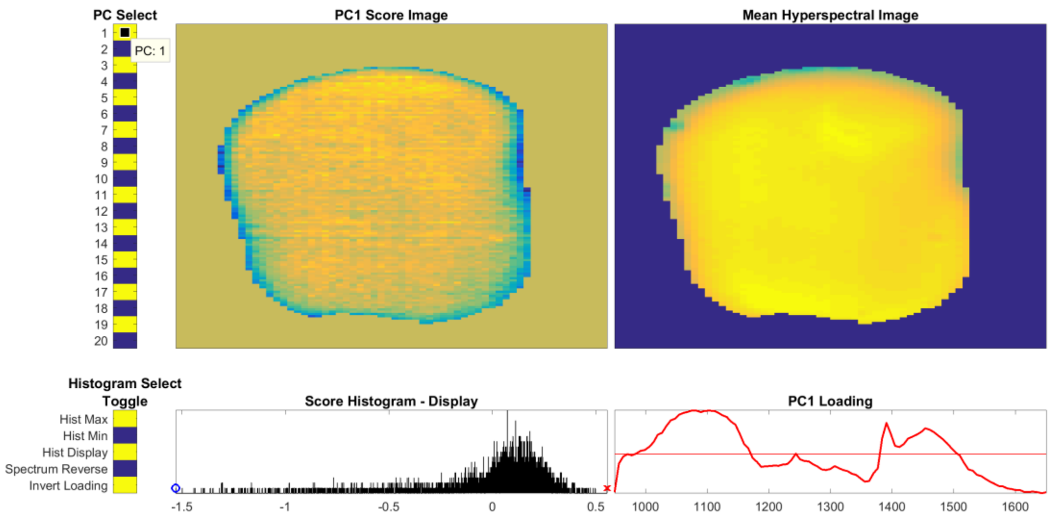

Figure 4. Visualisation 3**:** PCA image inspection function visualisation

Visualisation 4: Correlation Inspection
Visualisation 4 displays the Pearson correlation between each measured wave-band and all other wave-bands. Variants of the function have also been developed to analyse the correlation between different imaging modalities. The user can select which wave-band combination to analyse by clicking on the correlation map, or by selecting the wave-bands of interest on the spectra line plots. A scatter plot is also presented for further insight into the nature of the correlation.

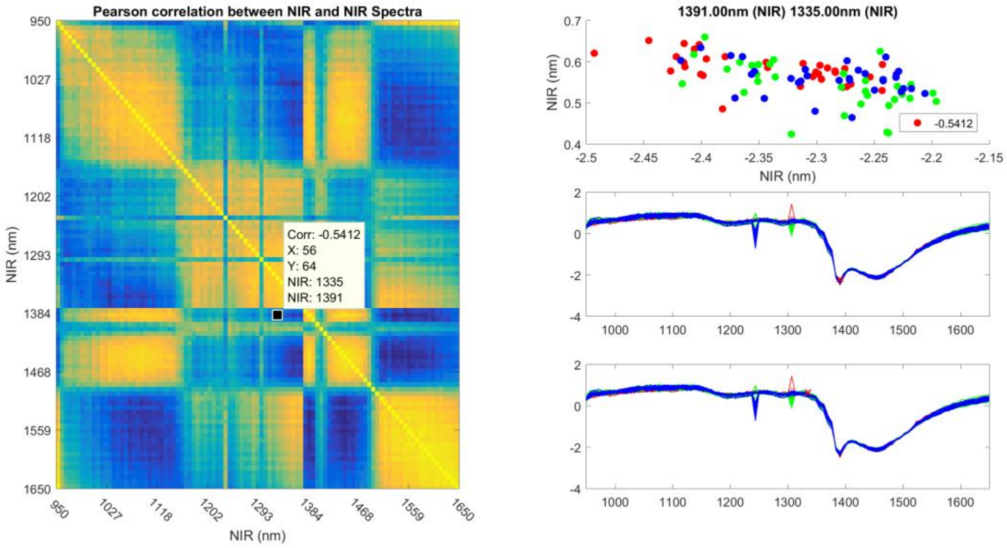

Figure 5. Visualisation 4**:** Correlation inspection function visualisation

Conclusions

With the above discussed interactive visualisation functions, data processing can be interpreted more efficiently than relying solely on on-the-fly scripting. However, when these visualisation functions are used in combination with on-the-fly scripting, users benefit from both quick, automated processing and specific, bespoke solutions when needed.

Acknowledgements

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CAN ATR-FTIR BE USED TO UNDERSTAND THE INTERACTION BETWEEN POLYMERS AND WATER? A HYPERSPECTRAL IMAGING STUDY

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Abstract

This study investigates the potential use of Attenuated Total Internal Reflection – Fourier Transfer Infrared (ATR-FTIR) imaging, a hyperspectral imaging modality, to investigate molecular level trends in the interaction of water with polymeric surfaces of varying hydrophobicity. The hydrophobicity of two categories of polymeric biomaterials is characterised using contact angle (CA) measurements and their relationship with the band area of the OH stretching $\overline{\nu}_S$ vibration of water over time is presented. Multivariate analysis of the spectra captured at the OH stretch for all polymers is carried out using Principal Component Analysis (PCA) to study the spatial variation in the interaction between the polymeric surfaces and water and a comparison between the univariate and multivariate strategies is presented to understand the interaction between polymeric biomaterials and water.

Introduction

Polymeric biomaterials are widely used in different applications for example, in packaging medical devices and implants. The surface properties of such polymeric biomaterials influence phenomena such as hydrophilicity (Bhattacharyya *et al.* 2010),protein adsorption (Stallard *et al.* 2012) and degradation (Donelli *et al.* 2010) which are affected by the nature of the interaction between such polymeric biomaterials and water. In order to understand the behaviour of polymeric biomaterials in biological systems that are largely composed of water, it is desirable to understand this interaction further (Vogler 1998). In this work, ATR-FTIR imaging, a hyperspectral imaging modality (Mukherjee and Gowen 2015) was investigated to study the interaction between water and polymeric biomaterials with a wide range of hydrophobicity.

The aim of the study was to investigate correlations between hydrophobicity and ATR-IR imaging spectroscopic measurements of wetted polymeric biomaterials.

Materials and Methods

Polymeric biomaterials & CA Measurements
Three commercial test samples of polymers PTFE, PET (Mylar™) and UHMPE were obtained from CS Hyde Company (1351 N. Milwaukee Avenue, Lake Villa, Illinois, USA), and characterised for hydrophobicity. Hexamethydisiloxane (HMDSO) coatings were polymerised using a modified plasma enhanced chemical vapour deposition technique described in more detail in a different paper (Stallard *et al.* 2013). All samples were stored in sealed petri dishes at room temperature for up to 4 months (bulk polymers) and 6 months (HMDSO coated wafers). CA measurements were recorded using a Dataphysics™ OCA-20 goniometry system under room conditions.

ATR-FTIR spectral acquisition and data analysis
A Thermo Scientific™ Nicolet™ iN™10 Infrared Microscope offering a fixed 10x magnification, fitted with a Mercury-Cadmium-Tellurium (MCT) detector, capable of imaging in the 7800–650 cm^{-1} range ($4cm^{-1}$ spectral resolution) with a germanium crystal (refractive index = 4) was used to collect spectra in Attenuated total reflectance (ATR) mode. 64 scans were co-added to increase the signal-to-noise ratio and the scans were collected in the 4000-750cm^{-1} range. Deionised (DI) water sourced from a Thermo Scientific™ Barnstead™ Smart2Pure™ water purification system producing Type I ASTM water, with a resistance of 18.2M Ω.cm at 25.6°C. Wetting of polymers was accomplished using Blu Tack™ to make a well on each polymer, which served as a water trap. Wet spectra were captured after hydrating the polymers with an equilibration time of 30 minutes. All wet spectra hypercubes were unfolded, and the band area of the OH stretching vibration OH $\bar{\boldsymbol{v}}_{\boldsymbol{S}}$ (3800-2800cm^{-1}) for each polymer were compared. Furthermore, the Pearson correlation coefficient was calculated between SNV treated OH $\bar{\boldsymbol{v}}_{\boldsymbol{S}}$ (3800-2800cm^{-1}) band area and CA data followed by looking into specific wavenumbers of the OH $\bar{v}_S$ vibration region showing the highest Pearson correlation coefficient. The spatial variation in wetting of the polymeric surfaces at this particular wavenumber was visualised. Principal Component Analysis (PCA) was applied on band areas of the OH $\bar{\boldsymbol{v}}_{\boldsymbol{S}}$ and principal component (PC) depicting maximum correlation with CA data was calculated and spatial images of this PC were examined. All spectra were visualised and processed using Matlab® 2013 (The MathWorks, Inc., Natick, Massachusetts, United States).

Results

The CA data of the bulk polymers (Table 1) indicate their hydrophobic nature as well differences in measured hydrophobicity at different spatial locations. According to the CA data collected, the hydrophobicity of the bulk polymers increased in this order: Mylar (PET), UHMPE and PTFE, consistently at all time points.

Table 1. CA data (mean value and standard deviation in degree) for the bulk polymers over 4 months stored in the laboratory (standard conditions).

	Month 1	**Month 2**	**Month 3**	**Month 4**
PET	86.95 ± 12.75	66.58 ± 9.83	72.69 ± 0.44	77.59 ± 2.31
UHMPE	87.91 ± 1.85	94.76 ± 4.58	95.53 ± 4.61	83.35 ± 2.48
PTFE	109.74 ± 9.97	131.12 ± 6.61	150.61 ± 3.81	128.87 ± 12.58

Table 2. Values of the mean and standard deviation for the band area $\bar{v}_S$ region for the bulk polymers over time.

	Month 1	**Month 2**	**Month 3**	**Month 4**
PET	6635 ± 3471.64	2611.72 ± 1905.29	7211.81 ± 1691.57	3092.28 ± 1076.54
UHMPE	738.13 ± 118.63	895.57 ± 441.48	1531.17 ± 252.94	1512 ± 263.96
PTFE	960 ± 324.268	1041.32 ± 457.07	1869.53 ± 241.31	1625 ± 225.81

More hydrophobic polymers minimise water from spreading their surface(Chandler 2005). The mean band area of the OH $\bar{\boldsymbol{v}}_{\boldsymbol{S}}$ over the four time points is presented in Table 2. The Pearson correlation coefficient between the band area pre-treated OH stretch for the bulk polymers and the CA data was calculated and found to be -0.34 indicating a weak decorrelation between the OH stretch band area and the CA data exists. On further investigation, the Pearson correlation coefficient between the intensity of the pre-treated mean spectra of each wavenumber of the stretching vibration and CA data for each polymer was calculated and found to be maximum at 3697 cm^{-1} with a value of -0.76. In previous studies on metallic oxides (Al_2O_3 and TiO_2) and lipid membranes, 3697 cm^{-1} was associated with the presence of dangling (Takeuchi *et al.* 2006) or disturbed (Binder 2007) hydrogen bonds as a response to the hydrophobicity of the surface. Following this, the spatial variation of the interaction between water and bulk polymers was analysed at 3697 cm^{-1}(Figure 1) where, PTFE shows darker pixels, indicating a lower intensity of the wavenumber 3697 cm^{-1} at each pixel followed by UHMPE and PET. This can be compared to the CA data (Table 2), where PTFE shows the highest CA values followed by UHMPE and PET in decreasing order of hydrophobicity. A relationship between level of hydration and hydrophobicity has been found at this particular wavenumber, indicating the spectral feature at 3697 cm^{-1} i.e., a univariate analysis with a single wavenumber image, could be used to visualise the interaction between water and a bulk polymer surface.

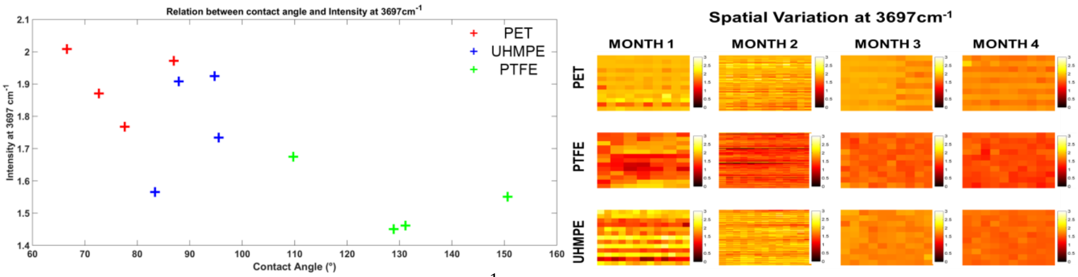

Figure 1. Absorption intensity at 3697 cm^{-1} (feature showing maximum correlation) plotted as a function of CA (left) and spatial variation at 3697 cm^{-1} for the polymers tested over time. A lighter pixel colour indicates higher % of intensity of the wavenumber 3697 cm^{-1} inferring lower hydrophobicity.

Principal Component Analysis

PC 1 accounted for 52% of the variance which is most likely due to use of the two different detectors. To investigate whether there was any correlation between PC scores and CA, the Pearson correlation coefficient was calculated between average PC score (averaged over each image) and CA. PC 11 had the largest absolute correlation coefficient (-0.55). On inspecting the loading plot of PC 11 a peak was found at 3690 cm^{-1} close to the spectral feature 3697 cm^{-1}. A comparison between the use of band area of the OH stretch and the use of PCA to explore the variation in the OH $\overline{\boldsymbol{v}}_{\boldsymbol{S}}$ region can be visualised in Figure 2. While bulk polymers with a high hydrophobicity show a lower value of average PC 11 scores, this trend deviates for UHMPE data when comparing the OH $\overline{\boldsymbol{v}}_{\boldsymbol{S}}$ band area.

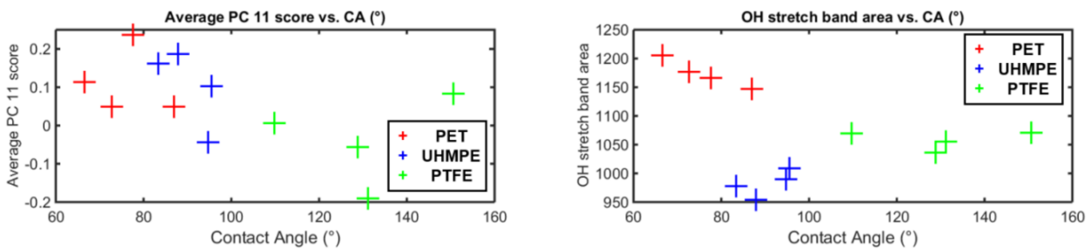

Figure 2. Comparison of average PC 11 scores (left) and OH stretch band area (right) as a function of CA for PET (red), UHMPE (blue) and PTFE (green) over time.

HMDSO coated silicon wafers

The CA data for the experimental sets of the HMDSO coated silicon wafers indicated that all the experimental HMDSO coated wafers reach a similar state of hydrophobicity (80-100°) after 5 months. On further examination of the relationship between CA data of the HMDSO coated wafers and the OH $\overline{\boldsymbol{v}}_{\boldsymbol{S}}$ band area, we found no consistent trend. The Pearson correlation coefficient was calculated between pre-treated mean spectra & CA data as a function of wavenumber (cm^{-1}) with a very low correlation at 3626 cm^{-1} and near 3200 cm^{-1} (3216, 3213 and 3190 cm^{-1}), with a value for each one of -0.35, 0.37, 0.36 and 0.35

respectively. However, no further trends with respect to individual wavenumbers and PCA of the OH $\overline{\boldsymbol{v}}_{\boldsymbol{S}}$ band were found.

Conclusions

The interaction between polymers and water using ATR-FTIR hyperspectral imaging was investigated, focussing on the OH stretching vibration $\overline{v}_S$ band region. We found a significant correlation between the CA data of the bulk polymers and ATR-IR spectra at 3697 cm^{-1} indicative of the disturbed or disrupted hydrogen bonding networks near such surfaces. The results indicated a significant correlation between PC 11 scores and CA, while lower OH $\overline{\boldsymbol{v}}_{\boldsymbol{S}}$ band areas were observed for bulk polymers with a higher degree of hydrophobicity. This indicates that ATR-IR imaging shows potential for studying interactions between bulk polymers and water.

Acknowledgements

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COMBINATION OF NOVEL EXTRACTION TECHNOLOGIES FOR BIOACTIVE COMPOUNDS IN THE FOOD INDUSTRY: A BRIEF REVIEW

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Abstract

Novel extraction methods are considered as clean, green and efficient alternative to conventional extraction technologies. This study focuses on the combination of novel extraction technologies for bioactive compounds in the food industry. The applications of novel extraction technologies in the food industry have been widely studied in recent decades. In the first part, the novel extraction methods, including ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE) and enzyme-assisted extraction (EAE), were discussed with reference to the principles and mechanisms of action as well as the comparison with traditional methods. In the second part, a brief review was given about the combinations of these novel extraction methods which are: ultrasound-assisted enzymatic extraction (UAEE), microwave-assisted enzymatic extraction (MAEE) and ultrasonic microwave-assisted extraction (UMAE).

Introduction

Extraction processes have evolved with the objective of purifying and maximising the yield of a target compound without affecting the properties of the compounds. Conventional solid-liquid extraction methods rely on mechanical or temperature enhancement such as maceration and 'Soxhlet', respectively, which are expensive as they require high volumes of solvents and long processing times. In addition, the solvents are often toxic and potentially carcinogenic (e.g. chlorinated solvents) which does not fit with current market trends for safe and clean ingredients (Tiwari, 2015). Novel techniques offer tremendous potential to reduce or to eliminate the use of toxic chemical solvents, while improving process efficiency, and enhancing extraction yields and quality of the extract. These techniques are also known as cold extraction techniques, as temperature during the extraction process is comparatively low and does not affect the stability of extracted compounds (Azmir et al., 2013). Nowadays, more and more researchers have paid attention to the combination of the novel extraction methods. It has been proved that combining the novel extraction methods can be a complementary technique and present some more advantages under the certain conditions.

The objectives of this study are (1) to discuss the novel extraction methods (UAE, MAE and EAE) with reference to the principles and mechanisms of action as well as the comparison with traditional methods; (2) to briefly review the combinations of these novel extraction methods including UAEE, MAEE and UMAE.

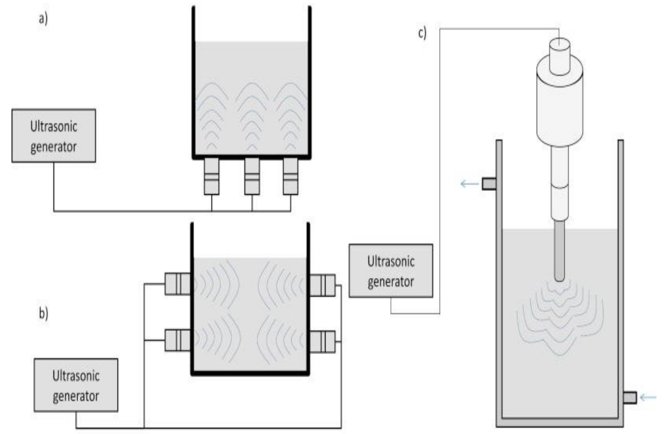
Novel extraction methods

Enzyme assisted extraction (EAE)
Enzyme-assisted extraction, which is considered as an eco-friendly, efficient and mild extraction technology as well as a potential alternative to conventional extraction methods, has been used in the extraction of various kinds of compounds in the food industry (Laroze et al., 2010, Gómez-García et al., 2012). Enzyme-based extraction is based on the inherent ability of enzymes, with the specificity and regioselectivity, to catalyze reactions under mild processing conditions in aqueous solutions. The addition of specific enzymes like pectinases and cellulases during the extraction process can enhance recovery of the target compounds by degrading and disrupting the structural integrity of the cell walls and membranes, thus enabling better release, more efficient extraction of biocompounds and

achieving higher extraction yields for bioactive compounds with reduced solvent usage and lower energy consumption (de Moura et al., 2008, Puri et al., 2012). Dominguez et al. (1995) found the oil extracted by EAE recovered higher amount of free fatty acids and phosphorus contents than traditional hexane-extracted oil with higher efficiency. Decreased solvent use during extraction is particularly important for both regulatory and environmental reasons, providing a 'greener' option than traditional extraction. EAE has been widely described as an ideal alternate for extracting bioactive components especially from oilseed, because of its nontoxic and noninflammable properties.

Ultrasound-assisted extraction (UAE)

Ultrasound propagates through any medium by creating cycles of expansions and compressions, which in liquid medium could induce the formation, growth and implosion of cavitation bubbles. This process produces a phenomenon called 'acoustic cavitation' which is the main motivating force of extraction enhancement by power ultrasound (Azmir et al., 2013, Chemat and Khan, 2011). Two different types of UAE devices are commonly used to apply high power ultrasound, namely ultrasonic bath (Figure.1a,b) and probe-type (Figure.1c) ultrasound system (Rostagno and Prado, 2013, Tiwari, 2015).



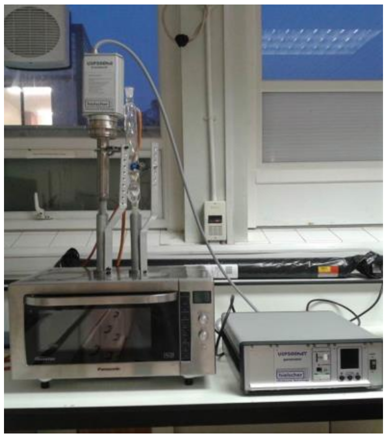


Figure 1 and 2. *Types of ultrasound-assisted extraction system (a, b) Ultrasonic baths; (c) Ultrasonic horn (Tiwari, 2015) and microwave-assisted extraction (MAE) photo*

In recent decades, microwave-assisted extraction (MAE) has been widely employed in the extraction of bioactive compounds from plant material. During extraction, microwave directly heats solvent inside the matrix, and increased local temperature and pressure, pushing the solutes from active sites of sample matrix, which results in the diffusion of solvent across sample matrix and release of solutes from sample matrix to solvent (Chan et al., 2011, Alupului et al., 2012, Azmir et al., 2013). Compared with the conventional extraction methods, MAE shows many advantages, such as reduced extraction time and solvent amount, higher extraction rate and better products with lower cost. Asghari et al. (2011) extracted some bioactive compounds (cinnamaldehyde and tannin) from various plants under optimum conditions and showed that, MAE is faster and easier method in comparison to conventional extraction processes.

Combination of novel extraction technologies

Ultrasound-assisted enzymatic extraction (UAEE)

Some studies have researched the combination of ultrasound-assisted and enzyme-assisted extraction of biocompounds which is usually called ultrasound-assisted enzymatic extraction (UAEE). UAE and EAE, as ideal alternatives to conventional extraction, are both environmental friendly, efficient and capable of reducing solvent usage and producing high extraction yields (Capelo and Mota, 2005, Ptichkina et al., 2008,). The UAEE has been used to isolate polysaccharides from epimedium leaves (Chen, Li et al. 2012), pumpkin (Wu et al. 2014), wheat bran (Wang et al. 2014), and blackcurrant (Xu et al. 2015), in which it observed that UAEE can significantly enhance extraction yields of polysaccharides. Wang et al. (2014) observed that compared with UAE and EAE, UAEE can be more effectively applied to enhance the extraction yield of arabinoxylan from wheat bran. UAEE has been proved by many studies that it is more efficient, less cost and can enhance the composition of must in a shorter time than other process in juice processing. Tchabo et al. (2015) observed a significant increase in yields of phytochemicals from mulberry must as well as higher efficiency of extraction for ultrasound-assisted enzymatic extraction compared to UAE alone, enzyme alone or a conventional extraction technique. Similarly, Dang et al. (2012) found that the UAEE of acerola mash achieved the yield of 87.4% which was 3.2% and 15.5% higher than that in the ultrasonic treatment alone and the enzymatic treatment alone, respectively and significantly improved the nutritional quality of acerola juice.

Microwave-assisted enzymatic extraction (MAEE)

MAEE possesses the combination of MAE and EAE of which have been accepted as the potential and powerful techniques in the extraction of bioactive components from plant material. Therefore, the chemical substances within the cell can be released more easily into the surrounding solvents (Cheng et al. 2015). MAEE has been studied for oil and polysaccharides extractions by many studies. Gai et al. (2013) found out that the MAEE-derived oil from Isatis indigotica exhibited better oxidation stability, as well as higher contents of valuable polyunsaturated fatty acids, tocopherols and phenolics compared with oxhlet extraction-derived oil. Cheng et al. (2015) investigated the feasibility of MAEE for extracting polysaccharides from S. chinensis Baill. The results showed MAEE had higher extraction yields, lower temperature and shorter processing time than UAE, EAE and HRE. Zhang et al. (2013) studied the MAEE of polyphenols from waste peanut shells. The results showed that the extraction yield of total polyphenols using MAEE was higher than HRE, UAE and EAE, which indicated that MAEE system was more efficient than the other three methods.

Ultrasonic microwave-assisted extraction (UMAE)

UMAE, the combination of UAE and MAE, is one of the most promising hybrid extraction technologies for efficient and eco-friendly extraction. UMAE of bioactive compounds has been studied in many researches which showed UMAE is a cost-effective extraction technique for fast sample preparation and a new strategy for process intensification due to high efficiency, short extraction time and high extraction yield (Cravotto et al. 2008). With the combinations of two irradiations, the apparatus of UMAE system (shown in *Fig.2.*) involves technical and safety considerations. Many studies have used UMAE to extract bioactive compounds. Bagherian et al. (2011) investigated the effect of ultrasound as a pre-treatment step for microwave extraction of pectin from grapefruit. Barrera et al. (2014) studied the extraction of anthraquinones (AQs) from Rubiaceae by UMAE which was proven to be an attractive extraction technique. UMAE generated highest efficiency when compared with UAE and Soxhlet extraction.

Conclusion

Combination of the novel extraction technologies can be ideal alternatives to conventional extraction due to the benefits of reduction of extraction time, energy and solvents consumption, unit operations, and economic costs as well as the clean and eco-friendly features.

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QUALITY EVALUATION OF MACKEREL FILLETS AFTER HIGH PRESSURE TREATMENT

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Abstract

High pressure processing (HPP) is a novel, non-thermal technology, which has been widely researched in food industry. The present study aimed to investigate microbial and physicochemical parameters of fresh mackerel fillets after high pressure treatment at 100, 300 and 500 MPa during 2 and 5 min at 10℃. The results demonstrated that total viable counts (TVC) decreased with the most intense treatments, while H_2S-producing bacteria load decreased to undetectable level except for treatments of 100 MPa during 2 and 5 min. Compared with untreated samples, minor changes on hardness were observed except for the treatment of 500 MPa, when significant increase ($p<0.05$) was detected. No significant differences on lipid oxidation were observed. L^* increased and a^* decreased with the most intense treatments except for 100 MPa during 2 and 5 min, however, no significant changes ($P>0.05$) were detected on b^*. HPP was effective in inactivating microorganisms on mackerel fillets, but it also affected some physicochemical attributes.

Introduction

Among foods, fish is one of the most important commodities, which is popular all over the world, due to its rich nutrition of proteins, vitamins, essential amino acids. Besides, fish is acknowledged as the natural resources of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which is significant for brain development. The highly perishable feature of fish requires appropriate processing methods to avoid microbial spoilage in order to extend its shelf life and remain nutrition at the same time.

Traditional sterilization method is normally thermal pasteurization, which is useful in killing microorganisms, but it can also lead to the damage of nutrition and organoleptic properties. Nowadays, consumers have growing demands for minimally processed, fresh-like, and free additives foods that are healthy and safe with superior nutritional and sensory characteristics, which triggered the exploration and development of hurdle and non-thermal techniques.

High pressure processing (HPP), also referred to as high hydrostatic pressure processing, is a novel, non-thermal technology of preservation for both liquid and solid foods. HPP is capable of inactivating harmful vegetative bacteria, spores and pathogens, while it has minor effect on low-molecular-weight compounds such as pigments, vitamins and flavour compared with thermal process, thus it can keep the colour, texture, taste and nutrition as fresh-like.

Due to these advantages, HPP has been widely used in many fruits and vegetables juice (Jayathunge *et al.,* 2015; Kaushik *et al.,* 2014), ham, turkey, beef (Pietrasik *et al.,* 2016) and so on. HPP is a batch process with intense pressure of 200-800 MPa at mild temperature (< 45 °C), but the process will increase the temperature of products, which is called adiabatic heating, while the increment depends on food characteristics and transmitting fluid, which is usually 2-9℃/100 MPa (Muntean *et al.,* 2016).

The objective of this study was to evaluate microbial inactivation and physicochemical changes of fresh mackerel fillets immediately after treated with high pressure at 100, 300 and 500 MPa during 2 and 5 min at 10℃ respectively.

Materials and Methods

Sample preparation
Fresh mackerel fillets were bought from Dublin, Ireland, and then they were sent to the lab with ice box in half an hour. Subsequently, the fillets were vacuum-packaged individually and treated with high pressure. Three replicates for each treatment were carried out on three different days.

HPP equipment and process
HPP was conducted in a high pressure machine (Stansted Fluid Power Ltd., Essex, UK), and a mixture of oil-water was used as pressure transmitting medium. The HPP unit was cooled to 10℃ before treatments, afterwards vacuum-packaged samples were pressurized at 100, 300, and 500 MPa during 2 and 5 min.

The process of HPP is that after the pre-packaged products transferred into pressure vessel, transmitting medium will be pumped into the vessel from the bottom. Once the desired pressure is obtained, the pump will be stopped. Nevertheless, no further energy is needed because the pressure will be held. During the process, the pressure is applied simultaneously and uniformly in all directions on the products regardless of their geometry and size, leading to the avoidance of temperature gradients, which usually happens in thermal pasteurization.

Microbial analysis
10 g mackerel taken from each sample was homogenized with 90 ml maximum recovery diluent (MRD), and then a series of decimal dilutions were prepared in MRD. Total viable counts (TVC) were determined on plate count agar (PCA) and incubated at 30℃ for 48 h, while H_2S-producing bacteria were determined on Iron agar with 0.8% L-cysteine and incubated at 25℃ for 72 h.

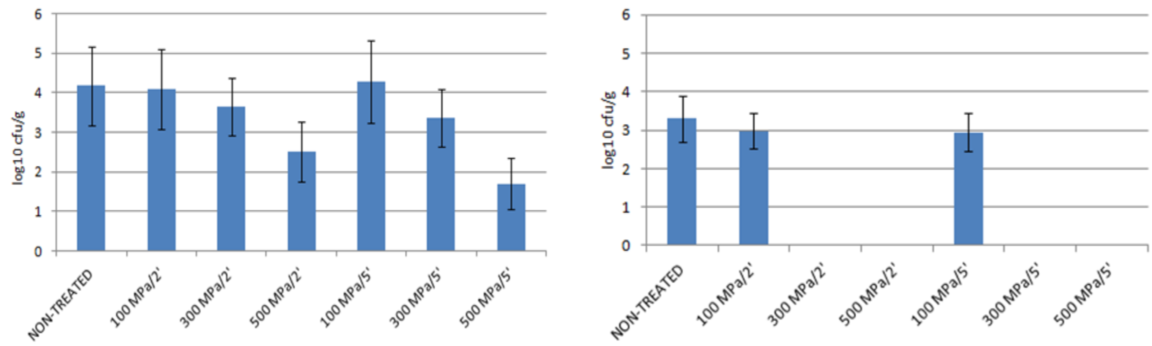
Texture analysis
Hardness was determined by texture profile analysis (TPA) method. Samples were cut into cylinders with the diameter of 13 mm, after that they were compressed with a cylindrical probe of 50 mm diameter. The load cell was 500 N at a speed of 60 mm/min, and 60% compression of the original height. Five measurements on each sample were carried out and replicated three times on three different days.

Lipid oxidation analysis
Lipid oxidation was estimated as thiobarbituric acid reactive substances (TBARS). Calibration was performed towards a standard curve of TEP (1,1,3,3-tetraethoxypropane). The level of TBARS was calculated as mg malonaldehyde (MDA)/ Kg sample.

Color analysis
L^*, a^* and b^* were measured with a colorimeter (UltraScan equipment) in different locations of each mackerel fillet, where L^*, a^* and b^* stand for lightness, redness and yellowness respectively. The average of three measurements per sample was expressed as the final result.

Results

HPP on microbial inactivation
The trend was that TVC decreased with the increasing of pressure and treatment time. No significant differences (P>0.05) were detected at 100 MPa during 2 and 5 min in TVC compared with un-treated ones. The highest reductions were obtained at 500 MPa during 2 and 5 min. The treatment of 100 MPa didn’t affect significantly on H_2S-producing bacteria. However, H_2S-producing bacteria load decreased to undetectable level under all the other conditions (seen in Figure 1).



(a) (b)

Figure 1. Microbial inactivation of (a) TVC (b) H_2S-producing bacteria after HPP.

HPP on texture analysis

Figure 2 showed minor changes on hardness except for the condition of 500 MPa during 2 and 5 min, when significant increase (P<0.05) were detected.

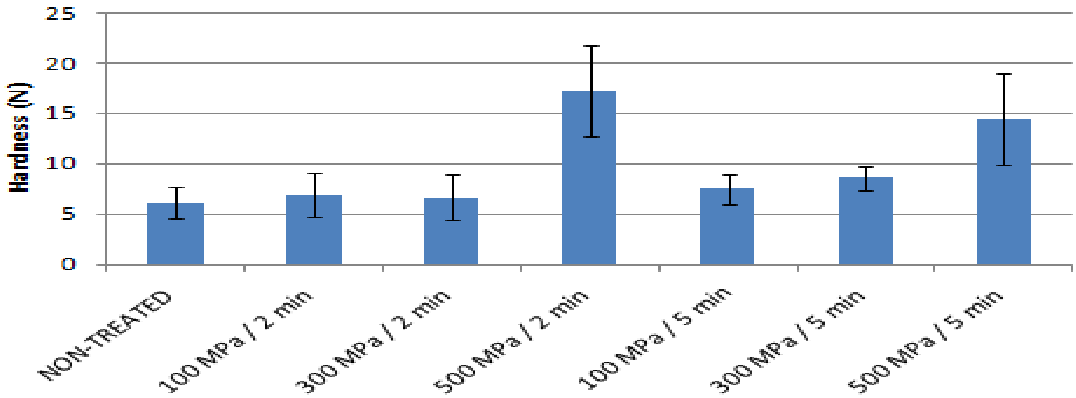


Figure 2. Hardness after HPP

HPP on lipid oxidation

Lipid oxidation was not significantly (P>0.05) affected by HPP treatments (seen in Figure 3).

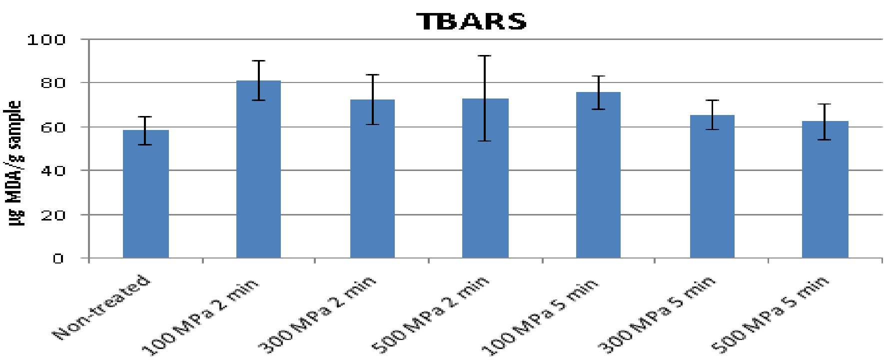


Figure 3. Lipid oxidation of TBARS after HPP.

HPP on colour

Figure 4 demonstrated that L^* increased significantly except for 100 MPa during 2 and 5 min, while a^* decreased significantly (P<0.05) with the most intense treatments. However, b^* remained almost the same.

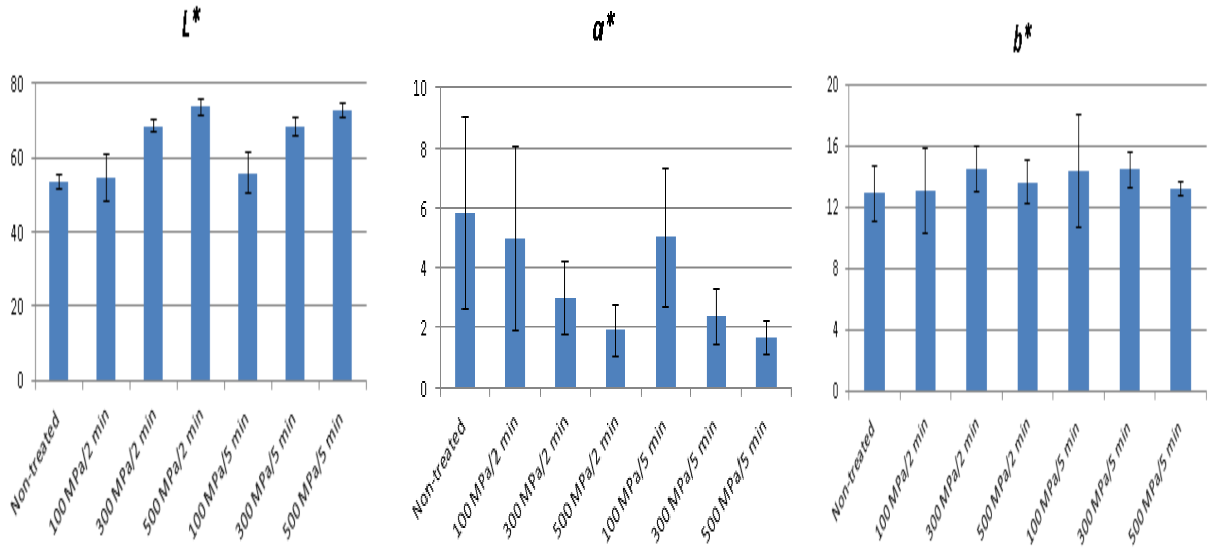


Figure 4. Colour parameters of L^*, a^* and b^* after HPP.

Conclusions

HPP can be considered as an alternative method in killing microorganisms and it has minor negative effect on texture, lipid oxidation and colour on fresh mackerel fillets.

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HYPERSPECTRAL IMAGING AS NON-DESTRUCTIVE ASSESSMENT TOOL FOR THE RECOGNITION OF SWEET POTATO CULTIVARS

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Abstract

The reliability and accuracy of hyperspectral imaging combined with chemometrics technique were investigated for recognition and classification of sweet potato cultivars. Hyperspectral images of tuber samples were acquired and corrected. Then the extracted data were analyzed by principal component analysis (PCA) and partial least squares discriminant analysis (PLSDA) for identification of different sweet potato categories. The spectra were pre-processed by second derivative (2^{nd} Der). Then, eight important wavelengths (1074, 1125, 1155, 1202, 1295, 1342, 1376 and 1406) were identified as characteristic wavelengths based on 2^{nd} Der spectra. These resulting wavelengths were used in PLSDA for classification of sweet potato samples, yielding 100 % overall classification accuracy in the cross-validation set. The results obtained in this study clearly showed that the combination of hyperspectral imaging and multivariate analysis has a great potential as a novel and rapid approach for identification and authentication of sweet potato cultivars.

Introduction

Sweet potato (*Ipomoea batatas* L.) is a main tuber crop that is rich in starch, complex carbohydrates, dietary fibre, beta-carotene, minerals, vitamins and phenolic acids. Furthermore, as the important vegetable and industrial raw materials, sweet potatoes are convenient for processing and can be processed into many products, e.g., dehydrated outputs, noodles, sweets and canned sliced tubers. The shelf-life of the sweet potato increases after drying and it is easily stored without refrigeration. Besides, sweet potato has strong adaptability, high yield, and a long industrial chain, which makes them one of the most popular healthy and nutritious foods. With the improvement in living standards, people currently pay more attention to the safety and authenticity of tuber products including sweet potato. Moreover, with the access to information, accurate labelling is of importance to help consumers to select appropriate types of sweet potato to meet their needs. In addition, accurate labelling is also important to support fair-trade. Unfortunately, regulations are not sufficient to prevent food fraud or mislabelling. To ensure adherence to regulations, and to get a comprehensive knowledge about authentication, robust analytical methods are extremely required. The identification of sweet potato from different cultivars is still performed manually in the tuber industry, which is laborious and low accuracy. Therefore, a rapid and reliable tool to discriminate sweet potatoes could be useful from the industrial point of view.

Hyperspectral imaging was developed for providing both spectral and spatial information of an object by integrating spectroscopic and imaging techniques into one system (Sun 2010). Hyperspectral imaging enabled this system to simultaneously provide physical and chemical characteristics of an object as well as their spatial distributions (Elmasry *et al* 2012). Recent years, hyperspectral imaging has emerged as a more powerful alternative tool of food safety evaluation than any other non-destructive techniques (Wu *et al* 2013; Su *et al* 2015).

The spectral signatures of hyperspectral image can be used to uniquely characterize, identify and discriminate among any types of given materials. Very few investigatiosn have been published for differentiation of sweet potato cultivars using NIR hyperspectral imaging, **the main aim of this study was to investigate the potential of hyperspectral imaging as a rapid and non-invasive tool for recognition of sweet potato cultivars.**

Materials and Methods

Samples preparation

The 144 sweet potato samples including sweet potato 1 (SP1) (variety: Covington, origin: USA) and sweet potato 2 (SP2) (variety: Evangeline, origin: Egypt) were collected from local supermarkets. Then all the fresh samples were transported to laboratories of Food Refrigeration & Computerized Food Technology (FRCFT), University College Dublin (UCD), Ireland. The number of sweet potato samples of each cultivar was 72 in this study.

Hyperspectral imaging system

The system used for acquiring hyperspectral images consisted of five parts which are an illumination unit including two 500 W halogen lamps (ViP V-light, Lowel Light Inc., NY, USA), a spectrograph (ImSpector N17E, Specim, Spectral Imaging Ltd, Oulu, Finland) with working spectral range from 897 to 1753 nm (256 bands) at 3.37 nm intervals, a C-Mount CCD camera (Xeva 992, Xenics Infrared Solutions, Leuven, Belgium) covering 320 × 256 (spatial × spectral) pixels, a translation stage connected with a stepper motor (GPL-DZTSA-1000-X, Zolix Instrument Co, Beijing, China), and a computer installed hyperspectral image acquisition software (SpectralCube, Spectral Imaging Ltd., Oulu, Finland) where the scan mirror, motor speed, exposure time, image acquisition and correction can be controlled.

Reflectance Calibration and Images Acquisition

Before image acquisition, reflectance calibration was carried out to account for the background spectral response of both the instrument ("W") and the "Dark" camera. The corrected reflectance value ("R") was calculated from the determined signal ("I") in a pixel-by-pixel basis as indicated by:

$$R_i = \frac{I_i - Dark_i}{W_i - Dark_i}$$

Where i is the pixel index, i.e. i=1,2,3…,n and n is the total number of pixels within the region of interests (ROI).

Data analysis

Average spectra of each sweet potato sample were extracted from the original hyperspectral image using Matlab software. Initial investigation was carried out using principal component analysis (PCA) to visualize the spectral data and to examine any possible grouping of samples according to spectral features of the tested meat species. As an unsupervised pattern recognition, PCA uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (PCs). The first PC covers as much of the variation in the data as possible and the second PC covers as much of the remaining variation as possible, and so forth. Each PC can be interpreted independently which permits an overview of the data structure by revealing the relationship between the objects. Then calibration models were developed using partial least squares discriminant analysis (PLSDA) for distinguishing sweet potatoes. PLSDA is a common chemometric technique for supervised classification of the spectra. Wavelength selection is a widely used technique to reduce the dimensionality of hyperspectral data. Second derivative (2^{nd} Der) by Savitzky–Golay method was used in this study for dimensionality reduction and to identify the most effective wavelengths that have the great contribution in discrimination. A calibration phase and a cross-validation phase calculating for are employed in the models for presenting model performance. The best model should obtain higher sensitivity, specificity, determination coefficients in calibration (R^2_C), in cross-validation (R^2_{CV}), and the lower classification error, and the root mean square error in calibration (RMSEC) and in cross-validation (RMSECV).

Results and Discussion

Figure 1 shows mean reflectance curves of SP1 and SP2 in the range of 944 to 1678 nm. The average spectra of SP1 and SP2 are displayed in similar trends and twisted together. The difference of reflectance values are related to the characteristics of the tested tuber slices.

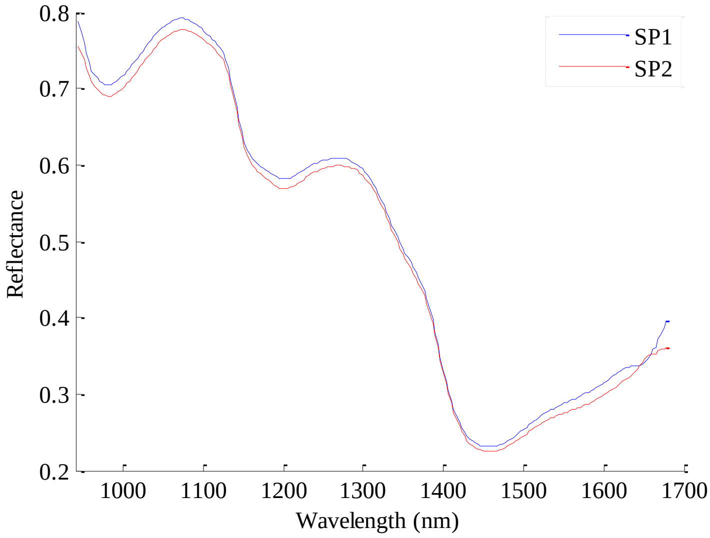

Figure 1. Mean spectra of SP1 and SP2.

The NIR range is an important spectral region containing spectral absorption features that are related to overtones and combinations of fundamental vibrations of C–H, N–H, O–H and S–H functional groups. The most intensive local absorption peaks were found at 977 nm (O–H stretching second overtones) and around 1456 nm (O–H stretching first overtones), which was related to the absorption of moisture. Absorption band at 1202 nm (C–H stretching second overtone) was attributed to starch content.

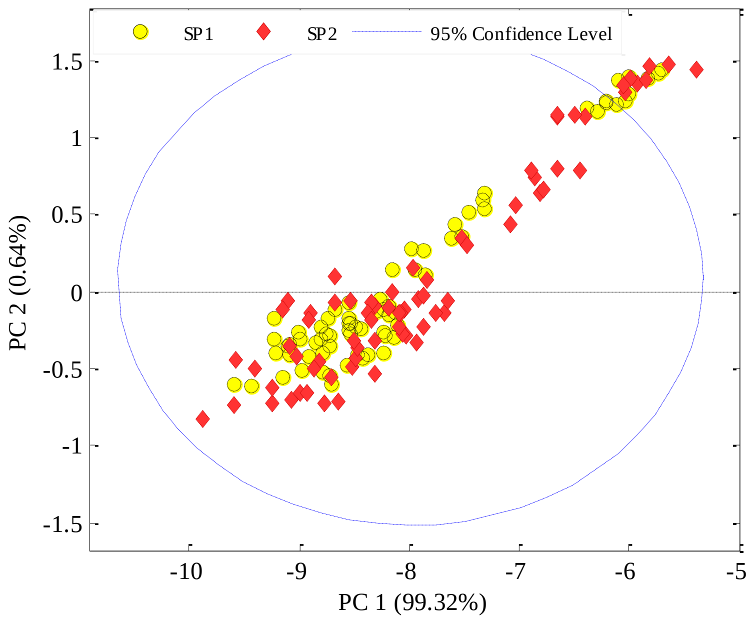

Figure 2. Scores plot of spectral data for first two PCs.

The score plot of first two PCs shown in Fig. 2b revealed that two sweet potato cultivars had similar grouping patterns. Because it was difficult to separate these two cultivars from each other easily by PCA, though the PC1 and PC2 were particularly representative of the spectral information and explained 99.96% of the total variance (PC1-99.32% and PC2-0.64%). This indicated that their composition and physicochemical characteristics are more similar among these potato varieties.

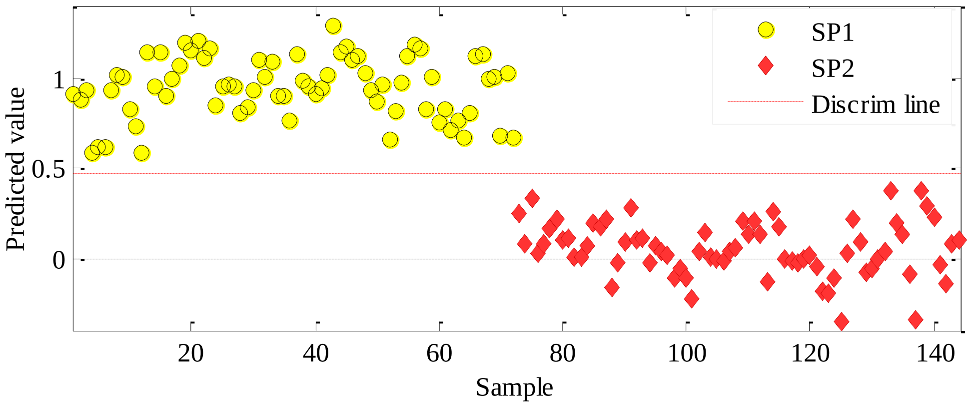

Figure 3. Estimated class values for discrimination of sweet potato cultivars

Based on the 2nd Der for spectra pre-processing, eight feature wavelengths (1074, 1125, 1155, 1202, 1295, 1342, 1376 and 1406) were selected from the full spectral range (900-1700 nm) and used to developed recognition 2nd Der-PLSDA model, with sensitivity and specificity of 1, R^2_{CV} of 0.90, and RMSECV of 0.16. As can be seen in Fig. 3, SP1 and SP2 were evidently separated using the 2nd Der-PLSDA model, achieving 100 % accuracy in the cross-validation set.

Conclusions

Hyperspectral imaging technique was utilized to authenticate sweet potato cultivars. Eight characteristic wavelengths (1074, 1125, 1155, 1202, 1295, 1342, 1376 and 1406) were selected using 2nd Der. The classification performance of sweet potato cultivars using 2nd Der-PLSDA was much better than PCA, with the correct recognition rate of 100%. The result showed that hyperspectral imaging technique combined with 2nd Der-PLSDA had a big potential in the tuber industry for rapidly and non-destructively classifying the sweet potato cultivars.

Acknowledgements

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RAPID CLASSIFICATION OF WHITE STRIPE AND RED MUSCLE PIXELS IN SALMON FILLET BY USING NEAR-INFRARED HYPERSPECTRAL IMAGING COMBINED WITH PCA AND MCR

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Abstract

This study was carried out to investigate the potential of a near infrared (900-1700 nm) hyperspectral imaging (HSI) system for discrimination of white stripe and red muscle pixels in conventional farm-raised salmon fillets. Hyperspectral cubes were acquired, calibrated and their corresponding spectra data were extracted. Principal component analysis (PCA) was applied to explore the variance. Satisfied unsupervised classification of 650 pixels of white stripe and 650 of red muscle was obtained by using PCA. Multivariate curve resolution (MCR) was then applied to build classification map with good performance achieved. This study confirmed the capability of the hyperspectral imaging for objective and rapid categorization of the white stripe and red muscle pixels of salmon fillets.

Introduction

Salmon is valued as a fat-rich fish with a large proportion of lipids congregated in white stripe of connective tissue (myocommata), segmenting the red-colored muscle tissue in vertical blocks and presenting a zebra-like appearance. Previous research has confirmed that the proportion of myocommata in a salmon fillet correlated well with its fat content (Segtnan et al. 2009). Stien et al. (2007) built an approach for the rapid and automatic measurement of fat content in salmon fillets based on computer vision system, and demonstrated that fat content could be estimated based on image analysis to calculate the area of the white stripes visible on the surface compared to the total area of the fillet. In recent years, Xu et al. (2016b) attempted to apply particle analysis on the images to extract only the spectra from white stripe in salmon fillet to assess lipid oxidation. Overall, it is important to classify white stripe from the red muscle because the proportions of white strip in one fillet might contain some valuable information about the fat content and/or lipid oxidation.

Principal component analysis (PCA) is a widely-used statistical procedure for unsupervised classification of the spectra and it is increasingly-used in hyperspectral data analysis. Meanwhile, multivariate curve resolution (MCR) has established itself as one of the most versatile chemometrics tools (Jaumot *et al.* 2005). Therefore, **the objective of this study was to investigate the suitability of using near infrared (900-1700 nm) hyperspectral imaging for rapid and non-destructive determination of the proportion of white stripe in salmon.**

Materials and Methods

Fish sample preparation

Conventional farm-raised Atlantic salmon (*Salmon salar*) fillets originated from a farm in Ireland were labelled and then transported to laboratories of Food Refrigeration and Computerized Food Technology (FRCFT), University College Dublin (UCD), Ireland. Each fillet was about 200 grams in different sizes and no any two fillets were cut from one fish. The details about the sample can be found elsewhere (Xu *et al.* 2016a).

Hyperspectral image acquisition and calibration

Hyperspectral images of this work were obtained in reflectance mode by employing a laboratory-based pushbroom hyperspectral imaging system working in the wavelength range of 900-1700 nm with a spectral resolution of 3.34 nm (a total of 256 bands were recorded for each spectrum).Each salmon fillet was firstly placed on the translation stage and then conveyed to the field of view (FOV) of the camera to be scanned line by line. After eliminating noisy signal at the beginning and end of the spectral region, 180 wavebands were retained for each spectrum.

Multivariate exploration of images

The final result of measuring a hyperspectral image is a 3-D dataset named as 'hypercube' with one spectral dimension (λ) and two spatial dimensions (x, y). Each hypercube in this study contains one class of salmon fillet and background. It usually comprises thousands of spectra (spectral signature) distributed over the measured area (spatial signature). Thus, it is essential to explore and understand the structure of the hyperspectral image in order to select the proper tools for dealing with the final aim. Among all the methods for multivariate exploration, principal component analysis (PCA) is the most versatile and widely-used. It aims at studying the variability (variance) by dividing the hypercube into a set of surface scores and spectral loadings.

Classification maps

Multivariate curve resolution-alternating least squares (MCR-ALS) has been widely used for the resolution of multiple component responses. It aims to decompose mixtures of spectra response into individual components resembling true chemical entities. In this work, MCR was conducted by using a new graphical user-friendly interface which is developed as a freely available MATLAB toolbox. Two hyperspectral imaging salmon samples were used to demonstrate MCR performance. Each sample was first calibrated and segmented. Pure spectra of white stripe and red muscle were obtained by manual selection. The pixel spectra without background were used as the input of the MCR toolbox. The output of MCR toolbox was the concentration for white stripe and red muscle, respectively.

Results and Discussions

Spectral feature analysis

The reflectance and absorbance spectral data extracted from the 650 pixels of white stripe and 650 pixels of red muscle in the 900-1700 nm spectral range pre-processed by standard normal variate (SNV) are shown in Figure 1. Second derivative transformation is a popular pre-processing method that is commonly used to eliminate background noise, and enhance spectral resolutions. Therefore, second derivative by Savitzky–Golay algorithm was used and presented. As shown, there is an obvious absorption peak located around 1150 which was assigned to the C-H stretching first and second overtones. Figure 1 also showed other 2 prominent positive peaks at 1405 nm and 1205 nm. The absorption peak at 1205 nm was attributed with an overtone for fat components, as reported by Osborne *et al.* (1993).

Image exploration by PCA

A PCA model was built in order to explore the variance in the 650 spectra of white stripe and 650 of red muscle. The detailed performance is present in Figure 2. This PCA model was performed based on spectra pre-processed by SNV and mean centre. The total amount of variance explained by the first four principal components (PCs) was higher than 99%, indicating that the main differences are presented within these three PCs. The loading plot further confirmed the waveband at 1205 nm has great significance in discrimination of white stripe and red muscle, which is in good agreement with the previous spectral profiles. The score plot showed that the white stripes display distinctive spectral signatures compared with that of red muscles, which revealed that it is possible to classify them into two clusters.

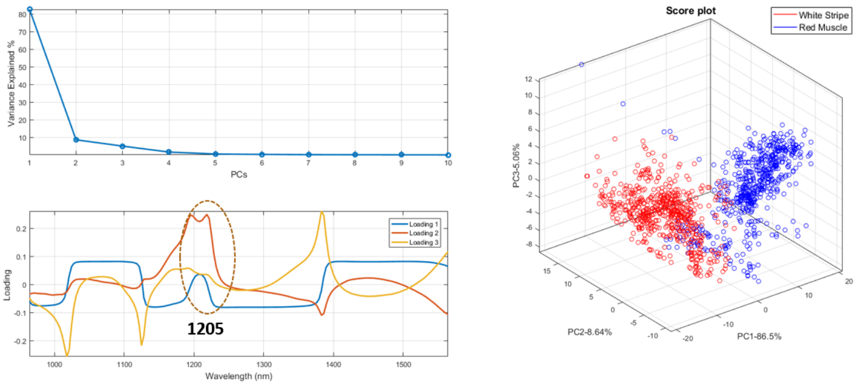

Figure 2. PCA model of 650 spectra of white stripe and 650 red muscle

Classification maps by MCR

Two hypercubes from different parts of salmon were selected to demonstrate MCR classification performance. When it comes to generate the prediction map, the first and fundamental step is to "unfold" hypercubes such that the three-dimensional information is rearranged in two-dimensional matrix where each row represents the spectrum from each pixel and each column refers to a certain wavelength variable. This matrix was used as the input of MCR toolbox and the output is the two-column concentration matrix which can be refolded and presented in Figure 3.

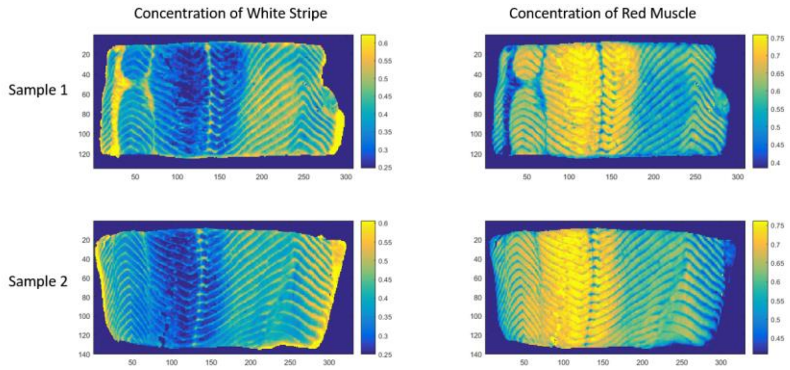

Figure 3. Concentration maps obtained from MCR.

After selecting optimal threshold values, prediction maps can be created. The first obtained matrix contains "0" if the pixel was identified as background; "1" if the pixel was classified as white stripe or "2" if it was recognised as red muscle. This matrix is then transformed to produce a classification map where white colour is assigned to white stripe class and red colour to red muscle to match the true colour in the real world. The final performance can be obtained in Figure 4. As can be seen, promising classification results were achieved with most pixels correctly identified.

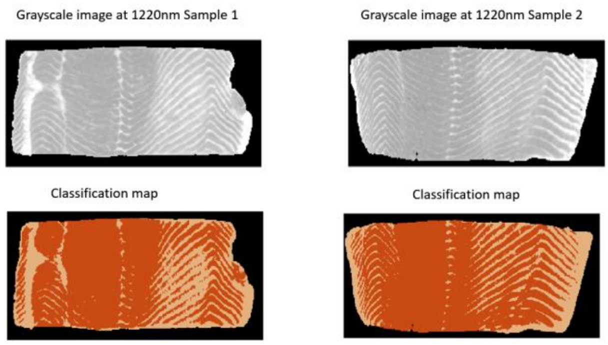

Figure 4. Grayscale images and classification maps obtained from MCR.

Conclusions

This study demonstrated the great potential of hyperspectral imaging for rapid and non-invasive discrimination between white stripe and red muscle pixels in salmon fillets. The successful outcome of this study would be very advantageous to fast determine fat content or lipid oxidation status in salmon.

Acknowledgements

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PRELIMINARY STUDIES ON SORPTION ISOTHERMS OF APPLES AND PEAR AT 25 ^{O}C

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Abstract
Moisture sorption isotherms of ‘Golden Delicious’ apples and ‘Conference’ pears were determined at 25 ^{o}C using the standard salt static method. A satisfactory agreement between experimental and predicted isothermal data was reached by using Guggenheim-Anderson de Boer (GAB) model. To get highly accurate regression results, the three constants of the GAB model were evaluated using Genetic-simplex Hybrid Algorithm. The calculated monolayer moisture contents indicates that, in order to avoid unnecessary energy consumption, the drying of ‘Golden Delicious’ apples and ‘Conference’ pears should not proceed to a moisture content lower than 9.99 and 11.71 g H_2O/100g d.b. respectively.

Introduction
Moisture sorption isotherm is a plot of moisture content versus water activity (a_w) at a certain temperature. It reveals information about food-water interaction. This information is extremely important for the storage stability of foods (Yu et al., 2013). The knowledge of sorption properties could also help to specify boundary conditions in the numerical simulation of food drying process (Viollaz and Rovedo, 1999). Apples and pears are two of the most consumed fruits worldwide. Their moisture sorption properties were reported by several researchers (Kaymak-Ertekin and Gedik, 2004, Mrad et al., 2012). However, the information on isotherms of ‘Golden Delicious’ apples and ‘Conference’ pears is still very limited. More than 70 isotherm equations have been reported in the literature (van den Berg, 1991). Among them, the Guggenheim-Anderson de Boer (GAB) model presents a great versatility and is mostly recommended in prediction of food isotherms (Maroulis et al., 1988, Kaymak-Ertekin and Sultanoğlu, 2001). **The objective of this study was 1) to determine moisture sorption isotherms of ‘Golden Delicious’ apples and ‘Conference’ pears at 25 ^{o}C; 2) to test the goodness of fit of their isothermal data to the GAB model ; 3) to calculate their monolayer moisture contents from the GAB model.**

Materials and Methods
‘Golden Delicious’ apples and ‘Conference’ pears were produced in Turkey and bought from local markets in Ireland. Samples were stored at 2 ^{o}C until use within one week.

Standard Salt Static (SSS) Method
Around 0.1 g samples were kept in sealed containers to get equilibrium with 11 saturated salt solutions at 25 ^{o}C (Table 1). Samples were weighed once a day until the difference between two consecutive measurements was less than 0.0002 g. After

equilibrium, dry basis of apple and pear samples was determined by oven drying (105 ^{o}C for 4 h).

Table 1. Water activity of the saturated salt solutions used in this study (25 ^{o}C).

Salt	Water activity	Reference
LiBr	0.068	This work[a]
LiCl	0.113	This work
CH3COOK	0.221	This work
MgCl2	0.325	This work
K2CO3	0.438	This work
NaBr	0.578	This work
SrCl2	0.7083	Greenspan (1977)
NaCl	0.753	This work
KCl	0.843	This work
BaCl2	0.9026	Greenspan (1977)
K2SO4	0.973	This work

[a] Water activity of salt solution were measured by Novasina LabMaster-Aw (Switzerland, Novasina Ltd.) in this work.

Mathematical modeling of the sorption isotherms

Isothermal data of apples and pears were fitted to Guggenheim-Anderson de Boer (GAB) model (Eq.(1)) by nonlinear regression using MATLAB R2012b software. A Genetic-simplex Hybrid Algorithm was used.

$$M = \frac{X_m C K a_w}{\left[(1-Ka_w)(1-ka_w+CKa_w)\right]} \tag{1}$$

where C and K are the constants related to the sorption heat, X_m is the monolayer moisture content (g H_2O/100g d.b.) (Maroulis et al., 1988).

Statistics

To evaluate the goodness of fit of GAB model, three statistic indicators were used (Cardoso and Pena, 2014, Vigano et al., 2014).

Root mean square error: $$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_{\exp,i} - M_{pred,i})^2} \tag{2}$$

Coefficient of determination: $$R^2 = 1 - \frac{\sum_{i=1}^{N}(M_{pred,i} - M_{\exp,i})^2}{\sum_{i=1}^{N}(M_{\exp,i} - \bar{M}_{\exp})^2} \tag{3}$$

Relative percentage deviation: $$P = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|M_{pred,i} - M_{exp,i}\right|}{M_{exp,i}} \tag{4}$$

Results and Discussion

The experimental data of equilibrium moisture content (EMC) versus water activity (a_w) for apples and pears are shown in Table 2 and Fig. 1. According to isotherm classifications by Brunauer et al. (1940), the sorption isotherms of both pears and apples showed type III behavior.

Table 2. Experimental EMC of pears and apples at 25 °C

a_w	EMC (g H_2O/100g d.b.)	
	Pear	Apple
0.068	5.80	6.45
0.113	6.34	7.057
0.221	7.88	7.588
0.325	9.79	10.43
0.438	13.76	13.73
0.578	21.70	20.93
0.7083	33.44	32.77
0.753	40.78	37.89

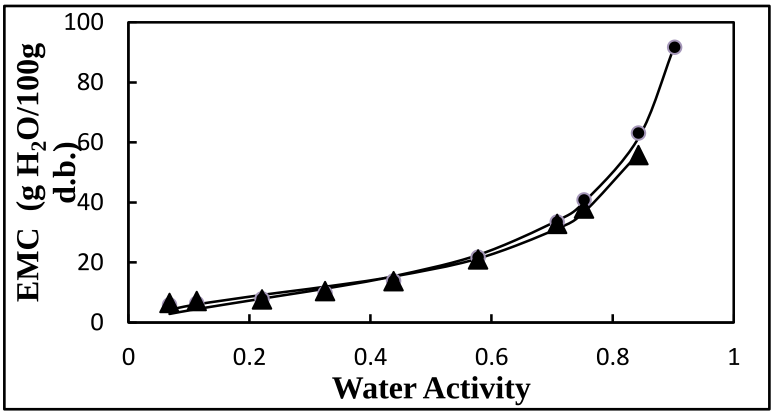

Figure 1: Moisture sorption isotherms of (●) pears and (▲) apples at 25 °C. Points denote the observed isothermal data and lines represent predicted data from GAB model.

Table 3. Fitted parameters of GAB model for pear and apple

Material	Constants			Performance/Statistical indicators		
	X_m	C	K	RSME	R^2	P
Pear	11.705	4.206449	0.971883	1.446402	0.99717	11.7937
Apple	9.98882	9.383251	0.980558	1.38884	0.99269	11.75683

Table 3 shows the fitting results of GAB model to isothermal data of pears and apples., The GAB model was confirmed to fit satisfactorily to sorption isotherms of ‘Golden Delicious’ apples and ‘Conference’ pears with a very good coefficient of determination ($R^2 > 99\%$) and a relatively small relative percentage deviation P. The monolayer moisture content (X_m) of apples and pears were calculated to be 9.983 and 11.705 g H_2O/100g d.b. respectively. Food is in its most stable condition at monolayer moisture. Thus, drying process should not proceed to a moisture content lower than $X_{m.}$ Otherwise, the water removal would consume significantly great energy.

Conclusions

The isotherms of ‘Golden Delicious’ apples and ‘Conference’ pears at 25 ^oC were classified to type III curves. The prediction ability GAB model was confirmed for sorption behaviours of both tested fruits. To avoid unnecessary energy losses, the drying of ‘Golden Delicious’ apples and ‘Conference’ pears should stop at a moisture content above 9.99 and 11.71 g H_2O/100g d.b. respectively.

Acknowledgements

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RIPENESS CLASSIFICAITON OF BANANITO FRUITS USING VISIBLE HYPERPSECTRAL IMAGING

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Abstract

Non-destructive and accurate determination of fruit maturity stage is important for its shelf-life prediction and marketability. This study investigated the use of visible hyperspectral imaging (Vis-HSI) technique (400-740 nm, 5 nm interval) for rapid and non-destructive classification of bananito fruits (*Musa acuminata*). Bananitos peel and flesh images were collected and classification models based on partial least square discriminant analysis (PLSDA) were established. Results showed that the peel Vis-HSI data performed better than flesh Vis-HSI data for ripeness stage classification. The PLSDA model based on peel spectra achieved a total correct classification rate of 93.3%, while the PLSDA model based on flesh spectra yielded a total correct classification rate of 83.3%. This study demonstrates the potential of using visible hyperspectral imaging system to acquire peel spectra for non-destructive classification of bananitos maturity stage.

Introduction

Bananito fruit (*Musa acuminata*) is a kind of small banana cultivated in tropical and subtropical areas. It provides all nutrients that the conventional bananas have, but in a sweeter, creamier and tasty flavour. Correctly classify banana fruits maturity stage is important for fruit transportation, quality control and shelf-life (Li et al., 2011). During the ripeness process, a significant change of banana fruits is the peel colour that changes from green to yellow. This is because the decomposition of chlorophyll and the synthesis of other pigments such as carotenoids (Hashim et al., 2012).

Traditionally, bananas maturity stages are mainly determined by the following methods: (1) visually evaluating the whole-fruit colour and comparing its colour with a standard colour chart; (2) measuring fruit firmness using a penetrometer; (3) or measuring some components such as the pulp to peel ratio, soluble solids content, titratable acidity and starch pattern. These strategies are based on apparent colour, texture and some chemical properties that are associated with fruit ripening. However, the determination procedure is generally time-consuming or even sample-destructive, which is not practical for widespread industrial application.

Several non-destructive methods, for example computer vison technique (Mendoza and Aguilera, 2004), electric nose (Eduard et al., 1999) and visible and near infrared spectroscopy (Zude, 2003) have been applied for classifying bananas maturity stages or predicting some quality attributes. Additionally, the use of hyperspectral imaging technique to predict total soluble solids, acid-Brix ratio, pH, and dry matter of banana fruits has been investigated (Rajkumar et al., 2012). However, for the bananito fruit, there is a lack of understanding the potential of using hyperspectral imaging technique for its maturity stage classification.

The objective of the study was to investigate the potential of hyperspectral imaging technique in visible spectral range (400-740 nm) for non-destructive classification of bananito fruits maturity stage.

Materials and Methods

Bananito fruits

Ninety bananito fruits were supplied by a fruit company (AL.MA s.r.l.) in Milan, Italy. Thirty fruits were in maturity stage 2, twenty-six fruits were in maturity stage 4 and thirty-four fruits were in maturity stage 6. The maturity stage was determined by visually inspecting the whole fruit colour according to a ripeness colour chart provided by the supplier. The weight and diameter (measured at the central part) of the fruits were measured and shown in Table 1.

Table 1. Weight and diameter of bananito fruits used in the study.

Ripeness stages	2	4	6
No. of fruits	30	26	34
Diameter (mm)	22.51±1.19	22.57±1.21	23.03±1.48
Weight (g)	47.00±6.26	48.90±5.31	48.64±7.07

The diameter and weight data are presented as 'mean±standard deviation' for each ripeness stage.

Hyperspectral imaging system

A desktop hyperspectral imaging system (DV S.r.l., Padova, Italy) was employed to simultaneously acquire the spatial and spectral data from bananitos skin and flesh, respectively. The HSI system mainly consists of a CCD camera (avA 1000-100gm, Basler AG, Germany), a spectrograph (V10H, Spectral Imaging Ltd., Finland) providing spectral information from 400 nm to 1000 nm with a resolution of 5 nm, and a cylindrical diffuser equipped with 150 W halogen lights. System configurations could be found in the study of Taghizadeh et al. (2009). Both sides of the whole-fruit were scanned. After that, each fruit was peeled and cut in lengthwise, one flesh-half was scanned.

Data analysis

Images and spectra processing were conducted by use of Matlab 2015a (The Math Works, Inc. USA) and PLS_toolbox 8.2 (Eigenvector Research, Inc., United States).

Mean-spectra extraction and dataset splitting

After removal of the background from the raw images using simple thresholding method (Pu and Sun, 2016), the mean-spectrum for each sample was extracted by averaging all pixels-spectra that belonged to the sample. The total ninety samples were divided into a calibration set (2/3 of the samples) and a validation set (1/3 of the samples).

PLSDA classification

PLSDA (Brereton and Lloyd, 2014) is a linear parametric classification method based on the partial least square (PLS) algorithm. The optimal number of latent variables (LVs) was selected in the plot of the average classification error as a function of the latent variable number. Classification performance was determined by total correct classification rate (TCC%), as shown in equation 1.

$$\mathrm{TCC}(\%)=\frac{N_c}{N_{total}}\times 100 \qquad (1)$$

where N_c represents the number of samples being correctly classified and N_{total} indicates the total number of samples in the prediction set.

Results and Discussion

Spectral profiles of bananito peel and flesh

Figure 1 shows the spectral profiles of bananito peel and flesh extracted from the hyperspectral imaging data. As shown in Figure 1(a), the raw peel spectra of stage 6 fruits had a relatively higher reflectance while the raw peel spectral of stage 2 fruits showed a relatively lower reflectance, indicating that the relative reflectance intensity on bananito peel increased with increasing the maturity stage. However, for the raw flesh spectra as shown in Figure 1(c), the spectra of bananito samples in three maturity stages were overlapped. Spectral scattering effect was observed in both peel and flesh spectra. With spectral pre-treatment of SNV, the scattering effect was significantly reduced, as shown in Figure 1(b) and (d).

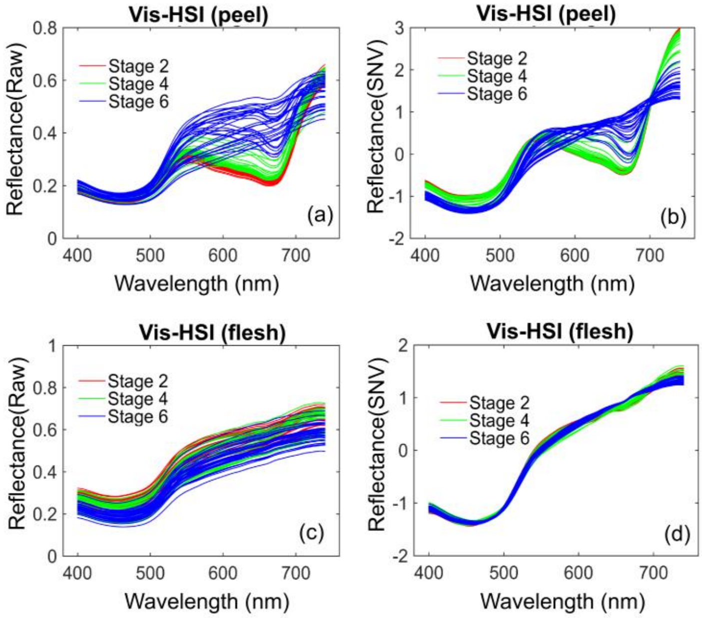

Figure 1. Spectral profiles of bananito peel and flesh. (a) and (c) shows the raw mean-spectra of bananito peel and flesh, respectively; (b) and (d) shows the corresponding mean-spectra with SNV pre-treatment.

PLSDA classification performance

PLSDA was applied to the full spectra that were pre-treated with SNV and mean-centring. As shown in Table 2, classification performance of PLSDA models developed on Vis-HSI and Vis-HSI flesh spectra were compared. For the PLSDA-peel model, of the actual ten samples in stage 2, this model predicted that nine samples were in stage 2 and one sample was misclassified as stage 4. Of the actual nine samples in stage 4, the above model predicted that eight samples were in stage 4 and one sample was in stage 2. All stage 6 samples have been correctly classified. Thus, the total number of samples being correctly classified was 28, giving a TCC%=93.3%. For the PLSDA-flesh model, the model classification performance for stage 2 and stage 6 fruits were the same as the PLSDA-peel model. However, a poor classification accuracy was obtained for the stage 4 samples, which had a ripeness level between stage 2 and 6. Of the actual nine samples in stage 4, the PLSDA- flesh model predicted that five samples were in stage 4, one sample was in stage 2 and three samples were in stage 6, leading to TCC% of 83.3%.

Table 2. Comparison of PLSDA models developed on peel or flesh Vis-HSI full spectra.

Model	No. of LVs	Confusion matrix in prediction set				No. of TCC samples	TCC (%)
			Predicted stage 2	Predicted stage 4	Predicted stage 6		
PLSDA-peel	5	stage 2	9	1	0	28	93.3
		stage 4	1	8	0		
		stage 6	0	0	11		
PLSDA-flesh	5	stage 2	9	1	0	25	83.3
		stage 4	1	5	3		
		stage 6	0	0	11		

Conclusions

Based on the full spectra extracted from bananito peel and flesh hyperspectral images, the developed PLSDA-peel model gave a total correct classification accuracy of 93.3% for bananito fruits maturity classification. The PLSDA-peel model performed better than the PLSDA-flesh spectra (TCC%=83.3%), suggesting that hyperspectral imaging technique in visible spectral range (400-740 nm) could be applied for fast, accurate and non-destructive ripeness classification.

Acknowledgements

The authors would like to thank Annamaria Stellari for technical support and the AL.MA s.r.l. company for bananito fruit supply. UCD-CSC Scholarship Scheme supported by University College Dublin (UCD) and China Scholarship Council (CSC) was also acknowledged for this study.

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EXPOSURE ASSESSMENT TO SALT FOR ARABIAN CONSUMERS

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Abstract

The World Health Organization has stated that the levels of salt in different food products pose a major concern to human health and that more research is required to determine the risk of dietary salt exposure. Salt is the primary source of sodium and increased consumption of sodium is associated with hypertension and increased risk of stomach cancer disease, high blood pressure, heart disease and stroke. This study will evaluate the likely human consumption of different food products using an Arabian Food Survey for each age group and evaluate the likely human health risk posed by salt in the diet. An exposure assessment model will be developed based on the principles of qualitative/quantitative assessment with the RASP simulation software to determine how predicted exposure concentrations relate to the regulatory requirements set out by WHO, in the range of 5g of salt for adults per day, and less than that for children. The model developed in this study will be useful to government agencies in assessing exposure estimates and of interest to Arabian consumers.

Introduction

A report by the World Health Organisation in 2016 found that the reduction of salt intake has been identified as one of the most cost-effective measures countries can take to develop population health outcomes. The key salt reduction measures will generate an extra year of healthy life for a cost that falls below the average annual income or gross domestic product per person. In addition, an estimated 2.5 million deaths might be prevented every year if global salt consumption were decreased to the recommended level (WHO, 2016).

Traditionally salt (sodium chloride) has been used as a food preservative that enhances human health by improving iodine deficiency through intravenous saline injection, oral rehydration treatment, diabetes, killing or limiting the growth of foodborne pathogens and spoilage organisms. However, in recent decades with rising consumption of many different processed food products containing a high level of salt, the perception of dietary salt has evolved to a point where it is now considered a potential health threat (Doyle and Glass, 2010). Many non-communicable diseases (NCDs) could be caused by salt intake, like cardiovascular disease, stomach cancer disease, high blood pressure, heart disease and stroke. Estimates of salt consumption range from 7.2 g/day per person in Lebanon to 19 g/day per person in Jordan. Approximately 20% of the total salt intake is from bread (Abdul Rahim *et al.,* 2014).

This study was carried out to accurately assess a range of different age groups within Arabian countries including children group (4-12 year olds), and adults group (18-65 year olds) for both male and females. The exposure to salt in food was determined using an Arabian Food Survey for each age group. The information is analysed using the RASP simulation modelling system.

The objective of this study was to develop a quantitative salt exposure assessment model to estimate exposure from a variety of food groups within the Arabian population.

Materials and method

Data inputs and model development
Food is known to make a significant contribution to total salt exposure by the general public. Levels of salt can vary considerably in many different foods. Salt in the diet can come from processed foods, either because they are particularly high in salt (such as ready meals, cheese, salty snack foods, potato

chips, and breakfast cereals) or because they are consumed frequently in great amounts (such as bread and processed cereal products). Furthermore, salt is added to food during cooking (bouillon and stock cubes) or at the table such as (soy sauce, fish sauce and table salt). Therefore, these are the foods that will be focused on during the analysis of an Arabian person's diet. However, many manufacturers are reformulating recipes to decrease the salt content of their food products and consumers should read food labels and choose products that low in salt.

The recommended average intake for the general population is estimated to be in the range of 5g/d of salt for adults per day, and less than that for children (WHO, 2016). Within a general population, it is anticipated that children will generally have a higher level of intake, two to three times that of adults when expressed on a body weight basis. Table 1 gives an overview of typical food groups that are consumed daily by the Arabian population.

Table 1. Sodium content of several typical food categories

Food type	**Level of sodium (g/d)***	**Level of salt (g/d)**	**Consumption rate (g/d)**		**Reference**
			Adult	Child	
Arabic Bread	0.579	1.44	136.8	68.4	(Almedawar *et al.,* 2015)
Potato Chips	0.200	0.5	20	20	('The Sodium Content of Your Food', 2015)
Cereals	0.256	0.64	28	28	('The Sodium Content of Your Food', 2015)

* 1 g of sodium equates to 2.5 g of salt

All data regarding sodium, salt and consumption rates were sourced from the peer reviewed literature. The body weight of adults and children were obtained from the USEPA Exposure Factors Handbook (2011). Mean child weight was 44.75±17.49 kg and was based on a population (N= 3,125). Mean adult weight was 75.61±18.02 and based on a population (N= 13,462). The amount of salt that may be ingested by a human through the aforementioned food groups was estimated by;

$$HE\ (g\ kg^{-1}) = Sc_{\text{food group}} \times Fc_{\text{food group}}/bw$$

Where HE is human exposure, Sc is salt content in food group (g/d), Fc is the food consumption (g/d) and bw is the body weight (kg).

Preliminary results and discussion

Preliminary results for the human exposure to salt using a limited range of common daily foods show that salt exposure and bread consumption was highest for adult with mean exposure value of 1.77 g kg^{-1} bw d^{-1}. This was followed by child salt exposure and bread consumption with mean salt exposure value of 0.74 g kg-1 bw d^{-1} (Figure 1). This is supported by Almedawar *et al.* (2015) who reported that bread can contain a mean sodium level of 579 mg which equates to 1.44 g salt. The report also stated that bread consumption rates were on average 136.8 g per day.

Figure 1 shows total salt intake per day for all the food groups analysed. With just three food groups, the adult salt intake has reached more than 2.5 g/kg/bw/d. For children, the total salt intake is 1.6 for all 3 food groups. The food groups do not constitute an average Arabian person's daily diet as dinner and lunch have not been evaluated, but this work is ongoing. The food groups evaluated in this study represent conservative values for adult and child consumption. For instance, the potato chips consumption rate is based on 10 chips only. The cereal is for 28 g per serving. If the consumer is to stay within the manufacturer's consumption guidelines, there would be no over consumption. However, human nature shows increased appetite to salt thus consumer want to eat salty food products, like snacks and canned food, which could be caused the risk on human health (Leshem, 2009).

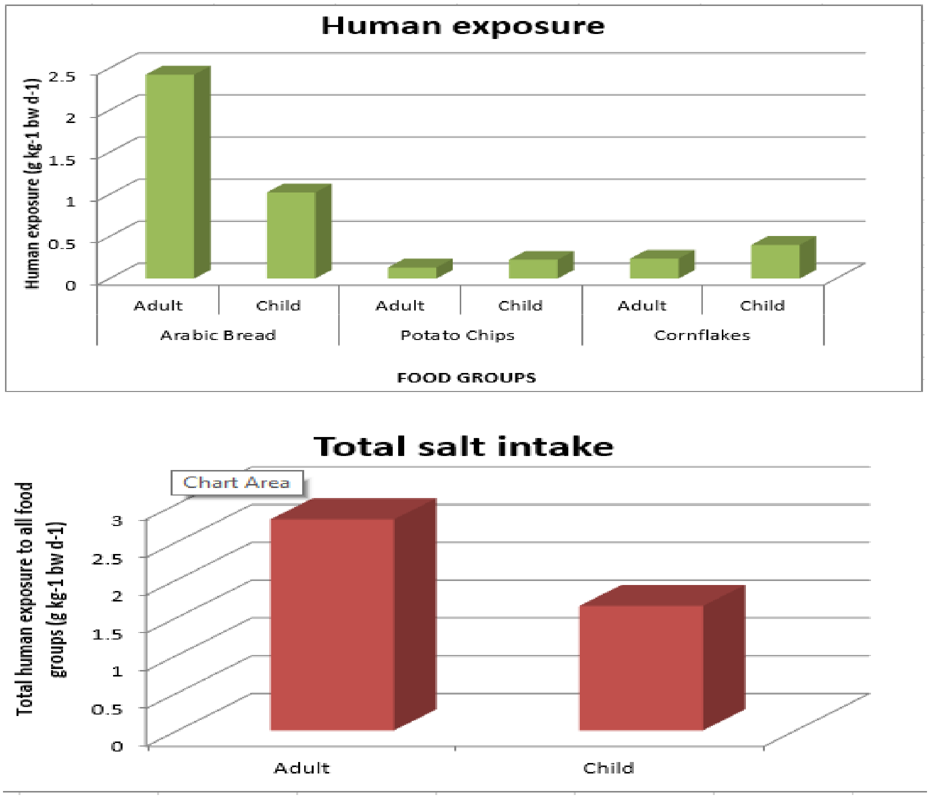

Figure 1. Human exposure and total salt intake

Conclusions

Preliminary salt exposure estimates across the range of different age groups was estimated based on the diet across much of an Arabian country. It's obvious that in order to reduce the salt intake in Arabian countries we must firstly reduce the salt levels in foods high in its concentration such as bread, potato chips and cereals. The World Health Organization stated that the levels of salt in a variety food products pose a major concern to human health and that more research is needed to determine the risk of dietary salt exposure. This information will then allow more accurate and comprehensive estimates of the Arabian dietary exposure. Although results do show that we safely fall within the boundaries of the WHO limited maximum exposure of 5 g/kg/bw/d for adults and less than that for children. The most at risk group may be the child group because of a significantly higher salt to body mass ratio.

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INFLUENCE OF SILVER NANOCOMPOSITE PACKAGING MATERIAL ON SHELF-LIFE OF FRESH ORANGE JUICES

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Abstract

The growing demand for fresh juice with high quality in terms of nutritional value, physiochemical properties, sensory characteristics, pathogen free products with increased shelf-life and minimal or no heat treatment led to the development of antimicrobial food packaging. Among the new packaging methods, polymer embedded silver nanoparticle (AgNP) based absorbent pad packaging have gained interest in present day researches. The application in food packaging is regulated by EU and USA food safety authorities, where the evaluation of the toxicity is given in terms of Ag^+ migration into the food. In this study 1 cm^2 of 0.5% Ag nanocomposite absorbent pads of packaging material are immersed in 10 ml of fresh orange juice samples at room temperature and 4 °C storage conditions. Microbial stability, sensory attributes (pH value) and metal ion release into the samples are evaluated. The preliminary results calculated at room temperature show an expected result in terms of microbial stability and with pH value not exceeding the FDA limits of 3.6 – 4.3. Further investigation at 4°C storage condition is required to establish consolidated conclusion.

Introduction

Orange juice is the globally accepted fruit juice product with short shelf life even under refrigerated conditions. In recent years, demand for non-thermal processing technique to improve freshness along with extended shelf life of juice have invaded into the field of nanotechnology that can potentially provide solution to the challenges in the shelf-life improvement, by adopting new packaging process (Emamifar *et al.,* 2010). Nano food packaging is one such new packaging technique to develop antimicrobial active packaging by incorporating metal nanoparticles into polymer matrix. The major reason for the antimicrobial activity of metal nanoparticle is due to high surface area/volume ratio leading to high performance in food preservation by migration of metal ions into the packed food (Damm *et al.,* 2005).

Metal nanoparticles are widely used in nanotechnology-enabled food packaging, where nanomaterials are mixed with polymer matrix to enhance gas barrier properties and used in active packaging due to its antimicrobial potential (Duncan, 2011). Among them silver has been known to have microbial inhibition property since long time, that can induce oxidative stress in the microbial cell membrane (Sawai, 2003). The European food safety authority (EFSA) provided an upper limits of Ag migration not to exceed 0.05 mg/kg in food (Carbone *et al*., 2016).

A promising form of active food packaging is the AgNPs based antimicrobial packaging which plays an important role in extending shelf-life of foods and reducing the risk of pathogens (Carbone *et al.,* 2016).

The objective of this study is to evaluate the efficiency of spray coated Ag nanoparticle LDPE nanocomposite packaging at different storage conditions as an approach to preservation and prolonging shelf life of orange juice.

Materials and Methods

Sample preparation

Fresh orange (*Citrus sinensis*) was procured locally. The fruit was peeled and the carpel pieces were pressed in a fruit juicer for one to two minutes to get the fresh orange juice. The juice was passed through the mesh filter to remove the pulp and was transferred to a sterile glass container under sanitized conditions. 10 ml of the prepared sample was used for experimental evaluation at 4°C and room temperature conditions.

Microbial evaluation

Microbial count was measured using Lang Paddle testers. The paddle testers well dipped in the samples were placed into the vial with tight capping and was incubated at 35-37 ºC for 24-48 hours. The contamination level in the sample was measured by analysing the bacterial colony density using standard reference table (Figure 1) given in the Paddle tester kit. To analyse this a standard graph was generated using standard calibration data (Figure 2) extracted from the reference table.

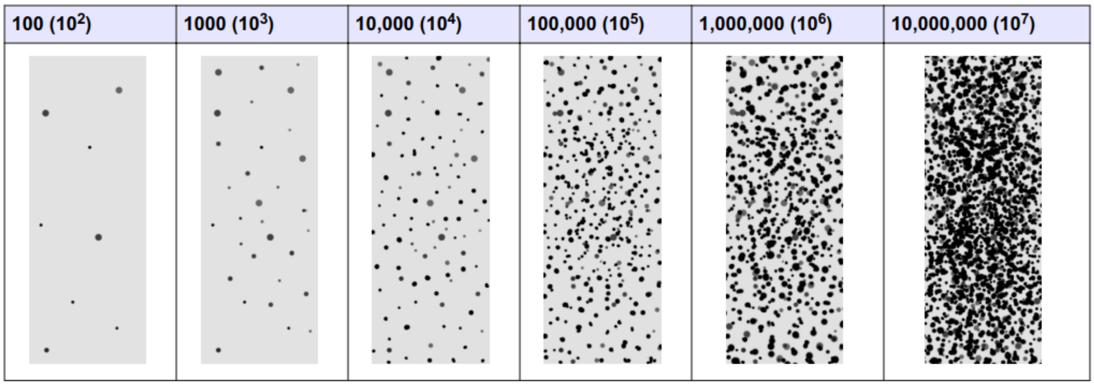

Figure 1. Bacterial colony density reference table

Density	log CFU	% black
100	2	0.44
1000	3	1.44
10000	4	3.99
100000	5	13.08
1000000	6	25.48
10000000	7	49.61

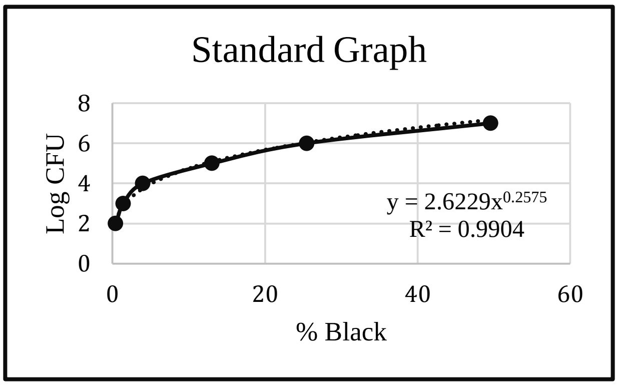

Figure 2. Standard calibration data and graph

pH evaluation

pH of orange samples was evaluated by Orion 520A pH meter (Manufacturer, Thermo Electron). The measurement was carried out in duplicates.

Measurement of metal ions release

The level of silver ions released into the orange juice samples were tested using a Hach Lange Spectrophotometer. The samples were prepared for testing using a silver testing kit LCK 354. A standard was carried out by testing a 0.1 mg/l silver solution using the Hach Lange to determine if the readings were accurate.

Preliminary Results and Discussion

Preliminary results of microbial count and pH evaluation of orange juice samples with 0.5% silver nanocomposite packaging material of 1 cm^2 immersed in 10 ml sample and control sample without the silver nanocomposite material showed a considerable result as expected (Figure 3). Table 1 outlines the effect of packaging material containing Ag during 24 hours storage at Room Temperature (RT). The initial population immediately after packaging was found to be 5.455 log CFU of bacteria in orange juice. In the sample with silver nanopackaging material, there was a significant decrease in the bacterial count than the control after 24 hours of storage time. The pH value was also observed to be within the FDA limits of 3.6 – 4.3.

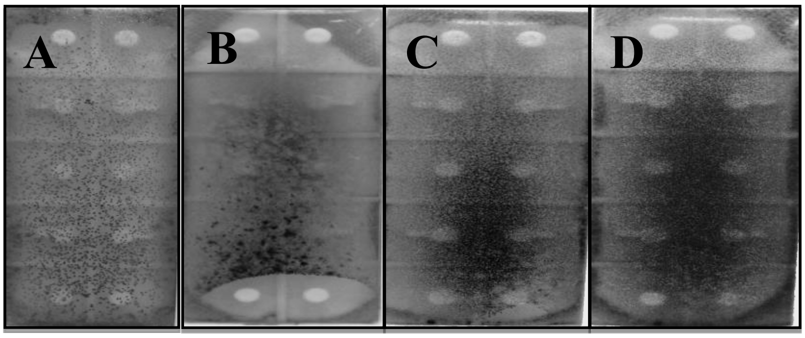

Figure 3. Paddle testers: A - 0day sample; B – 1day control sample; C – 1day trial 1 sample; D – 1day trial 2 sample

Table 1. Effect of packaging containing Ag nanoparticle during 24 hours storage at RT

Sample	Storage time (days)	Total bacteria		pH
		% Black	Log CFU	
Control	0	13.08	5	4.43
	1	17.19	5.455	4.21
Trial 1	0	13.08	5	4.43
	1	13.81	5.156	4.25
Trial 2	0	13.08	5	4.43
	1	13.84	5.159	4.27

Conclusions

Packaging material containing nanosilver are innovative concepts in food packaging industry to produce food with prolonged shelf-life and for preservation of food with quality maintenance. Preliminary results calculated for microbial stability and pH at room temperature storage showed average values within the specified limits of FDA regulation. Further investigation into the different storage conditions of fresh orange juice may show which conditions are more stable and have extended shelf-life with Ag nanopackaging material. Silver nanopackaging can act as an alternative to non-thermal technology and can be applied in combination with mild thermal technology to have prolonged shelf-life of fresh orange juice.

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USE OF ALTERNATIVE PRIORS IN A BAYESIAN INFERENCE MODEL FOR CRONOBACTER SPP. SAMPLING.

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Abstract

Cronobacter spp. (formerly *Enterobacter* sakazakii) is a pathogen associated with powdered infant formula (PIF). Due to the high number of neonatal fatalities and illnesses associated with this pathogen, stringent legislative microbiological criteria (MC) have been introduced to prevent any contaminated PIF reaching the shop shelves. A Bayesian model used to quantify the uncertainty associated with MC sampling plans and was run with different priors to quantify the effect of the priors on the uncertainty of clusters per tonne of bacteria in the PIF.

Introduction

Cronobacter spp. (formerly *Enterobacter* sakazakii) is an opportunistic pathogen widely associated with powdered infant formula (Healy *et al.* 2009, Yan *et al.* 2012). As a result of its high mortality rate in neonates, it is a pathogen of concern for the PIF industry. Under the Commission Regulation (EU) 2073/2005 (FSAI 2015) for powdered foods, the MC for PIF is an absence of *Cronobacter* spp. in thirty 10g samples. The ISO method (2006) is used for *Cronobacter* spp. detection as part of the MC. MC are a potential tool in evaluating the effectiveness of a food safety management system (van Schothorst *et al.* 2009). Whether a specific microorganism is present, and in which quantity can help decide on the acceptability of a food lot.

The Bayesian model used (von Westerholt et al. 2016) quantifies the confidence associated with sampling plans in PIF arising from the MC test outcomes. It quantifies the uncertainty in clusters per tonne, justified by the heterogenous distribution of Cronobacter in PIF (Jongenburger et al. 2011, Gonzalez-Barron et al. 2013) and the occurrence of the *Cronobacter* spp. cells in clusters or clumps which are distributed in a Poisson distribution (Mussida et al. 2013).

A Bayesian approach allows for the quantification of the uncertainty associated with sampling plans, even in the event of 0 positives, of the quantity of a microorganism that is present. The Bayesian inference is the use of Bayes' theorem for using data to improve an estimate of a parameter (Vose 2008). The prior allows for the use of a distribution that describes a state of knowledge about the parameters before the observation of the data (Vose, 2008). The prior originally associated with the model is a uniform prior. The uniform prior allows the designation of all values as being equally likely. With increased sampling the prior knowledge may change. This may be reflected with the use of a different prior. **The objective of this study is to quantify the effect that different priors have on a Bayesian inference model used for quantifying *Cronobacter* spp. in PIF.**

Materials and Methods

The Bayesian model (von Westerholt et al. 2016) was run using three different priors (Figure 1.). Firstly, the original uniform prior, denoting an equal probability to all the values occurring. Secondly a "0 positives" prior, denoting that a positive is unlikely to occur, and that the clusters/tonne are likely as in the prior distribution. And finally, the "1 positive prior" which shows the clusters/tonne distribution associated with one positive.

The model was run for the sampling plan appropriate to the MC of thirty samples of ten grams each.

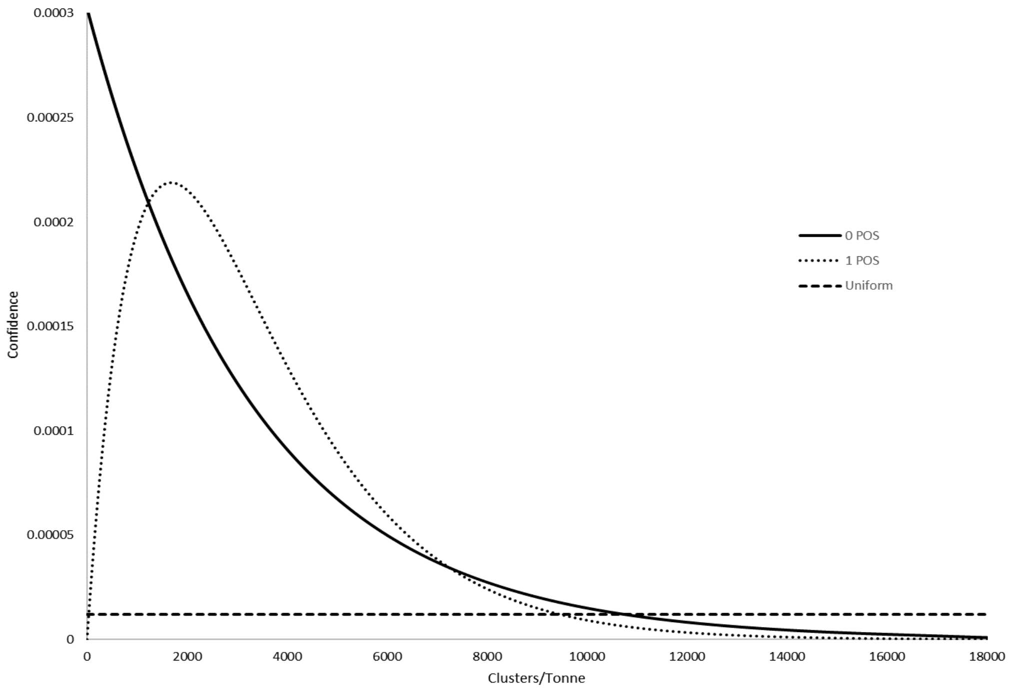

Figure 1. The uniform, 1 positive and 0 positive priors.

Results and Discussion

Figure 2. shows the effect of the various priors on the final distribution. The results can be seen as being in proportion to the prior chosen in each scenario. The 0 positives prior model shows the highest confidence of having a 0 clusters/tonne batch, and the 1 positive prior model has a very low likelihood of there being no bacteria clusters in the batch. Compared to the 1 positive prior model, the uniform prior model is more confident of lower cluster numbers, but at about 8000 clusters/tonne there is a higher likelihood associated with the uniform prior.

While there is still a considerable amount of uncertainty, the results show that the confidence in a sampling plan tested with this model can be increased by selecting the appropriate prior. As the prior chosen is subjective however, variation in prior could theoretically lead to results away from what is reality.

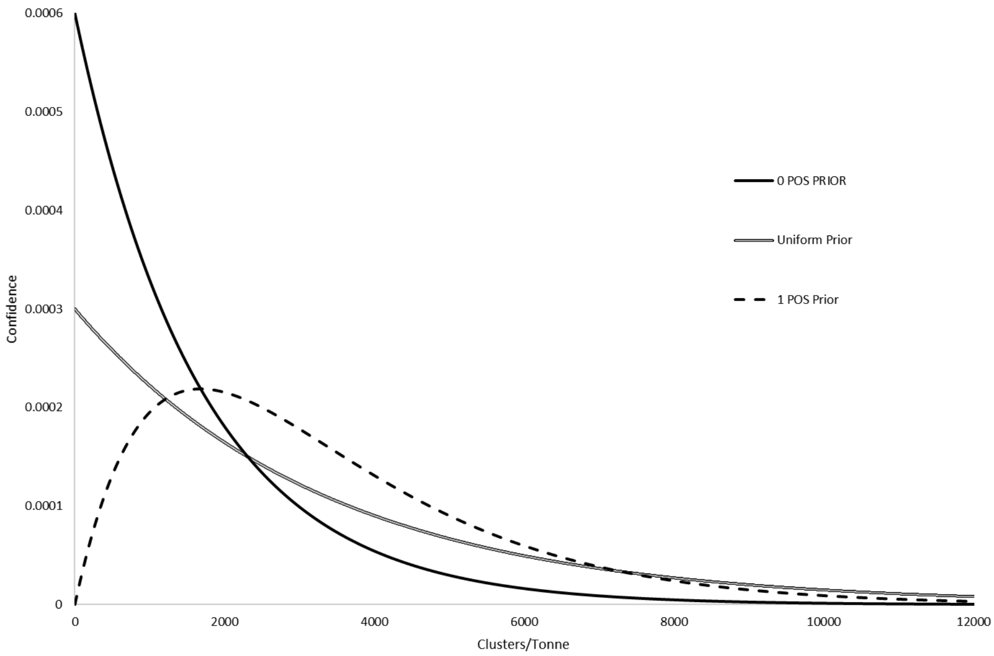

Figure 2. The confidence values for different priors in the event of 0 positives.

Conclusions

The choice of the appropriate prior has the possibility of improving the quantitative confidence in a lot of PIF. A better knowledge of the concentration of *Cronobacter* spp. can be achieved. However, the selection of the correct prior requires a good knowledge of the food production system and of previous sampling results. It is debatable whether the sampling results of one batch can be applied to the prior for another batch, as each batch may be considered independent of each other.

Acknowledgements

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RISK ASSESSMENT OF LISTERIA MONOCYTOGENES IN SMOKED SALMON

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Abstract

Exposure to *Listeria monocytogenes* at the time of consumption from the initial microbiological condition of the food and its history from production to consumption can be inferred using predictive microbiology. Predictive models can be used to estimate the changes in food product parameters such as temperature, pH, water activity and salt content from the point of its production to its final consumption. The performance of Combase and Pathogen Modelling Programme were evaluated to model the growth of *Listeria monocytogenes* to assess its risk during the storage of the vacuum packed smoked salmon. The final pH and water activity of the packed product was taken into consideration for modelling the growth of this bacteria during its shelf life when stored under refrigeration conditions. The results show the importance of these parameters in the control of *Listeria monocytogenes* during its storage.

Keywords: Predictive modelling, *Listeria monocytogenes*, refrigeration, shelf life.

Introduction

Smoking was initially used as a preservation process to cure salmon but it has recently been adapted on large scale due to its sensory influence. Smoked salmon is available in the market as ready to eat product that are generally vacuum packed. However, the pH, water activity and salt content of the final packed product is such that it provides optimum environment for the growth of *Listeria monocytogenes*. (Rorvik 2000). *Listeria monocytogenes* is a pathogen that causes a disease called Listeriosis, which has serious clinical manifestations in highly susceptible population like foetus, neonates, elderly and immunocompromised people. It has been isolated from various processed seafood products and is associated with sporadic outbreaks of Listeriosis. Since *Listeria monocytogenes* can grow under refrigeration conditions high incidences of Listeriosis due to consumption of the ready to eat seafood products have been documented. 28% of the samples collected from the supermarkets of Spain were reported to be contaminated with *Listeria monocytogenes*. Contamination rates in cold smoked salmon were found to be higher than in hot smoked salmon. However, the postprocess contamination of hot smoked salmon resulted in faster proliferation of *Listeria monocytogenes* during storage due to the absence of any competitive microflora. Fish products obtained from a retail shop in Sweden estimated the prevalence of *Listeria monocytogens* in cold smoked fish to be 11.5% while, the highest concentration of this bacteria was found in hot smoked rainbow trout which was estimated to be 13,200 cfu/g. (Lianou and Sofos 2007). Therefore, these products are considered high risk products and their handling and storage is therefore of utmost importance.

This paper describes the prevalence of *Listeria monocytogenes* in smoked salmon and also identifies the data and models the rate of growth and limits to growth of *Listeria monocytogenes* in smoked salmon.

Materials and Methods

1. *Prevalence and predicted growth of Listeria monocytogenes in smoked salmon*

In a study conducted to investigate the contamination of route of Listeria monocytogenes in vacuum packed smoked salmon in a processing plant it was observed that 16% per cent of the samples contained *Listeria monocytogenes.* Neither the seawater from the slaughterhouse nor the ice block was contaminated. 17% thawed fish entering the smokehouse, before filleting, contained *Listeria* *monocytogenes*. No *Listeria monocytogenes* was found in fish after smoking, before further handling. 11% of the vacuum-packed, smoked salmon samples, were found to be contaminated. ((Rørvik et al. 1995)

Experiments performed to demonstrate the growth of *Listeria monocytogenes* led to the estimation of parameters that influenced the growth of this bacteria during and post smoking procedures. It proved that marination and smoking procedures had no significant effect on the initial level of inoculated bacteria (10^3 cfu/g). Also, the storage of the finished product at 4ºC for 10 days did not influence the inoculum level, however bacteria showed a significant two-fold growth at this temperature after a storage period of 20 days. Also, freezing of the finished product had no significant effect on the concentration of *Listeria monocytogenes*. The pH and aw values varied between 5.8 to 6.3 and 0.93 to 0.96, respectively. These physicochemical properties had no major influence on the growth rate of *Listeria monocytogenes* during processing. (Guyyer and Jemmi 1991).

2. *Modelling of Listeria monocytogenes in smoked salmon*

The growth of *Listeria monocytogenes* was modelled using Combase according to the parameters suggested by (Guyyer and Jemmi 1991). Of which the pH and aw were varied in a range to determine the growth rate of the product under refrigeration conditions over its shelf life duration which is 15 days when it is vacuum packed.

Results and Discussions

The lower limit of the final pH (5.8) of the vacuum packed smoked salmon was used to model the growth rate of *Listeria monocytogenes* during its storage in a retail store under refrigeration condition over its shelf life of 15 days that is 360 hours. The predicted results are shown in the figure 1 below

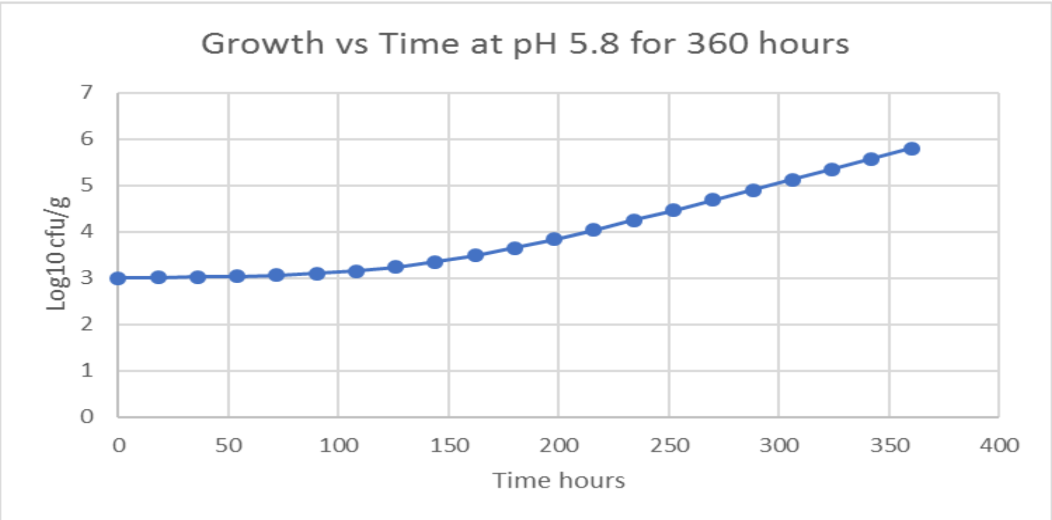

Figure 1: Growth model of Listeria monocytogenes at pH 5.8 for 360 hour at 4ºC.

A substantial increase in the level of *Listeria monocytogenes* over the period of 360 hours is evident from the above plot. The level of bacteria increased over 2 log cycles. However, neither the growth rate nor the doubling time of the bacteria was affected during this period of storage.

Similarly, the growth of *Listeria monocytogenes* at water activity of 0.93 of the final ready to eat product was modelled for 360 hours under refrigeration condition of the retail store. The pH of the vacuum-packed product was set to an optimum growth pH of 7.

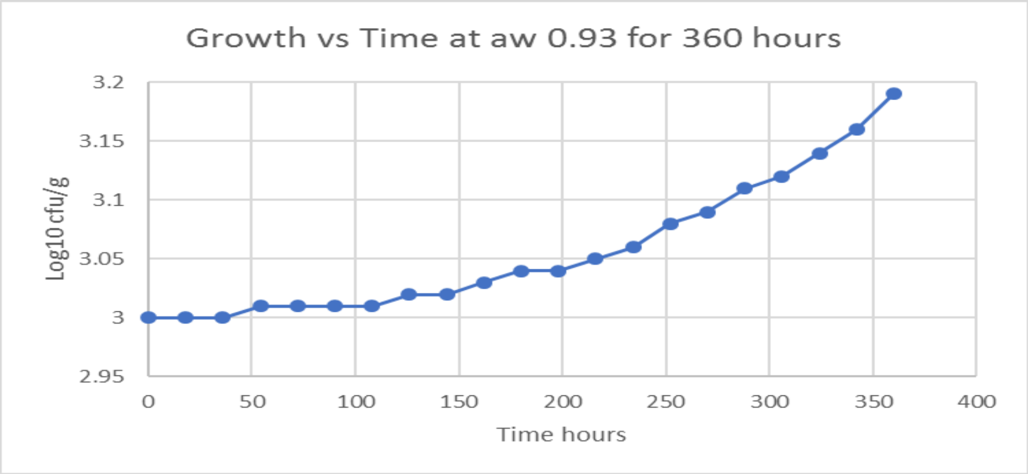

Figure 2: Growth model of *Listeria monocytogenes* at water activity 0.93 for 360 hours at 4ºC

It is evident from model in figure 2 that the level of *Listeria monocytogenes* increases over 15 days although the increase in the initial level is not drastic. Although, the pH of the product was set to optimum for the growth of Listeria monocytogenes the increase in the level was lesser when compared to pH 5.8 and water activity 0.97. This demonstrates a marked influence of the water activity in the control of *Listeria monocytogenes* during its storage.

Conclusion

Due to the ability of *Listeria monocytogenes* to survive under lower temperatures, it poses a threat to humans. The bacteria remain dormant until the return of favourable conditions which occurs during the storage period. Different parameters of the final vacuum packed smoked salmon can be manipulated to control the growth of Listeria monocytogenes during its storage in the retail stores. The parameters can be manipulated in relation to other to check on the feasibility of lowering the risk of *Listeria monocytogenes* in smoked salmon.

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QUALITY ANALYSIS OF VODKA USING NIR AND UV-VISIBLE SPECTROSCOPY

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Abstract

Vodka is a clear, distilled spirit, which is commonly adulterated with ethanol and water and rarely methanol. UV-Visible Spectroscopy has proven to be an inexpensive technology to detect adulteration in distilled spirits over the spectral range 200-450 nm approx. NIR spectroscopic techniques can be used for analysis of alcohol quality in the spectral ranges 780-2600 nm. Chemometric methods PCA and SIMCA analysis must be applied to spectra obtained from spectroscopic techniques.

Introduction

Vodka is an extremely popular alcohol in Russia, Poland and other Eastern European countries. It is made from ethanol of agricultural origin, eg. *via* fermentation of rye or potatoes. Since it is a high-end liquor, it has been associated with issues of adulteration and misbranding. Misbranding is done in case of premium or brand spirits, and substitution usually occurs in bars and restaurants. Apart from that, adulteration is another common fraudulent practice. There are various economic and health implications depending on what adulterants are used. Use of water or low grade ethanol causes major economic loses, while consumption of methanol adulterated vodka may cause nausea, headache, vomit and in rare cases, blindness. Also despite distillation and multiple rounds of filtration, it is impossible to produce vodka with 100% ethanol concentration, and the product will almost always contain trace amounts of higher alcohols, aldehydes, esters, acetic acid, methanol and fuel oil. The minimum strength of Vodka is 37.5% by volume, Vodka Finlandia being the purest in the world at 40%. Commercially, brand frauds in vodka can be detected by analysing the composition of inorganic anions using ion chromatographic techniques, although it is a very expensive technique, needing trained personnel and cannot be conducted off site. Chromatography is another powerful analytical technique that can be used particularly for detecting adulteration in distilled spirits, however, this too has disadvantages like high cost of instrumentation and high reagent consumption.

Spectroscopic techniques are preferred in alcohol analysis since they are rapid, reagent free; thus, non-invasive and non-destructive. UV-Vis spectrometry is a cheap and simple technique while NIR is rapid and precise. Both can be efficiently set up in alcohol production or bottling houses as at-line, on-line or in-line instrument. NIR is exceptionally accurate with almost 100% of correct prediction at a confidence level of 95% (Pontes *et al.,* 2005). Each Vodka sample will have and unique spectral signature due to varying ethanol and water compositions. Principal Component Analysis (PCA) and soft independent modelling of class analogy (SIMCA) help to classify and analyse the data obtained from the spectral evaluation in a multi-dimensional space. PCA that delimits a region of multi-dimensional space is created for a given group or class of samples. SIMCA classifies the alcohol samples based on the PCA models. The direction of the PCs in the PCA model and the limits established for these PCs define the model of a class by SIMCA (Beebe *et al.,* 1998). Multiplicative Signal Correction (MSC) could be used to reduce the spectral noise. This study plans to evaluate the efficiency of the mentioned spectroscopic and chemometric techniques to authenticate vodka samples, and if a conclusive method can be indeed formulated to detect brand fraud.

The objective of this study is to assess the quality of Vodka samples using NIR and UV-Vis spectroscopy and chemometric techniques.

Materials and Methods

NIR and UV-Vis spectroscopy equipment at the School of Biosystems and Food Engineering (UCD) laboratory will be used to process the samples. Samples will include cheap and premium quality vodka and deionized water will be used to dilute the samples serially. The experiment would be divided into two parts based on the two adulterants; water and cheap vodka. Part one would evaluate influence of dilution with water (Weight ratio: 0, 1, 2, 4, 8, 16% w/w) while part two would investigate changes due to addition of cheap vodka (adulteration ratio: 0, 2.5, 5, 10, 20, 40% w/w) on NIR/UV-Vis spectra and PCA/SIMCA models. The data from NIR and UV-Vis spectral analysis will be pre-treated by MSC to reduce the noise in the data. The Unscrambler X software (v10.4, CAMO Software AS, Oslo, Norway) needs to be applied to build the PCA and SIMCA models.s

Predicted Results and Discussion

In the paper presented by M.J.C. Pontes et al. in Food Research International (2006) where the technique used was NIR, a database set was created using pure beverage samples and since they presented very similar spectral profiles, PCA and SIMCA were used to characterised each group. After modelling it was observed that two PCs were enough to characterize whiskeys and vodkas samples, and thus the same can be expected in the present study. The former study used 10 samples per beverage and observed the robustness of the models to increase with an increase in the number of samples.

In the paper presented by Elaine C. et al. in Sociedade Brasileira de Química (2011), the average spectra of each pure alcoholic beverage processed in the range 200 to 400 nm. It can be seen clearly that the alcohols do not present relevant spectral information above 350 nm. Similar spectral analysis can be expected in the present study.

After pre-treatment of NIR data, a 3-D PCA/SIMCA score plot can be expected just like results presented by Pontes *et.al*. The first principal component, PC1, can influence the model more obviously than other components like PC2, PC3. PC1 accelerates the distinction of whiskey and brandy to rum and vodka which means without PC1, the boundaries of two groups will be fuzzy. PC2 represents nearness between whiskey and brandy as well as between rum and vodka

A clear linear relation of points can be found in whiskey samples which spread in a middle size circle. Vodkas are spread into a line showing a strong connection. Thus a positive correlation has been presented on the plot. Except whiskeys group, the rest groups (rums, brandies and vodkas) have low sensitivity on PC1. Maybe another model with small units of PC1 is suitable to describe these samples, which could be worked on in the present study.

For the UV-Vis spectral analysis, the PCA models provided by the study conducted by Elaine C. *et al.* can be evaluated. It shows the presents the PC1 × PC2 score plot for the calibration set, which consists of 50 non-adulterated samples. The five beverage types are clearly separated in the PC1 × PC2 space, which shows that the chosen spectral range conveys appropriate discriminatory information, thus it can be safely used for the current study on Vodka and similar spaced out and clear PCA graphs can be expected.

Conclusion

This study will demonstrate the potential of NIR and UV-Vis spectroscopy along with chemo-metric modelling techniques like PCA and SIMCA in the classification and verification of adulteration in Vodka. This technique can be an attractive and powerful tool to curb the problem of alcohol adulteration.

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DETECTION OF ADULTERATION OF WHISKEY USING NIR AND UV-VIS SPECTROSCOPY.

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Abstract

Whiskey is one of the most popular, commonly consumed and commercially important alcohol products. Due to its high commercial value it is widely targeted by counterfeiters. Its adulteration is commonly achieved by adding or diluting the whiskey with a mixture of alcohols, water, dyes or artificial coloring. Using NIR and UV-VIS spectroscopy along with using certain chemometric methods of analysis will help in determining and distinguishing the level of adulteration present in samples of whiskey.

Introduction

The issue of authenticity of food and drinks is on the rise and it is of vital consideration due to the increasing cases of food fraud (Cantarelli et al. 2014). Adulteration has always been a problem with high-end, commercially important alcoholic beverages like whiskey. As per the European definition of whiskey, it is a distilled spirit drink made from fermenting and distilling the mash of malted grains like rye, barley, wheat or corn. The process of distillation is carried out at less than 94.8% by volume so that the flavor and aroma from the raw materials can be preserved and later on they are aged in wooden barrels for atleast 3 years for maturing. Only water and plain caramel (for colour), in proper proportions are acceptable to be added in the distillate, anything else is considered as an adulterant (Wiśniewska et al. 2014). Adulteration primarily occurs either in the form of dilution (which is the less harmful on human health) or by addition of poor quality, unregulated or toxic ingredients. Consumption of such adulterated whiskey can cause a series of grave complications like headache, nausea, blindness, seizures, kidney failure and in acute cases even death. Thus it is of prime importance to come up with techniques to help curb this danger.

UV-VIS spectroscopy refers to the absorbance or reflectance spectroscopy in the ultraviolet and visible region (wavelength range approximately 190-750 nm) while NIR spectroscopy utilizes the infra-red region (wavelength range approximately 700-2500 nm) of the electromagnetic spectrum. Whiskey has its own spectral properties which acts as its unique fingerprint. This data can be used to verify the authenticity of the product sample by comparing its spectral properties to that of the established spectral database. There is an increasing need for the alcohol and beverage industry to come up with cheaper and non-invasive techniques of adulteration detection. Spectroscopy is a relatively inexpensive technology which is used for rapid and easy qualitative analysis. It is a non-destructive technique and reagent free method of component analysis. After obtaining the spectroscopic data, it is subjected to chemometric analysis like Principal Component Analysis (PCA) and Soft Independent Modelling of Class Analogy (SIMCA) to help read and deduce the meaning of the spectral scores. SIMCA is used to evaluate the PCA model predictions. SIMCA shows sensitivity to the quality of the data accessed and generated by PCA. Thus the samples with similar spectral points will near to each other in the principal component map. The data is pre-treated with Multiplicative Signal Correction (MSC) to reduce spectral noise.

The objective of this study is to distinguish high quality original whiskey from cheaper commercial grade or blend or adulterated whiskey with added water using NIR spectroscopy, UV-VIS spectroscopy and analyzing the data using chemometric techniques

Materials and Methods

Different whiskey brands (cheap and premium) will be obtained from supermarkets. The other equipment and material to be used include the NIR and UV-VIS spectroscopy available in the UCD Food Engineering laboratory, deionized water prepared in the laboratory and pipettes and containers. Two experiments that will be carried out are: First, to determine the influence on the value on diluting the sample with water (0, 1, 2, 4, 8, and 16 %). Second, to determine in the influence of adding cheap whiskey (0, 2.5, 5, 10, 20 and 40 %) to the original testing sample. These experiments will be carried out in duplicates. Data pre-treatment is essential to reduce the spectral noise and is achieved by using MSC. The data will be evaluated using PCA and SIMCA for which Unscrambler X software will be used. The models will need to be adjusted at regular intervals.

Expected results

For NIR spectroscopy

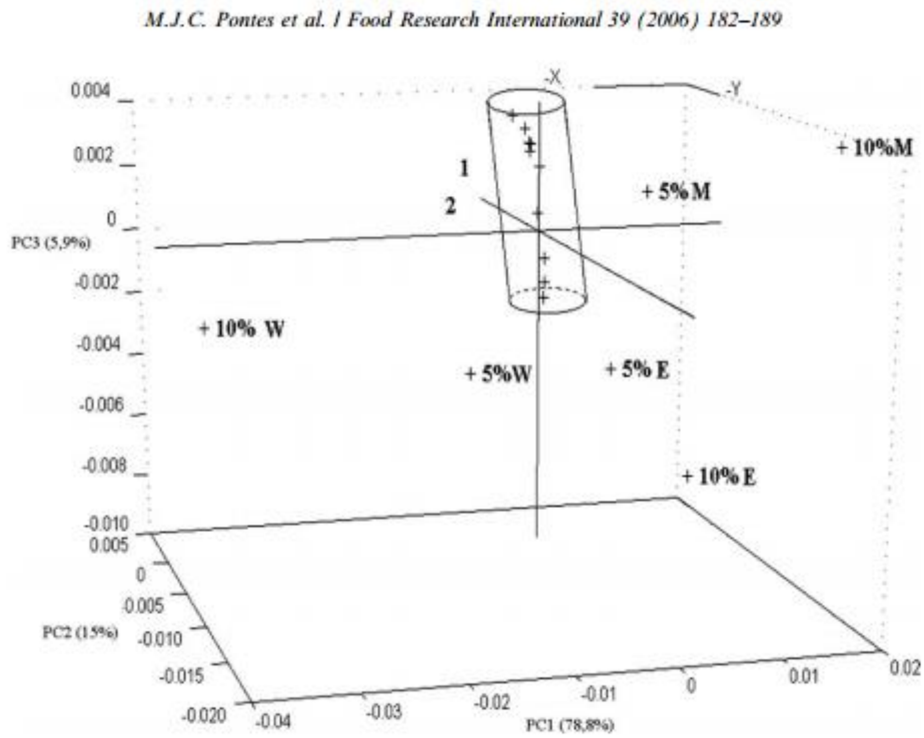

Figure 1: Score plots were obtained by PCA to verification of whiskeys adulteration. + – whiskeys used on the training set; +E, +M and +W – whiskeys adulterated on the laboratory using ethanol, methanol and water, respectively; 5%/10% – grade of the adulteration (v/v); 1 and 2 – whiskeys considered adulterated by an official regulatory agency.

The expected results should be similar to those shown in Figure 1. As seen in the works of Pontes et al. 2006, the results must be grouped into different classes depending on the data variance. PC1 shows adulteration by water and has negative score while those adulterated with alcohol (methanol and ethanol) will have positive score. An increase in the PC1 score means that the alcoholic content is more. Thus from the above figure we can conclude that samples 1 and 2 are adulterated with water. Whereas, PC3 suggests adulteration with alcohol due to its positive scores.

For UV-VIS spectroscopy

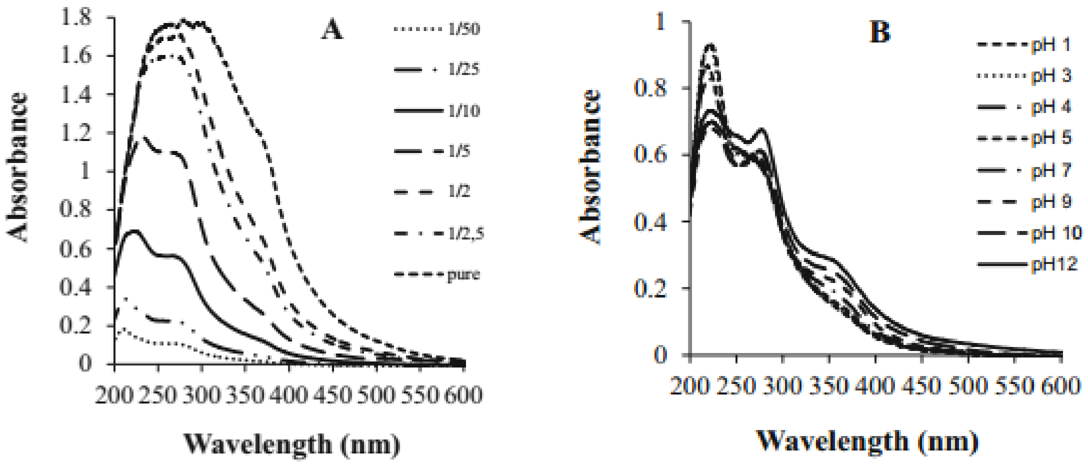

Figure 2: (A) Spectral curves of whisky sample at different dilutions and (B) spectral curves at eight different pH values (Cantarelli et al. 2014).

The expected spectral wave results from UV-VIS spectroscopy should be similar to Figure 2. From the above figure2 we see that, on performing the experiment for different dilutions and pH, the dilution of $1/10^{th}$ and pH 12 seem to be the most fitting as they show the most appropriate spectral curve at wavelengths 200-300 nm and could be used for classifying the various qualities of whiskey.

Conclusion

Whiskey is a premium quality alcoholic beverages is subjected to a lot of counterfeiting issues. Using NIR and UV-VIS this study spectroscopy will create database containing information regarding the likely adulterants.

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ADULTERATION DETECTION IN MILK PRODUCTS USING NIR SPECTROSCOPY

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Abstract

Near-infrared spectroscopy (NIRS) is widely used in food testing. The near-infrared region of the electromagnetic spectrum is from about 700 nm to 2500 nm. Adulteration is a common phenomenon in today's food industry. Common adulterants of milk are water and melamine. This work will focus on the testing of adulteration in milk by using Ocean Optics NIR system and principal components analysis (PCA) model to analyze the data. It is expected that this technology will be an efficient tool for adulterant detection in milk products.

Introduction

With the improvement of people's living standards, the demand for milk and dairy products is increasing every day. Adding water, dextrin to the raw milk to increasing the density of milk has become a common adulteration means in part of the milk industry. The protein content of milk will be reduced after adding water, and this means the products cannot pass the national minimum standards of dairy protein content detection by the Kjeldahl method. The Kjeldahl method is a way to test the total nitrogen content without analyzing its sources (Chen et al., 2017). The criminals began adding melamine to increase the nitrogen content. In 2008, a dairy incident occurred in China which was the largest food safety events (World Health Organization WHO). This event made food inspectors start looking for a more efficient technology to test milk.
Near-infrared spectroscopy (NIRS) is a spectroscopic method utilizing the near-infrared region of the electromagnetic spectrum. Its region is from about 700 nm to 2500 nm. A common source for near infrared spectrum light is a diode laser, a common incandescent or a quartz halogen light bulbs. These light sources can offer a greater lifetime, the spectral stability and the reduced power requirement (Bozkurt et al., 2005). Typical applications include pharmaceutical, food, and agrochemical quality control (Borin et al., 2006).
The principal components analysis (PCA) model is a commonly used mathematical tool in the analyzing of the NIR spectroscopy data. PCA can get information from the original data sets by setting the new uncorrelated variables which are called principal components (PCs) (Chen et al., 2017). It can be used to investigate the sample classification problems.

The main objective of this work is to carry out a preliminary investigation on the application of a rapid low cost, but a powerful analytical technique of adulteration in liquid milk products.

Materials and Methods

The raw materials of this work include the whole fat milk, the low-fat milk, and the skimmed milk. The adulterants are deionised water and melamine. The equipment is the NIR spectroscopy equipment placed at the UCD food engineering laboratory. The PCA model will be used to analyze the data. The whole fat milk, the low-fat milk, and the skimmed milk will be tested in the first step. Each small sample will be picked from the big sample and will be tested 3 times. From the result spectrums, each set will choose one result as the good sample to compare with the adulterations' spectra. The adulteration will start from 0.00% level and it will be tested each 0.02% level. Specific details will be adjusted with the experiment. The spectra of the adulterants will be compared with the good sample spectrum and find the differences. Then the data will be presented classification and put in the PCA 3D model to calculate the percentage of the variance.

Expected Results and Discussion

Chen and others (2017) latest study showed that the small differences between pure milk and adulterated milk in the mean NIR spectra. As Figure 1 shows, it is hard for naked eyes to distinguish the pure milk and the adulterated milk spectra. The differences were very small. They did several pre-processing techniques like standard normal variate (SNV), but these methods did not help to improve the performance of the data analyze (Chen et al., 2017). Thus, principal component analysis (PCA) is necessary to build and analyze the spectral data. Figure 2 shows the huge differences between pure milk and adulterated milk. The score scatters plot for the first three PCs accounted for 93% of the variance in the spectra (Chen et al., 2017). However, there are some obvious overlaps between pure and adulterated milk samples in this 3-dimensional spaces. Thus, the expected result is that the huge differences can be found by the PCA model. And in the further experiment, presenting classification is an important task to get a more accurate testing result.

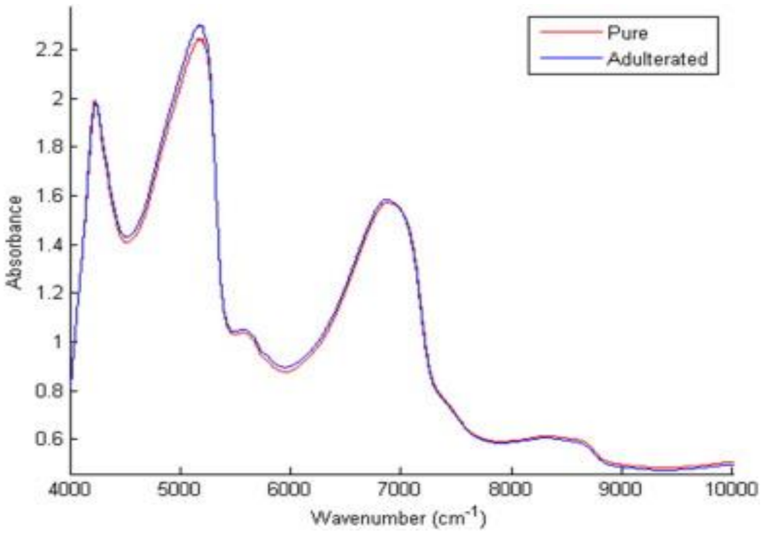

Figure 1: Mean NIR spectra of pure and adulterated milk

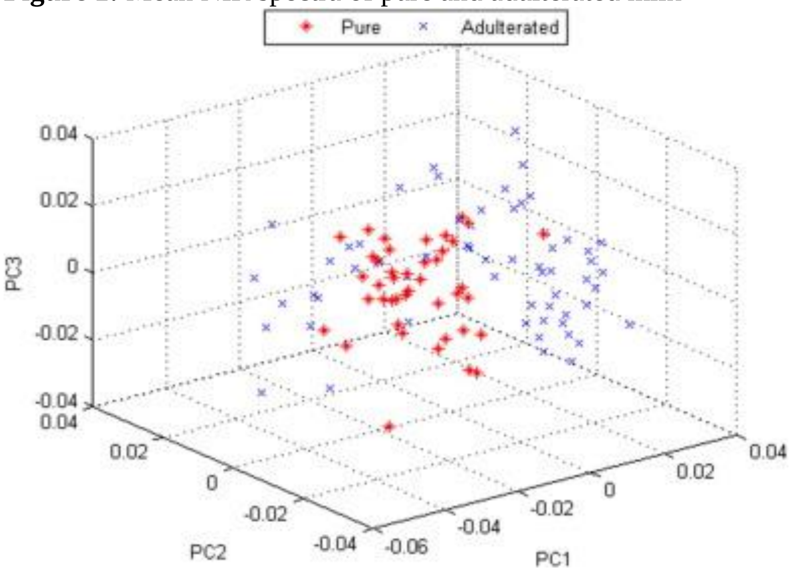

Figure 2: The score scatter plot for the first three principal components (PCs)

Conclusions

In this project, whole fat milk, low-fat milk, and skimmed milk will be tested as the raw materials. The adulterants include deionised water and melamine. Using PCA modelling to analyze the spectra data, over 93% differences will be found. As there are some overlaps in the 3D spaces, presenting classification is an important task to get a more accurate testing result. The expected result of this work is NIR Spectroscopy is a low cost and efficient analytical technique to find the huge difference between pure milk and adulterations.

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PRELIMINARY STUDY ON SHELF-LIFE OF DAIRY PRODUCTS WITH NANOPACKAGING

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Abstract

Nanotechnology is a technology holding great potential in the manufacturing industry and can bring a positive influence to improve products' quality. However, consumers are not clear what exactly nanotechnology is and its potential applications. In research, nanotechnology has been applied to packaging in the food industry. It can block oxygen and carbon dioxide from passing through the packaging and extend the shelf-life of the food, when it is injected into the packaging materials. Different nanomaterials have been developed, and it is a trend in today's traditional packaging environment. For the milk production, nanotechnology is tested in lengthening the shelf life period. Traditional pasteurized whole milk can keep fresh in the fridge for 7 days, while the nano packaging for the milk is expected to extend this shelf-life.

Introduction

Nanotechnology is a useful and important tool in engineering technology based on the molecular scale and is between 1 and 100 nanometres (Sekton, 2010). It can be used to measure, manipulate and develop innovative products in functional systems, and it has a wide range of applications in different areas including medicine, food, fuels, electronic, space, etc. In the food industry, 10 million dollars are invested into applying nanotechnology in food processing, packaging and production (Chaudhry *et al.*, 2008). Due to this global background, nanotechnology advances the development of packaging materials in food. There are lots of advantages of nano packaging including improved taste, texture and improving the processability of food. In addition, it can also extend the food's shelf-life (Sekton, 2010).

Several nanomaterials are used in food industry. Nano-silver and titanium dioxide are known as antimicrobials in the food packaging material. Nano-clay injected into packaging can also prevent spoilage by inhibiting oxygen, moisture and carbon dioxide contact with the food. Nano-selenium is applied in green tea because of its enhancement of intaking selenium (Wesley *et al.*, 2014). Apart from these, coatings could also contain nanoparticles and become watery-based nano-barrier coatings. Oxygen is blocked by the anti-oxygen barrier under micron coatings. In this way, it is efficient to cut off the oxygen but keeping carbon dioxide to extend the shelf-life of products, which could complement the traditional method of packaging technologies (Sekton, 2010).

When it comes to the milk storage, according to Sidney Barnard's research, one of the important factors to extend the shelf-life of milk is to keep the temperature below 7°C (Barnard, 1974). In addition, Janzen illustrated that a whole milk's shelf-life is 9 days at 7°C, and every increase of 5°F would decrease shelf life by approximately a half (Janzen, 1972). On the other hand, nanotechnology applied in the milk packaging is a possible method to extend its shelf-life and contribute to the storage time.

The objective of this study was to test if the shelf-life of milk could be significantly extended with the use of nano packaging.

Materials and Methods

Experimental design

Materials in this experiment include 3C-5%, 3C-0.5% nanoparticles which are nano-polymers with three times silver coating in 5% and 0.5% concentration as well as the pasteurized fresh whole milk bought in the supermarket. Bacteria in the overdue pasteurised milk includes thermophilic bacteria as well as *Escherichia coli*, and the amount will be tested by paddles. Three parameters evaluated are temperature, pH and microbial count. Each 10-ml milk used 1 cm^2 nanoparticles. Total experiments could be divided into four groups as shown in Table 1. Each group uses the whole milk which will expire on the same day. The day before Day 1, fresh whole milk is put into three containers. One of them is the raw milk and others are milk with nanoparticles. These containers are kept at room temperature (out of direct sunshine) or in the fridge for 24 hours. On Day 1, the pH in containers is tested. Three paddles are put into containers and the growth media is fully covered by the milk. Paddles are then marked and kept in the temperature of 35 °C. After 48 hours, bacteria amount could be observed on the paddles. Following this operation, on Day 3 and Day 5, the milk in containers will be tested. In this way, the day before the expiry day and two days after expiry day were evaluated in one group experiment, which can show the bacteria growth and the comparison between the raw milk and milk with nanoparticles.

Table 1. Experimental record

The shelf-life of whole milk using 3C-5% nanoparticle							
Temperature	Day 1		Day 2	Day 3		Day 5	
	pH	Microbial count		pH	Microbial count	pH	Microbial count
Room	*p1*	*C1*	Expiry day	*p2*	*C2*	*p3*	*C3*
Fridge	*p1*	*C1*		*p2*	*C2*	*p3*	*C3*

The shelf-life of whole milk using 3C-0.5% nanoparticle							
Temperature	Day 1		Day 2	Day 3		Day 5	
	pH	Microbial count		pH	Microbial count	pH	Microbial count
Room	*p1*	*C1*	Expiry day	*p2*	*C2*	*p3*	*C3*
Fridge	*p1*	*C1*		*p2*	*C2*	*p3*	*C3*

Methodology

This experiment uses the pH meter as well as paddle tester to test the pH and microbial count of the milk, respectively. Figure 1 shows the density of bacterial colonies in DOC316.53.01223. The black percentage of these images (Figure 1) stand for the bacterial coverage, which is calculated using MATLAB (Table 2). Figure 2 shows bacteria colony density curve based on results in Table 2, which illustrates that the coverage increases with the bacteria amount. When the coverage is below 5%, the growth rate is high, while after 5%, it becomes lower. This curve is a sample in the following experiment.

Figure 1. Bacterial colony density (HACH COMPANY, 2015)

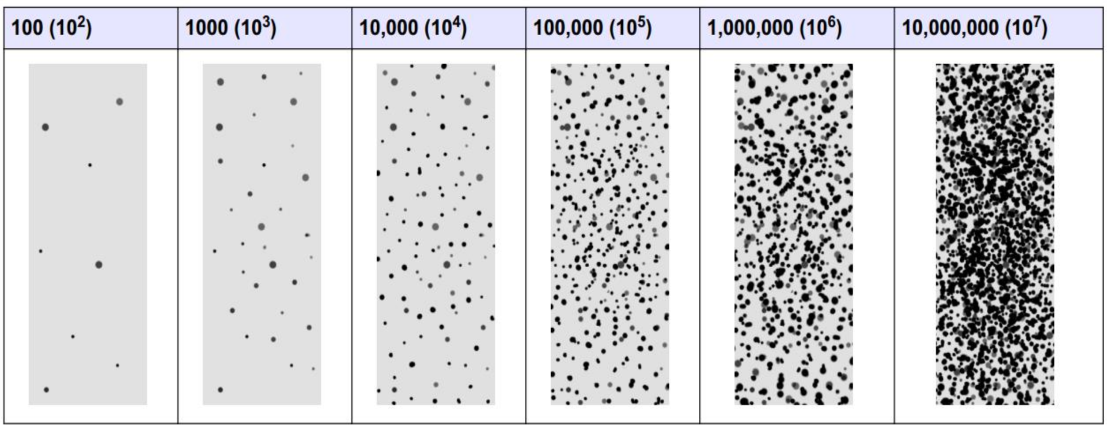

Table 2. The result of MATLAB

MATLAB						
Bacteria amount	10^2	10^3	10^4	10^5	10^6	10^7
Percentage (%)	0.47	1.41	4.4	13.54	28.15	55.06

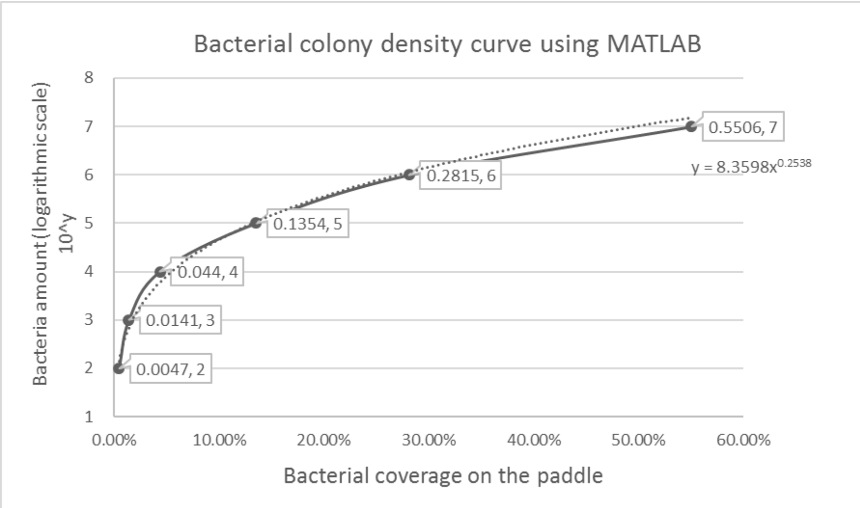

Figure 2. Bacterial colony density curve using MATLAB

Data analysis

This study uses the same processing mode with the methodology to analyse data. For each test, images of the paddles will be recorded. Photoshop is then used to make them into black and white images. MATLAB software is then used to calculate the black percentage which is the bacterial coverage. The X value (bacterial coverage) will be recognized in the bacteria colony density curve. Along with this value, across the curve, the Y value of the intersection point stands for the bacteria amount. In this way, the data in this experiment could be analysed.

Expected Results

Prediction of the shelf-life of milk with nanoparticles

Agrindus is an agricultural corporation in Brazil, and it has applied the nanotechnology into the pasteurized fresh whole milk to double its shelf-life from 7 to 15 days. This application was achieved through injecting the plastic bottles with antimicrobial silver-based nanoparticles as packaging materials for the milk (Nanowerk.com, 2017). In this way, expected results of the whole milk with 3C-5% nanoparticles are predicted to extend its shelf-life. After the experiments, the bacteria growth rate of the raw milk would be expected to be faster than the milk with nanoparticles.

Conclusions

This study tests the shelf-life of pasteurized fresh raw milk with different concentrations of nanoparticles based on the bacterial population. The bacteria level in milk one day before and two days after the expiry day is found through the bacteria colony density curve following the samples in Figure 1. After the experiment, it will be concluded whether the nanoparticles can significantly extend the shelf-life of the whole milk comparing with the raw milk stored in both room and fridge temperature.

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MEASUREMENT OF TENDERNESS OF RED MEATS USING HYPERSPECTRAL IMAGING: A BRIEF REVIEW

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Abstract

Hyperspectral imaging (HSI) has gained wide regard as a fast, chemical-free, and nondestructive method for detecting meat quality in the modern meat industry. It, has ability for effectively quantifying and characterizing quality attributes. This study focuses on the recent applications of hyperspectral imaging on quality assessment for sensory attributes of red meat. The first part of this review is the basic principles, major instrumental components and data analysis methods of hyperspectral imaging. The second part is to review of hyperspectral imaging on measurements of sensory attributes of red meat.

Introduction

Red meats, such as pork, beef, and lamb, are a significant part of people's daily diet, because these meats can provide necessary nutrition to promote health (McAfee et al., 2010). With the improvement of living standards, people pay more attention to the quality of food products. Therefore, quality is one of the most important concerns in modern food industry. Typically, meat quality is defined as a measurement of characters or attributes that can determine the suitability of meat (ElMasry et al., 2012a). What is more, meat quality attributes could include sensory attributes, chemical attributes, microbiological attributes, and technological attributes (Andrés et al., 2008). These attributes have a significant effect on the quality of red meats because of the great variability in these attributes. Traditionally, sensory attributes such as color, flavor, firmness, marbling, and tenderness are inspected by well trained operators, but manual inspection is tedious, time-consuming and destructive. Furthermore, some important attributes such as acidity and nutritional constituents cannot be inspected by manual inspection.

Recently, many studies have reported as predicting quality attributes for red meats using spectroscopic techniques (Prevolnik et al., 2010). However, conventional spectroscopic techniques cannot provide compositional gradients due to the measurements focusing on a relatively small part. Different from conventional spectroscopy offering only spectral information, hyperspectral imaging can detect not only spectral information but also spatial images as provided by conventional technology.

The objective of this study are (1) to provide the basic principles of hyperspectral imaging and the critical methods for data analysis; (2) to review the applications of this technique for the measurements of tenderness of red meat.

Materials and Methods

Principle of hyperspectral imaging

Hyperspectral imaging is a novel technology that combines conventional imaging and spectroscopy to measure both spatial and spectral information from one sample (Gowen et al., 2007). Hyperspectral image is composed of two dimensional spatial information and one-dimensional wavelength information. Regions of an object with similar spectral properties would have similar chemical composition, HSI can image the biochemical components of an object by applying the developed prediction model on particular areas of the image (Wu and Sun, 2013).

Instrumentation

Knowledge about the instrumentation of HSI is the fundamental and necessary step to gain images with high reliability and high quality, which requires a good understanding of the system (Wu and Sun, 2013). The essential parts for setting up HSI system usually include the following components: light sources, which is to illuminate the target; wavelength dispersion devices for the purpose of dispersing broadband into different wavelengths; detectors, which is to quantify the intensity of the received light; and the calibration of HSI system to ensure the reliability of the received hyperspectral image data. Figure 1 shows the components of a HSI system.

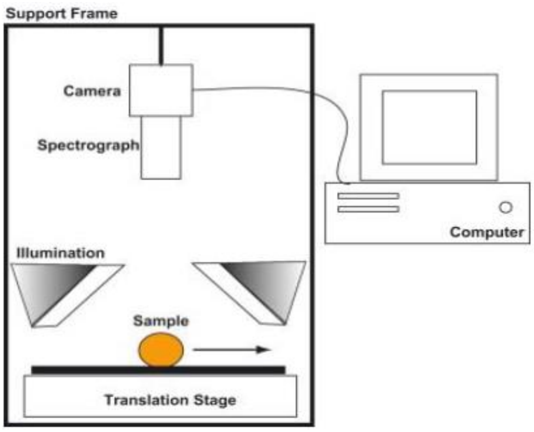

Figure 1. Components of a HSI system (Gowen et al., 2007)

Data analysis

For getting useful spatial information from hyperspectral images, the problems might be bad illumination and the presence of artefacts or noise in the images; therefore, some useful image processing methods and algorithms are essential (Lorente et al., 2012). There are some commonly used statistical techniques for classification including principal component analysis (PCA), linear discriminant analysis (LDA), partial least square (PLS), artificial neural network (ANN), support vector machine (SVM), and cluster analysis (CA).

Measurements of Tenderness

Tenderness is an expression of texture of meat, and it is one of the most important sensory quality attributes because it has significant effect on consumer satisfaction (Rødbotten et al., 2000). The most common method to evaluate meat tenderness is to measure the mechanical properties of red meats by using a Warner Bratzler shear force (WBSF) or slice shear force (SSF), however, both of them are not suitable for on-line applications and rapid prediction. In recent years, there are some interests in using instruments to fast and non-destructively assess meat tenderness. According to this consideration, hyperspectral imaging has great potential, which has been proved by many studies (ElMasry et al., 2012c). For instance, Naganathan et al. (2008) used a visible and near infrared hyperspectral imaging system for the assessment of tenderness of 14-day aged beef samples. The hyperspectral images of beef products acquired at 14-day post-mortem. The next step was to extract spatial and spectral features of the hyperspectral images by using principal component analysis (PCA) and a co-occurrence matrix. A discriminant model was set on the basis of the extracted features. Then, the model predicted three tenderness categories (tender, intermediate, and tough) with a leave one-out cross-validation procedure, and the accuracy is 96.4%. Besides, some authors predicted tenderness of red meats using hyperspectral scattering techniques, because the changes in tenderness can be represent by scattering profiles. For example, Tao et al. (2012) predicted tenderness of pork meat by using the hyperspectral scattering technique, and the final prediction model was established with multi-linear regression (MLR) methods which gave high R^2, which is from 0.831 to 0.930. Furthermore, Cluff et al. (2008) has developed a hyperspectral scattering imaging system to predict tenderness of beef meat. According to their study, 61 beef steaks were measured, the scattering profiles were derived from the hyperspectral images, and these profiles extracted parameters for predicting the Warner Bratzler shear force (WBSF) values. The result of this study showed that hyperspectral scattering imaging techniques have ability to predict WBSF values with R^2 of 0.67.

Results and Discussion

Recently, studies about the assessment of beef tenderness which using hyperspectral imaging have showed encouraging results. For example, Naganathan et al. (2008a) have developed a push broom hyperspectral imaging system in the visible and near infrared that ranges of 400-1000 nm to predict tenderness of 14-day post-mortem, beef from hyperspectral images of fresh beef-ribeye steaks between the 12th and 13th ribs. Values for slice shear force as a tenderness reference and beef steaks were classified in three categories, which are namely tender ($SSF \leq 205.80$ N), intermediate ($205.80 \text{ N} < SSF < 254.80$ N), and tough ($SSF \geq 254.80$ N). After reflectance calibration, a region of interest of 200 × 600 pixels at the center on each beef steak was selected and principal component analysis (PCA) was carried out on the region of interest images. The first five main components explain more than 90% of the variance of all spectral bands in the image. Through a leave-one-out cross validation process, the system predicted the three tenderness categories that accuracy was 96.4%.

Conclusions

As a rapid and non-destructive technique, hyperspectral imaging has already obtained wide acceptance among researchers for non-invasive evaluation of meat products. Hyperspectral imaging is a chemical-free assessment method where sample preparation is not necessary and then reduces processing time for analysis and reduces the cost of traditional methods. However, it is necessary for researchers to overcome technological limitations for implementing hyperspectral imaging in the food industry for meat quality assessment.

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PREDICTIVE MICROBIOLOGY OF SALMONELLA IN DRY-CURED AND SMOKED ROMANIAN PORK SAUSAGE

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Abstract

The dry-cured and smoked Romanian sausage (salami) is a product that can generally be considered safe for consumption. Because of the long shelf-life, approximately 3 months, that the product normally has, as time passes by, the product can become unsafe for human consumption because of the bacteria multiplication. This study uses Combase predictor to calculate the bacteria increase. It was noticed that after 24 days it reaches its peak and the lag phase is installed, if the product is kept at the same temperature as it is predicted, 10°C. In case of inappropriate storage with a higher temperature, the multiplication can occur days before.

Introduction

Salmonella bacteria is the most frequently reported cause of foodborne illness. In order to reduce salmonellosis, a comprehensive farm-to-table approach to food safety is necessary. Farmers, industry, food inspectors, retailers, food service workers, and consumers are each critical links in the food safety chain (FSIS, 2013).

The Salmonella family includes over 2,300 serotypes of bacteria which are one-celled organisms too small to be seen without a microscope. Two serotypes, Salmonella Enteritidis and Salmonella Typhimurium are the most common in the United States and account for half of all human infections. Strains that cause no symptoms in animals can make people sick, and vice versa. If present in food, it does not usually affect the taste, smell, or appearance of the food. The bacteria live in the intestinal tracts of infected animals and humans (FSIS, 2013). Salmonellosis is an infection caused by the bacteria Salmonella. According to the Centers for Disease Control and Prevention (CDC), salmonellosis causes an estimated 1.4 million cases of foodborne illness and more than 400 deaths annually in the United States. The Surveillance Report from the Food Diseases Active Surveillance (FoodNet, 2007), identified Salmonella as the most common bacterial infection reported.

Fermented sausages are cured sausages and to produce salami of a consistent quality one must strictly obey the rules of sausage making. In European countries, the temperatures of 22º -26º C (72º -78º F) are used and the drying, instead of the acidity (pH) is the main hurdle against spoilage bacteria which favours better flavour development. The final acidity of a traditionally made salami is low (high pH) and the sourly taste is gone. North European sausages such as German or Hungarian salamis are made faster, with nitrite addition and are usually smoked. The Romanian dried cured and smoked salami does not contain nitrite addition, because it is left for slow cold drying. It is considered to have a long shelf life because of all the hurdles used.

Materials and Methods

Combase predictor

ComBase Predictor is a predictive modelling tool comprising a set of predictive models, including growth and thermal death models. Models can be used for predicting the response of a range of pathogens and spoilage microorganisms to key environmental factors (temperature, pH and salt concentration). Some models also include an additional, fourth environmental factor, such as the concentration of carbon dioxide or acetic acid.

Parameters that are of particular importance in the dry-cured and smoked romanian pork sausage are: pH, water activity, NaCl and temperature. Being a long-lasting product NO_2 is not used. Combase also has some restrictions when it comes to the lower limit: temperature does not go under the 10°C limit for Salmonella and the water activity for this type of product is normally approximately 0.92 , while Combase's lower limit is 0.973.
All the romanian dry-cured salami manufacturing process takes place at temperatures below 12°C, we will consider 10°C the average temperature for all the manufacturing processes, and the lower Combase water activity will be taken into consideration, but also the NaCl parameter will be considered. The product's pH is set at 5.5, which is the normal pH for this sort of products and NaCl is 4%.
Combase predictor also takes into consideration the initial levels of the bacteria and the physiological state. The initial levels will be set at 3 considering that the meat contained some of the bacteria before being processed and the physiological l state will be set at 1. The Phys. state (or "initial physiological state") is a dimensionless number between 0 and 1 expressing the physical suitability of the cells to their environment. If its value is 0, then growth will not occur (infinite lag); if the value is 1, then growth will commence immediately, without lag. The data points obtained from Combase were imported in Excel and the graphs were generated.
The products shelf life can be months, because the product is cured and smocked. 3 month shelf life means approximately 2900 hours, which is also parameters that Combase needs to use so it can generate a graph.

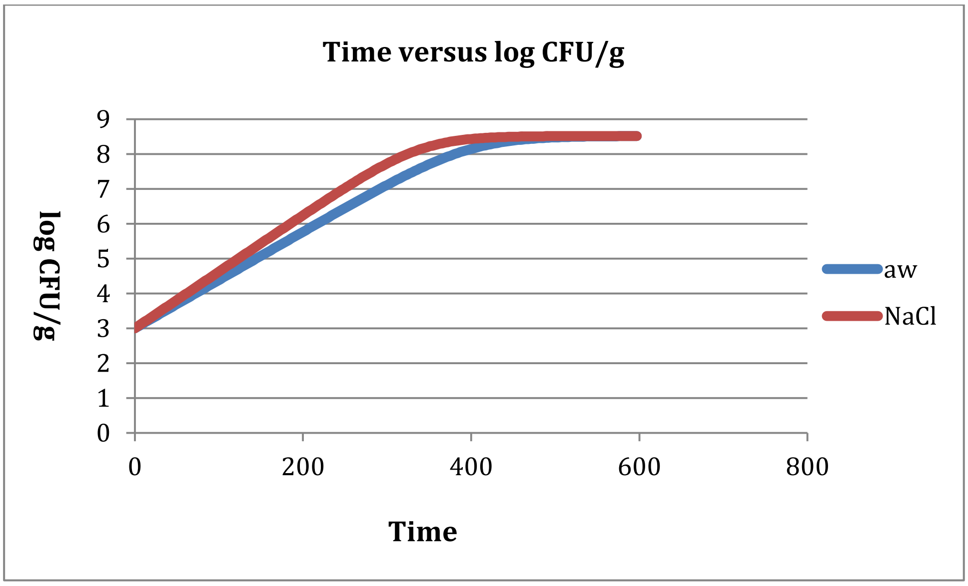

Figure 1: Salmonella growth

Combase can create 2 types of scenarios when it comes to Salmonella spp. as shown in the Figure 1. One scenario refers to the water activity and one to the NaCl concentration that is contained. After 576 for aw and 489 for the NaCl , the lag phase is established. The initial levels were set to 3, after 24 days the levels of Salmonella Spp. increased to 8.52. Another scenario to be considered is temperature. If the temperature increases, the growth will increase as well and the lag phase will be installed much sooner. For the 11°C the lag phase is established after 567 hours, for the 13°C after 429 and for the 15°C after 324 hours (13 days).

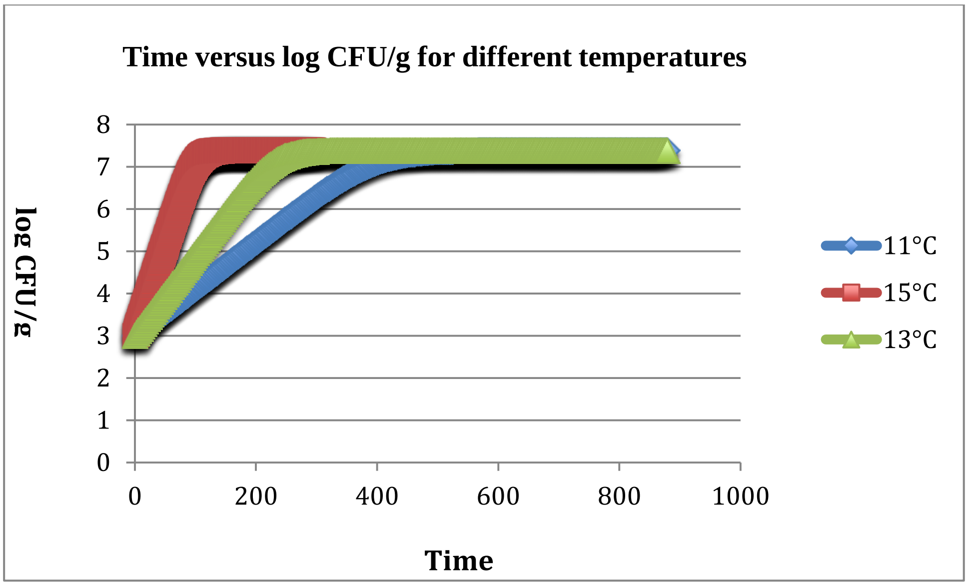

Figure 2: Salmonella growth over temperature ranges

Results and Discussion

It is noticed that the product becomes safer if NaCl is inserted, the dry-cured sausage normally contains approximately 4% NaCl solution. There will be other hurdles that are contained into the product that also reduce Salmonella concentration, but Combase cannot apply them, but it can be assumed that they will reduce the bacteria. Also, temperature has a huge impact on the microbiological growth. 5°C , from 10°C to 15°C can help *Salmonella Spp*. multiply in almost the half time, from 24 days to 13 days.
The product is a dry cured and smoked sausage, this meaning that the product can be kept outside of a fridge as well. If the temperature is high enough, *Salmonella* can reach its peak in just a couple of days if the product was contaminated, which makes it unsafe for consumption.

Conclusions

The product is a dry cured and smoked sausage, this meaning that the product can be kept outside of a fridge as well. If the temperature is high enough, *Salmonella* can reach its peak in just a couple of days if the product was contaminated, which makes it unsafe for consumption.

Acknowledgements

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MONITORING MILK COAGULATION BY USING MICROWAVE SPECTROSCOPY

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Abstract

Milk coagulation is an important step in cheese making processing which can affect final product's nutritional and sensory quality. It is necessary to explore an effective tool for monitoring milk coagulation in cheese processing. Guided microwave spectrometer (GMS) is a fast, non-contact method for monitoring multiple components in liquid, solid or multiphase materials. It has been shown that it can determine multiple constituent concentrations of a process with varying particle sizes. This project aims to demonstrate the potential of microwave spectroscopy for monitoring milk coagulation. A GMS and a rheometer will be used in the test with the same conditions, the data will be analysed by chemometric analysis (multivariate data analysis).

Introduction

The dairy industry has come under increasing pressure to deliver products of high and constant quality into the market. Milk coagulation is the primary step in the production of numerous dairy products, for example, during the manufacturing processes of cheeses it plays an important role in the development of the product's quality. Cheese, a generic name of a group of fermented milk-based food products which produced in a wide range of flavours and forms throughout the world, it account for about 30% of total dairy product sales (Fox 2004). For that reason, there is an emerging need in cheese processing for monitoring milk coagulation. Technologies such as mechanical system, vibrational system, hot wire, ultrasonic system and optical system can be used for this purpose (O'Callaghan *et al.* 2002). However, at today's cheese dairies, plant operators predominately do cutting time evaluation manually, which hinders process automation. Consequently, there is a need for automatic methods of optimized cutting time determination.

Electromagnetic (EM) sensors, namely those which operate at radio or microwave frequencies, are widely used in a variety of industrial sectors. Examples include, civil engineering materials analysis, timber imaging, chemical processing and medicine (Muradov *et al.* 2016). However, there has not yet to be a significant impact of these sensors in the food industry, it is mainly used to determine water content, water activity or fat content in the food (Zhao *et al.* 2017). The particular benefit of this technology is its non-invasive nature and on-line monitoring, which, holds the potential to eliminate fears over instrumentation contributing to food contamination which has disastrous consequences for consumers and suppliers. This might provide the food engineer with tools to identify expected (e.g. seasonal changes) and unexpected (e.g. suboptimal equipment) trends or differences (e.g. in parallel production lines) by comparing every-day variations with observed tendencies, while plant managers could use the same information for a long-term economic maximization.
Thus the purpose of this study is to demonstrate the potential for microwave spectroscopy in monitoring milk coagulation.

Microwave spectroscopy is a rotational spectroscopic method which can measure molecular rotational motions originating in electronic, ionic or molecular levels of energy transitions (Zhao *et al.* 2017). Microwave energy is sensitive to the concentration of polar, semi-polar and non-polar molecules such as water, protein, fat, oil and ion/salt concentration in a process or sample. Thus, the principle of GMS is it applies a sinusoidal (AC) microwave signal to the material that passes through the sample in the chamber providing a representative measurement of the bulk product. In the presence of microwave energy, the polar molecules in the sample such as water rotate and align with the electromagnetic field, similar to aligning the poles on a magnet. The movement of the molecules causes the microwave signal to be attenuated and the velocity of the wave decreases as it passes through the sample.

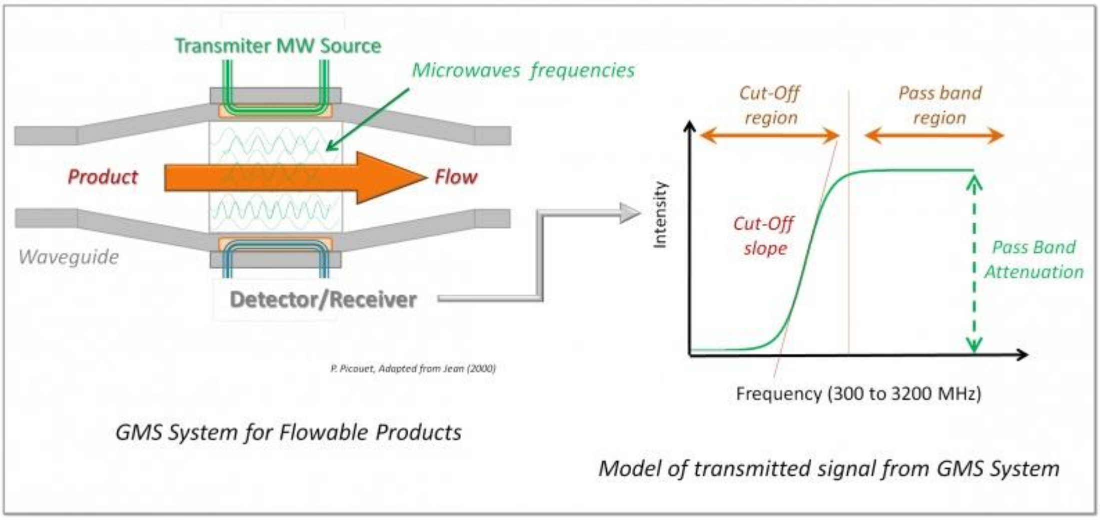

Figure 1. A diagram of GMS system and model of its transmitted signal (http://www.foodtech-portal.eu/index.php?title=File:2_1_1_GMS_pierre_picouet.jpg)

The resulting GMS spectrum has two characteristic features, the cut-off frequency and the passband region. (See fig. 2) The cut-off region is the characteristic high slope "rise" in the spectrum which is determined by the dielectric constant of the sample. This cut-off region is the result of the sample attenuating and reducing the velocity of the energy, which changes its wavelength. The pass band region is generally fairly horizontal. It shifts primarily in the vertical direction with small changes in the slope. The amplitude of the pass band region is determined by the conductivity of the sample and how much energy is lost in the transmission from the transmitter to the receiver antennae of the chamber. The cut off region is generally sensitive to moisture and the passband region to other constituents. Using a well-defined calibration, the changes in the passband and cut off regions are correlated to the amount of change in the concentration of the component of interest in the mixture.

Materials and Methods

Samples preparation

Figure. 2 shows the flow chart of the testing procedure. Before each experiment, a 700 mL skim milk sample will be heated to the target coagulation temperature (32 °C) using a water bath. When thermal equilibrium was achieved, the rennet will be added at a concentration, E_0 = 27 μL^{-1} milk, and the skim milk will be quickly stirred during 30s and immediately, split into two aliquots. A 600 mL aliquots will be placed in the measuring vat of the microwave spectroscopy measurement and a 100 mL aliquot will be placed in the rheometer cup to determine the rheological parameters.

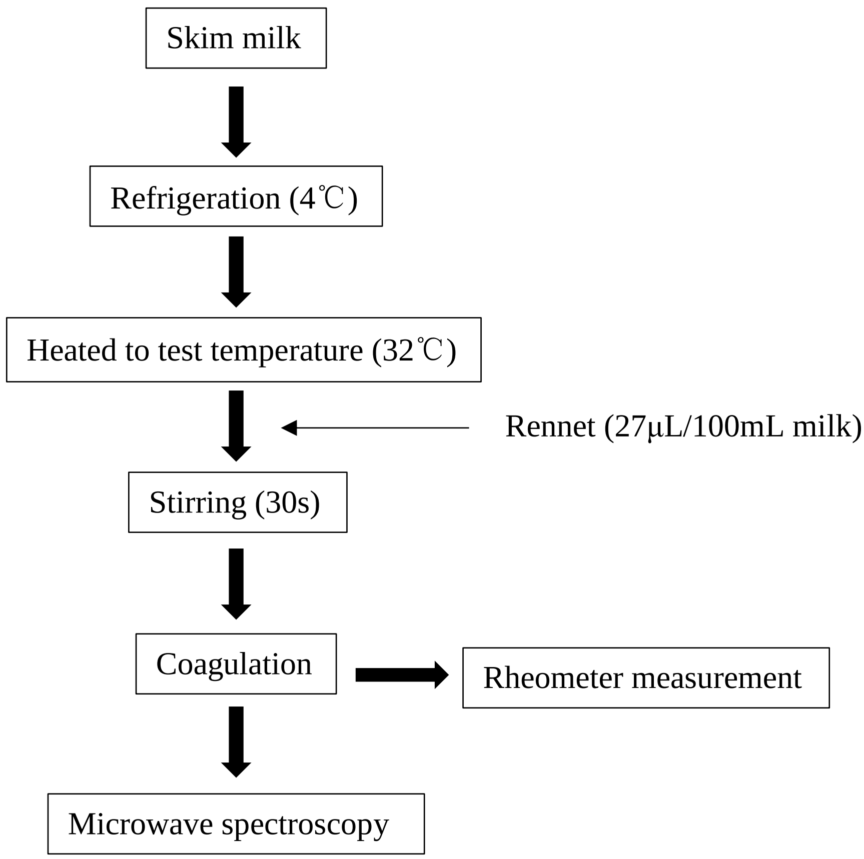

Figure 2. A flow chart of test procedure

Rheometer

Modular Compact Rheometer MCR92 with C-PTD 150/XL/AIR/18P temperature device and CC39 measuring system will be used for this project to determine physical cheese gel characteristics.

Guided Microwave spectroscopy instrumentation

Guided Microwave Spectrometer (GMS) from Thermo Electron Corporation will be used.

Multivariate data analysis

The data acquired from experiment will be pre-treated by few methods, such as multiplicative scatter correction (MSC), standard normal variate (SNV) transformation and Savitzky Goly derivative to remove baseline shifts, slope change, scatter effect and reveal greater structure in the spectral data. The multi-variant approaches, like principal component analysis (PCA) and partial least squares (PLS) regression are common methods used in the chemometric operation.

Expected Results

The expected result is the three coagulation stages (I) κ-casein proteolysis, (II) paracasein aggregation and (III) gel network formation can be identified from the spectral profile and developing a model which can use to determine the cutting time of cheese making. For the further exploration, parameters affecting milk coagulation will be evaluated.

Conclusions

The objective of this project is to demonstrate the potential for microwave spectroscopy in monitoring milk coagulation. The expected results will be obtained by collecting data from samples and analyzing by multi-variant data treatment approaches combined with chemometric methods. The data collected from different measurement methods will be compared.

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DEVELOPMENT OF PAT TOOLS FOR THE QUANTITATIVE ANALYSIS OF MINERALS IN INFANT FORMULAS

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Abstract

This study investigated the potential of Process Analytical Technology (PAT) tools for the quantification of eight elements i.e. Ca, K, Fe, Mg, Mn, Cu, Zn and Pb in liquid infant formula samples (n = 83). Inductively coupled plasma-atomic emission spectrometry (ICP-AES), Raman and Fourier transform midinfrared (FTIR) techniques combined with chemometric approaches (i.e. principal component analysis (PCA), partial least squares regression (PLS-R) and data fusion were used in this study.

Introduction

Commercially produced infant formulas are enriched with minerals and other nutrients that provide adequate nourishment among infants and toddlers (Soyeurt *et al.* 2009). Therefore, quantification of mineral content in the infant formula during manufacturing process is a critical quality control issue.

Currently, most dairy manufacturers facilities use conventional methodologies such as atomic absorption spectrometry (AAS) (Kazi *et al.* 2009) and inductively coupled plasma atomic emission spectrometry (ICP-AES). However, these methods are time consuming, labour intensive, and require complex methods of sample preparation. In this study ICP-AES will be employed as a chemical reference method to determine mineral contents in liquid infant formula samples. It simultaneously analyses multiple elements. An inductively coupled plasma source is used to dissociate the sample into its constituent atoms or ions, exciting them to a level where they emit light of a characteristic wavelength. A detector measures the intensity of the emitted light, and calculates the concentration of that particular elements in the sample (Birghila *et al.* 2008). Detection limit of ICP-AES is typically at the 1-10 parts per billion (ppb) level.

In recent years, spectroscopic methods have been extensively used in quantification of dairy constituents. Recent advancements in instruments and chemometric approaches have facilitated its economical application in process control and product evaluation (Soyeurt *et al.* 2009; McGoverin *et al.* 2010). In contrast, there have been a limited amount of studies conducted to assess liquid infant formulas. In the current study, Raman and Fourier transform infrared (FTIR) spectroscopy techniques in combination with chemometric approaches will be used to quantify eight elements (Ca, K, Fe, Mg, Mn, Cu, Zn and, Pb) in liquid infant formula samples. A total of 83 samples in five concentrations, i.e. 3%, 5%, 8%, 10% and, 13% will be analysed.

The objective of this study is to investigate the use of Raman and FTIR spectroscopic techniques for the development of process analytical technology (PAT) tools for the quantitative analysis of Ca, K, Fe, Mg, Mn, Cu, Zn and, Pb in the liquid infant formula.

Materials and methods

Sample preparations

For this study, infant formula powder samples were produced in Teagasc food research centre (Moorpark, Cork) and stored in sealed aluminum bags at ~ 15 °C. After storage powders were dissolved in deionised water to produce homogeneous solutions at five concentrations, i.e. 3%, 5%, 8%, 10% and, 13% w/w.

1. ICP-AES analysis

Acid digestion

To determine the mineral content in the liquid infant formula using ICP-AES, acid digestion of the sample was performed to remove all the organic materials from the sample. 8 mL of liquid infant formula samples were transferred into ceramic crucibles and heated into the furnace at ~ 550 ºC temperature until the white ash was formed. After cooling ash was dissolved into 25 mL nitric acid (5% w/w HNO_3). Furtherly, samples were diluted using 5% w/w nitric acid to get the contain minerals in part per million (ppm) or parts per billion (ppb) levels for the use of ICP-AES analysis.

Apparatus

Vista RL-CCD Simultaneous ICP-AES (Varian, USA) apparatus was used to perform the analysis of the liquid infant formula samples. Instrument operating parameters are summarised in Table 1.

Table 1: Operating conditions for ICP-AES

Spectrometer	Vista RL-CCD Simultaneous ICP-AES (Varian, USA)
Radio frequency (RF) power (kW)	1.0 – 1.3
RF frequency (MHz)	27.12
Plasma gas flow rate (L/min)	15
Nebuliser gas flow rate (L/min)	1
Auxiliary gas flow rate (L/min)	1.5
Observation height (mm)	12-15
Elements with respective detection wavelengths (nm)	Ca (396.847), Mg (279.553), K (766.491), Mn (257.610), Cu (324.754), Fe (238.204), Zn (202.548), Pb (220.353)

Calibration

Standard solutions were prepared by accurate dilution of a multi element stock standard. Mineral concentrations were quantified calibration curves were established using external standards which were diluted using 5% w/w HNO_3 to develop a standard method for sample analysis.

2. Raman spectroscopy

DXR Smart Raman spectrometer (Thermo Fisher Scientific Inc., USA) was used for analysis of liquid infant formula samples. Calcite is a common food additive used to increase the calcium content in the dairy products. Some studies suggest, Raman spectroscopy as an effective tool to quantify mineral contents in dairy products. Figure 1 shows the Raman spectra of milk powder, calcite spiked milk powder and calcite (Smith *et al.* 2013).

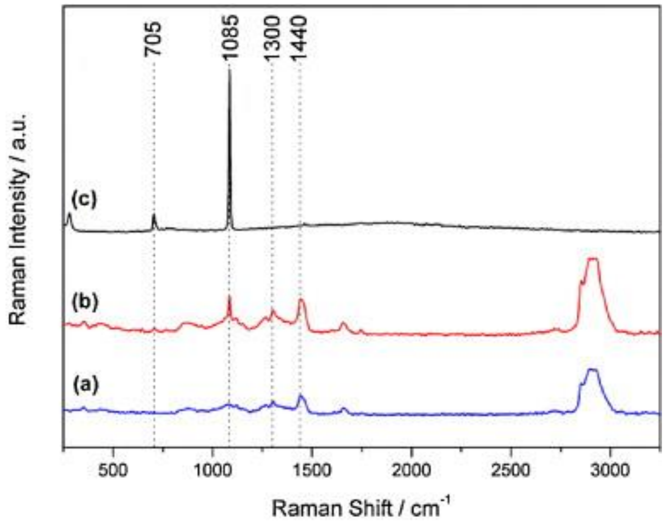

Figure 1: Raman spectra of (a) milk powder, (b) calcite spiked milk powder and (c) calcite (Smith *et al.* 2013).

3. FTIR spectroscopy

Nicolet iS 5 FT-IR Spectrometer (Thermo Fisher Scientific Inc., USA) was used to acquire mid infrared spectral data of infant formula samples. Examples of spectral readings obtained from dairy products can be found in different research papers (Soyeurt *et al.* 2009). Figure 2 is an example of typical FTIR spectra of various milk types.

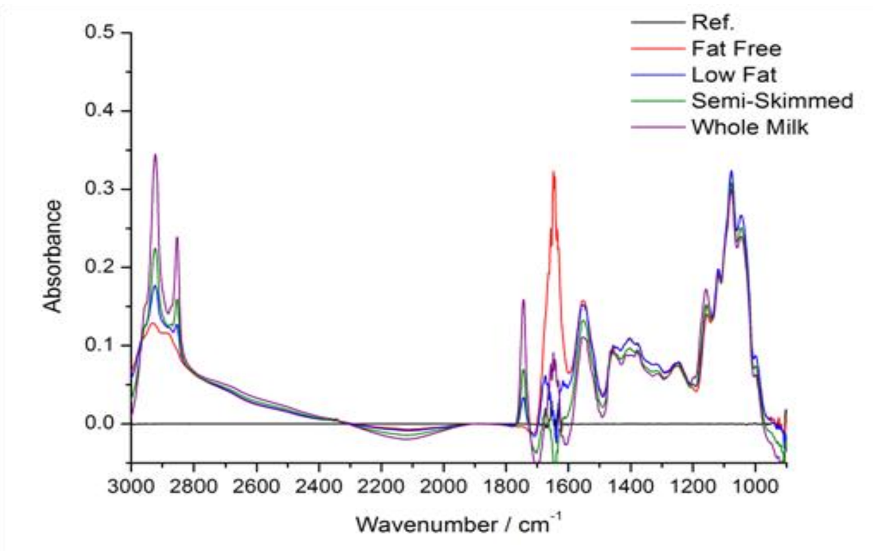

Figure 2: Spectra of various milk types (Specac Ltd 2017).

4. Multivariate data analysis

After the analysis of all the infant formula samples using ICP-AES, Raman and FTIR spectroscopy, all the data were imported into R (Rstudio Team 2015) for data analysis. Different chemometric approaches such as principal component analysis (PCA) and partial least squares regression (PLSR) were used to explore the properties of the acquired spectra. Furtherly, data fusion will be carried out using Raman and FTIR spectral data to improve the prediction performance of PLSR models.

Work flow

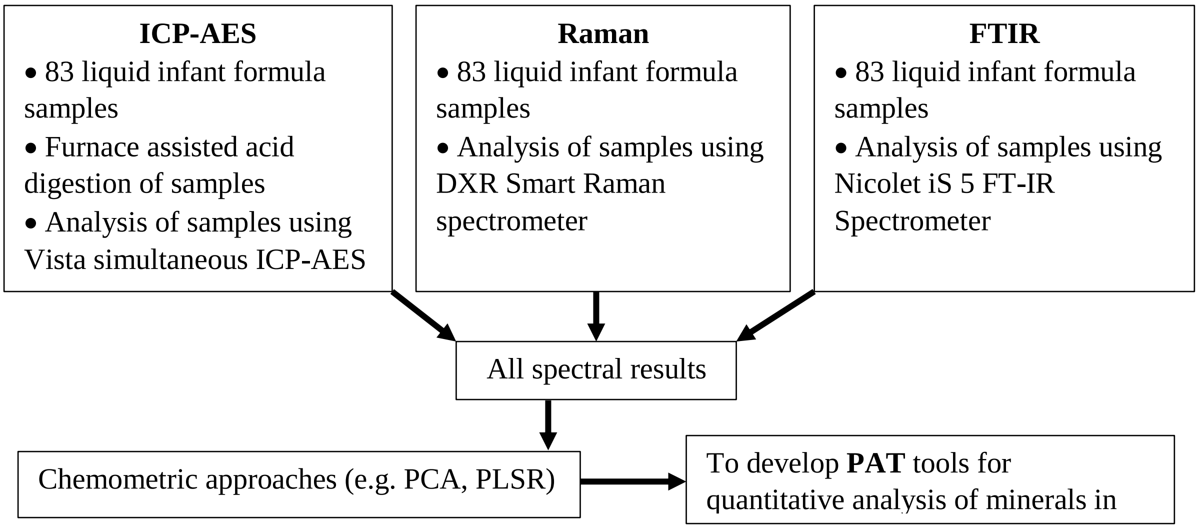

Figure 3: Schematic of work flow

Conclusions

This study explored the potential of FTIR and Raman spectroscopy with different chemometric approaches which can be implemented as PAT tools for the quantification of mineral contents in infant formula products.

Acknowledgments

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NIR - HYPERSPECTRAL IMAGING AND CHEMOMETRICS AS A PAT TOOL FOR THE PREDICTION OF FOOD POWDERS MIXING KINETICS

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Abstract

Near Infrared – Hyperspectral Imaging (NIR-HSI), was investigated in combination with chemometric techniques (Principal Component Analysis (PCA), Partial Least Squares Regression (PLS-R), and Ensemble Monte Carlo variable selection (EMCVS) for food powders mixing kinetics evaluation. Mixture kinetics was evaluated using the PLS-R model based on selected NIR-HSI bands which accurately predicted icing sugar (IS) concentration in corn flour (CF) in order to evaluate the quality of the mixing process, the best model was constructed with 7 selected variables (1391, 1419, 1426, 1454, 1475, 1482 and 1503 nm) and had a RMSECV of 0.58%, RPDCV 55.4, RMSEP 1.00%, RPDP 48.6, R2 1.000 and 2 latent variables.

Introduction
Powder mixing is one of the most common unit operations in the food processing industry. The ultimate physical, chemical, nutritional and organoleptic characteristics of final products depend on the mixing process (Cullen and O'Donnell, 2009). The kinetics of mixing in any type of mixer can be followed by measuring (or estimating) the standard deviation of mixture composition for various mixing times (Equation. 1), where x_i = is the fraction of the key component in the samples and μ = is the observed mean.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}} \quad \dots \text{(Eq.1)}$$

A typical kinetic curve begins with an exponential decay followed by an asymptote that can be approximated by a series of oscillations. The exponential decay is a rapid reduction in heterogeneity (large scale re-arrangements of the bulk induced by convection and shear mechanisms). The oscillations in the tail of the kinetic curve can be attributed to a competition between mixing and segregation (Massol-Chaudeur et al., 2002).

Process Analytical technology (PAT) comprises analytical measurements and understanding of chemical, physical and microbiological parameters governing processing. In 2004, the US Food and Drug Administration (FDA) defined PAT as "a system for designing, analyzing, and controlling manufacturing through timely measurements (i.e. during processing) of critical quality and performance attributes of raw and in-process materials and processes with the goal of ensuring final product quality" (FDA, 2004). Adoption of PAT in the food industry is driven by the requirements of regulators, consumers and companies. Other considerations include business and environmental sustainability (O'Donnell, Fagan and Cullen, 2014). Spectroscopic tools for PAT practices such as near infrared (NIR) and hyperspectral imaging, have been employed for in-line, on-line and at-line process monitoring in pharmaceutical, agricultural and food processing industries. Some features include: high measurement speed, non-destructive analysis, lower cost than other screening methods (chromatography, mass spectroscopy, microscopy or DNA-based techniques) and samples can be measured directly using solid state detectors, fiber optics or micro, in-process spectroscopic analyzers in combination with chemometrics.
The aim of this study was to apply the best PLS-R model based on selected NIR-HSI bands as a Process Analytical Technology (PAT) model combining Near Infrared Hyperspectral Imaging (NIR-HSI), and chemometrics for the prediction of food powders mixing kinetics.

Hyperspectral imaging integrates conventional imaging and spectroscopy to obtain both spatial and spectral information from a sample. Hyperspectral images or hypercubes are three-dimensional blocks of data, comprising two spatial and one spectral dimension. Each pixel in a hyperspectral image contains the spectrum of that specific position, representing the light-absorbing and/or scattering properties of the spatial region represented, which can be used to characterize the composition of that particular pixel (Gowen et al., 2007). Spectral pretreatments, principal component analysis, partial least squares regression and variable selection are chemometric analysis tools that are suitable to extract information from HSI data.

Materials and Methods

Powder characterization:

The binary mixtures under study namely corn flour (CF) and icing sugar (IS) were chosen as they are similar in colour and particle size distribution, and are widely used in food industry as ingredients for pre-mixtures (confectionary). Particle size distributions (PSD) were determined using a Mastersizer® 3000 Laser diffraction instrument. Particle density was determined with a Micromeritics AccuPyc II 1340 gas pycnometer.

Binary mixtures preparation

Binary mixtures were prepared by mixing corn flour (CF) and icing sugar (IS) in proportions of 10, 20, 30, 40, 50, 60, 70, 80, and 90% expressed as concentration (w/w) of CF in IS for model development.

Time series experiment

Seven samples of mixtures of 50:50 (W/W) concentration were mixed at different period of times (0, 1, 3, 7, 10, 15, and 30 s) in a VWR international Vortex Mixer (UK), at 2000 RPM and scanned in a NIR-HSI system.

Hyperspectral imaging system

The hyperspectral imaging system and calibration procedure used is similar to that reported by (Achata et al., 2015).

Data analysis

PCA and PLS-R were performed in combination with spectral pre-treatments on logarithm transformed (log (1/R)) NIR spectral data. Standard normal variate (SNV), median scaled (MS), Savitzky-Golay 7 points, second order polynomial first derivative (FD), Savitzky-Golay 7 points, second order polynomial second derivative (SD) and lineal detrending (LD) pretreatments, and all combinations of any two pretreatments. To improve the performance of PLS-R models, the variable selection method EMCVS (Ensemble Monte Carlo Variable Selection) was applied to the combination of pretreatments that produced the best PLS-R (Esquerre et al., 2011). Concentration prediction of each sample was calculated by multiplying the mean spectrum by the PLS regression vector.

Results and Discussion

Powder characterization:

Table 1 lists the results of the particle size and density of both CF and IS. IS had a wider particle size distribution than CF.

Table 1. Powder Characterization

Sample	Particle size (µm) D10	Particle size (µm) D50	Particle size (µm) D90	Particle density (kg L^{-1})
IS	7.3	51.5	202.3	1.4
	(0.05)	(0.91)	(4.04)	
CF	7.9	14.3	24.9	1.5
	(0.05)	(0.00)	(0.23)	

NIR-HSI model prediction:
Table 2 lists the best spectral pretreatment combination and PLS-R in the first two rows, after one iteration of the EMCVS method, 7 wavelengths were selected (1391, 1419, 1426, 1454, 1475, 1482 and 1503 nm) to build the calibration model as presented in third row. This model was selected for use in prediction of mixture kinetics and quality of mixing.

Table 2. *NIR-HSI model prediction*

Pretreatment		Log(1/R)				
1	2	LV	$RMSE_{CV}$ (%)	RPD_{CV}	$RMSE_{P}$ (%)	RPD_{P}
LD	SNV	3	0.8	41.4	0.5	57.6
FD	SNV	3	0.7	48.1	1.0	51.8
EMCVS		2	0.58	55.4	1.0	48.6

Figure 1(a) shows the mean log (1/*R*) spectra of the samples. The maximum value around 1440 nm may be assigned to the O-H stretching first overtone. IS samples showing the characteristic narrow peak of crystalline sucrose at 1440 nm. In Figure 1(b), the SNV over FD of log (1/*R*) spectra, shows the differences in spectra according to powder concentration around 1410 nm (OH stretching first overtone (ROH)) and around 1480 nm.

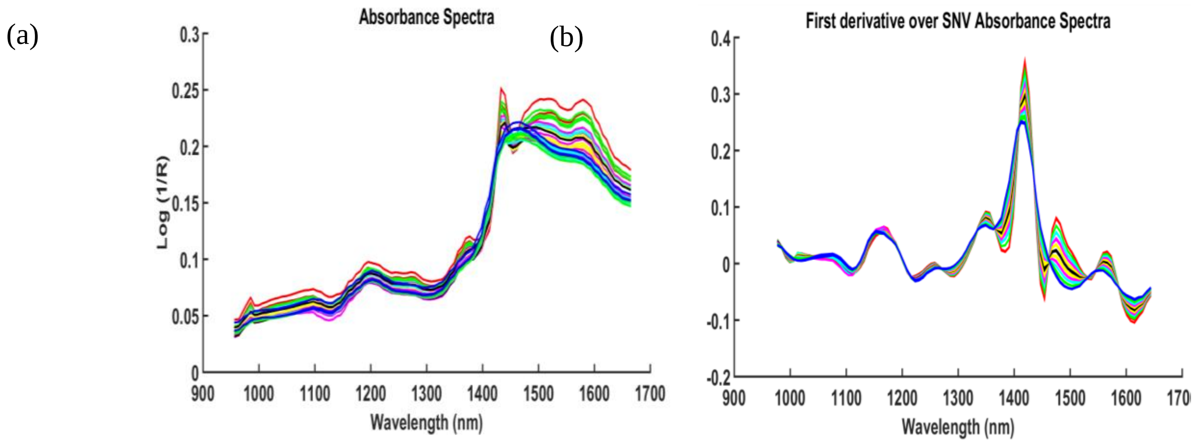

Figure 1. (a) Mean log(1/*R*) spectra of the samples, (b) SNV over FD of log(1/*R*)

The mixing kinetics curve (Figure 2a), shows the typical kinetics behaviour of powder mixing, beginning with an exponential decay before 15 s indicating the rapid reduction in heterogeneity due to the mixing mechanisms, followed by an asymptote after 15 s mixing time, that can be approximated by a series of oscillations favouring the mixing process, but at the same time segregation is favoured in this period. Figure 2 (b) Partial least squares regression validation plots of predicted versus actual predicted time**.**

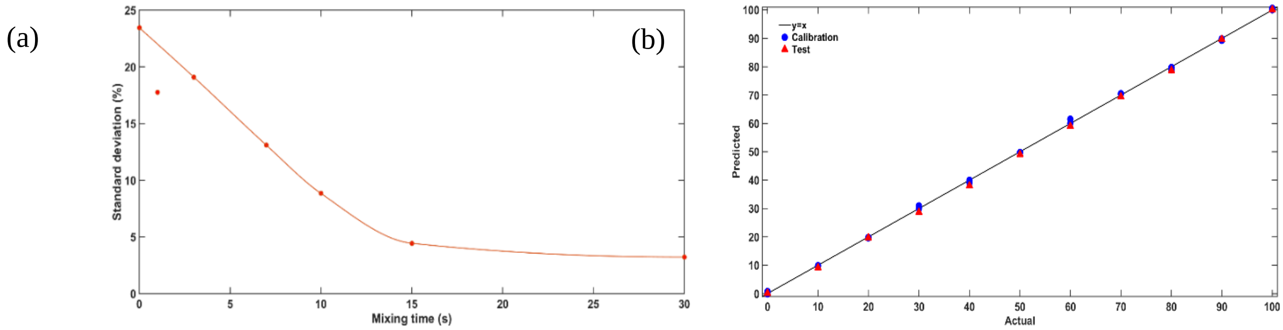

Figure 2. (a) Mixing kinetics curve (b) PLS-R validation plot of predicted versus actual time.

Conclusions

The mixing kinetics for the proposed mixing times were successfully predicted using hyperspectral imaging by applying the best regression model obtained in the concentration detection test. The results of this experiment were achieved using two powdered systems mixed at seven different times, demonstrating the ability of hyperspectral imaging combined with chemometrics to assess binary mixtures of food powders providing information on mixture homogeneity through the kinetics of mixing. Further work included additional time points should be carried out in order to construct better model for the application at the processing line.

Acknowledgements

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EXPLORATIONS OF GUIDED MICROWAVE SPECTROSCOPY (GMS) FEATURES FOR INFANT MILK FORMULA DETECTION

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Abstract

This study originally explored the spectral features of infant milk formula samples (INF; n=83) using a guided microwave spectroscopy (GMS) system at 22 ºC and 50 ºC. The cut-off region and pass-band region of GMS for INF samples are 160-732 MHz and 760-1200 MHz at 22±1.5 ºC, 192-768 MHz and 800-1200 MHz at 50±2.5 ºC respectively. Principal component analysis (PCA) was used to detect principal components and outlying samples.

Introduction

Ireland is one of the biggest producer and exporter of dairy products in the world. Ireland exports 90% of all dairy products to approximately 140 countries all over the world; exports of infant milk formula occupy 10% of the entire global infant formula. With the abolition of milk quotas in 2015, it is expected to have a 50% growth of Irish milk outputs in the years of 2015-2020 (*Dairy & Ingredients - Enterprise Ireland* 2015). Therefore, Irish dairy industries require to establish an implement system for production quality control of the products they produced. Combined with multivariate data analysis, GMS system has been investigated to determine fat and moisture in ground beef and other quality parameters (i.e. soluble solids content, titratable acidity and Bostwick consistency) of tomato paste (Zhang *et al.* 2014, Zhao *et al.* 2017). However, there are limited amount of studies investigated on the potentials of GMS system in the dairy industry. **The current study originally explored the GMS features on Infant milk formula at different temperature and concentration levels which were measured in a static condition. Principal component analysis (PCA) was employed to detect the principal components and outliers of INF samples.**

Material and methods

INF sample preparation:

INF calibration samples were produced following the first band (0-6 month) formula in Teagasc Food Research centre (Moorepark, Cork). Five first-band Irish commercial infant milk formulas (i.e. Aptamil, SMA, Cow&Geat, Mamia and Similac) as INF validation samples were purchased from local supermarket. Each INF sample was well dissolved in deionized water (600 ml) to make liquid test samples in 5 different concentration levels (i.e. 3%, 5%, 8%, 10% and 13% w/w) using a 4-blade impeller (Silverson L4R, Silverson Machine Ltd., Bucks England) with 6 RCF (g) for 20 min. In total, 83 INF test samples including calibration samples (n=58) and validation samples (n=25) were used in the current study.

Sample measurements (ε scan):

Dairy products were measured using a ε scan in-line GMS analyzer (Thermo Fisher Scientific Inc., Takkebijsters Breda, The Netherlands) in a static condition; samples were fully filled into the electro-magnetic field of the measurement chamber. Microwaves (100-2200 MHz in 4 MHz increments) were generated in the electro-magnetic field to penetrate through the sample from the transmitter to the receiver. The ε scan analyser temperature probe was also inserted into the sample for temperature reference. In this study, each INF sample was tested in triplicates at 22 ºC and 50 ºC. 12 normalized spectra were collected and saved as .csv files after each scan. 36 normalized spectral data of each sample were imported in Matlab (2014a The Mathworks, Natick, MA, USA), and were also imported into The unscrambler x.10.4 (Camo, Trondheim, Norway) for chemometric analysis.

Multivariate data analysis:

For each sample, visible abnormal spectra were removed directly. Furtherly, PCA using leave-one-out full cross-validation was used to detect some other outlying spectra. Averaged spectrum of each sample was obtained from the rest of spectra. Based on mean normalized spectral data, PCA (leave-one-out full cross-validation) was carried out to present sample clustering, outlying sample detection was performed using Hotelling T^2 ellipse with a 5% significance

Results and discussions:

GM spectral features of INF:

Fig 1. shows all normalized GM spectra of INF samples in the range of 0-1200 MHz. The cut-off frequency (fc) ranges of INF samples are 160-732 MHz, 192-768 MHz when samples were measured at 22±1.5 ºC and 50±2.5 ºC respectively, which reflects the differences of samples' dielectric constant (ε'). Due to polar molecules moving violently at higher temperature, cut-off frequency of all GM spectra measured at 50 ºC shifted 36 MHz towards to a higher frequency range in comparison of them at 22 ºC. Pass band frequency ranges of INF sample were showed as 760-1200 MHz of the measurement at 22±1.5 ºC, 800-1200 MHz of the measurement at 50±2.5 ºC, which referred to energy loss due to heat generation by molecular rotational movement, namely dielectric loss factor (ε'').

Fig. 2 shows normalized GM spectra of all INF samples measured at a) 22±1.5 ºC; b) 50±2.5 ºC respectively, the spectral grouping is depending on samples' concentration levels (i.e. 1= 3% conc; 2=5% conc; 3=8% conc; 4=10% conc; 5=13% conc). When sample concentration level increases, spectral signal peaks of INF samples measured at both temperature drop. It was probably explained by the number of polar molecules increase at higher concentration levels to stored more wave energy.

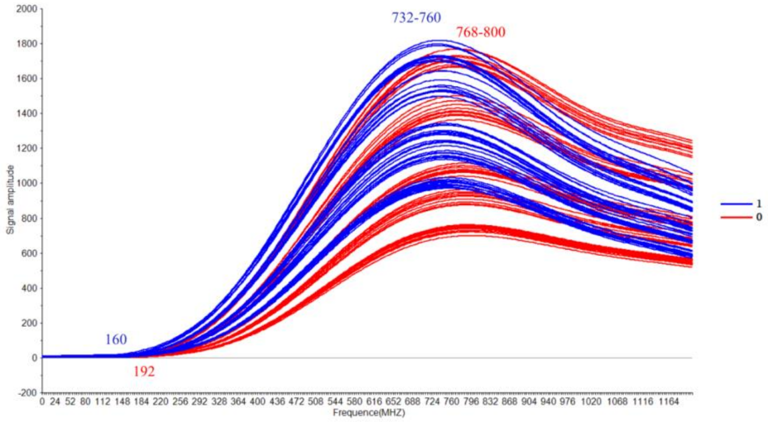

Figure 1: All normalized GM spectra for INF over 0-1200 MHZ at 22±1.5ºC **(1)** and 50±2.5ºC **(0)**.

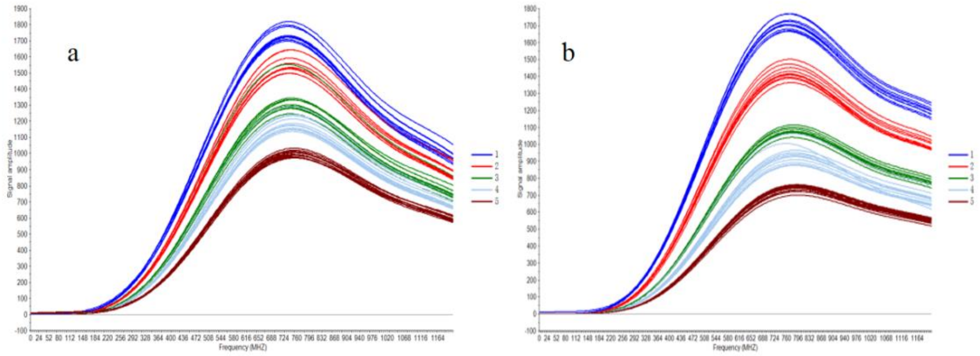

Figure 2: All normalized GM spectra of INF at a) 22±1.5 ºC; b) 50±2.5 ºC in 0-1200 MHz (1= 3% conc; 2=5% conc; 3=8% conc; 4=10% conc; 5=13% conc).

PCA results:

In Fig 3a and b, PC 1 and PC 2 can explain 100% of the spectral variance at both 22±1.5 ºC and 50±2.5 ºC. Five clusters (representing 3%, 5%, 8%, 10% and 13% w/w concentration levels) are identified along the PC 1 direction.

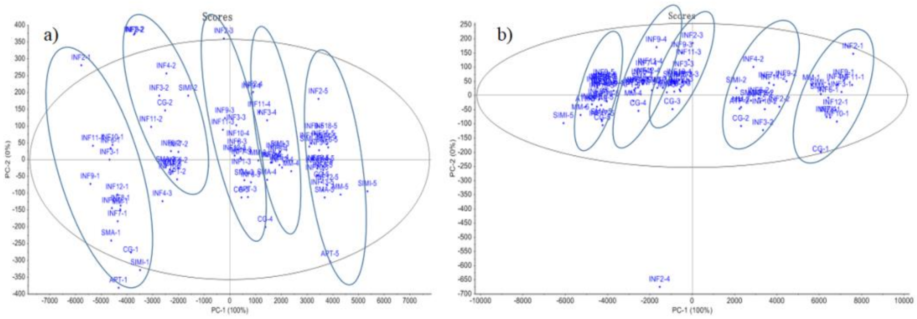

Figure 3: PCA score plot for INF samples a) n=82 at 22±1.5 ^{0}C b) n=81 at 50±2.5 ^{0}C

The Hotelling T2 ellipse with a 5% significance was used to detect the outlying samples. In Fig 3a, most samples are inside the ellipse, 5 samples are located in a small distance outside the ellipse, however, these samples' spectra did not show any unusual features, they will be included for further analysis. In Fig. 3b, all samples are located inside the ellipse expect the one sample lying far away the ellipse boundary, therefore, this sample will be excluded in further analysis. The abnormal sample spectrum was probably caused by air bubble bursting in the test chamber during sample scan,

Conclusions and future work:

In this study, the INF samples with 5 different concentrations were measured using a ε scan in-line GMS analyzer at 22 ºC and 50 ºC respectively. The GM spectra of INF samples was investigated in the frequency range of 0-1200 MHz. PCA scores showed clear results for sample cluster identification and outlier detection. In future work, chemical analysis of INF will be carried out using: 1) refractometer to determine **total solids** (AOAC Official Method 932.14c & 932.12); 2) a bench-top nuclear magnetic resonance (NMR) instrument (SMART Trac Fat Analyser; CEM Corporation USA) to test **crude fat** (Cartwright, G. et al 2005); 3) gas chromatography (GC) to determine **fatty acids** (AOAC official method 996.06; Fat (total, saturated, and unsaturated) in foods); 4) Dumas apparatus (LECO) to achieve **protein** determination (AOAC Official Method 997.09) (ES ISO 14891:2012); 5) Atomic Absorption Spectrophotometry to carry out determination of **main mineral contents** (AOAC official method 999.10). PLS regression models will be developed for prediction of chemical components of liquid infant milk formula using GMS system in both static and motional condition.

Acknowledgements

The author gratefully acknowledges the Irish Department of Agriculture, Food and the Marine (DAFM) for their funding under the FIRM programme (Reference No: 14/F/866) and UCD-CSC scholarship for financial supports.

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AIRBORNE ULTRASONIC TECHNOLOGY FOR MICROBIAL INACTIVATION IN DRIED FOOD INGREDIENTS

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Abstract

Conventional methods for decontamination of died foods present various drawbacks including undesired effects on food quality and nutritional value. Airborne acoustic technology could be a potential technology to reduce the microbial loads with limited impact on food quality. In this paper, tapioca starch and black pepper grains have been submitted to airborne acoustic waves at different powers at 170 W and different treatment times from 0 to 90 min at room temperature. Significant reduction of 2.5 log have been observed in tapioca starch. In order to assess if this technology has any significant effect on the food quality of each dried ingredient, rheological properties of tapioca starch have been assessed. Significant results were observed in the viscosity of the starch after treatment.

Introduction

Dried food ingredients including grains, spices and powders are widely used as an ingredient in various food formulations. However they are frequently contaminated with spoilage and/or pathogens microorganisms. The conventional methods of decontamination are by employing thermal treatments or chemicals (e.g. Chlorine) which may have negative impact on quality. Nevertheless applying high temperatures on food products present various disadvantages, as it can alter the quality (e.g. colour, texture, flavour) and reduce the nutritional profile of the food matrix. Others techniques consisting in heating with super-heated steam, fumigating with ethylene oxide gas (EOG) or irradiating with ultraviolet irradiation and ionizing radiation are inadvisable due to the loss of sensory properties and high moisture content propitious to mould development following super-heated steam treatment (Schweiggert *et al.* 2007), the potential carcinogenic effect of the residues of EOG fumigation (Fowles *et al.* 2001) and the oxidation and degradation of components such as lipid occurring after gamma-rays, X-rays or electron beams applications (Wu and Yang 1994). Since most of the microorganisms reside on the surface of dried foods, it is not necessary to expose the inner parts to heat, gas or radiation.

The ability of ultrasound for decontamination has been widely demonstrated on liquid foods or foods immersed into liquid media using contact type systems (waterbath and probe-based system). Non-contact ultrasonic applications are more and more investigated in the food industry for defoaming (Rodríguez *et al.* 2010), drying (Gallego-Juárez *et al.* 2007) and inactivation of microorganisms (Pisano *et al.* 1966). Airborne acoustic ultrasound is characterised by its non-contact transducers, which are capable of transmitting ultrasonic waves to the product using air as the coupling medium. Airborne acoustic ultrasound could be a potential technology for decontamination dried foods with limited effects on food quality.

The objective of this study was to investigate the effect of airborne acoustic technology on vegetative cells and bacterial spores in various dried food ingredients including starch and spices, and evaluate its impact on food quality.

Materials and Methods

Sources of dried food ingredients
Tapioca starch obtained from AllinAall Ingredients Ltd (Product No 7111, Dublin, Ireland).

Microbial growth and inoculation
Bacillus subtilis was grown in nutrient broth for 24 h at 30 ^{0}C under shaking conditions (150 RPM). 10 mL of *B subtilis* culture at 10^7 CFU/mL were inoculated into 5 g of the selected dried food and submitted to gentle agitation (170 RPM) at 30 ^{0}C for 2 h. This inoculation method allowed a recovery of approximately 95-99 % of the cells in the food matrix. The mixture was then dried at 35 ^{0} C for 1h30. The treatment was conducted as described in the following section. 1 g of sample was recuperated after 0 (the control was not submitted to sonication), 30, 60 and 90 min and resuspended in Maximum Recovery Diluent (MRD) in order to obtain 1-fold dilution. Decimal dilutions were carried out and spreaded on nutrient agar plates. After 24 h at 30 ^{0}C, the CFU was counted. All experiments were replicated three times.

Airborne acoustic treatment
The experiments were done using an airborne ultrasonic system at 26 kHz provided by Pusonics S.L (Madrid, Spain). It consists of an electronic power generator which comprises a dynamic resonance controller, a power amplifier, a high impedance matching box, and a circular stepped-plate transducer. The sample was placed at 42.5 cm from the focus centre of the transducer, as the maximum acoustic intensity of 10 W/cm^2 is reached at this distance. The ultrasound power was varied from 10 to 170 W. The experiments were done at room temperature (Figure 1).

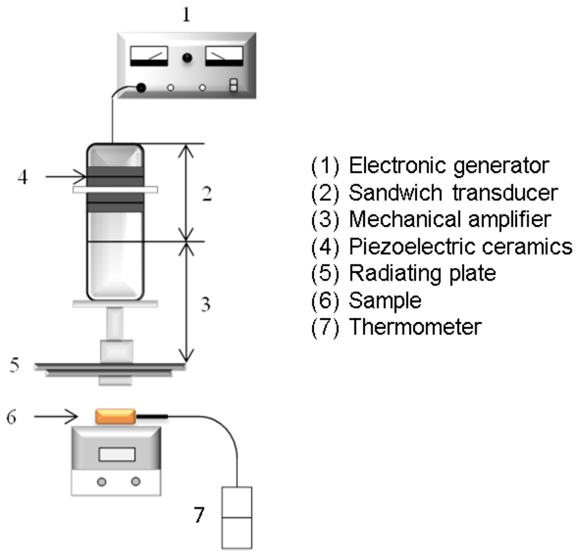

Figure 1. Experimental setup for airborne acoustic system

Pasting properties
Pasting parameters were determined with a Rapid Visco Analyzer (RVA) (Model RVA 3D+, Newport Scientific, Australia). Tapioca starch suspension (2.5 g of starch added in 25.0 g of distilled water) was heated from 50 to 95 °C at 6 °C/min (after an equilibration of 1 min at 50 °C), held at 95 °C for 5 min, and cooled at 6 °C/min to 50 °C. Peak viscosity (PV), breakdown viscosity (BD), final viscosity (FV), setback viscosity (SB) and pasting temperature (PT) were evaluated from the pasting profile. The experiments were done in triplicate.

Statistical analysis
Analysis of variance (ANOVA) and separation of means was carried out using the PROC ANOVA procedure (SAS V.9.1, SAS Institute, NC, USA). Treatment means were separated using Tukeys' test and considered significantly different at $p < 0.05$.

Results and Discussion

Tapioca starch experiments
A significant reduction of 2.5 Log for *B subtilis* cells inoculated into tapioca starch was achieved after 1 h of treatment (Figure 2).

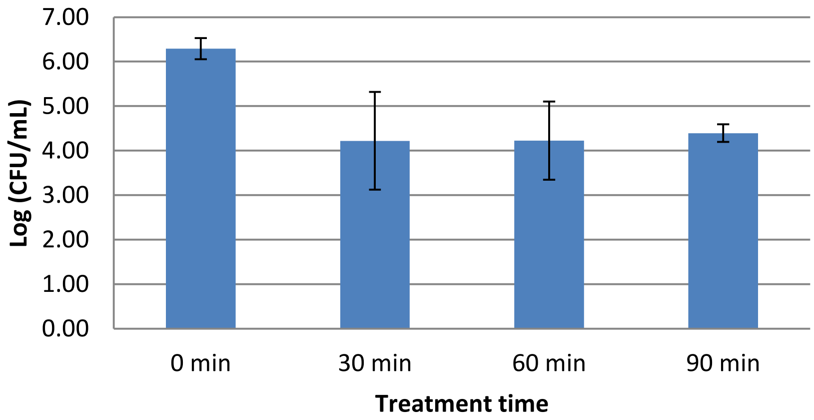

Figure 2. Inactivation of *B subtilis* cells inoculated in tapioca starch

Pasting curves of untreated and treated samples are presented in Figure 3. Table 1 summarises the pasting properties of tapioca starch before and after different sonication treatment times. The peak viscosity and the pasting temperature of the untreated samples were 589 cP and 71.85 ^{0}C respectively, compared to the sample treated during 3 h which were 3812 and 70.30 ^{0}C. This shows that longer is the treatment time, higher is the peak viscosity. Airborne acoustic technology has a significant impact on starch as it increases its viscosity.

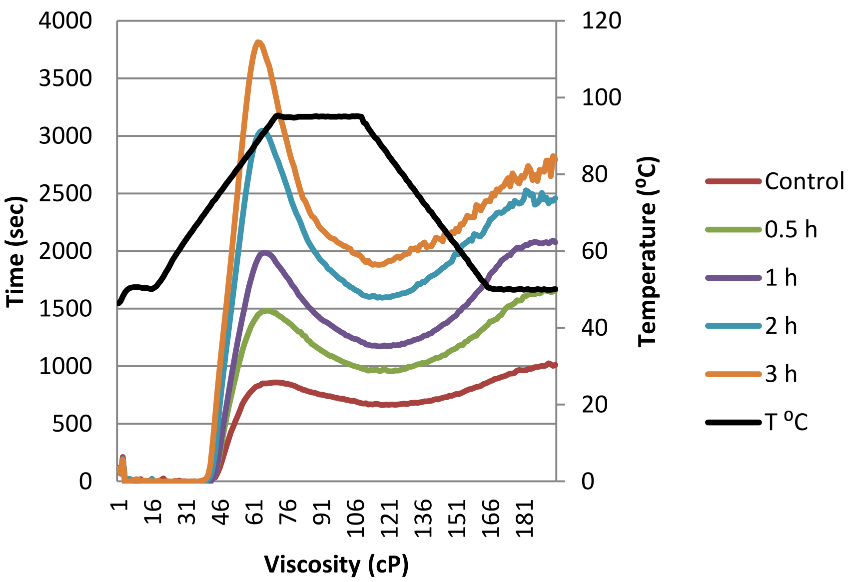

Figure 3. Viscosity measurement of tapioca starch

Table 1. Pasting properties of tapioca starch before and after airborne ultrasound treatment

Samples	Peak	Trough	Breakdown	Final Viscosity	Setback	Peak Time	Pasting Temperature
Control	859	662	197	1010	348	4.67	71.85
0.5 h	1482	956	526	1657	701	4.47	71.85
1 h	1985	1171	814	2075	904	4.40	71.95
2 h	3045	1593	1452	2459	866	4.33	70.25
3 h	3812	1879	1933	2794	915	4.20	70.30

Conclusions

This study demonstrates that airborne acoustic technology has the ability to inactivate vegetative cells at a high power, with an impact on the food quality of the product. Indeed, 2.5 log reduction were observed and the starch suspension presented a highest viscosity after 1 h of treatment. Further investigations have to be done regarding this aspect.

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EFFECT OF OZONE IN COMBINATION WITH CLEANING IN PLACE REAGENT(CIP) TO CONTROL BIOFILMS OF SPORE-FORMERS IN FOOD PROCESS ENVIRONMENT

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Abstract:

Biofilms are immobile communities of micro-organisms found attached to solid surface, such as stainless steel, food matrix surface or on packaging material present in food process environment. They may be composed of a single species or mixed species together with an extracellular matrix. Bacterial spores accumulate to form biofilms in processing areas and resist routine sanitation procedures due to their unique cell structure which can lead to food contamination and food borne illness. Current strategies adopted by factory settings to maintain hygiene in process areas stands ineffective therefore novel technologies are required to act in conjunction with regular cleaning regimes to achieve complete decontamination against biofilms and spores. In the present study ozone effect with cleaning in place reagent (NaOH) is combined to decontaminate stainless steel coupons pre-inoculated with spore-formers (*Bacillus subtilis* and *Bacillus amyloliquefaciens*) biofilm. Results indicate higher inactivation of biofilms within 60 secs and 120 secs using 1.4 ppm of ozone in combination with 1% NaOH as compared to 1% NaOH used alone for *Bacillus amyloliquefaciens* and *Bacillus subtilis* strains respectively. NaOH applied alone to biofilms required 240 secs to completely dislodge the film from stainless steel coupons.

Introduction

Biofilms are microbial communities that are found adhered to solid surfaces, surviving inside the matrix of exo-polymeric substances(Hayrapetyan *et al.* 2016). Microbes develop biofilms by colonising with each other which provides shelter from antimicrobials and other sanitation procedures which may have otherwise killed them in planktonic state/free cell state(Faille *et al.* 2014). Biofilm formation enhances the ability of the microbes to persist in a given environment.Pathogenic and spoilage bacterial species capable of forming biofilms are a significant problem to food industries. A biofilm is formed when planktonic (or free/stand-alone) cells in an aqueous environment attach to a solid surface to form aggregates or layers resulting in a biofilm(Meyer 2003). *Bacillus subtilis* and *Bacillus amyloliquefaciens* are sporeforming gram positive bacilli which frequently colonise in dried food factory settings to form biofilms(Akbas and Cag 2016). Current biofilm control strategies employed in the food industry eg. cleaning and disinfection, material selection and surface preconditioning are not found wholly effective to remove or control bacilli biofilms.(Simões *et al.* 2010). Therefore, there is a need to develop a robust technology which can inactivate biofilms and cells in liquid state in short span of time with no loss to food integrity. Ozone has been found to be effective against biofilms and number of bacteria (Kaur et al., 1992 and Mahfoudh et al., 2010).Combining ozone with current cleaning regimes such as 1% NaOH which is frequently adopted by factory personnel's in process environment will be helpful to get rid of biofilm formation and therefore need to be tested.

The objective of this study is to control bacillus biofilms relevant in food process environment using ozone technology with CIP reagent(NaOH) commonly used in factory settings.

Material & Methods

Biofilm formation and Ozone treatment

Vegetative cells of *Bacillus subtilis(110649 Merck)* and *Bacillus amyloliquefaciens DSM 7* were cultured in tryptic soya broth for 48 hours at 37 °C in a rotatory shaker at 200 rpm. After 48 hours 10^7 cells in 1ml of culture were aseptically transferred to sterile stainless steel (grade 304) coupons(Fig 1) (50 mm x 50 mm x 0.7 mm) and were allowed to form biofilm for 48 hours at room temperature.Further,1%NaOH was prepared for treating spore-formers in aseptic conditions.1.4ppm of ozone gas was generated using Ozone generator (Ozone lab solutions, Canada) connected to oxygen cylinder delivering oxygen with flow rate of 0.03125 litres/minute. Corona discharge principle was followed by the ozone generator to produce pure ozone gas at 24 °C & RH 70%. Concentration of ozone (1.4 ppm) was kept constant for all the treatments. After every 30 seconds sample was collected and serially diluted in sterile ringers solution, plated using spread plate method in total plate count agar to obtain plate counts. After plating, agar plates were incubated at 37 °C and colonies were counted after 18 hours. For treatment of biofilms deposited over stainless steel coupons ozonized water was used in combination with 1% NaOH. Coupons were dipped in 1% NaOH for particular time interval and then dipped in ozonized water. For control samples water was used to dip the coupons with and without ozone. Plate count was also performed after biofilm formation to determine the number of cells present over the coupons. CIP reagent was tested against sporeformers without ozone for log reductions before synergistic treatment with ozone gas.The success of the cleaning regimes was determined based on the removal of cells,organic debris and the number viable cells in logs after treatment.Log reduction can be calculated further by reducing the number of viable cells from initial load in inoculum.Traditional plate count methods were utilized to determine the viable cells after ozone and CIP reagent treatment. Coupons were heat sterilized before experiments.

Stainless steel coupon heat sterilization protocol:

(1) Coupons were sterilized by soaking overnight in a 1% (wt/vol) solution of disinfectant (Distel High Level laboratory disinfectant) and transferred to 70% ethanol for 3 hours to remove any disinfectant residue.

(2) Further, coupons were washed with sterile water and placed in aluminum foil package.

(3) For heat sterilization packed coupons were placed in the oven (pre-heated from room temperature to 200 C) and thoroughly sterilized for two hours. Before every experiment heat sterilization was performed.

Staining of pre-inoculated Biofilms:

Before treating the biofilms with decontamination methods they were visualized on stainless steel coupons using crystal violet staining (Tachikawa *et al.* 2009).

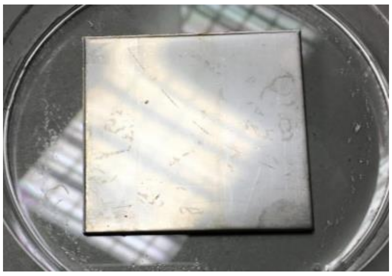

Figure 1: Sterile stainless steel (grade 304) coupons (50mmx50mmx0.7mm) used for biofilm formation.

Results

Aqueous ozone gas at lower concentrations in combination with water for control and 1% NaOH was applied to biofilm of aerobic spore-formers in closed sterile conditions**.** Graphs were plotted with treatment time of reagents and ozone on X-axis and Log_{10}CFU/ml of microbes on Y-axis for both the strains forming biofilms**.** $Log_{10}CFU/ml$ corresponds to number of cells surviving after individual treatment which can be utilized to calculate Log reduction by subtracting it from initial cells treated for experiments which was 10^7 CFU/ml for this study. According to plate count results in biofilms of *B.amyloliquefaciens* (Fig 2) NaOH synergistically with ozone wash gave inactivation of 6 logs within 60 secs of treatment time whereas NaOH required 90 secs for biofilm removal. Ozonised water required 150 secs for biofilm removal acting as control measurement. *Bacillus subtilis* biofilms cells(Fig 3) were inactivated by NaOH and ozone in combination within 120 secs of treatment time whereas NaOH alone required 240 secs. Ozonised water required 270 secs slightly similar to inactivation received with NaOH. 1% NaOH is already utilized in food processing industries for cleaning-in-place systems, and was found successful in removing biofilms but require longer exposure time and multiple rounds of cleaning(Langsrud *et al.* 2000). No inactivation was received with water when used alone for treatments. *Bacillus subtilis* cells were found more resistant in terms of getting dislodged from coupons and required more exposure to receive complete inactivation as compared to *Bacillus amyloliquefaciens* cells. They required mechanical stress to get completely dislodged from the coupons whereas *B.amyloliquifaciens* cell debris were easily washed off after NaOH treatment without applying any mechanical stress.

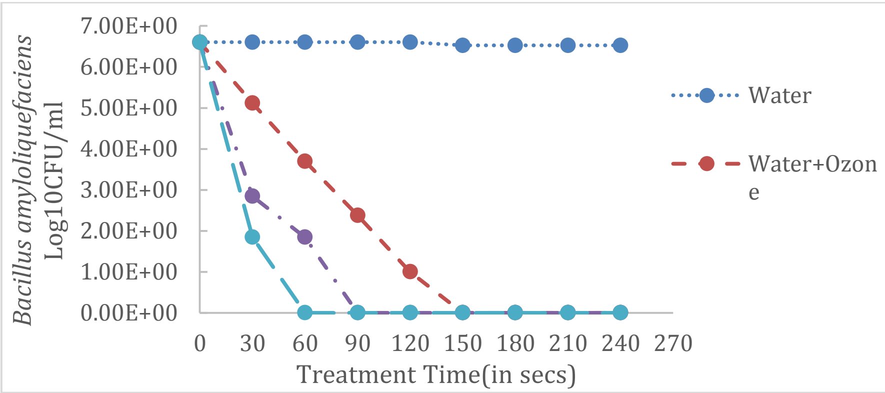

Figure 2: Treatment of *Bacillus amyloliquefaciens* vegetative cells in biofilms with 1.4ppm ozone with and without combination of 1% NaOH.

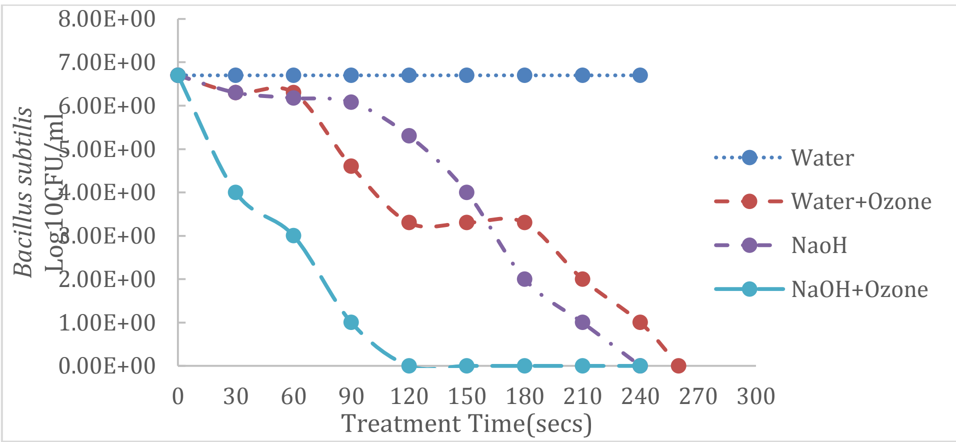

Figure 3: Treatment of *Bacillus subtilis* vegetative cells in biofilms with 1.4ppm ozone with and without combination of 1% NaOH.

Conclusion

Bacillus amyloliquefaciens biofilms was found to be more sensitive to CIP regimes as compared to *Bacillus subtilis* biofilms. *B.subtilis* exhibited exceptional adhering ability over coupons even after treatments which can be a serious problem for cleaners and can be recurrent. Ozonised water in combination with 1%NaOH gave 6 log reduction in both the bacilli within 2 minutes of treatment time which included removal of organic debris from dead cells, also no corrosion was observed on the stainless steel coupons. Ozone therefore can be considered as a potential disinfecting reagent in combination with basic CIP regimes for sanitizing in factory environment against dried biofilms. Overall NaOH synergistically with Ozone gave best results in inactivating the spore formers in the current study. Confirmation of these results should be carried out in a pilot plant through clean cycles.

Significance

Development of robust cleaning procedures for food manufacturing plant to prevent contamination with spore-former bacilli that threaten food product quality. Also, provides information for future work in developing novel biofilm decontamination strategies.

Acknowledgement

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PREDICTION OF PREHEAT TEMPERATURE OF SKIM MILK POWDER USING VIS-NIR SPECTROSCOPY AND CHEMOMETRICS

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Abstract

This study explored the feasibility of predicting pre-heat treatment temperature of skim milk powder (SMP) using Vis-NIR spectroscopy coupled with chemometrics tools. Partial least square regression (PLS) models were built to assess the pre-heat temperature of SMP samples. The best pre-heat treatment temperature prediction models was developed using PLS over the wavelength range 1100-2498 nm. The models' root mean square errors of cross-validation (RMSECV) for SMP pre-heat treatment temperature predictions was 1.0 ºC, and square of correlation coefficients (R^2) was over 0.99.

Introduction

Skim milk powder (SMP) is a common ingredient powder produced in the dairy industry (Patel et al., 2007). Preheat treatments (i.e. thermal process prior to concentration) reduce the microbial load, extend the shelf-life, and improve the nutritional and functional properties of final dairy products (Patel et al., 2006, Patel et al., 2007, Raikos, 2010, Ayala et al., 2016). Whereas, pre-heat treatment process could lead to the denaturation and aggregation of milk proteins, and the change in carbohydrate, including isomerization, degradation and Maillard browning reaction of lactose (Patel et al., 2007; Ayala et al., 2016), which subsequently results in the influence of the functional properties of these ingredients and other dairy products manufacturing from them. Visible Near-Infrared spectroscopy (Vis-NIR) is a well-established rapid and non-destructive vibrational spectroscopy technique which has become one of the most popular analytical methods in the food industry. In recent years, NIR is widely used for analysis of dairy products (Aernouts et al., 2011, Inácio et al., 2011).
The objective of this study was to investigate the feasibility of Vis-NIR spectroscopy coupled with chemometric analysis as a rapid and non-destructive method for the prediction of pre-heat treatment temperature of SMP samples.

Materials and Methods

Materials
SMP samples were initially reconstituted to 10% TS, 28 L batches were preheated at three different temperatures (low heat: 72 ºC; medium heat: 95 ºC; and high heat: 115 ºC) using a MicroThermics Lab heat exchanger (MicroThermics, North Carolina, U.S.A.) at a flow rate of 2 L min^{-1} with a holding time of 15 s. Preheated samples were then evaporated to 30% total solids (TS) at 60 ºC and dried in a single stage spray dryer, with inlet and outlet temperatures of 180 ºC and 95 ºC, respectively. Four replicates were produced from SMP at three pre-heat treatment temperatures, which gave in total twelve SMP samples.

Vis-NIR Spectroscopy
Vis-NIR spectra were collected on a NIRSystems 6500 instrument (NIRSystems. Inc., Maryland, USA). A ring cup (7.5 cm diameter and 1.5 cm-height) incorporating an optical window of diameter of 5.5 cm was filled with the respective powder samples and sealed with a backing lid. Reflectance spectra log (1/R) were acquired and recorded over the spectral range 400 - 2498 nm at 2 nm steps. Samples were scanned in duplicate in random order at room temperature (~ 20 ºC). Spectra acquisition and file conversion were performed using

WINISI software (version 1.04; Infrasoft International, Port Matilda, USA). The mean of the two duplicate spectral data was used for NIR spectral analysis.

Chemometrics analysis

The acquired NIR spectra were imported into The Unscrambler software (v9.7; Camo, Trondheim, Norway), and three selected spectral ranges, i.e., 400 - 2500 nm (1050 wavelengths), 700 - 1098 nm (200 wavelengths) and 1100 - 2498 nm (700 wavelengths), were analysed. Principal component analysis (PCA) was performed as an exploratory chemometrics analysis using the three spectral ranges. Partial least square regression (PLS) was performed to predict the pre-heat treatment temperature of SMP. It is worth noting that, due to the batch effects influencing individual ingredient samples; data used for pre-heat treatment prediction were mean cantered by each batch. The optimum number of factors for the models was selected using the leave-one-out cross-validation option in Unscrambler. To optimise the performance of the PLS models developed, subsets of selected wavelengths for each spectral range were determined using the Martens uncertainty test in Unscrambler. The performance of PLS regression models was assessed on the basis of the root mean square error of cross-validation (RMSECV) and determination coefficient (R^2).

Results and Discussion

Vis-NIR spectra

Spectra of all SMP samples are shown in Figure 1. It can be observed that sample baseline variability increases over the spectral range of 1100 - 2498 nm and that the spectra for the 3 different preheat temperatures overlap.

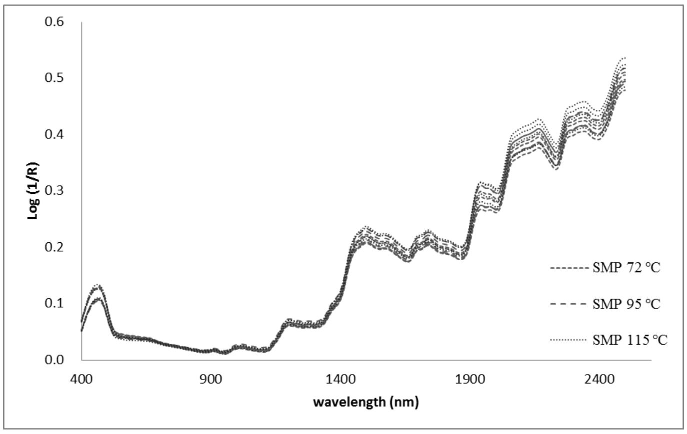

Figure 1. Log(1/R) Vis-NIR spectra of SMP

Prediction of pre-heat treatment temperature

CA analysis was employed to visually explore sample distribution and clustering. Figure 2 shows PCA score plots of preheated samples based on the full spectral range. PCA score plots showed similar distributions for the 2 other spectral ranges (not presented in this paper). A significant influence of batch effects may be observed for SMP samples. To reduce batch effect, raw spectral data were mean centred for each batch prior to further chemometrics analysis using PLS modelling.

Table 1 shows the performance of PLS models developed for SMP preheat temperature using each spectral range in entirety and a subset of selected wavelengths determined as described in materials and methods. Overall very good predictions were observed for all preheat temperature prediction models for SMP.

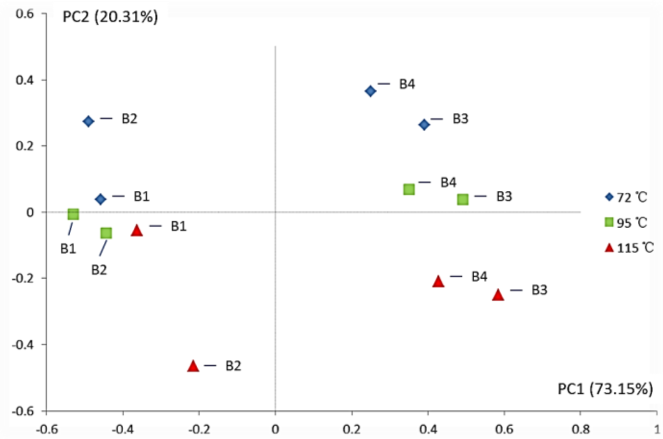

Figure 2. Score plots of PC1 vs PC2 of SMP (full spectral range: 400-2498 nm)
B1: batch 1; B2: batch 2; B3: batch 3; B4: batch 4

Table 1 Summary of PLS cross-validation statistics for SMP pre-heat temperature prediction

Spectral range	Wavelength	No. of Wavelengths	Factors	RMSECV (ºC)	R^2
400-2498 nm	All	1050	7	1.6	0.993
	Selected	277	7	1.5	0.993
700-1098 nm	All	200	7	2.7	0.981
	Selected	199	7	2.7	0.981
1100-2498 nm	All	700	7	1.6	0.993
	Selected	313	7	1.0	0.997

Figure 3 shows the best preheat temperature prediction models developed for SMP samples over the spectral range 1100-2498 nm using all 700 wavelengths (RMSECV 1.6 ºC, R^2 0.993) and 313 selected wavelengths (RMSECV 1.0 ºC, R^2 0.997). A plot of predicted versus actual preheat temperature for SMP samples is shown in Figure 3a. Large regression coefficients are located at 1442, 2216-2226, 2466 and 2498 nm Figure 3b. The coefficient at 1442 nm is associated with O-H stretching first overtone and combination of C-H stretching and deformation, the high coefficients observed at 2166-2226 nm are associated with combination of N-H stretching and NH^{3+} deformation (Osborne et al., 1993). The coefficients at 2466 and 2498 nm are both associated with combination of C-H and C-C stretching (Osborne et al., 1993). PLS models were recalculated using only selected wavelengths identified using the uncertainty test in Unscrambler. Figure 3c and d show the performance of the optimized calibration model. The RMSECV decreased to only 1.0 ºC in the new model, and the square of correlation coefficients (R^2) was 0.997.

Conclusions

This study demonstrated the potential of Vis-NIR spectroscopy combined with chemometrics to predict pre-heat treatment temperature of SMP samples. The best prediction models for pre-heat treatment temperature of individual dairy ingredients which had RMSECV values of 1.0 ºC was obtained using selected wavelengths in the NIR range of 1100 – 2498 nm. This study demonstrates the potential of NIR spectroscopy as a PAT tool for dairy processing, the robustness of the models developed should be validated using larger datasets including the effects of seasonality on milk composition.

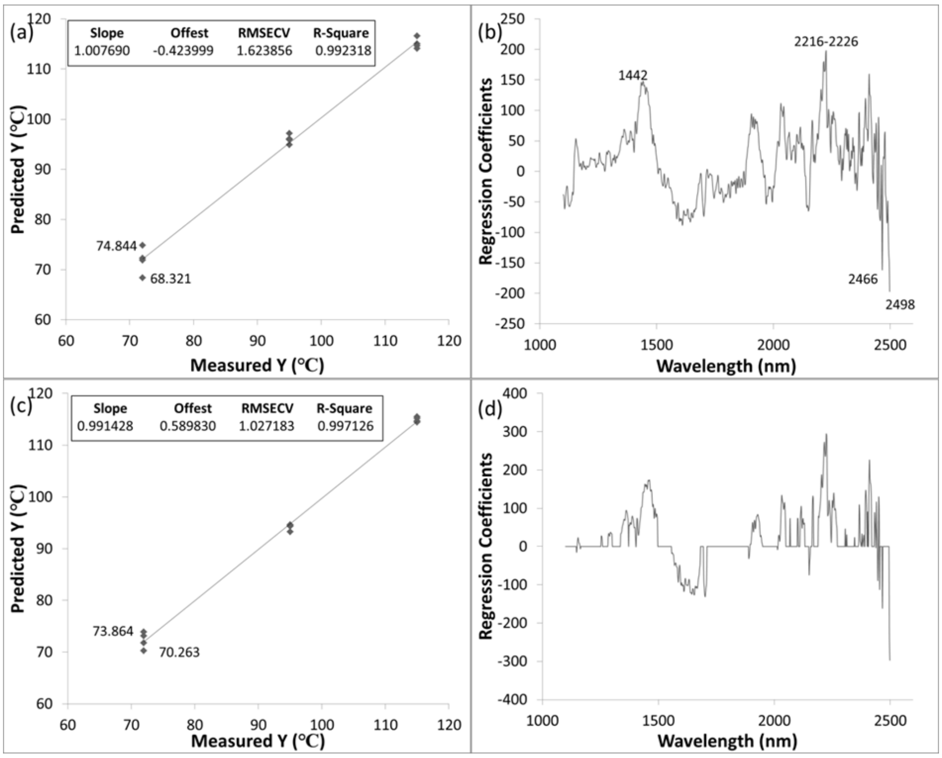

Figure 3. PLS regression models for SMP preheat temperature prediction over the spectral range 1100-2498 nm, using all 700 wavelengths, (a) and (b), and using 313 selected wavelengths, (c) and (d). Predicted versus measured preheat temperatures are shown in (a) and (c); and the regression coefficients vs. wavelength are shown in (b) and (d).

Acknowledgements

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BATTERY ENERGY STORAGE FOR INTERMITTENT RENEWABLE ELECTRICITY PRODUCTION IN IRELAND

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Abstract
Wind is fast becoming one of the most popular sources of renewable energy in Ireland. In order to meet 2020 national targets for electricity production from renewable sources, the trend of deployment of wind energy infrastructure is likely to continue well into the future making wind curtailment a significant issue. This study investigates the potential of a large scale battery energy storage facility for Ireland in providing a solution to this growing issue of wind curtailment, helping Ireland reach its 2020 energy goals.

Introduction

In Europe, Ireland is ranked as having some of the highest average wind speeds and is regarded as a country that has an ample natural resource in the form of wind energy (Mc Garrigle *et al.* 2013). The Irish government is committed to a binding target of 40% of the nation's electricity production to be generated from renewable sources by 2020 (Carton & Olabi 2010) with the main bulk of this target to be met by large scale wind energy deployment. Currently 14% of Ireland's electricity requirements is generated from 3000 MW of installed wind capacity and it is projected that 5900 MW of wind capacity is required if Ireland is to reach its 2020 target of 40% renewables (Denny *et al.* 2010).

Under existing development plans, wind generation will sometimes exceed total demand for power due to the intermittent, unpredictable nature of wind energy (Howley *et al.* 2015). This is more often the case in wintertime when Irish winds are strongest. The surplus wind energy can be dealt with in three ways (McKenna *et al.* 2014); the first option is to export the surplus energy via interconnector to Great Britain however, the two countries have a highly correlated wind climate and therefore the Great British (GB) system will not always be able to accept imports of surplus wind from Ireland. The second option is to reject (curtail) the surplus wind energy. It is predicted that 7-14% of wind production in Ireland will be lost due to curtailment in 2020 (Mc Garrigle *et al.* 2013). The third option is to store the energy through the wide range of energy storage devices available (Weiss *et al.* 2013). Turlough Hill is home to Ireland's first and only bulk energy storage facility with an installed capacity of 292 MW (Coburn *et al.* 2014) - the need for extra storage on the grid will become critical.

The necessity of energy storage is predominantly evident when there is a demand for electricity generation in unpredictable, intermittent wind conditions (Sovacool 2009). The storage of energy allows for utilisation of the resource when it is required and stored when it is not required therefore essentially reducing the amount of energy wasted as much as possible (Huggins 2010). The benefits of battery energy storage are clear (Zhang 2013); the main advantage being peak shaving which is the process of creating a smoother, more stable, supply of electricity. Also, as mentioned before, a battery energy storage facility will allow for the exploitation of potentially wasted energy therefore improving the reliability of the energy supply. The technology furthermore enhances the quality of power received by the consumer and reduces the risks associated with connections to the grid (Kaldellis 2010).

The objective of this study is to perform a technical and economical evaluation of the application of a large scale battery storage facility in Ireland that will address the issue of wind curtailment and therefore provide extra storage to the Irish grid, helping Ireland reach its 2020 target of 40% electricity production from renewables.

Materials and Methods

Current Market

Total gross electricity generation in Ireland was 52,323.4 GWh in 2015, 25.3% of which was sourced from renewable energies (Howley *et al.* 2016). The current installed wind power capacity in Ireland is 3025 MW (Eirgrid *et al.* 2015), and the current installed energy storage capacity is 290 MW (Turlough Hill pumped hydro bulk energy storage facility). The electricity requirement for Ireland in 2017 is around 27 TWh however, by 2020 this figure is likely to increase to around 31 TWh.

HOMER Simulations

To fully comprehend the technical and economic implications of the proposed battery energy storage system (ESS) in Ireland, the Hybrid Optimization of Multiple Energy Resources (HOMER) program will be utilized to model the various electrical demand and supply scenarios. This software allows the user to utilize the program as an analysis tool therefore, allowing for the input of data to reflect the type of system that needs to be modelled. Through complicated algorithms, HOMER has the ability to simulate the designed system and generate results for detailed sensitivity scenarios, with the optimum system design specified according to the data inputted. This makes HOMER an appropriate tool for the purpose of this project, to model a battery energy storage system.

Demand and Supply Scenario

In order to calculate the energy storage requirements in Ireland, two bulk energy storage systems have to be integrated into the simulation. The first system that will be integrated accounts for the already existing energy storage facilities, so therefore the pumped hydro storage facility in Turlough Hill that has a capacity of 292 MW will be taken into consideration in the model. The second system that will be integrated is the proposed battery energy storage system that will be given unlimited capacity in the model (Weiss *et al.* 2013). The actual power and capacity used in this scenario will then give an indication of what would be required in a 2020 scenario, whereby the target is to maximise integration of renewable energy sources for electricity (RES-E). When simulating the bulk energy storage system in this scenario, a realistic demand profile is very important. The demand profile in this case will represent the entire composition of electricity generation within the country. The demand data used for the simulations is critical in determining the energy storage capacity required. The data needed to model the supply and demand scenarios will be sourced from the Single Market Electricity Operator (SEMO).

Energy Storage System

The various types of batteries that can be utilized in the facility will be assessed in accordance to their effectiveness as energy storage devices. Therefore, these systems need to be simulated correctly in order to achieve the most accurate results. The multiple array of batteries available differ in that their individual characteristics determine their success at storing energy (Goodenough *et al.* 2007). Thus, it is important that HOMER can model these characteristics in order to precisely simulate the scenarios. As experimental work is on-going, the range of batteries considered in the model are not yet defined. The capacity value of each type of battery, which is one of the most imperative variables will be considered in the model. This variable can be defined in HOMER and other key variables will also be considered as project development continues e.g. battery lifetime, maximum charge.

Economic Aspects

In order to understand and assess the economic feasibility of the battery energy storage facility, data that can be considered reliable must be used for each individual component of the system that makes up the simulations. For instance, the pricing of each battery type must be sourced from the manufacturer or from dependable literature. The operating cost (based on the value of all costs excluding the initial capital cost) will be simulated in HOMER also and this will include battery replacement costs and maintenance costs. Net present cost (NPC) which is the value of all costs of installing and operating the component over its lifetime minus the present value of all the revenues that it earns over the project lifetime is calculated in HOMER (Farret 2006). This economic aspect includes capital costs, replacement costs, maintenance costs, fuel costs and import/export costs (Dodds *et al.* 2015).

Results and Discussion

As work is on-going, only expected results are shown in this section of the report.

Proposed Battery Energy Storage Facility

The energy storage facility will consist of a few notable features that include (Zhao *et al.* 2015*)*:

- A large battery energy storage system (BESS) that utilizes a large format design of storage cells. These cells will be connected in series to form a high voltage string.
- The BESS will incorporate a Battery Management System (BMS) that is suitable for maintaining the cells at near equal state of charge and reporting cell condition to a master controller (BCU, Battery Control Unit).
- An inverter charger unit (ICU) suitable for taking power from the battery and putting it on the grid as AC of correct voltage and phase, and later recharging the battery from available energy on the grid. This ICU is directed by the BCU.
- Capability of operating multiple strings, forming an ESS with central BCU command and expandability to the extent the control system can accommodate.
- Structure to support and protect from the elements.

Figure 1 below shows the components that make up the energy storage system.

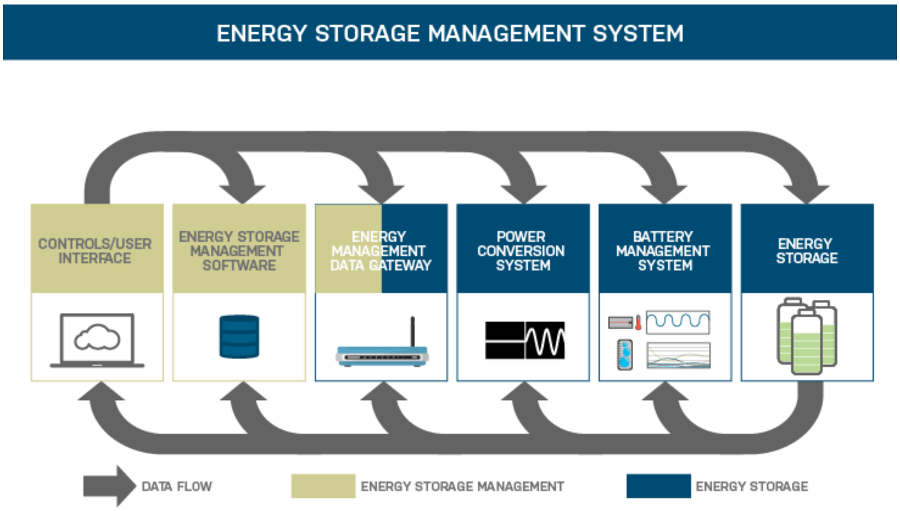

Figure 1. The likely design of the proposed battery energy storage facility that is to be implemented in Ireland. Source: Green Tech Media.

Progress towards 2020 targets

The proposed battery energy storage system will bring extra storage to the grid network and so wind curtailment levels will be reduced. This will allow Ireland to tap into potentially wasted energy and therefore help Ireland reach its goal of sourcing 40% of its electricity production from renewable technologies. If the facility is significantly large enough to allow the 40% target to be met then wind curtailment levels will likely be of medium level. The system that will be developed is likely to allow for the reduction in energy rejection and overall the model will exhibit scenarios that aim to minimise energy rejection.

Cost Analysis

The cost of electricity is likely to fluctuate as different types of batteries are modelled in the system. This means that the most cost effective battery type can be determined. By simulating various scenarios, the optimum system for integrating energy storage with wind for the Irish electricity grid will be defined. Thus, now that the optimum facility design can be defined, an economic analysis can be applied to determine the initial capital cost, maintenance costs and operation costs for this optimum system.

Conclusions

The results from the 2020 scenario show that under current development plans there will be higher supply than demand, especially in Autumn. Most of this surplus energy will be curtailed and so therefore there is a potential for a utility scale battery energy storage system in Ireland (BESS) to help abate the otherwise rejected energy. However, it is likely that a bigger energy storage facility will be required than initially though if Ireland is to meet its target of 40% of electricity from renewable technologies.

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FOOD VS FUEL – A SYSTEM ENERGY BALANCE

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Abstract

The dedication of land for the production of fuel crops has been controversial and debated for the past decade. There are several processes involved in the production of crops that are very energy intensive. Most of the time crops are rejected from cultivation for this exact reason. The common misconception among farmers that fuel crops are too energy intensive has stifled its potential in Ireland. With the aim to reduce energy dependence on fossil fuels the government of Ireland has pushed for an increase in biofuel usage. However, without adequate allotments of land Ireland has failed to reach stipulated quotas and had to resort to importing biofuels. This study looks to isolate all the inputs into the cultivation systems of food and fuel crops and find their individual impact on overall energy consumption by developing an effective comparative model. The model will help to demonstrate which crop is more energy intensive and where process changes can be made to reduce energy inputs.

Introduction

During the 2006-2008 global food price crisis, concerns were raised in the UN about the soaring prices of food, the price volatility in the market was associated with competition of biofuels for croplands. A UN special rapporteur Jean Ziegler opined that the conversion of crops to fuels was driving up food, land and water prices by stating "*it is a crime against humanity to convert agricultural productive soil into soil which produces food stuff that will be burned into biofuel*" (Hamelinck 2013). In April 2008 the president of the World Bank Robert Zoellick said that biofuels were a significant contributor to the soaring food prices along with six other contributors, but most articles publicizing his speech assigned the complete blame on biofuels (Hamelinck 2013). However, the solution to this argument may not be as straightforward as it seems because the cultivation of food and fuel crops are interdependent.

The global food consumption statistics published by the Food and Agricultural Organization of the UN show, with the increase in urbanization the food consumption per capita has increased over the years (Pocketbook 2015). This increase in demand for food lays pressure on expected food crop yield. Any yield values below the expected crop yields results in an upsurge in food prices. Climatic conditions are chief parameters that determine crop yield. Global warming caused by excessive pollution causes unusual climatic conditions. The CO_2 emissions from fossil fuels are the largest contributor to global warming and to replace fossil fuels we need biofuels which absorb a large amount of CO_2 throughout cultivation. The competition from biofuel crops for land again increases food prices and the problem has come back full circle (Platform 2017). Amidst all this chaos, under keen observation one may notice a consistently recurring theme that is energy consumption. The energy consumption involved in the cultivation of food and biofuel crops and the energy consumption of fossil fuels leading to climatic changes. Thus a thorough investigation on the relationship of energy consumption of the crops could shed some light on the issue. The most prominent food and fuel crops of Ireland are Barley and Rapeseed respectively, so the energy comparison among these two crops would be the most logical choice.

The objective of this study is to develop a model to compare the energy consumption of food crop and fuel crop, to help establish the more economic and low energy intensity crop for cultivation.

Materials & Methods

From an energy perspective, Ireland is quite vulnerable since 90% of the energy needs are fulfilled by fuel imports of which a major part comes from fossil fuels. Such a large dependence leaves the country at an unsustainable position (McDonnell 2009). Ireland has a land base of 6.9 million hectares and a population density of 67 per square kilometer which is the 6th lowest in the European Union (Data.worldbank.org 2017). Possessing mild temperature climate and long growing seasons with high productivity soils, there is excellent potential for biofuels. The cultivation of biofuels would promote self-sufficiency of the economy and sequester significant quantities of atmospheric carbon.

The study is conducted under the hypothesis: The production of Barley crop is more energy-intensive than the production of Rapeseed. A model will be developed to test this hypothesis and provide solutions to any energy hotspots identified along the way based on the agricultural scenario.

Figure 1. Barley Farming (AOI 2017)

Figure 2. Rapeseed Farming (AOI 2017)

Barley (Hordeum spontaneum)
It is the 4th most commonly produced cereal in the world. It is grown and cultivated for the edible part of the seeds that is a rich source of carbohydrates, vitamins, minerals, fats and proteins. It is a staple crop that can be stored throughout the year (Rasmusson and American Society 1985). Based on the quality of barley it can be divided into two grades namely malting barley and feeding barley. The feeding barley is used to feed livestock, it is commonly grown in Wexford and Louth. The malting barley is high-value product and grown for brewing and distilling industries. Malting barley is grown in south Dublin, Meath, Kilkenny, Carlow and Cork (PDST 2016). Based on the season it is divided into winter barley and spring barley, it has an average yield of six tonnes per hectare. The winter barley has a higher yield than spring barley.

Rapeseed (Brassica nupus)
It is the most commonly grown oil crop in Europe. It is grown and cultivated for its high energy value oil. The seeds of rapeseed are high in dry matter with thick seed coat from which the oil is extracted by the process of cold pressing (Appelqvist and Ohlson 1972). The oil cakes are protein rich feedstocks for livestock. It is produced mainly in counties Wexford, Carlow, Kilkenny and Donegal. There are two varieties of rapeseed based on seasonal cultivation that is winter grown and spring grown. The winter grown variety has a yield of 5-6 tonnes per hectare while spring grown variety has a yield of 3.5-4 tonnes per hectare. Rapeseed is conventionally used as a break crop grown once in four years. The oil produced is edible and used to produce biofuels. But policy restrictions on fuel crops prevent its use for biofuel production (Faisal Zahoor 2015). To develop the model it is essential to understand the methods of cultivation of the two crops, this is completed with thorough review of production reports and life cycle impact assessments (Unakitan *et al.* 2010, Baran and Gökdoğan 2014, Kusek *et al.* 2016). All the major steps involved in cultivation process of the two crops is noted down. The energy consumption values of each of these inputs would be found or estimated. The energy values will be tabulated in an excel sheet to make a preliminary comparative model of the

crops. It will be followed by in-depth investigations into Irish barley and rapeseed to identify all the agricultural inputs including traditional practices, wastages and damage control with the energy consumption at each step. These energy values will be utilized to make the final model by using the Monte Carlo simulation technique. This model can be used as a general template for the comparison of any food or fuel crops by inputting the energy values into the required fields and also to identify energy requirements for alternate agricultural scenarios like low fertility, drought etc.

Preliminary Results

The major inputs considered for the preliminary report are human labour, land preparation, seeding, fertilizing, spraying, harvesting, bailing, transport and machinery. The review of data from journals like (Unakitan *et al.* 2010, Baran and Gökdoğan 2014, Kusek *et al.* 2016, Faisal *et al*. 2015) have given the values of energy inputs for the barley and rapeseed cultivation. These values are tabulated in Excel worksheets to make the primary comparative table and graph as seen below.

Table 1. Energy Consumption of Major Inputs

Major Inputs	Barley (MJ/ha)	Rapeseed(MJ/ha)
Human Labour	25.28	34.34
Land Preparation	287.07	260
Planting/Seeding	129.2	108.43
Fertilizing	98.1	141.07
Spraying	34.36	45
Harvesting	61.85	152
Bailing	53.41	0
Transport	33.38	54.69
Machinery	622.08	85
Total	1344.73	880.53

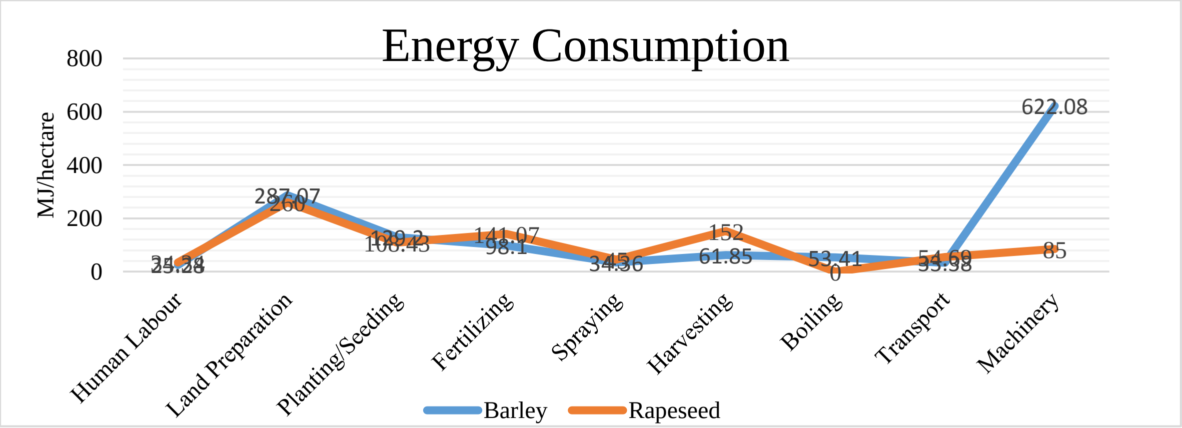

Figure 3. Comparison of Barley to Rapeseed

From the data, we see that for the major agricultural inputs, Barley is indeed more energy intensive than rapeseed. The hotspot in barley cultivation exists in the machinery usage whereas the hotspot in the energy usage for rapeseed is in the harvesting phase.

Future work

The next portion of the project work involves the breakdown of inputs like machinery and land preparation to its elementary processes, finding the legislations governing the application of fertilizers, pesticides and herbicides, land usage policies and market policies. Identification of cultivating and harvesting practices indigenous to Ireland finding their corresponding energy values. Tabulating the energy values for the second comparison and then application of the Monte Carlo simulation technique to create a generalized model for comparing the crops for varying agricultural scenarios. For the current system, the model would determine if the hypothesis is proved or disproved.

Conclusions

Upon successful completion of the project, an effective model will be developed displaying conclusive results for the comparison of barley and rapeseed. By inputting the energy values for the required fields, this model would be applicable for comparing other varieties of food and fuel crops too. The model would help to find the energy requirements for "what if" agricultural scenarios, identify the hotspots within the production chain, find the impact of policy restrictions on the crops and show the benefits of making alterations to these energy hotspots.

Further, the model can specially be used to avoid or mitigate the major shortcomings of the fuel crop production system. The impact of policy restrictions on fuel crops can be analyzed and policy revisions can be suggested to uplift biofuels in Ireland so that self-sufficiency in energy can be attained.

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ELECTRICAL ENERGY STORAGE POLICY IN THE EUROPEAN UNION

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Abstract

EU policy and market design are vital players in meeting the challenges of climate change and energy dependence. Energy storage technologies provide many benefits with regards to climate strategy, energy market design and security, and renewable energy integration to create a sustainable living environment for future generations. Despite the developments in this field, EU policy such as the Renewable Energy Directive and Energy Union Strategy, make little mention of energy storage or provide financial support schemes. Additionally, there is no comprehensive EU level energy storage legislation, to regulate the market. Both the involvement of energy storage policy in major energy directives and the creation of a comprehensive energy storage policy are necessary to enhance innovation and integrate the technology into the energy market to reap the benefits. This thesis will provide tangible policy recommendations and provide potential guidance on implementation. The methodology involves an extensive policy review, semi-structured interviews, and questionnaires. The case of Germany will be examined in detail to evaluate, why their success rate for energy storage technology diffusion is one of the highest in Europe.

Introduction

European energy markets are evolving towards a fully-integrated single market, which is outlined in the major EU energy strategy called the Energy Union (Friedrichsen *et al* 2015). Its objectives are increasing energy security, creating a single European energy market, increasing energy efficiency, creating a near-zero carbon economy, and improving the competitiveness of the member states (Hills *et al* 2016). This strategy includes specific targets regarding efficiency measures, renewables, and greenhouse gas (GHG) emissions are included as well (Fischer *et al* 2016).

Energy storage systems, such as pumped hydro, batteries, compressed air energy storage, and thermal storage are valuable in meeting the targets and objectives laid out in the Energy Union Strategy (Ibrahim *et al* 2008). It can improve grid capacity and energy security, integrate renewables into the electricity grid, smooth the electrical load, provide voltage support, reduce peak demand, and remove grid congestions by monitoring the energy output carefully (Friedrichsen *et al* 2015). From a policy perspective, the integration of indigenous renewable resources is vital to the success of the Energy Union objectives (Hills *et al* 2016). Unfortunately, the current electricity grid is not equipped to enable large-scale integration of renewable resources (Friedrichsen *et al* 2015). Flexibility options to reduce the pressure on the grid are needed for successful grid integration, which is achieved through energy storage systems (Bruel *et al* 2014).

Major EU electricity frameworks and policies make little or no mention of energy storage as a key player. Additionally, there is no provision which outlines support mechanisms or frameworks for energy storage operation and grid connection (Friedrichsen *et al* 2015). This leads to high levels of uncertainty in the industry and thwarts developments and innovation (Friedrichsen *et al* 2015). Despite the continued acknowledgement of the necessity of energy storage, the Energy Union strategy and renewable energy directive do not include a specific section on the tasks of energy storage and support mechanisms (Bashir *et al* 2014). This gap must be filled in order for EU member states to meet their specific targets and objectives (Friedrichsen *et al* 2015).

The objective of this study is to make policy recommendations for the integration of energy storage policy in the European Union.

Methodology

This project is mainly an evaluation of current policy in various jurisdictions. This examination will focus on European Union policy, but the case of Germany will be examined in more detail, since its rate of diffusion of energy storage technology is one of the highest in Europe. The case of Sweden will be taken into consideration, as well, since it has a large share of renewable energy, yet does not have large amounts of energy storage installed (Jacobsson & Lauber 2006; Friedrichsen *et al* 2015).

In addition to the review, a questionnaire will be sent to energy storage companies in the EU. It will include sections on their technology, perception of government support, understanding of current policy, their preferred support scheme, the incentives and policy they require to get their business started, and the level of government involvement. The questionnaire will be refined, once the final literature review is produced. Finally, interviews with renewable energy actors, such as energy storage companies, energy policy makers, utilities, and renewable energy companies will be conducted to assess their opinions, refine their stance in the questionnaire, and assess the potential for energy storage policy in general.

Literature Overview

Energy Storage Technologies

Energy storage technology is described as a facility which receives energy with the purpose of storing and makes it available later (ACER 2012; Bashir *et al* 2014; Ibrahim *et al* 2008). These are divided into four types: Low-power supply in remote locations which feed emergency systems, medium-power supply in remote locations which provide electricity for towns, grid-connected supply involving peak load levelling, and energy quality control systems (Ibrahim *et al* 2008).

This paper focuses on energy storage policy, therefore only a brief technological abstract will be included. The EU is currently focused on large-scale services and grid support (Friedrichsen *et al* 2015). The main technologies in this field are pumped hydro storage, thermal energy storage, and compressed air energy storage (Bruel *et al* 2014). Batteries are purposely omitted, since there is ample information and research in this field (Bashir *et al* 2014). Pumped hydro storage uses a combination of gravitational forces and water to store energy. It is abundantly available and has potential and commercial application for large-scale systems up to 100s of megawatts (Ibrahim *et al* 2008). The conversion efficiency of this system is between 65% and 80% (Agrawal *et al* 2014). Thermal energy storage is divided into latent and sensible heat storage (Ibrahim *et al* 2008). Hereby, a bulk material is used to transfer heat to a liquid. Salt, sodium hydroxide, or water is used in this system. This system can reach an efficiency over 60% (Bruel *et al* 2014; Chen *et al* 2009). Compressed air energy storage uses the expansion of air in a combustion chamber to store electricity (Ibrahim *et al* 2008). This storage system is not very energy dense, producing 12 kWh/m^3, and has an efficiency of up to 70% (Bain & Hall 2008).

Table 1: Energy storage service types and relation to technologies (Friedrichsen *et al* 2015).

Service Type	Characteristics
Bulk energy storage	Size: Large scale Technology: Hydrogen, compressed air storage, pumped hydro storage, redox flow batteries
Renewables integration	Size: Medium to large scale Technology: Hydrogen, batteries, pumped hydro storage
Ancillary	Size: Small to large scale Technology: Superconducting magnetic energy storage, double layer capacitor, flywheel, batteries, hydrogen
Transmission and distribution	Size: Medium to large scale Technology: Batteries, large flywheel, superconducting magnetic energy storage, small compressed air storage, pumped hydro storage
Customer energy management	Size: Small to medium scale, off grid or on grid Technology: Batteries, hydrogen

Energy storage provides several services (Bashir *et al* 2014). Bulk energy storage increases grid capacity and energy security, renewables integration services compensate for the intermittency and provide flexibility in use, ancillary services regulate the output frequency to smooth the electricity load and provide voltage support, transmission and distribution services remove grid congestion and omit the necessity for capital-intensive grid expansion, and customer energy management reduces peak demand and improves customer flexibility (Bashir *et al* 2014; Friedrichsen *et al* 2015). Currently, Europe has 145 GW of grid-connected energy storage installations (Friedrichsen *et al* 2015). This amounts to approximately 30% of global energy storage installations. Spain, Italy, and Germany are the main players in this field (Friedrichsen *et al* 2015).

Energy Policy in the EU

In the 1960s and 1970s, energy storage projects were aimed at large-scale storage of overcapacity from nuclear energy (Friedrichsen *et al* 2015). Following the oil crises in 1973, the European decarbonisation strategy was introduced, which enabled the research and development of renewable energy technologies (Kitzing *et al* 2012). Due to their intermittent nature, flexibility options were required, such as energy storage systems. These did not enjoy the same policy support (Friedrichsen *et al* 2015).

Currently, EU energy policy is aimed at a low-carbon and energy secure future (Fischer *et al* 2016). The main objectives are the integration of renewable energy systems in the electricity grid, creating an integrated European market, improving energy efficiency, creating a near-zero carbon economy, and improving competitiveness (Friedrichsen *et al* 2015). These objectives are defined by the Energy Union Strategy (Arabatzis & Kyriakopoulos 2016). The Energy Union Strategy was created in 2015 to unify the European energy supply. The specific targets by 2030 are 40% reduction in GHG, 27% demand from renewables, and 27% increase in energy efficiency; it is the most important regulatory framework to consider in energy developments (Friedrichsen *et al* 2015). In communications, the EU Council, Commission, and Parliament have acknowledged the benefits of energy storage and its ability to aid in meeting the objectives and targets in the long term. Unfortunately, this policy makes little mention of energy storage and does not include a comprehensive section on energy storage matters (Fischer *et al* 2016).

EU policy drives national policy (Friedrichsen *et al* 2015). A clear policy hierarchy must be established, which should include a clear division of policy for member states (Hills & Michalena 2016). The major prerequisite for a successful integration of commercialized and large-scale energy storage technology is policy and political support (Jacobsson & Lauber 2008)8. Current EU policy makes little or no explicit mention of energy storage as part of its energy future (Fischer *et al* 2016). The electricity directive 2009/72/EC, which mandates common rules of internal electricity markets, and the framework guidelines on electricity balancing make no specific mention of energy storage (ACER 2012; Friedrichsen *et al* 2015). This implies that major policies on grid integration, load smoothing, and renewables integration omit energy storage as a potential key tool (Friedrichsen *et al* 2015). This is a major barrier to financial support through feed-in tariffs or other subsidy schemes (Fischer *et al* 2016). In addition, a lack of grid fee regulation in the electricity directive and EU renewable energy directive is problematic for the integration of technologies, which are not currently market mature (Friedrichsen *et al* 2015). Grid fees are paid by the consumer, but can include generator fees for grid access (Arabatzis & Kyriakopoulos 2016). Energy storage neither specifically generates, nor does it consume electricity, yet it is generally perceived as a generator, yet various countries in the EU regard energy storage as both generator and consumer, leading to double-payment (Friedrichsen *et al* 2015). This makes the already expensive technology even less feasible (Friedrichsen *et al* 2015). As a result, member states must design regulation themselves (Bergek *et al* 2009). Grid operators on the other hand are weary of the lack in clarity pertaining to energy storage regulation, which deters the development of new technology (Friedrichsen *et al* 2015).

Finally, the lack of supranational support or policy pertaining to financing of production of renewable energy creates a disparity amongst EU member states (Friedrichsen *et al* 2015; Kitzing *et al* 2012). Feed-in tariffs, net metering schemes, and investment subsidies are programmes employed by member states to support renewable energy technologies (Bain *et al* 2014). A common EU approach must be designed and include energy storage, to ensure that the targets and objectives of the Energy Union Strategy are met (Friedrichsen *et al* 2015).

Conclusion

The gap in EU policy pertaining to energy storage is apparent and must be filled with adequate policy measures to support the technology. This thesis will make policy recommendation for the integration of energy storage in the EU, based on the technology readiness level, policy success in member states, and potential future developments. General development of renewable energy and the energy market, as well as how energy storage fits into policy will be examined, in order to establish long lasting success with regards to energy storage. Expected results cannot be included at this stage. Both a pan-European and country-specific approach to energy storage policy are possible and cannot be excluded.

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FEASIBILITY STUDY OF A HIGH ALTITUDE AERIAL WIND TURBINE

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Abstract

This paper will discuss the potential of a high altitude aerial wind turbine. The initial results of theoretical power output from the proposed turbine will be used to determine the capabilities of these devices to produce orders of magnitude more electrical energy than current systems. The study when complete will use various methods to verify the theoretical predictions.

Introduction

Wind speeds generally increase relative to the gain in altitude (Arya 2001). High altitude aerial wind turbines are lightweight aircrafts, either configured as a kite or balloon based craft that houses a turbine. Aerial wind turbines are kept stationary using conductive ground tethers (Bronstein 2011). The key objective of high altitude aerial wind turbines is to harness stronger, more consistent winds than current devices (Arya 2001, Lunney *et al.* 2016). Low altitude wind turbines have limited and intermittent access to high velocity wind, whereas high altitude aerial wind turbines can harness powerful, abundant, and nearly inexhaustible jet stream winds (Lunney *et al.* 2016). With up to 100 times more energy than the global demand available in the jet streams, high altitude aerial wind turbines an attractive energy source (Archer and Caldeira 2009).

Current ground based wind turbines experience issues regarding visual, noise and bird and wildlife impacts (Katsaprakakis 2012). High altitude aerial wind turbines hope to address these issues by operating out of visual and acoustic range, plus at altitudes far out of reach of most birds (Finn *et al.* 2012, Katsaprakakis 2012, Fijn *et al.* 2015). Contemporary ground based wind turbines encounter complications due to wind intermittence (Rahimi *et al.* 2013, Ayodele and Ogunjuyigbe 2015). High altitude aerial wind turbines can counter the intermittence issue as a low altitude wind turbine has a fixed hub height. High altitude aerial wind turbines have variable hub heights and therefore alter their operating altitude if necessary to harness more favourable winds at different altitudes. Another issue that can be addressed by the increase in operating height is avoiding interference or high surface roughness from large objects upstream of the turbine. Modern low altitude wind turbines have increased in size in recent years to capture as much energy from the wind as possible. This is achieved by increasing the hub height and diameter of the rotor blades (Lunney *et al.* 2016). Due to the large size of current multi-megawatt wind turbines, they are restricted to operating in wind speeds below 25 ms^{-1} to prevent catastrophic failure (Ali 2012). Hence current low altitude wind turbines are limited in power output (Adhikari *et al.* 2016, Lunney *et al.* 2016).
The proposed high altitude aerial wind turbine design in this study is instead focused on high wind speed energy concentration. This can be achieved with the use of a Venturi tube, where the incoming wind is concentrated into a small area. Due to a drop in air pressure, the wind is accelerated through the constriction where the kinetic energy is converted. Four horizontal turbine blades each with alternating directions of rotation are used to generate electrical power. The alternating rotation of each rotor is to cancel out the gyroscopic reactive coupe (Castellani and Garinei 2013).

The objective of this work is to establish whether the proposed high attitude aerial wind turbine design can produce more energy and more efficiently than current systems.

Materials and Methods

Theoretical Modelling

In order to establish the power output of the proposed high altitude aerial wind turbine the operating conditions, such as the air velocities leaving the constriction had to be found. Using $A_1 v_1 = A_2 v_2$ (Acheson 1990) the formula was manipulated, leaving v_2 on its own. Air velocity exiting constriction was found using $v_2 = \left(\frac{A_1}{A_2}\right) v_1$, where A_1 is the inlet diameter, v_1 is the air velocity entering the inlet and A_2 is the constriction area. Using air density data from NASA's standard atmospheric model (Administration *et al.* 1976), a sensitivity analysis was conducted varying the diameters of the inlet and constriction. The available wind power density was calculated using the following formula $P_a = \left(\frac{16}{27}\right)\left(\frac{1}{2}\right)(\rho)(A)(v)^3$ (Ali 2012, Castellani and Garinei 2013, Rahimi *et al.* 2013). Where, ρ is the air density at pressure layer, A = area of constriction and v is the final air velocity leaving the constriction. Using the same formulae, a feasibility study will be conducted based on global climatic conditions using (IRI/LDEO Climate Data Library 1981-2010) to find out the turbines suitability in different geographic locations.

Computer aided design and simulations

Moving on from the mathematical calculations the physical design of the proposed high altitude aerial wind turbine commenced. Initially, 2D drawings such as Figure 1.0 were created using AutoCAD design software. The 2D design will then be imported into Autodesk Fusion 360 to be converted into a 3D model. When the 3D model is complete, the design will be optimised using flow and finite element analysis simulations. Autodesk Flow Design and SolidWorks software applications can also be used to improve the design, taking advantage of their unique features. Using the previously mentioned software applications a highly optimised design will be produced virtually and efficiently, ensuring the amount of physical prototypes are kept to a minimum. The HOMER (Hybrid Optimisation of Multiple Energy Resources) software application will also be utilised to establish the proposed designs potential compared to existing systems.

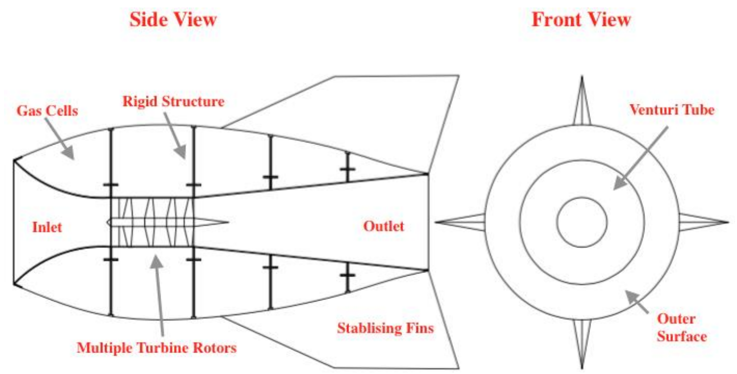

Figure 1. Proposed high altitude aerial turbine design

Manufacture and real world evaluation

Once an optimised design is finalised, a scaled prototype will be produced. The production method chosen for the prototype is 3D polymer filament printing. The prototype will then be taken to the college test site where the prototype will log energy output over a period of time. This method will validate the theoretical predictions (Adhikari *et al.* 2016b).

Results and Discussion

Preliminary results from mathematical modelling

Taking the average climatic wind speeds at different pressure gradients or altitudes (MET Éireann 2017), the calculated power output associated with that altitude is show in Figure 2.0. Three different cases were used to show the power output correlation with the increase in the inlet diameter of the turbine. A 40% constriction ratio was used for each turbine. There was a 4.47 fold increase in energy output between the lowest elevations and highest for all turbine variations, this result is consistent with current literature (Castellani and Garinei 2013).

Table 1. Calculated wind power vs. altitude graph input data

			Calculated Wind Power (MW)		
Average Wind Velocity (m/s)	Atmospheric Pressure (hPa)	Approx. Altitude (m)	Inlet Ø 0.3 m	Inlet Ø 19.2 m	Inlet Ø 38.4 m
25	850	1000	0.01421745	465.877404	931.754808
30	700	3000	0.02008944	658.290804	1316.58161
40	500	5000	0.03856476	1263.69011	2527.38022
55	300	9000	0.06359088	2083.74595	4167.49190

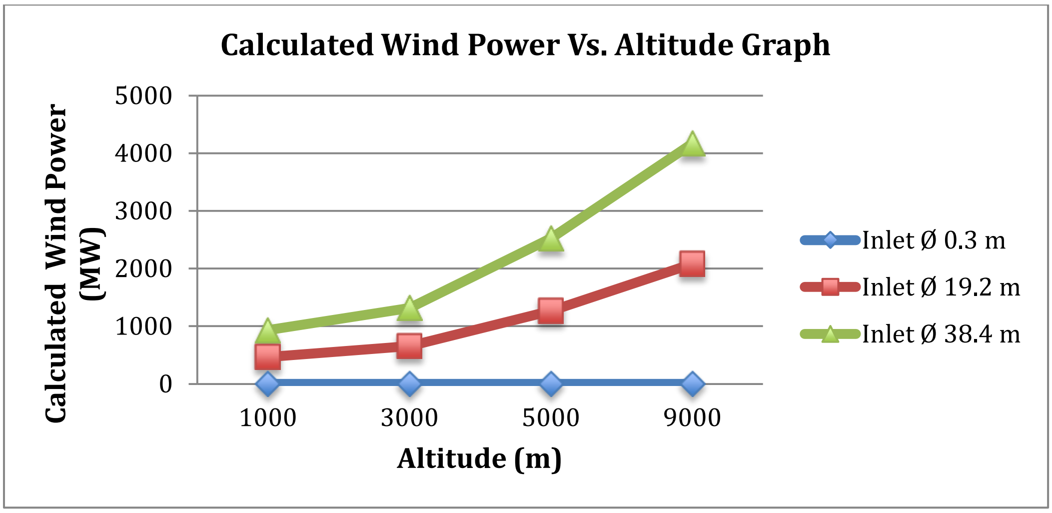

Figure 2. Calculated wind power output from proposed high altitude aerial turbine design

Conclusions

From the preliminary results from mathematical modelling, it can be concluded that the proposed design can produce a significant amount of energy. This initial result will be verified following the next stages in the study. The theoretical performance will be compared with conventional land based wind turbines such as the Enercon E-126. The Enercon E-126 is the largest onshore wind turbine in current operation with a power rating of 7.58 MW, a hub height of 135 m and a rotor diameter of 127 m (Enercon 2016). The expected result upon completion of the study is that the output power will be slightly less than the calculated result, as the efficiency of the proposed design is still to be established, yet the overall performance will exceed the E-126 and address the issues previously mentioned. Progressing forward, the design is likely to incur problems relating to the stability in flight and forming a no fly zone around the turbine. These issues will be addressed in the feasibility aspects of the project.

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A METHODOLOGY FOR ASSESSING RIVERS FOR THE DEPLOYMENT OF A VERTICAL AXIS HYDROKINETIC TURBINE

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Abstract

In-stream hydrokinetic energy generation projects are currently progressing from research and development stages through to full commercialisation. In order to complete this transition significant levels of time and resources must be invested in the selection and assessment of suitable sites. Using both estimated and measured river data, the performance of a vertical axis hydrokinetic turbine will be assessed at a number of sites in Ireland. The results from each of the performance assessments will then be compared to assess the sensitivity of the hydrokinetic river potential assessment methods. From the results of the sensitivity analyses a suitability index will be created which may then be utilised to aid in future potential river site assessments.

Introduction

Hydrokinetic energy conversion (HEC) technologies are quickly becoming the main focus of development for harnessing the large energy resources that are present in rivers, estuary's and tidal zones worldwide (Khan *et al* 2009). In many countries the scope for development of conventional hydroelectric power generation is limited by the lack of suitable sites and opposition to large scale disruption to river courses (Miller 2010). As a result of this there has been a shift in interest towards the development of HEC technologies (Khan *et al* 2008). HEC technologies extract energy from the natural flow of water. In comparison to conventional hydroelectric generation, hydrokinetic devices can be operated without the need for a hydraulic head differential (Ladokun *et al* 2013).Consequently, there is no requirement for water to be stored allowing HEC technologies to be applied in both marine and river settings with very minimal environmental disturbance (Khan *et al* 2009).The working principle of HEC technology is similar to wind however the maximum power extraction is 61% higher due to the fluid density (Kumar and Sarkar 2016).

Hydrokinetic energy devices are categorised based on the orientation of the axis of rotation with regards the water flow (Guney 2011). When the flow direction is perpendicular to the axis of rotation the device is known as a vertical axis turbine. The GKinetic DPM Hydrokinetic Turbine (Figure 1) consists of two vertical axis water turbines mounted either side of a flow-accelerating 'bluff' body (Brett 2015). The blade pitch is controlled to maximise blade lift which produces very high power outputs when combined with the accelerated flow velocity around the bluff body. The device is deployed as a ballasted modular unit attached to the river bed (Brett 2015).

Many hydrokinetic resource assessments have been carried out at different scales from regional (Previsic and Bedard 2008; Lalander 2010; Duvoy and Toniolo 2012; Brett 2014) to site specific, (Toniolo 2012; Lalander 2013) utilising numerical models to characterise the resources. The numerical models used varied in complexity. One dimensional models were used to estimate water depths and velocities and two-dimensional models were used to estimate vertical averaged velocity distributions. Three dimensional models, such as the model to be used in this study, assess the effects of the turbines on the entire flow field and provide an indication of the device's performance rating. The use of three-dimensional models in assessments is quite limited due to the high costs that are associated with their development (Lalander 2010).

The objective of this study is to develop a suitability index that would aid in the feasibility assessment of river resources for hydrokinetic devices.

Materials and Methods

Site Selection

The river sites to be studied are required to have minimal constraints of depths over 2m and flow velocities over 1m/s (Brett 2015). Ideal sites locations are rivers that have a large level of transect data already available through water management bodies or previous energy yield assessments. The scope of investigation is currently limited to sites in Ireland. The data required includes physical, bathymetric and hydrographic surveys as well as measured flow velocities and velocity distributions. If necessary site visits will be carried out to acquire further data.

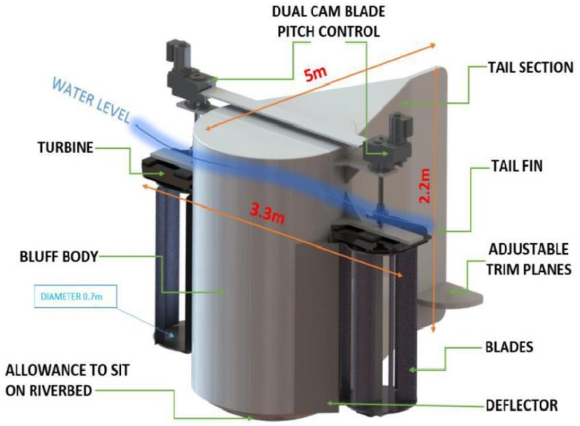

Figure 1. Components of the DPM Hydrokinetic Device (left) and full frontal view of device (right) (Brett 2015)

Hydrokinetic Potential Assessment

The following steps apply to sites located within unregulated river reaches, the regulated river methods is mentioned last. The river sites are assessed using data gathered through GIS and mathematical equations relating to flow, discharge and channel geometry. In GIS the drainage areas are delineated and channel widths (w) and slopes (S) are estimated (Brett 2015). If the rivers are ungauged the discharge will be scaled to that of gauged river reaches using the drainage area ratio method (1):

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^m \tag{1}$$

where Q_u and Q_g are the ungauged and gauged discharges, A_u and A_g are the ungauged and gauged upstream drainage areas and m is the calibration factor (Lalander 2013).

In order to quantify the hydrokinetic power of a river, its channel geometry must be known. The following equations (2) by Leopold and Maddock (1959) relate discharge and sediment load to river depth, width and flow velocity. The relationships are:

$$\begin{aligned} w &= aQ^b \\ d &= cQ^f \\ v &= kQ^m \end{aligned} \tag{2}$$

where Q is discharge, w, d, and v represent width, depth and flow velocity respectively, and where a, b, c, f, k and m are numerical constants. It was noted by Singh (2003) that the scale factors a, c, and k show variation between locations but b, f, and m remain largely consistent. However, as described by the equation of continuity (3) there are restrictions on what the values the constants can take:

$$Q = wdv \tag{3}$$

The geometric shape of the channel is assumed to have a rectangular cross sectional profile. Considering this, the equations (2) can then be combined with the continuity equation (3) to develop the following relationship (4) (Canadian Hydraulics Centre 2010):

$$Q = ackQ^{(b+f+m)} \tag{4}$$

The hydrologic flow data must be transformed to velocity data using the hydraulic characteristics found in the previous equations. The channel velocity is most commonly estimated using a hydraulic open-channel flow equation such as the Manning equation (5).

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{5}$$

This equation relates the average flow velocity *V*, to a hydraulic radius *R*, with a roughness *n* and water surface slope *S* for uniform flow conditions (Canadian Hydraulics Centre 2010). The roughness coefficient *n* is estimated from the local site topography and geological information and it is then assumed constant throughout the site.

In regulated river reaches the upstream flow velocity is determined depending on the regulated capacity of a downstream dam. According to Lalander (2010) for small variations in water level the flow velocity is linearly proportional to discharge (6). The relationship is dependent on the use of a time series of discharge:

$$v(t) = \left(\frac{1}{A}\right) Q(t) \tag{6}$$

Device Performance Assessment
A three-dimensional computational fluid dynamic (CFD) performance model has been created by Cure (2017) for the device. Utilising the performance outputs from this model it will be possible to create a range of parameters that will indicate the requirements of sites for use in the creation of the suitability index.

Sustainability Index Development
The data collected from the device performance assessments will be analysed to identify relating characteristics. When the characteristics of each are defined the results are then correlated to identify the physical characteristics that have the largest influence and control on the device performance. With the correlated values it is then possible to create a suitability index. This index would highlight how variations in river parameters would affect the energy yield of the device.

Expected Results

The results found using current hydrokinetic potential methodologies will be assessed against the actual values found from on the site assessment data. This will provide an indication of the percentage error that occurs using the methodologies and any over skewed or erroneous result parameters will be assessed to locate inaccuracies. If the errors are limited, the data correlation will be more seamless. As the hydrokinetic potential of the sites is already known as is their suitability for installations of this type the results will provide the bases of the suitability index. Once the range of values that affect the performance of the device are known they can then be varied to assess the robustness of the index.

Conclusion

Hydrokinetic energy potential assessments are costly undertakings for companies which are often in the early stages of their development. However, their importance cannot be overlooked as they are a key investigation step in the development of sites that have large amounts of generating potential. With the development of a suitability index for site assessment it will be possible for industry developers to gain a better understanding of sites of interest without heavy investment. This however would depend on the availability of previous survey data of the sites. Data of this type is commonly provided by government agencies but is often difficult to locate. The suitability index would provide a range of values that could be changed as required to reflect the physical parameters of the river site. This may then be further developed to aid in the device configuration for optimum energy production yields.

Acknowledgements

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REPLACEMENT OF STANDBY GENERATORS WITH BATTERY SYSTEMS IN KNOXVILLE, TENNESSEE: A TECHNO-ECONOMIC ASSESSMENT

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Abstract

Battery energy storage systems have witnessed rapid technological and industrial growth in recent years, leading to more efficient batteries at cheaper production costs. This study outlines the research to be conducted in examining the current economic feasibility of utilising battery energy storage systems in lieu of traditional fossil fuel based standby generators for emergency standby power in Knoxville, Tennessee. The results and discussion in this study are based on the calculated results and also using existing literary reviews.

Introduction

Stationary standby generators which utilise Reciprocating Internal Combustion Engines (RICE) are the traditional provider of emergency standby power (ESP) for buildings and service structures during power interruption from the utility provider (Benton *et al.* 2017). RICE is defined by the U.S. Environmental Protection Agency (EPA) as engines which "...use pistons that alternatively move back and forth to convert pressure into rotating motion" (2017). This pressure is provided by the combustion of fossil fuel resources, most commonly diesel and natural gas. As the EPA has increasingly targeted both on and off-road emissions delineated by the National Emission Standard for Hazardous Air Pollutants (NESHAP), stationary RICE generator producers have witnessed increasingly stringent air pollution emissions standards since initial policy implementation in 2004 targeting these emission sources (U.S. EPA). These standards have led to mandatory Operating Permits for applicable RICE generators under section 25.7 of the Knox County Air Quality Management (KCAQM) Regulations (2017). These permits cost operators a yearly *de minimis* fee or a flat-rate fee per Ton Per Year (TPY) of total emissions beyond the *de minimis* value, as calculated according to annual run time hours of the specific generator. As such, these generators cannot be altered in any without the notification of KCAQM.

These permits and subsequent lack of flexibility for RICE generator owners are merely a new layer of associated generator costs. From initial capital to routine maintenance, weekly running periods to maintain "wetness", replacement of old fuel, energy consumption by block warmers and even man hours spent meeting with inspectors, RICE generators have the potential to cost owners a significant amount over the period of operation (Wang and Chen 1996). The overall Net Present Cost (NPC) of ownership is one which is traditionally unquestioned during the planning and development of building electrical systems as RICE generators have long been the only reliable, predictable form of emergency power generation.

A potential substitute to RICE generators for emergency power are batteries. Battery technologies have witnessed substantial growth in both power density and life cycles as well as lowering manufacturing costs in recent years (Telaretti and Dusonchet 2016). Battery Energy Storage Systems (ESS) are now being installed in locations across the U.S. and other countries for levelling the peak demand curves in grid systems, peak shaving and emergency energy (Patel and Perusse 2012). While grid-scale battery ESS have been extensively researched, field tested and implemented into real-world scenarios, there has been minimal research into implementing the same technologies for small-scale ESP for individual buildings and service providers.

The objective of this study was to investigate the economic feasibility of implementing battery energy storage systems in lieu of, or in replacement of, RICE standby generator systems for stationary demand structures.

Materials and Methods

Demand Structure Type and Delineation
A "demand structure" for this study shall be defined as any stationary structure which requires the assurance of emergency power in order to maintain necessary functionality of demand components. Not all demand structures are suitable for battery ESS due to demand loads or potential duration of emergency demand. As such, demand structure types investigated shall be examples which ensure the comparison of RICE generators and battery ESS is appropriate. The assessment shall be conducted comparing the NPC of the systems across a spectrum of demand structure examples. At a minimum, this assessment shall incorporate U.S. legislative requirements for emergency exit lighting, ventilation and all other emergency services. Beyond this initial demand, various hypothetical demand systems shall be investigated based off real-world examples utilising demand structure energy (in kW) demands and average duration of regional grid power loss events (in hours).

Emergency Power Instances
The average annual occurrence and duration of emergency power instances shall be estimated according to records of grid power loss from real-world examples in Knoxville, Tennessee. This determination is believed to be a potentially significant impactor on economic feasibility between the technology choices. This is due to the fuel costs and potential increased permitting fees of running RICE generators for higher runtime hours, and, oppositely, the higher capital cost of equivalent battery ESS being unrealised through lower utilisation hours.

RICE Generator NPC Analysis
From the results of initial demand structure delineation, RICE generators and associated components adequately sized to match specific demand structures shall be considered from for use over a period of 20 years. Diesel and natural gas generators of necessary kW output shall be considered for: capital costs, installation, required maintenance, fuel consumption, permit fees, block warmer electricity demand and all other associated costs with the operation of the RICE generator. Depreciation of components' values shall be incorporated into the calculation based on statistical resale values of similar units.

Battery ESS NPC Analysis
Also from the results of initial demand structure delineation, battery ESS and associated components adequately sized to match specific demand structures shall be considered for use over the same period of years. Lithium ion (Li-ion), lead-acid and Na/S battery ESS of equivalent kW outputs shall be considered for: capital costs, installation and required maintenance. Depreciation of components' values and performance shall be incorporated into the calculation based on statistical resale values. Cost savings from proposing necessary drain cycles during peak electricity rates for peak shaving shall also be incorporated, as well as battery recharge cycles during off-peak hours.

Present Value Calculation
An example of the calculations which will be used in this analysis can be seen in the present value of costs or benefits equation as defined by the Electric Power Research Institute (EPRI) Handbook of Energy Storage for Transmission & Distribution Applications (2003):

$$PV = \sum_{t=0}^{n} \frac{X_t[(1+i)(1+e)]^t}{[(1+r)(1+i)]^t}$$

Where:

PV = Present Value (of a series of cost or benefit components, X_t)
X_t = Cost or Benefit (occurring during the time period, t)
n = Number of Time Periods

e = Real Escalation Rate
r = Real Discount Rate
i = Inflation Rate
t = Time Period

Like any other type of investment, the choice of these technologies shall be based on the economic advantages of the technologies over their cost. As such, this calculation shall be used to create ratios between the technologies, in various demand structure scenarios, of net present values of projected benefits minus the costs of each technologies. Time Period (*t*) shall be in a number of years to examine the project, Inflation Rate (*i*) shall equal a rate consistent with typical annual inflation in the U.S. and Real Escalation Rate (*e*) shall be based on estimated annual change in grid electricity price in the demand structure area. Real Discount Rate (*r*) will require specific investigation into the predicted value of the used technologies in the future at the end of Time Period (*t*), and is likely to be the calculation's area of most assumptions.

For this study, "benefit" shall be defined solely as energy production, based on a quantitative $/kWh basis according to average grid prices per kWh of the demand structure area. It should be noted that the PVs of benefits minus the associated costs of producing those benefits (i.e. capital, installation etc.) will almost certainly be negative in most cases for both technologies as the cost of generating electricity via standby generators or by battery systems to recycle grid energy will cost more than that of solely grid energy on a $/kWh basis. Battery ESS have the potential to create a positive NPC when combined with drainage cycles over peak demand rate hours, but this is unlikely as these ESS will not be designed solely for this purpose. As these systems are intended for ESP, negative PVs and overall NPCs are to be expected and are accepted as necessary for energy security. Valuations of other benefits associated with providing ESP shall not be addressed by this study.

Battery Costing
An example of costing data to be utilised for RICE generator and battery ESS comparison can be seen below (Table 1) where the average capacities, power, durations, efficiencies and costs of three viable battery technologies are described. Similar data for comparative RICE generators shall also be incorporated as well as all associated costs of each technology choice.

Table 1: Battery technology details. [Dunn *et al.* 2011; EPRI 2003]

Technology Option	Capacity (MWh)	Power (MW)	Duration (hours)	% Efficiency (total hours)	Total Cost ($/kW)	Cost ($/kWh)
Advanced Pb-acid	3.2-48	1-12	3.2-4	75-90 (4500)	2000-4600	625-1150
Na/S	7.2	1	7.2	75 (4500)	3200-4000	445-555
Li-ion	4-24	1-10	2-4	90-94 (4500)	1800-4100	900-1700

Results and Discussion

As research is ongoing, only expected results are discussed here. Based on initial research, economic feasibility of implementing battery ESS in lieu of RICE standby generators is expected to follow a general pattern where the annual frequency of ESP events greatly affects technology choice. In circumstances where demand structures are likely to witness fewer annual ESP events, it is likely to favour the installation of RICE generators due to lower capital costs and low costs associated with fuel consumption and emissions. In the event of higher annual events, it is likely to favour battery ESS as there is no additional costs beyond capital costs – whereas with RICE generators more fuel would be consumed, raising NPC significantly. Additionally, ESP events which average long demand durations are expected to favour RICE generators due to the effective charge duration of batteries. Such long durations would require more capital investment into battery banks and equipment to ensure adequate power over the entire period.

The combination of these two factors is predicted to result in high annual frequency of short average duration emergency power events favouring battery ESS. The economic feasibility of battery ESS in situations of less annual frequency and/or longer average durations is unpredictable at this time.

Conclusions

Further research into the economic feasibility of replacing RICE generators with battery ESS needs to be conducted. This study has outlined several potential methods which will contribute to that investigation. It is believed that the implementation of battery ESS has the potential to lead to higher energy security and cost savings through lack of permitting requirements, extremely low maintenance, less man hours dedicated to attention, peak shaving of peak-rate grid electricity through drain cycles during non-peak hours as well as other factors. The implementation of battery ESS also has the potential to eliminate air pollution and noise associated with RICE standby generators – strengthening the argument for stored energy solutions over the combustion of fossil fuels for ESP.

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WASTE PLASTIC RECOVERY AND REUSE IN IRELAND

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Abstract

Appropriate farm plastic waste disposal is an issue in Ireland. This waste can be disposed of inappropriately *via* burning or illegal dumping. Disposal centres have been set up to help deal with such issues. These centres provide a farm plastics recycling scheme to improve the recovery and recycling efficiency of farm plastic waste. For this scheme to be effective, recovered plastics must be in good condition with low contamination rates. In this study, the quality of used farm plastic samples will be assessed in the laboratory regarding contamination, with a primary focus on reducing this via developing a framework of best practice for farmers.

Introduction

It is widely recognised that plastic recycling makes a significant contribution towards a sustainable waste management system relieving the pressures of society on the environment. Recycling reduces the demand for energy and resources, mitigates water and air pollution, helps with solid waste management and can be economically beneficial (Briassoulis et al. 2013). Plastic makes up a large portion of farm waste yearly in Ireland. As a result of farming intensification and changes in farming practices, more plastic is being utilised on farms in recent times and due to this more plastic wastes are being generated (rx3 2011). Plastics on farms are utilised for packaging, silage making and horticulture including many other purposes.

As reported by the EPA, agricultural plastic waste arising amounted to an estimated 32,000 tonnes in 2010 (rx3 2011). Most of this plastic waste is composed of low density polyethylene (LDPE) silage wrap and sheets accounting for 75% of agricultural plastic wastes, with other wastes being composed of feed and fertiliser bags, netting, twine, and high density polyethylene (HDPE) chemical containers. LDPE silage wrap plastic is managed by the Waste Management (Farm Plastics) Regulations S.I. No. 341 of 2001 ("Irish Statute Book" 2017). Under these regulations yearly targets are set with a recycling target of 65% set in 2013 (rx3 2011). Due to the large quantities of waste plastics produced from the agricultural sector, the government has set up a licenced farm plastic recycling scheme managed by the Irish Farm Film Producers Group with 225 recycling centres nationwide. The waste plastic is collected yearly from April to July, it is cleaned shredded and extruded producing a plastic pellet which can be utilised in a variety of ways ("Bring Centre - IFFPG" 2017). This scheme was set up to mitigate pollution and environmental damage caused by illegal dumping, burying or burning of such wastes. For this programme to operate successfully, cooperation between farmers and recycling centres is of pivotal importance as farming practices affect the quality of the waste plastics being recycled.

The objective of this study is to assess contamination rates of a variety of plastic samples collected from farms, and compare these results with bring centre sample data.

Materials and Methods

One major quality issue affecting the recycling process is contamination of the plastics from water, soil, or manure. The complex nature of plastic waste streams in terms of the presence of impurities necessitates extensive cleaning and separation pre-treatments prior to reprocessing (Briassoulis et al. 2013). High contamination rates affect the recycling process making it economically unfeasible due to the cleaning process necessary prior to reprocessing. Therefore, a framework of best practice will be developed in this study which will educate farmers about best practice in dealing with, and storing farm plastic waste prior to its collection at a recycling facility. This framework will ensure that plastics contain the least amount of contamination and are in good condition prior to processing and recycling.

Sample Selection

A variety of plastic samples will be collected from farms around the Connacht region and brought to the laboratory in UCD. Plastic samples will include pit cover, bale wrap (from base of bale) and bale wrap (typical). Plastic samples collected from farms will be compared with samples previously collected from bring centres regarding their moisture content, organic material content and other contaminants.

Moisture Content Characterisation

The contamination rates of each sample will be assessed using a laboratory oven. Each sample will first be weighed and this weight will be recorded as W1. The samples will then be spread on a foil tray and placed in a fan assisted laboratory oven at 105 ± 2°C for 24 hours. After baking samples are allowed to cool to room temperature before being reweighed. This weight will be recorded as W2. The moisture content of each sample will then be calculated in accordance with this formula $\% H_2O = [(W1-W2)/W1]*100$.

Soil/Organic Material Characterisation

Any dried organic matter on the samples after the baking period will be collected, weighed, and recorded.

Expected Results

Quantification of Contamination

The expected results of the contamination characterisation analysis will be shown in tabular form similar to Table 1 and Table 3 taken from previous reports. Graphical illustrations of the data collected will also be included. The table will include the sample weights recorded in grams, origin of sample, the moisture content percentage of each sample, the average moisture content for all samples and a standard deviation. Residue and solid organic material content will be displayed in grams for each sample and a percentage of solid contaminants by weight per sample similar to Table 2. The contamination results of the farm samples will be compared to previous results taken from samples collected from a bring centre. This comparison will portray how the farm plastic waste recycling scheme set up by the IFFPG is affecting the management and treatment of agricultural plastic wastes in Ireland.

Table 1: Selected agricultural plastic wastes and contaminants (Briassoulis et al. 2012)

Plastic type	Characteristics	Crop	Origin	Removal	Wet sample weight (g)	Dry sample weight (g)	Plastic weight (g)	Dirt weight (g)	Water weight (g)	Sand weight (g)	Loam and clay (%)	Organic matter weight (g)
Mulching and tape												
Mulching film and tape	Transparent film	Melon	Tegedor Mauguio	Mechanically	37.05	35.58	15.79	19.79	1.47	4.51	77.21%	7.26
Mulching film and tape	Transparent film	Melon	Tegedor Mauguio	Mechanically	67.7	65.39	19.09	46.3	2.31	14.35	69.01%	20.42
Silage film	Black for bunker silo	Silage		Manually	42.92	40.26	36.32	3.94	2.66	3.52	10.66%	0.42
Silage film	Black for bunker silo ERI	Silage		Manually	182.06	177.5	161.52	15.98	4.56	8.21	48.62%	
Wrapping film	Green film	Hay	Farmer of Vesoul	Manually	58.09	56.58	54.8	1.78	1.51	1.69	5.06%	1.04
Wrapping film	Green film	Hay	Farmer of Vesoul	Manually	25.31	25.2	24.38	0.82	0.11			

Table 2: Percentage of solid contaminants in various agricultural plastic waste samples (Briassoulis et al. 2012)

Category	No. of samples	Plastic wt.% (%)	Solids wt.% (%)
Greenhouse film	10	93	7
Low tunnel	18	77	23
Mulching	24	58	42
Mulching and tape	7	47	53
Substrate cropping bag	2	93	7
Silage film	2	91	9
Wrapping film	9	94	6

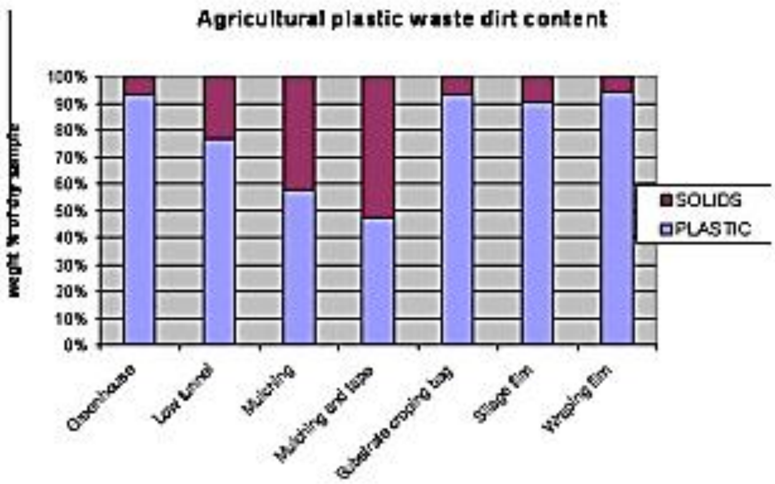

Figure 1. Dirt content of various agricultural plastic wastes (Briassoulis et al. 2012)

The degree of soil contamination is one of the key quality specifications for recycling of agricultural plastics (Briassoulis et al. 2012). As shown in figure 1 above, soil contamination varies considerably within each plastic category. High variations in soil and organic material contamination is also expected for the samples collected in this study.

Table 3: Moisture content of samples (Unpublished Report)

	Sample #	Description	Mass wet (W1) (g)	Mass dry (W2) (g)	MC (wet basis) (%)	MC (dry basis) (%)
Samples taken (loose)	1	Pit cover	75.67	73.31	3.1	3.2
	2	Bale wrap (base)	162.86	96.54	40.7	68.7
	3	Bale wrap	124.99	55.02	56.0	127.2
				Average	33.3	66.4
				Standard Deviation	27.2	62.0

Discussion and Conclusions

The expected contamination results of plastic samples collected from a bring centre will be highly variable. Moisture content of samples could range from 3% up to 56% with an average of approximately 33%. Residue and organic material taken from the samples could range from 3% to 7%, up to nearly 2 grams per sample of silage/bale wrap. Contamination rates for samples taken directly from farms are expected to have a wide variation similarly, however with much higher dry residue and organic material contamination as generally these plastics won't be stored appropriately, and are often left exposed and unprotected. Plastic thickness may also affect moisture content results where thicker films such as pit cover can lose moisture more easily during transit when compared to thinner films such as bale wrap. This makes it difficult to get representative moisture content results for these plastic types. To conclude this study will attempt to improve management and recycling practices of farm plastic wastes in Ireland, by improving the quality of the plastics being utilised. It will also attempt to improve the effectiveness of the nationwide agricultural plastics recycling scheme set up by the IFFPG and the Irish Government. The benefits of such improvements include reducing open burning of such wastes on farms which could pose risks to human health, reducing illegal dumping which could compromise water quality and reducing unsightly environmental pollution from used and degraded plastics (Levitan and Barros 2003).

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IDENTIFYING BELOW THRESHOLD INTENSIVE AGRICULTURE UNITS IN IRELAND

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Abstract

In 2014 agriculture produced 98% of Ireland's ammonia emissions. This high contribution of agriculture to ammonia emissions is common throughout Europe. In many countries there exists a database of farms available to government bodies or institutions who carry out atmospheric modelling. In both Ireland and the United Kingdom locations of intensive farms below Industrial Emissions Directive (IED) thresholds are not available. This study uses local authority planning applications and satellite imagery in order to identify all unlicensed / below threshold pig and poultry farms across the Republic of Ireland. This is necessary in order to gauge the potential for cumulative impacts of multiple farms in relatively close proximity to each other. The Environmental Protection Agency has on record 198 pig and poultry farms above IED licensing thresholds, this study has thus far identified the locations of an additional 738 farms.

Introduction

Agriculture is the primary source of atmospheric ammonia across Europe, accounting for 98% of Ireland's 2014 emissions. Though pig and poultry farming contributed only 8.1% of the overall total (EEA 2016), the discrete locations of these farms plays a very important role in their impact. As pig and poultry in Ireland are farmed in intensive units, their emission source is concentrated when compared to diffuse emissions from grazing. As such, the location of these farms is vitally important when trying to understand their impact. Pig and poultry farming across Europe has a record of emitting ammonia concentrations high enough to cause an impact on local sensitive sites (Jones et al., 2013, Frati et al., 2007).

There are currently 198 pig and poultry farms licensed under EU Council Directive (2010/75/EU) on industrial emissions in the Republic of Ireland. These constitute poultry farms with capacity over 40,000 birds and pig farms with either more than 2000 production pigs (over 30 kg) or more than 750 places for sows. Farms which fall below these thresholds do not require licensing from the Environmental Protection Agency, and their locations are not available on any public database. Though farms below the IED thresholds may be too small to be considered having an impact in isolation, depending on their number they can make a significant contribution to the cumulative impact of atmospheric ammonia. This relates to both areas with large clusters of farms and areas where they contribute to already high ammonia concentrations from other sources.

As no database of sub-threshold pig and poultry houses is available for use, the locations of houses will need be identified manually by this study. This was carried out using a combination of local authority planning systems and reviews of satellite imagery.

The objective of this study was to locate below threshold intensive agriculture units in the Republic of Ireland.

Materials and Methods

Data availability
A database of planning applications for intensive pig and poultry houses was compiled for 16 available counties. The remaining 10 counties planning authority websites were not capable of carrying out keyword searches, which is an essential part of compiling the planning database. Based

on Central Statistics Office data eight of these available counties represented 95% of poultry production in Ireland whereas only 62% of pig production was represented across the 16 available counties. A manual review of satellite imagery of County Cork boosted the estimated coverage of poultry to 99% and pigs to 80%. By incorporating the number of animals licensed in the areas where planning is unavailable in excess of 95% of intensive pig houses can be identified.

Compiling planning database

Keyword searches for planning applications consisting of words such as “poultry”, “broiler”, “layer”, “pig”, “sow”, etc. were carried out across all 16 available county council planning authority websites, the results of which were compiled in an excel spreadsheet. This spreadsheet was inputted into Google’s “My Maps” online software, which allows for the generation of multiple point locations based on a word address.

Review of satellite imagery

Once the approximate addresses of the pig and poultry farms were inputted into “My Maps”, satellite imagery was used to fine tune the location of each planning application. Using this method, it was possible to identify areas likely to contain pig or poultry farms, following which the farms were identified by characteristics unique to each industry. For example, figure 1 shows a standard layout of a poultry and pig farm. Poultry farms are generally one or more long buildings with either natural or mechanical ventilation visible from aerial review, each house usually has its own feed silo. Pig houses are generally a cluster of smaller houses, though long houses are also present. Their ventilation systems are usually more scattered and diverse, with feed silos usually clustered at one point on the farm. Many pig houses will also have an outdoor slurry tank, though this trait is also common with many cattle sheds.

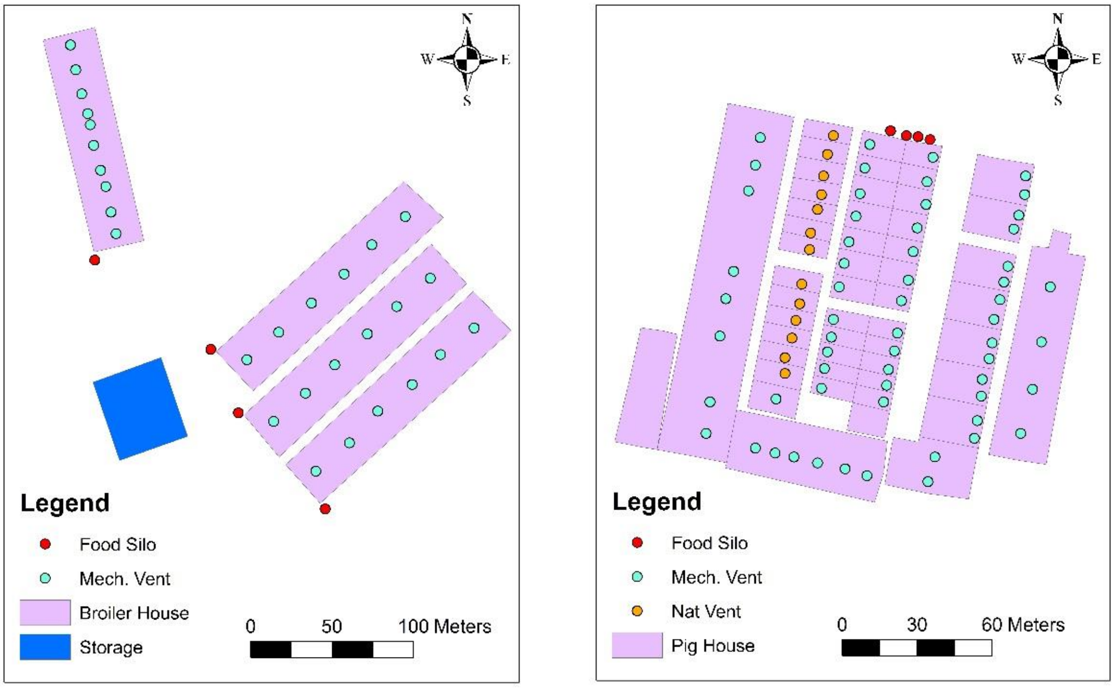

Figure 1: Typical layout of broiler farm (left) and pig farm (right).

Results and Discussion

Following the review of local authority planning, a database of 2704 planning applications for either the development of new or modification of old pig and poultry farms was compiled. This data was reviewed for duplicate applications for the same farm, following which the locations were identified using Google's "My Maps" and satellite review. A total of 738 additional farms were identified. When considering local ecological impacts, the location and proximity of houses to each other is vitally important. The locations of identified unlicensed and licensed houses are shown in Figure 1. Clusters of poultry houses are immediately apparent in Monaghan, Cavan and Limerick whereas pig houses are more evenly distributed across Munster, South Ulster and North Leinster.

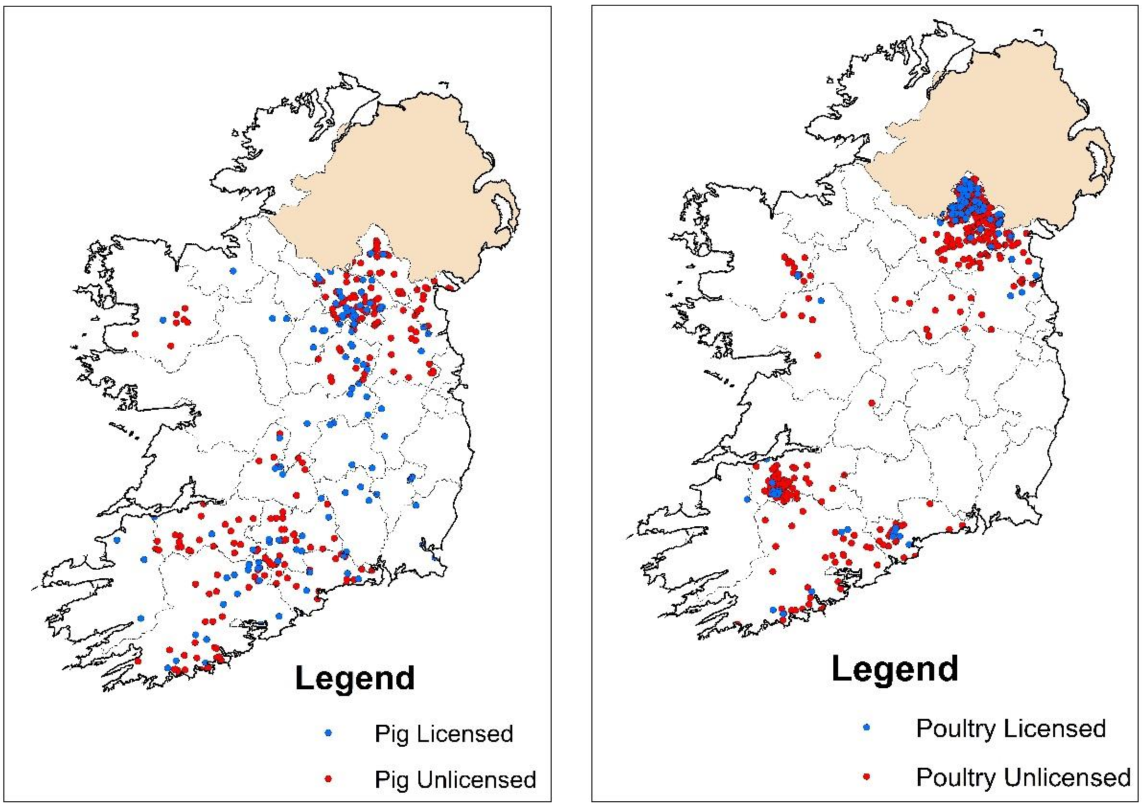

Figure 1: Left: Locations of licensed and unlicensed pig farms. **Right:** Locations of licensed and unlicensed poultry farms.

As the locations in figure 1 represent dense clusters of houses, the data is easier to interpret when presented as density of houses. Figure 2 (Left) shows the density of both pig and poultry farms across Ireland. The density of farms in Monaghan is immediately obvious, followed by Limerick and Cavan. Kernel density analysis was used to further analyse these clusters, which were then reclassified on a scale of 0 – 5 using geometrical intervals to represent the areas with larger clusters of pig and poultry farms (Figure 2 Right). This map more accurately represents the areas for concern in terms of cumulative impact from pig and poultry farms clearly showing Monaghan, Limerick and Cavan as hotspot areas for intensive agriculture. It also highlights areas potentially at risk, such as Cork, South Tipperary and Waterford.

Conclusions

Reclassifying the output of kernel density analysis along geometric intervals is a useful method to identify areas most likely at risk of impact from clusters of pig and poultry houses. This analysis could be incorporated into a larger model incorporating cattle populations, ecological indicators and monitored ammonia concentrations in order to provide a qualitative risk assessment for atmospheric ammonia.

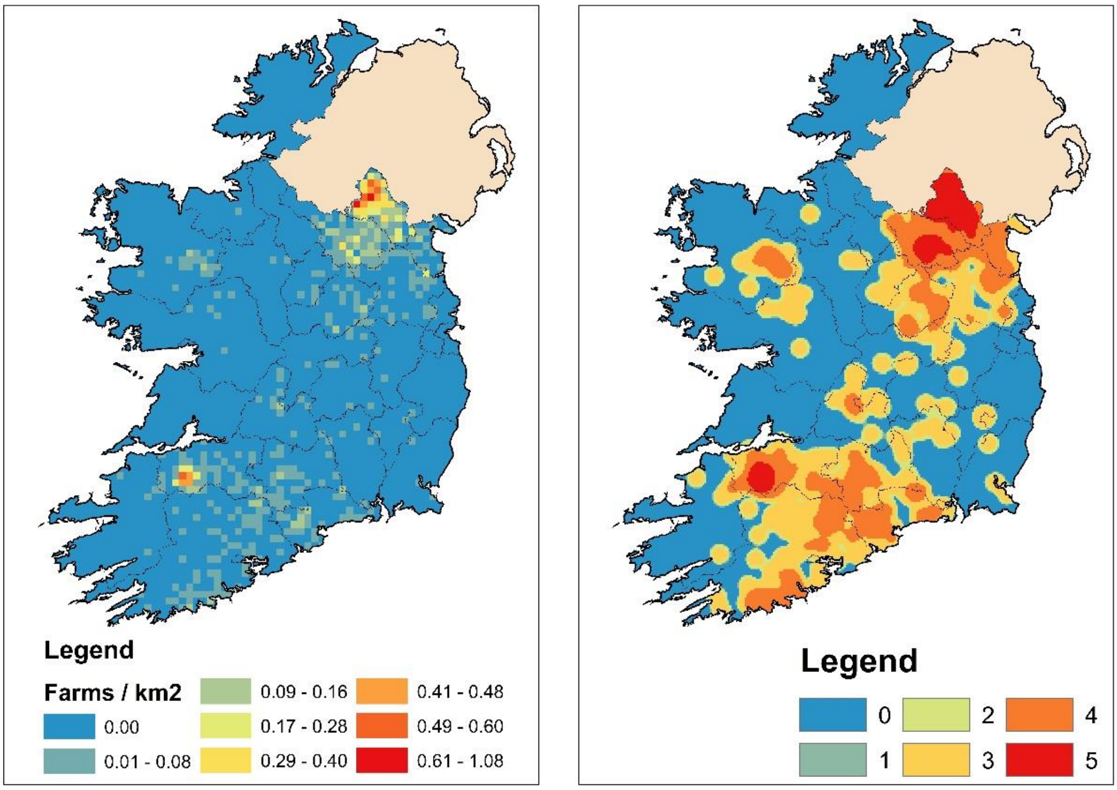

Figure 2: Left: Basic density analysis of intensive agriculture units presented in number of farms per square kilometre. **Right:** Kernel density data reclassified on simplified scale from 0 -5.

Acknowledgements

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THE COMMUNITY ACCEPTANCE OF THE OFFSHORE WAVE ENERGY TECHNOLOGIES IN BELMULLET, CO. MAYO

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Abstract

The successful development of renewable energy technologies can be significantly influenced by the level of community acceptance which can make its establishment a difficult or smooth process. In this paper, the community acceptance for the offshore wave energy developments off the coast of Belmullet, Co. Mayo will be assessed. The controversial history with energy developments in the area make it imperative that the community are in acceptance with the project. This paper will determine the level of community acceptance for the Atlantic Marine Energy Test Site (AMETS) but will also provide a good indication of any potential areas of concern for future projects.

Introduction

The AMETS off the coast of Annagh Head, west of Belmullet Co. Mayo is being developed by the Sustainable Energy Authority of Ireland (SEAI) to facilitate the full-scale testing of wave energy converters in the open ocean (Cahill and Lewis, 2013). The location for this test site was chosen because of its favorable seabed and wave power conditions but also its existing grid connection (Atan, Goggins and Nash, 2016). The Corrib gas project was subject to considerable local opposition resulting in both onshore and offshore protests making progress very difficult. Social factors can influence the development of energy technologies just as much as other issues such as resource capacity or grid connection making community acceptance for the AMETS a considerable issue (Storey, 2014).

Social acceptance in the implementation of renewable energy technologies has traditionally been neglected because of the high levels of support for the technology. The issue with public support has often been viewed as 'non-technical' factors and overlooked but quickly became an area that it couldn't be taken for granted which was experienced with wind power where public objections led to local political support hindering its development (Wüstenhagen, Wolsink, and Bürer, 2007). With regards to wave energy projects, social and public acceptance has largely been ignored because of the immaturity of the technology and the positive public opinion. But given the history in the Belmullet area with regards to energy developments, the issue should not be taken for granted to unsure the successful implementation of the technology (Heras-Saizarbitoria, Zamanillo, and Laskurain, 2013).

This paper will look at the interactions between the offshore energy technologies from the AMETS and local communities in Belmullet. The level of community acceptance in Belmullet will provide a good indication of how smooth the adoption of this technology will be in Ireland. Wind energy development, a similar renewable development, has been hindered in Ireland by the lack of public acceptance, resulting in a 'Not in My Back Yard' (NIMBY) attitude (SEAI, 2008), this paper will look at how to take lessons learned from the wind industry and apply them to the development ocean energy industry in Belmullet.

The objective of this study is to determine the level of community acceptance with Offshore Energy Technologies in Belmullet, Co. Mayo

Methods and Materials

Background review

This paper will examine the specifics of the AMETS project shown in figure 1 and an assessment of historical community issues from the Belmullet area will be made. A study will be done with communities that embrace energy technologies versus communities that resist them to determine the effect on the development of the technology.

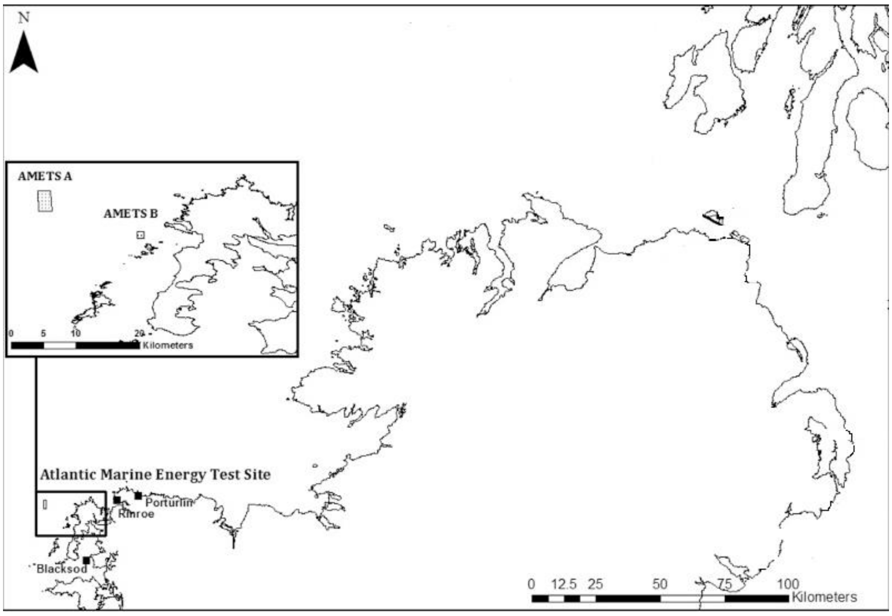

Figure 1. Map showing location of the AMETS project (Reilly, O'Hagan, and Dalton, 2016)

Interviews

Interviews with the SEAI local liaison for the AMETS project will be conducted to determine the level of interaction between the SEAI and the local community. Local environmental groups and TDs will also be contacted to develop a comparison with the other energy developments in the area.

Surveys

A survey will be conducted with the local residents to understand their understanding and relationship with the AMETS project with a comparison to the existing energy developments in the area. The level of trust between the local residents and the project will be evaluated. An indication of the effort SEAI have committed to accommodate local residents will also be determined from the surveys.

Economic potential

From the potential economic impact of the AMETS, an assessment will be made as to how this can affect the local economy. Opportunities for local businesses and consumers will be identified.

Stakeholder engagement

The impact the AMETS will have on the key stakeholders will be examined. Local business that may be affected by the implementation of the test site will be contacted to gauge whether there is positive or negative interaction between the existing industry in the area and the test site. The level of consultation with local fisherman will also be assessed to determine if they are happy with sharing the marine resources with wave energy technologies.

Figure 1. Triangle of social acceptance of renewable energy technologies (Wüstenhagen, Wolsink, and Bürer, 2007)

Data analysis
The data collected in this study will cover the three dimensions of social acceptance of renewable technologies shown in the triangle of social acceptance in figure 1. Quantitative and qualitative analysis of the data will be used to generate results.

Expected results and discussion

Community acceptance for marine renewable energy has been closely linked with the level public precipitation in the project which will be a significant factor in the acceptance of the AMETS in Belmullet (Sandberg *et al* 2016). This is something that is to be expected to have been considered by the SEAI before the AMETS project was developed. As offshore wave energy is not yet fully developed in Ireland and there are no fully commercial projects established, the results of this study will provide information on how the AMETS project is accepted amongst the local community but also on the expected acceptance for the development of wave energy in Ireland.

As this project is in the early stages of its completion, the results have yet to be developed but an overall acceptance and support for the AMETS is the expected outcome from this paper. This expected result is largely due to previous experiences with energy development in the area where a gas pipeline was constructed for the Corrib gas field which was met with intense opposition. The Corrib gas field project represents the polar opposite to the AMETS. The gas field is a non-renewable energy being developed by a foreign owned multinational oil and gas company which required a pipeline going through the local community. The AMETS on the other hand is a renewable energy run by the SEAI where no potentially dangerous material needs to be transported and the infrastructure required is minimal. Form the previous experiences in the area it is expected that the overall development of wave energy will be encouraged. However, this does not assume that the acceptance for the projects is widespread throughout the community. Stakeholder involvement can play a major role in the project acceptance as was seen with the Corrib gas field where there was major opposition from the fishing community and environmental groups about the potential damage to fish stocks resulting in offshore protests hindering development. Interestingly, unsuccessful consultation with local fisherman in the development of wave energy converters in Tillamook County, Oregon eventually led to the abandonment of the project (Chozas, Stefanovich, and Sørensen, 2010). This indicates that the results from this paper may not deliver a universal acceptance.

Conclusion

This paper aims to provide an assessment of the community acceptance for the offshore wave energy technology that are being developed off the coast of Annagh Head, west of Belmullet Co. Mayo. The mixed method research approach used in this study involves interviews and surveys with local representatives as well as desk based study of the history of the AMETS project and of the areas interactions with energy developments. The trust between the local community and the AMETS project will be determined with interactions between the local economy and local stockholders also evaluated. Currently, it is expected that the community are in acceptance with the project, however, it is uncertain whether this acceptance will be universal throughout the community.

Acknowledgements

The author of this paper would like to thank Brendan Cahill from the SEAI for facilitating the interaction with the local liaisons for the AMETS and relevant stakeholders.

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INTEGRATING SOLAR POLICIES IN IRELAND

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Abstract

Solar radiation is the most abundant energy resource available on the planet and solar power is also the most rapidly growing energy technology in the world. The cost of solar power has reduced by a significant amount over the past decade and many countries have chosen solar energy as their main renewable source. In some regions in the world, the cost of solar has even hit grid parity. But, initially it is not the technology but the policies laid down by governments which makes solar feasible for citizens and companies to invest in. This paper compares policies of UK, Germany, USA and India to find the appropriate solar policy framework to be established in Ireland.

Introduction

Solar power has been ignored in Ireland primarily because of the abundance of wind energy at Ireland's behest. According to (SEAI 2016), wind energy accounted for 21.1% of Ireland's gross electricity consumption which is way higher than hydro power which is second among renewables at 2.5%. Solar stands at 0.01% which is negligible and can be attributed to lack of utility scale projects. Ireland's share of electricity from renewables is currently at 25.3% and it needs to achieve a target 40% by 2020. Solar power could assist in achieving this target at a fast rate if the right policies are implemented. Photovoltaic solar energy can also complement wind energy. Solar outputs peaks during mid-day which corresponds to a high electricity demand. Similarly, wind output starts to pick up at the end of the day as the solar output declines thereby maintaining a balance between demand and supply (ISEA 2014).

In recent years, the interest amongst solar developers has increased in Ireland. This is indicated through the number of solar grid applications which increased from two in 2014 to 329 in 2015 (*O'Donoghue* 2016). The figure 1 shows the current distribution of about 500 solar PV grid applications in Ireland.

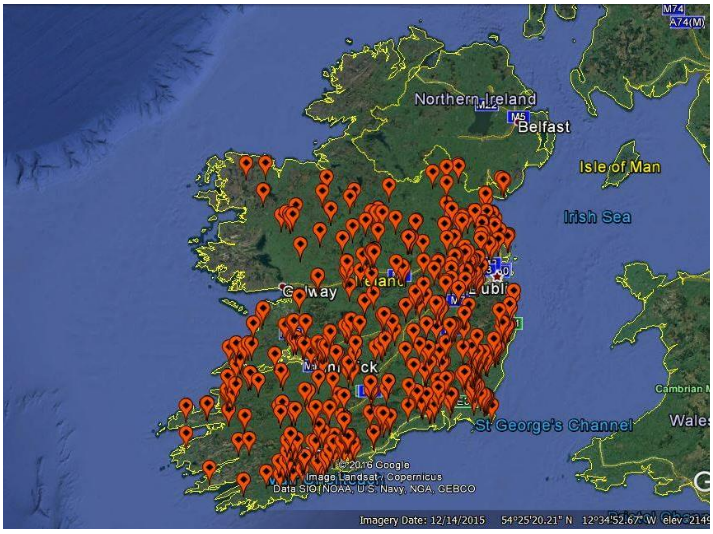

Figure 1 Distribution of solar grid applications in Ireland (JBM Solar 2016)

Figure 1 contradicts the popular belief that solar electricity generation is limited by the poor Irish weather. UK, which has similar irradiation as that in Ireland, has installed about 8,915 MW of Solar PV capacity (UKGOV 2016). Also, the solar irradiation in Wexford is about 78% of that in Madrid. Even Northern Ireland has granted planning permission to a utility scale Solar PV plant in Bishopscourt, county Down emphasizing the feasibility of a solar plant on the island of Ireland (ISEA 2014). Having said that, solar PV is still not commercially viable in Ireland without some sort of state benefit. The interest in solar which is evident from figure 1 must be supported by a Solar specific policy framework.

The objective is to define 2025 solar targets and arrive at the right policy framework for Solar technology for utility, commercial and residential scale projects in Ireland. The study involves benchmarking with other countries like the UK, Germany, USA and India.

Material and Methods

Ireland has the late mover advantage and could learn from the mistakes of other countries. The Irish situation could be compared with the United Kingdom because of number of reasons. It has a similar climate to Ireland, it's solar market developed quite late which means the policy framework evolved to be more sustainable and suffers from the same high import rates imposed by the European Commission on solar modules as Ireland. Although UK has installed a significant number of solar farms, not everything went as smoothly as expected. Initial forecasts failed to predict how rapidly utility scale projects would be deployed, therefore the support mechanisms were modified in 2011 and a cap was placed on the size of the solar farms in 2014 (ISEA 2014). Also, the deployment of commercial rooftop structures was slower than earlier anticipated.

Germany is another example. Though Germany's strategy has by and large been successful in de-fossilizing the electricity sector and reducing the capital cost of solar technology, it has come at a significant cost. The Erneure-Energien-Gesetz (EEG), is an important factor in the solar framework which requires transmission system operators to purchase solar energy from both small and large scale PV systems at a rate which is fixed for 20 years. The operators in turn sell the power to the wholesale market at cost, which fluctuates but is invariably lower than the Feed-In tariffs paid to renewable energy producers (Killoran 2014). The difference is recovered through a surcharge which is collected from retail customers via their electricity bills. Also 'industrial' users were exempted from this charge which led to large surcharges levied on the average domestic consumer.

USA and India are the other countries which have shown commitment to solar energy. Potentially each state in these countries is a market in itself. Both have similar policies at the national level. US has the renewable portfolio standards (RPS) in which utilities must generate a certain percentage of their electricity through renewables. Some states have a separate solar carve out within their RPS. Its counterpart in India is the Renewable Energy portfolio (RPO) which mandates states to produce 15% of their electricity through renewables. Solar has been given particular emphasis with 8% reserved for it (Goel 2016). These targets then percolate down to the utilities in the state. Renewable energy Credits (RECs) is a market mechanism developed where states or utilities could buy or sell the credits on the open market to meet their portfolio. At the state level, schemes like net metering, feed-in tariffs and tax exemptions are then implemented. Some of the schemes and issues to be focussed on are mentioned below-

Tax Credit/Exemption

Like USA, Ireland could look into investment tax credit (ITC) proportional to direct investment into a solar technology. The Federal Solar Investment tax credit was influential in encouraging companies and individuals to establish solar systems on their roofs or in their premises. This greatly reduced the payback period of the technology. Property tax exemption is another such policy which waivers any tax that an entity has to pay when using land for building a renewable energy technology.

Net metering

Net metering is a billing system where excess energy generated by the system is exported to the grid and an equivalent amount is credited into the customer's electricity bill. It usually involves rooftop installations and is popular within cities where there is marginal availability of open land for large utility scale projects. Virtual net metering is another concept which is being used in some US states like California, Connecticut, Massachusetts and Indian states like Delhi and Karnataka where the energy system is not on site but is installed externally and is shared among subscribers. A customer receives credits on electricity bills for electricity produced by their share of the solar farm.

Feed-In Tariff (FIT)

Germany pioneered this system to increase the share of renewables in the electricity sector. The generator of renewable electricity gets compensated by a tariff over a long-term contract. The FIT usually includes a year on year tariff reduction which is different for different renewable energy technologies. Micro-generation scheme is one such scheme started by Electric Ireland but only on a pilot scale for domestic customers. The system capacity was capped at 6KW and 11 KW for single and three phase connection respectively. The electricity producers get a standard rate of 9 cents/KWh over the course of the scheme which ends in Dec 2017 (ElectricIreland 2016).

Grid Application process

The Irish government has planned a hefty budget of 3.2 billion Euros to upgrade the grid. But, another thing to look at is the grid application process. Processing time for some applications is as long as 1 year as per developer JBM Solutions. The grid operator (EirGrid) needs to commit to the standard processing time of 2 months from the formal application date which is mentioned on their website. Information regarding the current capacity and future available capacity at an interconnection point should be publicly displayed based on the grid queue and upgradation projects. Where multiple projects are competing for limited capacity at an interconnection point, a scoring matrix could be devised to sort out the most suitable projects, rather than relying on a first come, first served system (ISEA 2014). More advanced projects, e.g. those with planning permission, should be given priority to avoid unnecessary delays.

Energy Storage

Traditionally, utilities alter the electricity supply to meet the variable but largely predictable demand. With more variable renewable generation resources (wind and solar) supplying energy into the grid, the equation becomes more complex as their output is intermittent or not 'dispatchable' the way conventional generation is (NREL 2016). Energy Storage technologies are receiving a lot of attention because of their potential to reduce the variability of renewable energy supply. Lithium-ion batteries seem to be ahead of most of the other electricity storage technologies because of its power density and high discharge rate. Though these technologies are very expensive, Ireland needs to start looking into these if they are to achieve high levels of penetration of renewables in the future.

Results and Discussion

Taking UK as the benchmark, a crude estimate of the Ireland's solar target could be made using the population and UKs target assuming the same Installed Solar target/population.

Table 1: Estimation of Ireland's Solar PV target

Country	Projected Population 2025 (million)	Installed Solar Target (MW)	Installed Solar Target/ population (MW/million)
UK	69.4	20000	288.18
Ireland	5.3	288.18 x 5.3 **=1527**	288.18

At least half of this target (765 MW) could be achieved by 2020. Using these high-level targets, the distribution between utility, commercial and residential rooftop could be decided. It is important to have a balance between the three since day one to avoid monopoly of a certain segment. The above analysis is quite basic but the final result will also take into account the land available and willingness of people to have installations on their roof. Given the positive perception of solar, the answer is quite likely to be yes.

For larger capacity plants (e.g. greater than 5MW), an auction based system could be created where developers bid for lowest cost of electricity and the difference (between the retail electricity rates and auction rate) will be paid by the government. This will encourage competition among developers and will drive the cost down quickly. Another mechanism which is already exists in Ireland is the Renewable Energy Feed-In Tariff (REFIT) but is applicable mainly to biomass and wind. According to (ISEA 2014), a tariff of 0.15 Euros/KWh with 5% annual reduction should provide fair returns to the developers. In case REFIT is introduced, it should be implemented across sectors with additional incentives for commercial and residential customers. As the installation costs per watt are higher for residential and commercial customers, the distribution companies will have to look at add on features e.g. a mobile application to monitor and control the use of electricity to provide greater value for the service.

After completion, this study hopes to establish an optimum policy framework for Ireland and how it fits into the EU Renewable energy directive by doing a detailed assessment of policies adopted by UK, Germany, USA and India.

Conclusion

Relying heavily on just one technology i.e. to achieve the 2020 renewable energy targets could lead to grid instability in the long run as most of the resource is available during the evening. Solar technology can complement wind energy and achieve high levels of renewable energy penetration in the future. Ireland has the 'Late mover Advantage' and could learn lessons from the mistakes of other countries and implement best practices. Energy storage could also be an option balancing out the variability in supply which results from high levels of penetration of solar and wind power. A feed-in tariff or a contract for difference should be implemented by the government to provide a fair return on investment for developers. The government should avoid overcommitting by providing a high FIT as the brunt of this cost will be paid by the tax payer. Ireland's grid infrastructure would require major restructuring to incorporate solar power and other renewables as well. The grid application process needs to improve and more clarity should be given about the available grid capacity at an interconnection point. Once grid parity is reached the Ireland should shift from government funded systems to more market driven mechanism like trading renewable energy credits.

Acknowledgements

The authors acknowledge Brendan O'Brien at JBM Solutions for his assistance in understanding the current solar energy scenario in Ireland.

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TECHNICAL AND ECONOMIC ANALYSIS OF CONSTRUCTING A BIOMASS POWER PLANT IN IRELAND

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Abstract
Many factors can influence implementation of renewable energy systems including aspects such as policy, energy supply potential, technological capabilities, and economic outcomes. The proposed research study will consider each of these areas with the aim of completing a technical and economic analysis of a potential biomass fuelled power plant in Ireland. The expected results will include a recommendation of power plant design, efficiency and financial outcomes considering the Net Present Cost (NPC), Payback Period (PBP) and Cost of Electricity (COE).

Introduction
In 2015, electricity consumption in Ireland increased to 29 Terawatt hours (TWh) which was an increase of 2.9% compared to the previous year. The majority of energy consumed in Ireland is currently provided by fossil fuels, with over 90.9% of the Total Primary Energy Requirement (TPER) being from fossil resources (SEAI, 2016). Combustion of fossil fuels releases significant amounts of greenhouse gas (GHG) emissions into the Earths' atmosphere. Anthropogenic GHG emissions are a contributing factor to global warming with effects such as climate change (IPCC, 2014). Continued fossil fuel consumption worldwide also contributes to negative impacts on human health (Perera, 2016) and reduced long term energy security due to resource depletion (Capellán-Pérez *et al*, 2014). Renewable sources of energy reduce the amount of harmful GHG emissions into the atmosphere compared to fossil fuels and provide a prospect for a sustainable energy option for future societies (Varun *et al*, 2009).

For these reasons, the European Union has set targets for each member state to reduce greenhouse gas emissions, increase renewable energy production and increase overall energy efficiency. The Renewable Energy Directive 2009 set targets for each member state to increase renewable energy production to certain levels by 2020. Ireland is required to meet 16% of total energy needs from renewable sources by this date, with further targets required after 2020. With only 8.3% of Irish TPER provided by renewable sources in 2015 (SEAI, 2016), there is clear need for further utilisation of Irish renewable energy resources to meet EU targets.

Renewable biomass represents an option for a sustainable energy source which has uses in providing electricity, heat and within the transport sector. Biomass resources which are indigenous to Ireland include forestry residues, energy crops such as willow, agricultural by-products and waste food waste. Under favourable bioenergy market and supply conditions, by 2035 the domestic bioenergy production could equal between 10% - 30% of the 2014 energy requirement for Ireland (SEAI, 2016).

Construction of a dedicated biomass power plant in Ireland will allow for the production of renewable energy and utilise the potential of domestic bioenergy supply within Ireland.

The objectives of this study are to provide a design recommendation for a biomass power plant in Ireland and to assess the long term economic feasibility of the facility.
Research Methods

In order to complete the study outlined, four main research topics were identified which must be researched. These include aspects related to the policy, supply, technical specifications, and economical outcomes required for the successful construction of biomass power plant in Ireland. In addition to this, energy modelling computer software such as HOMER Energy will be used to aid in the understanding and financial aspects of the project. The objective of the research is to gain a full understanding of the processes required in setting up a successful power plant in Ireland.

Policy

As mentioned previously, renewable energy targets have been imposed from the European Union to each member state. The current plan requires 20% of EU energy production to be supplied by renewable resources by 2020, although a recent EU publication has stated that an amended target of 27% will be required for the year 2030 (Procedure 2016/0382/COD). In addition to these general renewable energy polices, the European Union also outlines recommendations specifically for biomass energy, such as the working document on 'the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU'. This document addresses the outlook and benefits of biomass renewable energy in particular, along with showing concern for sustainability in relation to land use change and life cycle greenhouse gas emissions.

Policy documents which address and promote biomass energy production within the Irish context must be considered while assessing the feasibility of a biomass power plant in Ireland. For example, the most recent Irish Renewable Energy Action Plan (NREAP) was published in 2016 and provides support for the production of biomass energy production. Policy instruments, such as the Renewable Energy Feed-in-Tariff (REFIT), are used in order to promote the expansion of renewable energy in Ireland. Under this tariff scheme, energy produced from biomass resources will be have a guaranteed purchase price if supplied to the national grid.

In addition to the documents mentioned, other policy related aspects must be considered. These include environmental legislation and planning steps which are required to construct an energy facility in Ireland. In order to construct a successful biomass power plant in Ireland, consideration must be given to any grid connection requirements. This requires communication between the energy developer and the system operator. In Ireland, the energy system operators are ESB Networks and EirGrid. These organisations facilitate the transmission and distribution of electricity through the national grid and an appropriate connection agreement must be arranged before an energy facility can supply and sell electricity (SEI, 2008).

Supply

As the energy source required is biomass, there exists many supply related aspects which must be researched and considered. The study will focus on the use of domestically produced biomass resources such as short rotation energy crops, forestry products and agricultural co-products such as straw. The use of agricultural co-products is appealing as it will reduce the impact on land use change as the energy source is produced alongside the food source (Sastre *et al*, 2015).

The choice of biomass type used within the power plant is important as it will determine the characteristics of the facility. For example, the chemical composition of the biomass feedstock may cause issues during combustion. This may be due to moisture content or, in

the case with straw, the high presence of chlorine and potassium (Hernández Allica *et al*, 2001).
The Sustainable Energy Authority Ireland published the Bioenergy Supply in Ireland: 2015 – 2035 report which outlines the current and future potential of biomass resources in Ireland. The report outlines that the specific availability of each biomass resource is largely dependent on feedstock prices and supply-side barriers. Finally, the choice of biomass used will affect the distance from feedstock to the power plant. This will determine the fuel costs and overall sustainability of each feedstock. It will be more beneficial if the power plant is located as close to the feedstock production location as possible .

Technical

In order to provide a feasibility study for a biomass power plant in Ireland, the technical specifications of the power plant must be determined. The plant is expected to be of medium to large scale, although the exact size will be determined depending on biomass availability and costs. It has been shown that larger scale biomass power plants allow for an increased electrical output efficiency (McIlveen-Wright *et al*, 2013), therefore the largest possible facility will be recommended as this will also contribute most to Irish renewable energy targets. It is planned that the facility will allow for both combined heat and power (CHP) production as this will increase the overall efficiency of the plant, although this is dependent on a suitable local heat demand.

As a power plant consists of various different components and sections ranging from biomass combustion, heat transfer and flue gas cleaning. The exact specification of the power plant will be determined and will take into account any particular requirements and any components which provide most potential benefit to the energy system.

Economics

The economical aspect of the feasibility study will take into account the considerations mentioned throughout previous research aspects. The cost of the facility will be largely dependent on the size of the plant, the biomass resource used and the plant location. It is also possible that policy and legislation will be considered as government schemes and incentives may have a role in the final analysis. It is vitally important that the financial outcomes of the project are considered as these will decide the success of the facility.

Other studies have completed an economic analysis of biomass power plants (McIlveen-Wright *et al*, 2013). The analysis of the power plant costs will take into account capital costs, operating costs and maintenance costs. The key findings obtained after economic analysis will include the net present cost (NPC) for the planned project, the cost of electricity (COE) and the payback period (PBP) of the project.

The NPC of the facility will determine the overall cost of the energy production facility during its operational lifetime. The COE for the project is the cost per unit energy output over the power plant lifetime, this can be used to compare to the facility to other power generation facilities. The PBP for the plant will advise how many years it will take for the initial investment amount to be earned and therefore profit will be earned thereafter.

Expected results

It is expected that the success of the project will be largely dependent on the economics of the facility. As biomass energy production is a ready to use technology, with many countries already utilising biomass in dedicated power plants, the technology is available and Ireland has suitable resources. The results of the study will define the economic costs of power plants of different scales over their operating lifetime. This must take into account biomass prices and transportation distances, which are important factors which will affect the project feasibility.

Conclusion

In conclusion, the study will cover a comprehensive scope of the requirements and factors related to construction of a biomass power plant in Ireland. Many aspects will be covered in the study including policy, supply, technology and economics. Unfortunately, previous attempts to construct a biomass power plant in Ireland have failed. Therefore, this project aims to provide an outline for a successful biomass energy project in Ireland.

It is of vital importance that Ireland, along with every country, increases their renewable energy production and decrease the use of fossil fuels. Biomass energy will allow for increased energy security and reduce our impact on the environment by reducing greenhouse gas emissions.

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FEASIBILITY OF MISCANTHUS COOPERATIVES AND THE RENEWABLE HEAT INCENTIVE IN IRELAND

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Abstract
Previous financial supports from the Irish Government have concentrated on establishing a biomass supply by encouraging farmers to grow the energy crop *Miscanthus giganteus*, however, in the absence of defined outlets for this product, this has led to an oversupply of the market. A potentially viable solution to this over supply is the establishment of cooperatives which would involve local producers and end users.

Introduction
The Maastricht Treaty defined one of the European Union's goals as sustainable and non-inflationary growth while respecting the environment (The twelve Member States of the European Union, 1992). This was further improved on by the Amsterdam Treaty where the integration of environmental protection into other community policies became a requirement (Council of the European Union,1997). This progress continued up to 2009 where the Renewable Energy Directive was introduced which requires 20% of all energy consumed in the European Union come from renewable sources (**Directive 2009/28/EC). The key ambitions of the directive were to reduce carbon dioxide emissions by 20%, reach 20% renewables and reduce energy savings by 20%.**

The European Union under the Renewable Energy Directive has mandated that Ireland reaches 16% of all energy consumed within the State comes from renewable sources by 2020 (**Directive 2009/28/EC**). This is further divided up into 3 main sectors: 40% of Ireland's electricity demand, 12% of its heat demand and 10% of its transport demand must be supplied using renewables.

The aim of this feasibility study is to examine the viability of a Miscanthus cooperative for both producers and end users.

Renewable Heat Incentive

The Renewable Heat Incentive (RHI), currently in the final stages of consultation, is a government scheme which aims to help Ireland meet the targets set out by the European Union for renewable heat generation, as current predictions from the SEAI suggest an estimated shortfall between 1 and 5% (Sustainable Energy Authority of Ireland,2015). The RHI intends to offer payments to producers of renewable heat on a "per unit of heat produced" basis in order to offset costs associated with renewable energy technology that would not be present if a conventional fossil-fuelled based technology was used (Department of Communications, Climate Action and Environment 2017). The 2015 Technology Review Consultation included 12 technologies to be included for consideration (Department of Communications, Climate Action and Environment,2015).

Table 1: showing 12 technologies under consideration for payments

- Biomass boiler
- Biomass combined heat and power (CHP)[7]
- Biomass direct air heating[8]
- Ground-source heat pump
- Air-source heat pump
- Water-source heat pump
- Deep geothermal
- Anaerobic digestion (AD) CHP
- Anaerobic digestion (AD) boiler
- Biomethane grid injection
- Energy-from-Waste
- Solar thermal

As can be seen from Table 1 above, biomass can play a major part in six of these technologies; biomass boiler, biomass combined heat and power (CHP), biomass direct air heating, Anaerobic digestion CHP, Anaerobic digestion boiler and biomethane grid injection consideration (Department of Communications, Climate Action and Environment,2015).

Miscanthus giganteus details

Miscanthus is a tall rhizomatous grass that originally came from East Asia which has potential as a biofuel as it requires low amounts of fertiliser and pesticides (Clifton-Brown *et al*.,2000). While trials in Southern Europe have produced yields of 30 tonnes per hectare, it was noted that within the central southern region of Ireland Miscanthus could have a predicted yield of 26 tonnes per hectare per year (Clifton-Brown *et al*.,2000). Yet actual yields varied over the lifetime of the crop from 11.5 tonnes to 17 tonnes per hectare per year which did not match the predicted levels (Clinfton-Brown *et al*., 2007).

Ireland planted a total of 2,266 hectares of Miscanthus as a result of Government grants from 2007 to 2010, there was however a shortage in demand for the end use of the product which led to a decline in the production of Miscanthus throughout Ireland (Department of Agriculture, Food and the Marine 2011). As a result of this, it is now a condition that producers of Miscanthus must have evidence of a buyer lined up if they wish to avail of grants under the Bioenergy Scheme (DAFM - Bioenergy Scheme, 2015).

Miscanthus is an attractive renewable energy resource to Ireland as it is an adaptable to a wide range of climates and soils which may improve Ireland's self-sufficiency while reducing its reliance on foreign fossil-based fuels (Wilfred, 2011). Previous grants have helped with supply but not with the demand issue, the renewable heat incentive may help with grants but a possible solution is cooperatives. Farmers could maximise prices by directly supplying the final consumer but intermediates may prove necessary to hedge contracts and hedge some of the risk (Styles and Jones, 2004).

Materials and Methods

This project shall not involve experimental lab work but will be a desk study.

Producers

This project will include potential producers and the cost of planting, managing, harvesting and processing Miscanthus. Transport range is another issue that will need consideration as this will further increase costs associated with producing Miscanthus.

Consumers

Suitable consumers for this bioenergy must also be found locally which could be large hotels, spa and leisure centres or possibly shopping centres. Data for electricity and heat demands need to be collected from these consumers which would then allow for the possible system options to be considered along with costs associated with each option including installation, maintenance and management. Moisture content is another factor which needs to be accounted for as moisture can affect the energy derived from the biomass.

Grants

Alongside this process, the grants available for planting of *Miscanthus giganteus* must be calculated as well as those granted “per unit of heat produced” (Department of Communications, Climate Action and Environment 2017). These grants intend to discourage any misappropriation of public money by use of biomass in inefficient boilers or non-insulated buildings with the main aim being to achieve maximum efficiency in the use of biomass.

The tiered system intended for use will split payments into different levels depending on the amount of biomass used with the idea being that the more biomass consumed will lead to lower rates paid to the consumer.

Results and Discussion

The results of this feasibility study will outline in detail the scenarios examined and the implications, strengths and weaknesses of each.

Conclusions

This study can be a valuable resource for those searching for alternative energy production means that can be provided at a more local level thus allowing for greener heat and energy. It could be used as a guide to those in the service industry considering using a biomass crop such as *Miscanthus giganteus*. It may also reduce time and effort needed to see whether or not using Miscanthus is beneficial to produce and consume for businesses, whether government incentives are worthwhile.

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FEASIBILITY OF USING THE TECHNOLOGY OF CO_2 CAPTURE, UTILIZATION AND GEOLOGICAL STORAGE TO ENHANCE GEOTHERMAL PLANTS IN IRELAND

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Abstract
Carbon capture technology has been widely researched as a means of reducing greenhouse gas emissions from fossil fuel power generation, however the storage and utilization of CO_2 are still big issues. The potential of using CO_2 as a working fluid in geothermal plant shows a positive opportunity to combine these two technologies together. This study focuses on the Moneypoint power station in Ireland to assess the feasibility of the integration of geothermal and carbon capture technology through optimization modelling and life cycle assessment. As the project is ongoing, only expected or predicted results could be provided in this paper, where it is believed that the feasibility will depend on several factors such as CO_2 quantity, thermal properties, soil properties, water supply and land use change etc.

Introduction
Injecting CO_2 into geological structures for storage has been considered as an effective and efficient method for reducing carbon emissions and mitigating global warming when conventional fossil fuel power generation is still the major energy producer around the world (Randolph and Saar, 2011). Geothermal energy, with a significant amount of reserves, is regarded as one of the most promising alternative option to replace conventional fossil fuel power production in terms of high energy efficiency and stable supply for energy generation.

CO_2 sequestration in “deep saline aquifers” and “depleted hydrocarbon fields” (Buscheck *et al* 2014) has been widely considered as a method for reducing carbon emissions to the atmosphere. Rather than treating CO_2 as a waste fluid, it can be utilized in geothermal plants as a working fluid (Castillo *et al* 2014). CO_2 has a higher heat conductivity compared to water at conditions of high pressure and temperature (Plaksina and White, 2016) that could be beneficial in regions with low to medium temperature level geothermal resources, where traditional geothermal energy production is not economically feasible. A study by Buscheck *et al* (2014) has concluded that at certain pressure and temperature, CO_2 has shown significantly higher mobility compared to water in fluid-mechanical simulations. Another study also indicates that CO_2 has an observable positive effect on enhancing density-driven flows in geothermal. As for Enhanced Geothermal System, Mohan *et al* (2015) has found that CO_2 is superior to water in its ability to mine heat from hot fractured rock. A comparative study has shown that CO_2 Plume Geothermal systems produce more electricity than brine-based geothermal systems at depths between 2 and 3 km (Garapati *et al* 2014).

The case study in this paper will focus on a 900 MW coal-fired power plant at Moneypoint in Co. Clare which will utilize the carbon capture technology with a potential integrated geothermal power plant. The local geothermal resource which has a temperature of 70℃ at 2500m and 140℃ at 5000m could significantly reduce the carbon emissions from the power plant by integration with the geothermal plant.

The objective of this study was to determine the feasibility of combining the technology of CO_2 capture from a coal-fired power plant, utilization and geological storage with a geothermal plant in Ireland.

Materials and Methods

Data Accumulation

This paper will consider the reported CO_2 emissions from the power plant in Moneypoint and assess the thermal property of the adjacent underground areas in order to set the system boundary for geothermal design. At the same time, factors such as soil property, land use change (Gouareh *et al* 2015), water supply and local residential area will also be considered to conduct a complete assessment of the feasibility of utilizing geothermal with carbon capture technology. Other potential sites for carbon capture and storage in Ireland will be taken into account in the data accumulation phase for comparison. All the factors will be inputted into the energy system optimisation model in order to assess the economic viability of designed system in comparison to conventional energy sources.

Optimization modelling

Energy system optimization models will be built using energy system modelling software, HOMER which is used for power system design and optimization. It will be applied to model the supply and demand chain for this geothermal plant and determine the best scenario to reduce the cost. Through HOMER modelling, electricity load will be created to reflect the average energy demand, then meeting this demand will be modelled by utilizing geothermal system as well as conventional energy generation to create models highlighting the optimal energy systems from an economic point of view and determine the best scenario with low capital cost and high performance.

Since the working fluid in the geothermal plant is going to be changed from water to a mixture of water and CO_2, the heat transfer configuration will be different. For modelling the heat transfer in geothermal plant, PetraSim TOUGH2 will be applied as an effective tool for this target (Wolff-Boenisch and Evans, 2014). With the temperature distribution and thermal property of CO_2 (Biagi *et al* 2015), this tool is able to model the entire heat transfer in the heating zone and the amount of CO_2 could be determined from the calculation.

Life cycle assessment

As the objective of this technology is to reduce carbon emission, life cycle assessment (Frank *et al* 2012), which allows the environmental impact from a system to be evaluated, will be carried out.

The goal of this life cycle assessment is to assess the impact on greenhouse gas emissions of using the technology of carbon capture, utilization and geological storage to enhance geothermal plant at Moneypoint power station.

The system diagram is shown in Figure 1 and it consists of a coal-fired power plant and a geothermal plant with a 1 MWh energy demand based in Moneypoint, Co. Clare. The function of this system is to use the CO_2 derived from coal-fired power plant as a working fluid into the geothermal plant to generate electricity for on-site energy demand and export to the national grid. The functional unit of this system is the production of one megawatt hour of electricity. The system boundary will include four phases which are; manufacturing, transport, utilization and disposal. Life cycle impact assessment will focus on global warming potential, resource depletion and water use. Data required for this assessment will be addressed from official report and journal articles which are considered to be reliable and authoritative. Gabi software will be applied to build the model and complete impacts calculation. The limitations of this assessment would be the limited data source and limitation of the software database. Although the limitations still exist, a certain amount of reasonable assumptions which aim to simplify the model and fill the data collection gap will be addressed to improve the quality of data and model.

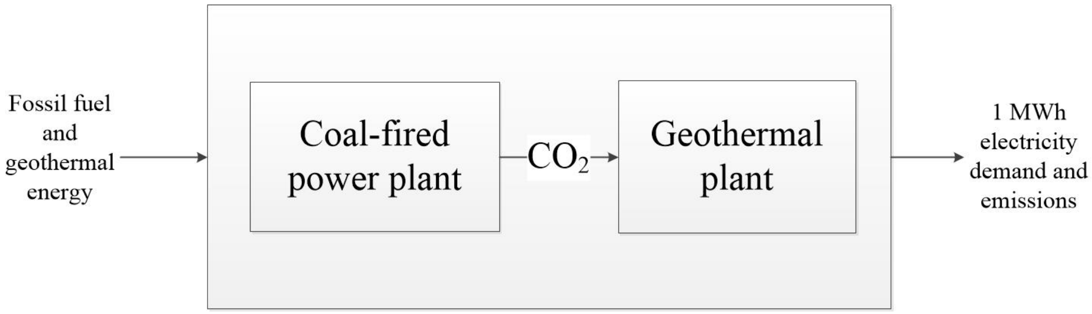

Figure 1. System diagram of life cycle assessment.

Results and Discussion

Expected results

The aim of the project is to assess the feasibility of using the technology of carbon capture, utilization and geological storage to enhance geothermal plant in Ireland. The case study has been chosen as Moneypoint power station in Co. Clare. There are many factors which require consideration during the system modelling phase such as CO_2 quantity, thermal property, site design and water supply etc. According to the geothermal map from SEAI (SEAI, 2017), the local geothermal resource which has a temperature of 70℃ at 2500m and 140℃ at 5000m shows a positive potential for the application of geothermal plant. With the HOMER software, optimization models will be built based on the various sizes, types and electricity loads produced by this system. At the same time, cross-analysis with conventional energy will be applied to determine the optimal energy system for a certain energy demand and the best scenario with best cost efficiency. Then the heat transfer configuration will be addressed by PetraSim and the quantity of CO_2 into the geothermal plant will be calculated. Results from life cycle assessment will demonstrate the impacts to global warming potential, resource depletion and water consumption by using this system in comparison to conventional energy. Finally, discussion of replacing fossil fuel to biomass will be considered to achieve negative carbon emission from the power plant.

Prediction of life cycle assessment results

Use phase life cycle impact can be predicted by preliminary system modelling which has been shown in Figure 2. It compares three scenarios which are geothermal plant with carbon capture technology, geothermal plant only and national electricity grid only. From the results, the CO_2 emission and resource depletion are expected to reduce significantly by the integration of geothermal and carbon capture technology.

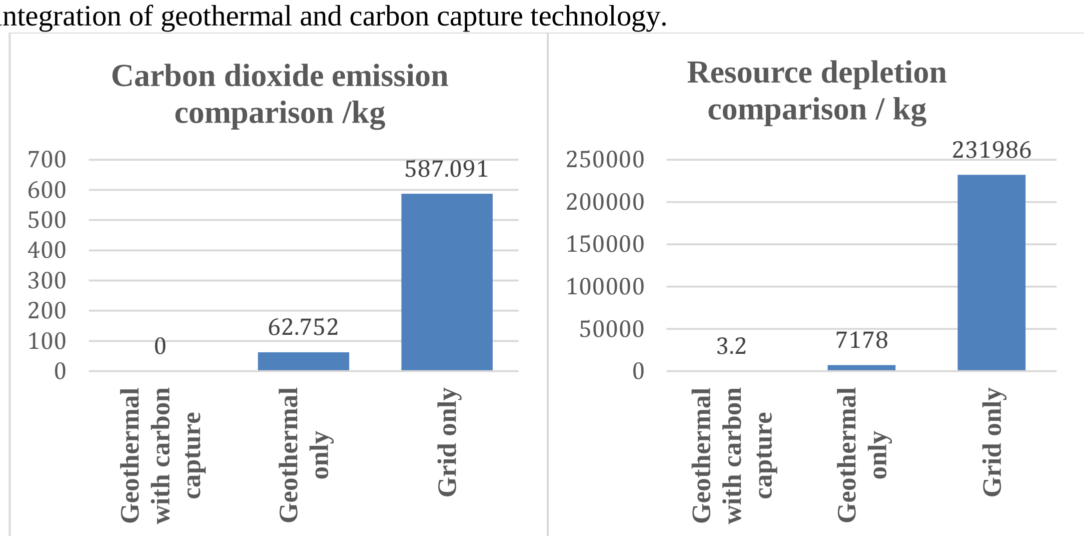

Figure 2. (a) CO_2 emission comparison and (b) Resource depletion comparison.

Conclusions

Currently, with the increase in greenhouse gas emissions from fossil fuel based power systems, geothermal has emerged as an abundant and stable energy supplier, rather than variable renewables such as wind or solar energy, and has the potential to achieve large scale energy generation target. In order to meet the EU emission target in 2020, geothermal and carbon capture technology can make significant contribution to reduce CO_2 emission and dependence on imported fossil fuels in Ireland. This study provides an assessment for a geothermal and carbon capture technology project with all necessary data through optimization modelling and the life cycle assessment method. The optimal energy system design and impact associated with global warming potential, resource depletion and water consumption are defined and compared to conventional energy.

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POTENTIAL WASTE FEEDSTOCKS FOR ANAEROBIC DIGESTION IN IRELAND; A BRIEF REVIEW

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Abstract

Ireland faces significant challenges in meeting targets for energy produced from renewable sources by 2020. One suitable source of renewable energy in Ireland is biomass, specifically organic waste streams that can be used to produce biogas through anaerobic digestion. In this paper potential sources of feedstock for anaerobic digestion are reviewed; from agriculture, food processing, domestic settings and wastewater treatment. Estimates of the quantities of feedstocks arising and the potential energy that can be derived are discussed. There are significant quantities of waste feedstocks that are suitable for anaerobic digestion in Ireland which are currently underutilised. Priority should be given to putting such feedstocks to a higher value use through anaerobic digestion whilst reducing environmental impacts.

Introduction

As part of the Renewable Energy Directive (2009/28/EC), Ireland needs to generate 16% of its energy from renewable resources by 2020. The Irish government aims to achieve 12%, 40% and 10% of heat, electricity and transport fuels generation from renewable sources respectively (DCCAE, 2017). Ireland faces significant challenges in meeting these targets; Ireland is ranked 23rd out of 28 member states for renewable energy, with just 9% of energy consumption derived from renewables in 2015 (European Commission, 2017). Ireland has significant quantities of biomass resources that are suitable for bioenergy production. Organic waste streams in agriculture, the food industry and domestic settings are particularly suitable for the production of biogas through anaerobic digestion. Anaerobic digestion (AD) is the conversion of biomass into biogas (composed mainly of methane and carbon dioxide) by means of bacterial action in the absence of oxygen (Caputo et al. 2005). Biogas can be combusted in a boiler to supply heat or in a gas engine to produce electricity and heat (SEAI, 2016). Biogas can also be purified to produce pure biomethane which can be injected into the natural gas grid, or used directly as a vehicle fuel. Despite the resources available, the utilisation of AD in Ireland remains low (Auer et al. 2017).

Small-scale biogas systems (<500 kWel installed capacity) are designed to handle predominantly agricultural waste and energy crop feedstock (Pöschl et al. 2010). The energy produced can be used locally or fed into the national grid. Large-scale biogas plants (>500 kWel installed capacity) co-digest agricultural feedstocks with industrial waste and municipal solid waste with capability to feed-in biomethane to the natural gas grid (Pöschl et al. 2010). Large-scale biogas plants typically produce more than 1.8 million m^3 of biogas per annum, with feedstock handling capacity of ca. 20,000 tonnes per annum, as distinct from small-scale biogas plants with typically up to 10,000 tonnes per annum (Pöschl et al. 2010).

The objective of this paper is review the waste streams arising in Ireland that are suitable for anaerobic digestion.

Agricultural waste

The land area of Ireland is 6.9 million hectares, two-thirds of which are used for agriculture and forestry (DAFM, 2017). The Irish livestock sector produces significant amounts of agricultural waste.

According to the Department of Agriculture, Food and the Marine, livestock numbers in Ireland were estimated to be 7 million cattle and 1.5 million pigs in 2015 (DAFM, 2017). Slurry can be digested in small scale on-farm systems or alternatively it can be co-digested in larger centralised plants which take waste from a number of farms. Centralised AD plants co-digest animal manure with a variety of other suitable co-substrates (e.g. digestible residues from agriculture, food- industries, separately collected organic household wastes, sewage sludge). It is estimated that 30 Mt of cattle slurry and 2 Mt of pig slurry were produced in Ireland in 2010 (Singh et al. 2010). This equates to an energy resource of 13.7 PJ and 1.06 PJ respectively (Singh et al. 2010).

Industrial food waste

Wastes and liquid effluents which arise from processing of food and have a high organic content are suitable for AD. Examples include milk processing waste and slaughterhouse waste (SEAI, 2016). Milk processing is a significant industry in Ireland. It is estimated that 5.6 billion litres of milk were processed in Ireland in 2014 (O'Shea et al. 2016). Milk processing generates significant volumes of wastewater which can be treated by AD. Browne et al. (2013) examined the potential for methane production in a milk processing plant in Ireland producing 6000 t of wastes per annum and estimated the total resource of biomethane from the facility to be 8.6 TJ/a. It is estimated that 8 million livestock (mainly cattle, pigs and sheep) and 12 million poultry are slaughtered for meat production in Ireland annually (Singh et al. 2010). The slaughtering process produces large quantities of organic waste that have the potential for methane production by AD. The potential resource from slaughterhouse waste in Ireland in 2010 was estimated to be 1.43 PJ arising from 440,000t of waste (Singh et al. 2010).

Fats oils and greases (FOGs)

Fats oils and greases (FOGs) from food service outlets (restaurants, etc.) and domestic households typically enter the sewer network, where they accumulate and form a hardened solid which can result in blockages. If FOGs are intercepted at source by installing grease interceptors or grease recovery units, then they can be collected and processed in an AD plant (SEAI, 2016). In 2015 there were over 2,200 licenced food service outlets in Dublin with an estimated 700 litres of waste recovered from each premise (SEAI, 2016). This suggests that a total of 1.4 kt of grease might be available to produce 2.8 TJ of biogas (SEAI, 2016).

Domestic waste

Waste regulations in Ireland require the provision of a 'brown bin' to households to collect organic waste (food waste and garden waste) in all population agglomerations greater than 500 persons (O'Shea et al. 2016). In 2012, 80 kt of organic waste were collected via these types of collection, most which went to composting plants (SEAI, 2016). Commercial premises are also required to separate out their food waste, which is collected separately. Household food waste can be used in AD following appropriate treatment under EU standards or national standards (SEAI, 2016). Singh et al. (2010) estimated the total resource of Irish household food waste and bio-waste to be 81 Kt in 2010, with an energy potential of 2.1 PJ.

Sewage

Sewage sludge from wastewater treatment can be processed in an AD plant to produce biogas. In 2014 an estimated 70,420 tonnes of dry solids (tds) of sewage sludge was produced in Ireland from primary and secondary treatment at wastewater plants (SEAI, 2016). Of these about 42,000 tds were anaerobically digested in 2014 (SEAI, 2016). If all wastewater treatment sites with AD plants were equipped with CHP plants and bought into operation, then about 57,000 tds could be treated, which would generate about 452 TJ of biogas (SEAI, 2016).

Table 1: Potential energy from anaerobic digestion of waste feedstocks

Waste	Quantity	Energy (TJ)	Source
Cattle slurry	30 Mt	13,700	Singh et al. 2010
Domestic food waste	81 Kt	2100	Singh et al. 2010
Slaughterhouse waste	440 Kt	1430	Singh et al. 2010
Pig Slurry	2 Mt	1060	Singh et al. 2010
Sewage	57 Kt	452	SEAI, 2016
Milk processing waste	6 Kt	8.6	Browne et al. 2013
Fats, oils and greases (FOGs)	1.4 Kt	2.8	SEAI, 2016

Conclusions

There are significant quantities of waste biomass streams that have potential for anaerobic digestion in Ireland without dedicated production of energy crops being required (Table 1). Biomass waste resources which are unavoidable do not compete with food production, unlike the dedicated production of energy crops. These waste biomass resources for bioenergy are currently underutilised in Ireland. Furthermore, Ireland is highly reliant on imports for bioenergy and the promotion of waste for bioenergy can help reduce this dependency. The utilisation of such biomass resources should be a key priority for bioenergy in Ireland, as these waste streams can be put to a higher value use whilst reducing environmental impacts.

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ONLINE TOOL DEVELOPMENT FOR DOMESTIC BER ASSESSMENT

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Abstract

In this paper, the basic concepts of Building Energy Rating (BER) will be introduced and briefly explained. This assessment is normally performed by a certified BER assessor and the outcome is reported by the assessor to authorities. This project focuses on development of an online tool which will carry out the assessment in a user friendly and effective way. In addition to the description of this concept, a few basic statistics of the current situation of buildings in terms of energy rating will be presented, and finally, the procedure and the methods that will be used to create the tool will be introduced.

Introduction

Considering the ever-increasing price of fuel in the world, the huge dependency on fossil fuels for energy production, and also with respect to the fact that use of renewable energy sources as the main supply of energy is only achievable in distant future, the energy consumption and efficiency of domestic buildings are always a concern for householders. The reason behind that is the wish of householders to reside in a comfortable home while paying appropriate energy costs, in addition to the increasing awareness of societies regarding global warming and the harmful impacts that wasting energy has on environment, since the release of carbon dioxide (CO_2) to environment is very harmful (Manne and Richels 1991).

Therefore, environmental and energy authorities of many countries enforce the BER regulations to ensure that, firstly the energy efficiency is kept at a reasonable minimum to avoid pressure on energy production section, and secondly to increase the awareness of the house buyers or tenants about the building they are going to buy or rent, so that they would have a perspective of their energy bills and its relation with their comfort while residing at their property (Pérez-Lombard *et al.* 2008).

The Sustainable Energy Authority of Ireland has defined the regulations regarding building energy rating and has made it mandatory for house owners to provide this rating to the prospectus buyers or tenants. These usually have a 10-year validity. In order to carry out this assessment, certified BER assessors are hired and after working out the necessary parameters, they will issue a BER certificate and also an advisory report on how to make the home more efficient in using energy for lighting and for space and water heating.

The objective of this paper is to develop an online tool to assess the domestic BER and provide an advisory report based on SEAI guidelines to improve the energy efficiency and BER of the building.

Existing patents

Since the concept of energy use in domestic buildings is of huge importance, research has been carried out by several researchers throughout the world and numerous patents have been

recognized by acknowledging bodies which suggest the efficiency of energy use in houses need to be refined and improved. To name a few;
- Apparatus for the combined production of electrical energy and heat (Palazzetti 1980),
- Appliance control,
- Building modules.

BER Assessment procedure

The BER is calculated according to the energy performance of the house and its carbon dioxide emission, considering the space heating, ventilation, water heating and lighting under specific standard conditions, and is always independent of occupants' behaviour or lifestyle. Major components of the house such as dimensions, insulation and space/water heating systems are taken into account for this calculation. At the end, the energy performance of the house is expressed in two ways as below:

A. Primary energy use per unit floor area per year ($kWh/m^2/yr$) represented on an A to G scale; and
B. Associated CO_2emissions ($kgCO_2/m^2/yr$) (Carmody 2007).

Calculation Components

The BER is carried out considering major components of the dwelling and different parameters, which are briefly described in the table below (Table1). The certified BER assessors use a computer software developed by SEAI, which is called "SEAI DEAP (Dwelling Energy Assessment Procedure)". The information below was extracted from an excel file available in the BER section of the SEAI website.

Table 1. The categories considered when calculating BER and their details (SEAI, 2016).

Categories	Examples of Parameters measured and/or calculated	Comments
1- Project	Dwelling address and type Owners and assessors details	The administrative information to start the project
2- Overall dwelling dimensions	Floor dimensions Room volumes	Basic dimensions of the house rooms and floors
3- Ventilation heat loss	Openings, structural air tightness, ventilation method	Heat lost with air exiting building
4- Windows and other glazed elements	Heat loss Passive solar gain and daylight	Heat lost through windows
5- Fabric heat loss	Heat loss	Heat loss through doors, floors, walls, etc.
6- Water heating	Water heating system Efficiencies	Energy spent on heating up water
7- Lighting	Internal gains	Heat gain from lighting
8- Space heat use	Internal heat capacity, solar gain	Energy spent on heating up the space
9- Space heating system	Control and responsive-ness, pumps/fans, emissions	Specifications of heating system
10- Energy requirements- individual heating systems	Space and water heating, Electricity for pumps and fans	N/A
11- Energy requirements- group/ community heating	Secondary systems, Boilers, Fuel data	N/A

Advisory report
Another document that is reported to the authorities as a result of BER assessment is the advisory sheet. In this report, the BER assessor makes suggestions for actions and improvements on different components and weak points of the building such as the space or water heating system, floors, windows etc. It is the homeowner's choice to act upon these suggestions or not, as it will be of their personal benefit if they do follow the advice since they will save energy and money and will also add to the value of their property.

Current Statistics
Figure 1 below shows the number of BERs that were active by end of 2016 and the allocation of grades between them. The figure suggests that most certificates were issued with grades between C1 to D1. This on average is equal to apartments that are built for 10-15 years in an old development, or a well-built rural property which is 15 – 20 years old (Thompson 2015).

Energy Rating	Quantity
A1	26
A2	3,104
A3	12,540
B1	8,475
B2	20,257
B3	48,383
C1	74,139
C2	86,874
C3	87,788
D1	88,882
D2	77,920
E1	45,468
E2	35,780
F	36,089
G	48,973
Total	**674,698**

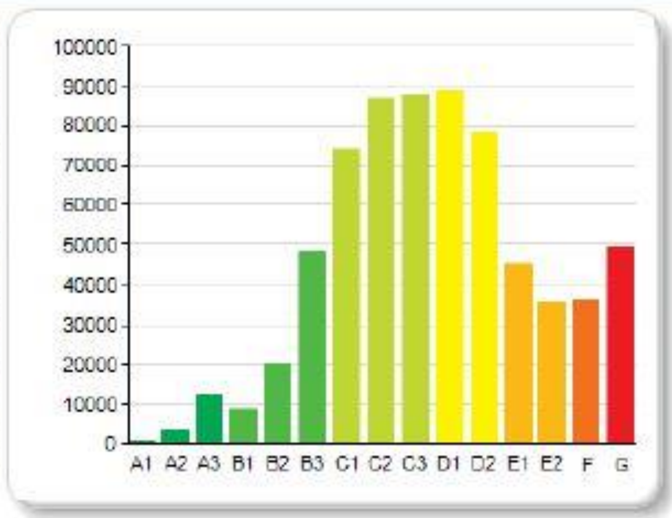

Figure 1. Active BERs in Ireland and distribution of grades (SEAI, 2016)

It is clear to observe that the number of properties with A grades are very low (approximately 2%), meaning the majority of the houses need to improve their energy rating.

Methodology

The proposed tool in this project will be an online based calculation tool which can be accessed through a certain web link address. The tool itself will be programmed using HTML5 coding language.

The overall interface that the user will be using is designed to look very similar like the following figure (Figure 2).

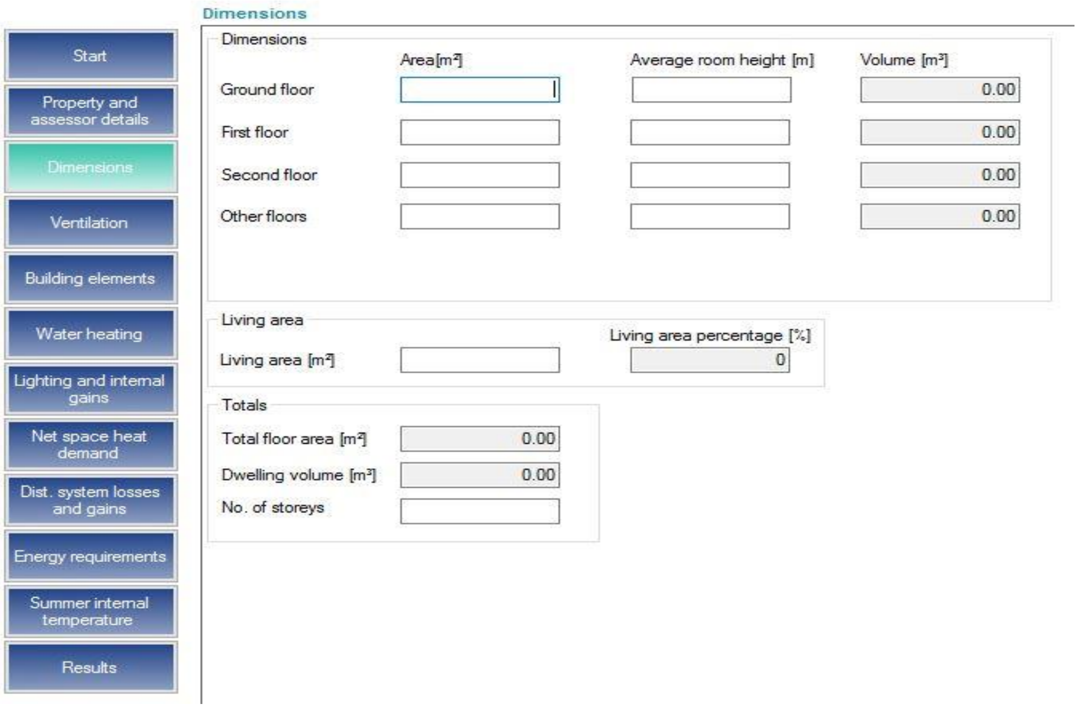

Figure 2- An example of interface which will be used by the user (DEAP of SEAI, 2016)

Conclusions

In this paper, the concept of BER, how it is calculated and the outcomes of the assessment were introduced and briefly explained. Then the proposed online tool in the project was described.

It is important to note that the main focus of the project is on supplying the advisory report on energy efficiency and the cost associated with the improvements that are needed to be carried out to obtain a higher BER grade.

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LAND USE CHANGES – GIS MODELLING AND IMPACTS ON FOOD PRODUCTION

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Abstract

Land use changes are becoming more common as global population rises and the demand for energy production increases. Coupled with a need to lower greenhouse gas emissions, this has led to an increase in the production of biofuels globally. Here, focusing on Ireland as an example, geo-spatial data will be modelled using GIS software to identify the land use changes associated with bioenergy crops. The formulation of an LCA will allow for the environmental impacts of both direct and indirect land use changes to be identified and compared between different bioenergy crops. The study also aims to investigate the impact of bioenergy crops on food production in Ireland.

Introduction

The rise in world population since the industrial revolution has led to an increase in demand on the Earth's natural resources. In order to support the worlds growing population forests, waterways, farmlands and air have been altered to provide food, water, energy and shelter to more than 7 billion people (Foley *et al* 2005). This has led to an increase in land-use changes globally as pastures, croplands and urban areas have all expanded (Foley *et al* 2005). Land-use changes have positive and negative effects associated with them. Changes in land cover allow for increases in energy and food production, but also increased consumption of fertilisers along with decreases in biodiversity. Land-use changes are a short-term solution to energy and food supply shortages, but in many cases, they can have long term effects on the sustainability of ecosystems (DeFries *et al* 2004).

Ireland hopes to reduce its greenhouse gas emissions in the energy by up to 80% by 2050 (SEAI 2016). If this target is to be reached bioenergy crops will play an important part in doing so, and will require expansion of current cropping areas. In 2014, the amount of bioenergy produced in Ireland was 468 ktoe (SEAI, 2016). Land-use changes have varying impacts on ecosystems but most common ones are soil degradation, loss of biodiversity and the effect that they have on the carbon cycle in soils and in the atmosphere (Searchinger *et al* 2008). The impact of land-use changes varies depending on what the land is used for before and after the land-use change. For example, if an area of forest is cut down and used for pasture farming it would have a different environmental impact to a plot of land being changed from pastureland to cropland, due to the differences in stored organic carbon in each land-use type (Styles *et al* 2015). The increase in demand for renewable, carbon-neutral energy has led to a rise in biofuel production over the last two decades (Lovett *et al* 2009; Styles *et al* 2015). This has resulted in more biofuel crops such as miscanthus and willow being plated. Biofuel crops are an attractive source of energy because they offer reduced greenhouse gas emissions when compared to fossil fuels, and they have the potential for carbon sequestration (McLaughlin and Walsh 1998). This study will use ArcGIS to model the land-use changes associated with bioenergy crop production and an LCA will be applied in order to identify environmental impacts and impacts on food production with specific reference to Ireland

The objective of this study is to model the land-use changes, the associated environmental impacts and the impacts on food production in relation to bioenergy land-use changes in Ireland.

Materials and Methods

Study Area

This project aims to investigate land-use changes and their impacts on the environment and food production in the Republic of Ireland. Land-use changes associated with bioenergy crops will be investigated in this study. The main sites of study will include areas of miscanthus crops, oil seed rape and willow as these are the most popular bioenergy crops in Ireland (Teagasc, 2010).

Data Sourcing

The geo-spatial data for land-use changes will be gathered from the 2012 CORINE (Co-Ordinated Information on the Environment) land use data base and the Department of Agriculture, Food and Marine's Land Parcel Information system (LPIS). The CORINE Land Cover (CLC) dataset maps present a 'snapshot in time' of the current state of the Irish landscape and how it is changing from one particular time period to another (EPA, 2012). The latest update to the CORINE land cover inventory for Ireland was published in 2012. The CORINE dataset provides information on land cover changes in Ireland since the 1990s and will be combined with the SEAI bioenergy mapping system to locate areas of land-use changes in relation to bioenergy crops. The LPIS geo-spatial vector database stores the outline of all registered farm holdings in Ireland (EPA, 2012)

GIS Modelling

Using GIS for land-use change modelling is a method that is widely used (Nagarajan and Basil, 2014; Abdullahi and Pradhan, 2016). Using GIS techniques, a model of land-use changes associated with miscanthus, oil seed rape and willow will be produced by combining the CORINE land cover data with the SEAI bioenergy mapping system. This map will be created using the ArcGIS 10.1 software. The ArcGIS map will show the each of the individual land-use changes and the period of time at which this land-use change occurred.

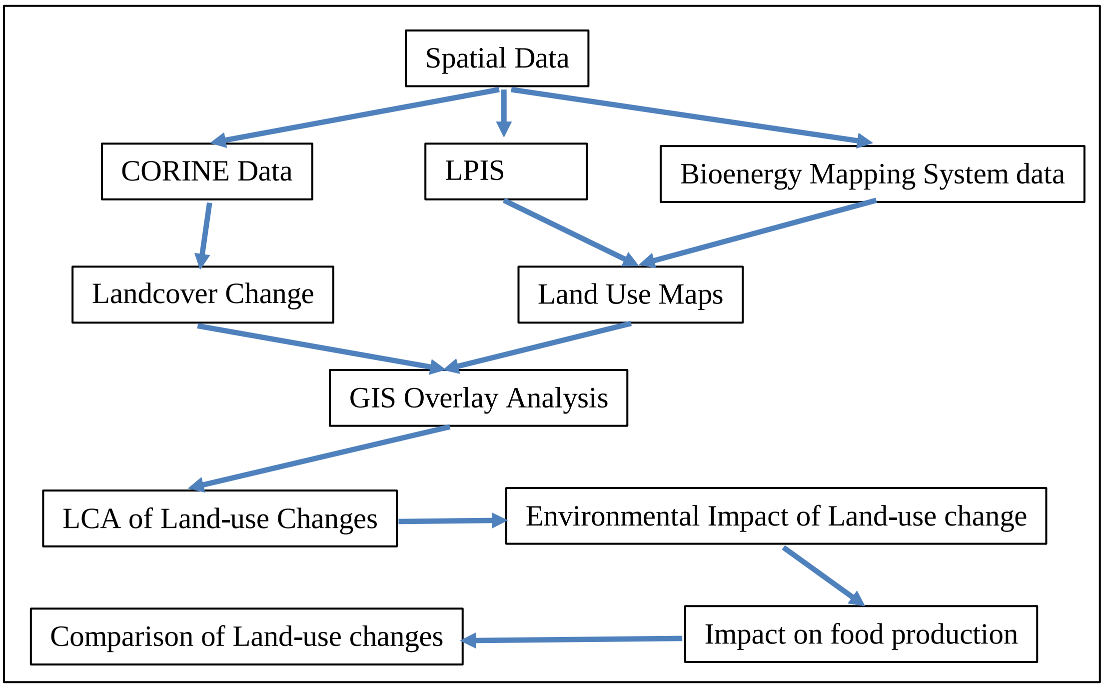

Figure 1.Flowchart of the methodology that will be employed.

Life cycle-assessment

The methodology for the coupling of LCA and GIS will follow the same approach as Geyer *et al.* (2010). This methodology uses GIS-based inventory modelling to generate input flows of different types of land-use. An LCA of the different land-use change scenarios for miscanthus, willow and oil seed rape will be built. The functional unit needs further consideration, but could be defined as: per m^2 or per kg of product produced.

Results and Discussion

ArcGIS Mapping
Figure 1 below is an example of how geo-spatial data can be used in combination with ArcGIS to model land cover changes in Ireland. The CORINE land-use data can be integrated into this map to help identify the different land-use categories. These are the kind of maps that will be modelled in this study.

Figure 2. LPIS data and ArcGIS can be combined to model land cover (EPA, 2012).

Expected Results
The aim of this project is to (1) discover the main land-use changes that have occurred in relation to increased bioenergy crop production, (2) investigate the environmental impacts and impacts on food production related to these land-use changes. Based on the study by Mueller *et al.* (2010) the most common type of bioenergy crops are miscanthus, oilseed rape and willow. The modelling and analysis are still in the accumulation stage and no results have currently been gathered so the expected results are discussed here. Environmental impacts such as soil degradation and CO_2 emissions will be investigated as well as the impact on the demand for food. Based on the results comparisons will be made to determine which land-use change has the biggest environmental impact and which has the largest impact on food production. Depending on the final results, suggestions will be made with regards to potential policy changes. Policies could be introduced to make certain land-use changes more sustainable both environmentally and from a food production perspective.

Discussion
The expansion of areas used in the production of bioenergy crops is a topic of much debate (Lovett *et al* 2009). Further expansion of these areas has led to increased concerns over food security and greenhouse gas emissions (Powlson *et al* 2005). There have also been suggestions that indirect land-use changes could potentially overcome carbon savings from biofuels (Lapola *et al* 2009). By using Ireland as a model, this study aims to present a holistic approach in terms of bioenergy crop yields and their impact on the environment (GHG) and food production.

Conclusions

This study aims to investigate the impact of bioenergy crop land-use changes and their impact on the environment and food production. The study will look at using geo-spatial data combined with ArcGIS to identify bioenergy crop land-use changes in Ireland. Once the modelling is complete, different LCA scenarios will be modelled to assess the environmental impact. This approach will identify land areas that are most suitable for bioenergy crop production and areas that need to be protected from land-use changes.

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CHARACTERISATION OF FAT, OIL & GREASE (FOG) WASTE FROM RESTAURANTS

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Abstract

A more practical method of managing the huge amount of fat, oil and grease (FOG) waste diverted from the sewer system is to utilise the FOG waste for biodiesel, anaerobic co-digestion or dual-fuel integrated approaches and biomaterials. For more effective utilisation, characterisation of FOG waste is important. The fatty acid content, thermal and rheological character, the moisture & volatiles contents and insoluble impurities are the parameters of the FOG waste that will be analysed in this project.

Introduction

Fat, oil and grease (FOG) is a by-product from food service outlets (restaurants, etc.), food processing industry (meat plants, etc.) and domestic households, along with the washing activity, entering the sewer network (Curran 2015). Accumulation of FOG waste from various sites with other non-flushable waste (e.g. used wipes and hygiene products, etc.) can be very dangerous, causing huge damage on public health (He *et al.* 2013), finance, transportation and eventually the environment (Curran 2015).

The effective management of FOG waste should follow the waste hierarchy (Wallace *et al.* 2017). According to the hierarchy (Council of European Parliament 2008), the primary approach is to prevent the FOG waste, however, it is very difficult if there is no dramatic change in diets and cooking habits (Curran 2015). Progress has been made by applying FOG trap systems (Wallace *et al.* 2017). The method of managing FOG waste i.e. the disposal to landfills is less acceptable in many regions (Razaviarani *et al.* 2013). Recent research has indicated that the FOG waste has great potential for utilisation for biodiesel, anaerobic co-digestion, dual-fuel integrated approaches and biomaterials (Wallace *et al.* 2017).

The waste management methods of recycling or reusing of the waste has specific requirements (i.e. nutrient content, moisture content, etc.) for the feedstock. In order to put the reusing and recycling of FOG waste on the right track, it is crucial to understand the character of FOG waste parameters (i.e. fatty acid content, thermal and rheological character, as well as the moisture & volatiles contents and insoluble impurities) (Canakci 2007).

The objective of this study is to (i) characterise the key parameters of FOG waste from restaurants and (ii) analyse the composition of FOG waste for different utilisation purposes.

Materials and Methods

Samples
Twenty groups of samples will be used in the experiment is shown in Table 1. FOG waste samples from different types of restaurant in Dublin city will be tested in different scenarios. The chosen types of restaurant have different cooking styles in terms of meat, oil and vegetable, etc., as well as the cooking method of frying, grilling, boiling, etc.

Table 1. Sampling plan

FOG waste Types	Test types				
	GC-FID	DSC	Rheological Analysis	Air-oven	Insoluble Impurities
Chinese restaurant	1a	2a	3a	4a	5a
Indian restaurant	1b	2b	3b	4b	5b
Italian restaurant	1c	2c	3c	4c	5c
American restaurant	1d	2d	3d	4d	5d
Irish restaurant	1e	2e	3e	4e	5e

GC-FID

Methylation of FOG waste will be needed, for GC-FID (gas chromatography-flame ionisation detector) method of measuring the composition of FOG waste. Dried samples will be solubilised by hexane along with the catalyst of methoxide. After vortexing and shaking in a water bath in certain conditions, samples will be added with sulphuric acid in methanol, along with using another water bath. Then, hexane will be added to recover the fatty acids, before the centrifuging. After the centrifuging the solvent will be dried out by nitrogen gas, the fatty acid will be diluted to the desired concentration of internal standard for GC injection. Analysis by GC of samples will be done on the same day of their preparation. Standard solutions will be prepared for analysis by dissolving the standards in hexane. The standards will be methylated using the same method mentioned before.

A gas chromatograph with a flame ionisation detector (FID) will be needed to test the fatty acid in FOG waste. Identification and quantitation of fatty acid compositions will be calculated as the percentage of total fatty acid present in a sample which is indicated by the peak areas using methyl as the internal standard.

DSC

FOG waste samples' melting and crystallisation curves will be determined using the method of differential scanning calorimeter (DSC). For crystallisation characteristics, samples will be heated to destroy the crystal structure, and then equilibrated for certain time. After the equilibration, the samples will be held isothermally for a while, followed by ramping at a certain rate. For melting characteristics, samples will be cooled to -35 ^{o}C, and then equilibrated for a certain time. After that, the sample will be held isothermally for a while, followed by ramping at a certain rate. The data of crystallisation and melting characteristics (i.e. extrapolated onset temperature, maximum peak temperature, and enthalpy) will be calculated by the software along with the DSC.

Rheological analysis

A rheometer will be used for rheological analysis, on both the viscosity and viscoelasticity behaviours of FOG waste samples. The instrument will be set at zero-gap before actual use. Oscillatory temperature stairs will be performed to test the temperature dependency of the viscosity, along with the melting strength and viscoelastic behaviour of FOG waste samples. The ramp with controlled stress-rotation shear rate will be performed to investigate the viscosity. The viscosity and viscoelasticity will be calculated with the software along with the rheometer.

Air-oven and Insoluble impurities test

The air-oven method will be used to determine the moisture and volatiles contents of samples. Different samples will be heated under specified conditions and the weight loss is measured to find out the moisture and volatiles contents.

The measurement of insoluble impurities contents in FOG waste is similar to the one in animal or vegetable oil. Different samples will be dissolved into excessive hexane or petroleum ether.

Then the sample will be filtered. The residue from the filter will be dried and the weight of dried residue is the insoluble impurities content of FOG waste.

Data analysis
A statistical analysis will be performed by the general linear model procedure after the experiments.

Results and Discussion

The following results are expected.

Fatty acid analysis
The fatty acid analysis will be approached by using GC-FID, along with the expecting results of following parameters: C14:0, C16:0, C16:1, C18:0, C18:1, C18:2, C18:3, C20:0, C20:1, Summary of SFA, Summary of UFA, UFA/SFA.

Thermal Character analysis
Thermal character indicated by melting and crystallisation curves of FOG waste is measured with DSC. In the result there will be two tables indicating the melting phase and the crystallisation phase.

Rheological Properties
The rheological properties of samples will be presented with figures showing the trend of different samples' viscosity with the change of shear rate. The correlation of viscosity and temperature will also be presented with figures. The character of viscoelasticity behaviours will also be presented.

Moisture and volatiles content, insoluble impurities
The moisture and volatiles content as well as the insoluble impurities weight will be presented in the form of tables.

Discussion

For different utilisation, there are different preferred characters of feedstock i.e. biomass. After the characterisation of FOG waste from restaurants, it will be promising to suggest the most preferred strategy of utilising the diverted FOG waste. The connection between cooking styles and the character of FOG waste will be analysed.

Conclusions

The characterisation of fat, oil and grease (FOG) waste from different types of restaurant by different parameters of fatty acid composition, thermal character, rheological character, moisture & volatiles content and insoluble impurities will be measured. The character for different utilisation as well as the relation between cooking style and FOG waste character will be discussed.

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PRELIMINARY ANALYSIS OF SPATIAL VARIATION OF SOIL PH FOR GRASSLAND NUTRIENT MANAGEMENT

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Abstract

Soil pH is a significant factor for grassland nutrient availability. Therefore, spatial variation of soil pH should be sufficiently addressed to increase precision management decisions. In this study, soil pH data will be collected from grassland in UCD Research Farm. The relations between variations in soil pH at distance will be determined, ranging from 0.05 m to 4 m. Furthermore, the spatial variation of soil pH will be mapped based on the ArcGIS and treatment methods will also be discussed.

Introduction

The concept of pH value is the negative logarithm of the molar concentration of hydronium-ions in a solution:

$$pH = -\log(aH+)\ [mol \cdot L{-}1] \qquad \text{(Rossel and McBratney, 1999)}$$

Soil pH is a key parameter to measure the acidity and alkalinity in soils. The range of pH values are from 0 to 14, below 7 presenting acidic and above 7 alkaline (Schirrmann *et al.*, 2011). The appropriate pH range for grassland is between 5.5 and 7.0 (ibid). Soil pH is related with many biochemical processes, especially, grassland nutrient availability, it is significant for grassland to maintain its proper yield potential. Due to assimilation by plants and natural losing of alkaline soil substances, acidification is a common issue among soils in temperate climates. Rare cases, for example, soil on glacial till or on limestone, the soil will present alkaline. Excessive acidic or alkaline soil conditions can be mitigated by applying alkaline or acid fertilizers, meanwhile increasing crop yield and resource efficiency (White, 2005). At present, soil pH management becomes an important concern worldwide due to soil pH can influence crop yield radically. According to Lal (2010), before 2050, global average crop yields must be increased by 60% to 120% to reach the demand of the human population. It is well known that pH is a variable medium, both time and space, in an agricultural field (Bringmark, 1989). Therefore, it may be beneficial to apply corresponding treatment methods to the spatial variation of soil pH within the fields.

The objective of this study is to determine the spatial variation of soil pH in UCD Research Farm and to propose treatment methods according to the soil pH map made by ArcGIS.

Material and Methods

Site description

Soil pH values will be collected in UCD Research Farm which is located near Newcastle, 17 km southwest of Dublin, Ireland. The primary geographic information is represented in Table 1 (James 2003; James 2004).

Table 1. Main Geographic information of UCD Research Farm

Factor	Details
Topography	A flattish to gently rolling topography
Climate	Maritime climate
Annual precipitation	750mm
Annual temperature	10℃
Humidity	75%-85%

Sampling methods

In this study, a grid will be defined to separate the whole site and each grid intersection will be taken a 1 m^2 quadrat described below. 8 soil cores will be collected in each quadrat with a 2.0 cm diameter auger down to a depth of 20 cm. First, auger about 10 cm, mix the sample and then determine 0-10 cm pH value. Next, clean the 0-10 cm sample in the hole and auger another 10cm (10-20 cm), then determine 10-20 cm pH value. Furthermore, a field pH meter will be applied for measuring the pH value.

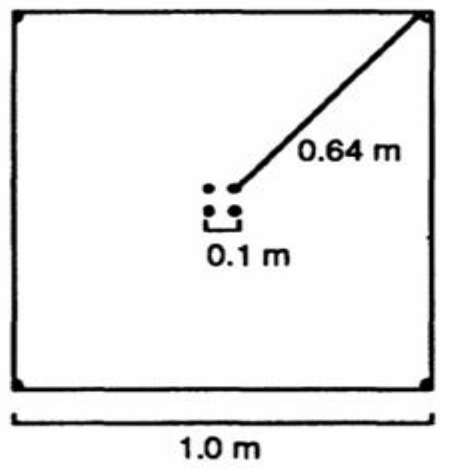

Figure 1. Sampling plan layout

ArcGIS

ArcGIS is a geographic information system. In this case, two functions of this software will be used: creating and using maps, compiling geographic data. ArcGIS can display data on the map directly. For example, figure 2 shows the spatial distribution maps of SOC concentrations in grassland of south-eastern Ireland (Zhang and McGrath, 2003). In this map, deeper colour represents the higher SOC concentration. Therefore, this study will present the spatial variation of soil pH on a map which is created by ArcGIS.

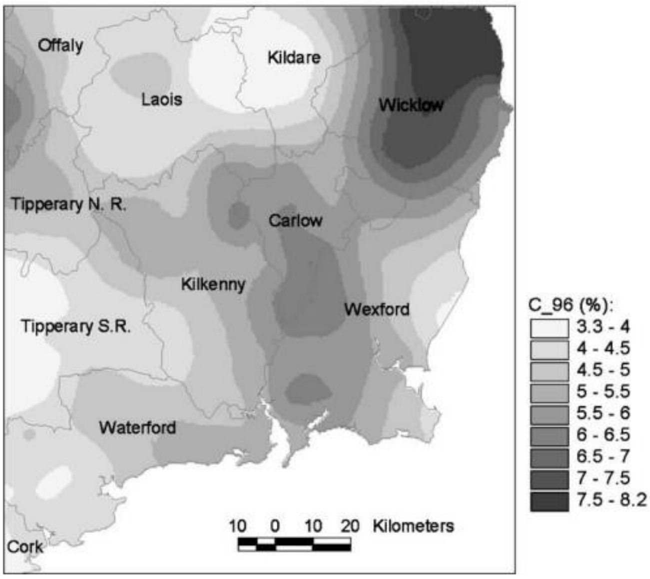

Figure 2. Spatial distribution maps of SOC concentrations in grassland of south eastern Ireland

Results and Discussion

Data are not yet collected. Due to assimilation by plants and natural loss of alkaline soil substances, acidification is expected as a result at present. Therefore, this section will discuss liming method for soil pH management.

Lime use

Liming is an essential method for soil to maintain its recommended pH level, also benefit to crop growth, nutrient availability and environmental protection (Goulding, 2016). Lime increases Ca^{2+} concentrations and enhances ionic strength in the soil solution and making a significant improvement in hydraulic conductivity and soil structure (ibid). Due to the advantageous effect of lime on soil structure, many studies have indicated that applying lime and other acid-neutralizing materials can have a great capacity for improving degraded soils, especially in semi-arid and arid countries (ibid).

Liming materials

The main types of liming materials are ground limestone ($CaCO_3$), chalk, ground chalk, dolomitic ground limestone, hydrated lime and burnt lime (Goulding, 2016). Approximately 70% of the material applied in the UK is ground limestone currently (ibid). Moreover, several waste products can be considered as liming materials: basic slag, sugar factory lime, wood ash, by-product of the paper and pulp mill and coal combustion, for example, bottom ash and fly ash (ibid).

Measuring the lime requirement

The dosage of lime needs to be calculated. Goulding (2016) has indicated that lime requirement does not increase linearly as pH declines. Apart from the target pH value, lime requirement also depends on soil type, plant species, the neutralizing value of material to be applied and acid deposition on a regional basis (ibid).

Conclusions

Soil pH is an important factor for plants to maintain their normal growth and full yield potential. However, pH value generally has a great spatial variation in a certain area of soil. Having considered the present result, acidic soil is expected to be detected. Furthermore, it is also expected that soil pH has spatial variation both in horizontal and vertical distance. A full report will be available at the end of this project.

Acknowledgements

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AN EVALUATION OF GREENHOUSE GAS EMISSIONS FROM DAIRY MANURE MANAGEMENT PRACTICES IN IRELAND

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Abstract

On a dairy farm, significant amounts of Greenhouse Gas (GHG) emissions are derived from manure management, therefore detailed assessment of manure management techniques and their impact on GHG emissions is required. The objective of this study was to evaluate the effects of manure management techniques for reducing manure management hotspots in the life cycle of dairy production from cradle-to-farm gate. In addition, the cost of these strategies was evaluated to calculate, in terms of carbon saving per euro invested, the most cost effective management option.

Introduction

The dairy industry is a vital part of the agri-food sector in Ireland, accounting for 7.6% of Ireland`s economy-wide GVA – Gross Value Added (Bordbia.ie, 2017). More than 17,000 dairy farms were operational across the country in 2013, with 5.4 billion litres of milk being produced (Teagasc.ie, 2017). The volume of milk is projected to increase significantly by the year 2020, due to the abolition of the EU milk quota (Kempen et al, 2011) and national agriculture policy (DAFM-Food Wise 2025, 2017). However, the production of milk leads to environmental impacts, particularly in relation to Greenhouse Gas (GHG) emissions, contributing around 10% of all Irish national GHG emissions (O`Brien et al, 2015). Further complicating the situation, under the terms of a 2009 agreement, all EU member states have legally agreed to continue reducing GHG emissions. In fact, as part of this commitment, by 2020, Ireland has actually agreed to decrease emissions from the non-emission trading sector (non-ETS), which includes agriculture, by a figure of 20% compared to 2005 levels (European Council, 2009).

On a dairy farm, the majority of GHG emissions (CH4 and N2O) are derived from enteric fermentation by dairy cattle, followed by manure deposited on pasture, storage, and spreading on land (O`Brien et al, 2014). In fact, according to some modelling estimates, globally, it is N2O emissions from manure management that are mainly responsible for the increase in atmospheric N2O over the last 140 years (Owen and Silver, 2014). As a consequence, much effort has recently been put into attempting to understand the effects of manure management on the direct and indirect production of Greenhouse Gas (GHG) emissions, given that manures contain substantial quantities of two essential elements in the production of N2O and CH4, namely Nitrogen (N) and Carbon (C), in addition to water. Thus, manure management practices selected by farmers will have scope to influence the magnitude of gaseous losses, and the potential to reduce those emissions. There is, therefore, a need for a detailed assessment of dairy cattle manure management techniques and their impact on GHG, incorporating increased efficiencies and/or available technologies applied at different handling stages, aimed at a reduction in environmental impacts. Furthermore, livestock manures represent a valuable resource that, if used appropriately, can replace significant amounts of chemical fertilizers.

The objective of this study was to evaluate the implication of manure management in reducing manure management hotspots in the life cycle of dairy production, from cradle-to-farm gate.

Materials and Methods

Baseline scenario - farm model

A standard farm was defined using the activity data reported by Yan et al. 2013, which describe a typical Irish commercial farm focused on milk production. In terms of manure management, the general farm practices identified by Teagasc 2011, and reported in the National Farm Survey of Manure Application and Storage Practices on Irish Farms, were used. It was also assumed that manure produced on a farm is completely used on-farm for forage production. These sources provide the information necessary to create the baseline scenario.

Estimation GHG emissions

A partial LCA (Life Cycle Assessment) model was developed to estimate GHG emissions from biotic sources and from the utilization of fossil fuel, encompassing all stages of the manure management, from manure excretion to collection to storage to land-application. Manure deposited by grazing cattle on pasture was also included in the study. The calculation of methane (CH4) and Nitrous oxide (N20) direct and indirect emissions, from manure management was estimated using International Panel on Climate Change (IPCC) guidelines (IPCC, 2006). CH4 and N2O emissions from manure on barn floors were estimated using literature emissions factors and equations presented in Aguirre-Villegas and Larson, (2017). CH4 emissions from stored manure were estimated using national average Emissions Factors published by Duffy et al. (2014), as was nitrogen emissions from animal excreta. CH4 emissions from manure deposited onto pasture by animals were not included, due to amounts of these being negligible (IPCC, 2006). CO2 emissions were limited to fossil fuel combustion used to manage manure on-farm. Biotic CO2 was not quantified, as it was considered to be neutral with respect to GHG emissions (IPCC, 2006 and IDF, 2010). The Global Warming Potential (GWP), characterized for a 100 years' time horizon, and measured in kilograms of carbon dioxide equivalent (Kg CO2-eq) was adopted as the unit of impact. Characterization factors were 25 Kg CO2-eq for CH4 and 298Kg CO2-eq for N2O.

Alternative scenarios

By modifying the slurry management strategies, alternative scenarios will be modelled, in terms of: a) manure cover during storage; b) extension of grazing season length; c) treatment technologies: Solid-Liquid Separation and Anaerobic Digestion; d) land spreading application methods: Ban Spreader and Tailing Shoe; e) land spreading timing: early spring, summer and autumn. Some strategies are based on increased efficiency, while others are based on technological interventions. Comparing the alternative scenarios with the baseline scenario, it will be possible to evaluate what the benefits might be in terms of GHG emissions. In addition, the cost of these strategies will be calculated in terms of carbon saving per euro invested to identify the most cost effective.

Results and Discussion

Some studies have been conducted on evaluating Greenhouse Gas emissions from manure management practices worldwide (e.g. Chadwick et al, 2013; Petersen et al, 2013 and Aguine-Villegas and Larson, 2017) and on potential mitigation strategies to reduce GHG emissions. On this point, it should also be noted, a line can be drawn between technical mitigation potential and economic potential. In the latter, the suitability of mitigation measures also takes into account the cost per unit of emissions abated.

In 2012, Teagasc published "A Marginal Abatement Cost Curve for Irish Agriculture" (Schulte and Donnellan, 2012) (Figure 1), which outlined some activities that could be undertaken to reduce emissions from a typical Irish farming systems, in addition to looking at relative costs associated with these measures. A similar approach will be used in this study, which expects to provide ranges of cost associated with each manure management strategy scenario modelled (cost in euro per tonne of CO2 equivalent per annum), and the relative expected mitigation potential, in terms of tonnes of CO2 equivalent reduction per annum. On Figure 1 two examples related to manure management are highlighted. The first is an extension of grazing for dairy cows. The graph shows it to be a cost-beneficial or win-win measure. Extending grazing is an example of an increased efficiency strategy, which saves money and reduces GHG emissions. The second example relates to the slurry spreading technologies of the Band spreader and Trailing Shoe. In these cases, the purchase of new equipment and farm inputs is taken into account, with costs of around 100 euro per tonne of CO2 reduced per annum for the Band Spreader, and around 200 euro per tonne of CO2 reduced per annum for the Trailing Shoe. The scenarios tested in this project will evaluate these estimates.

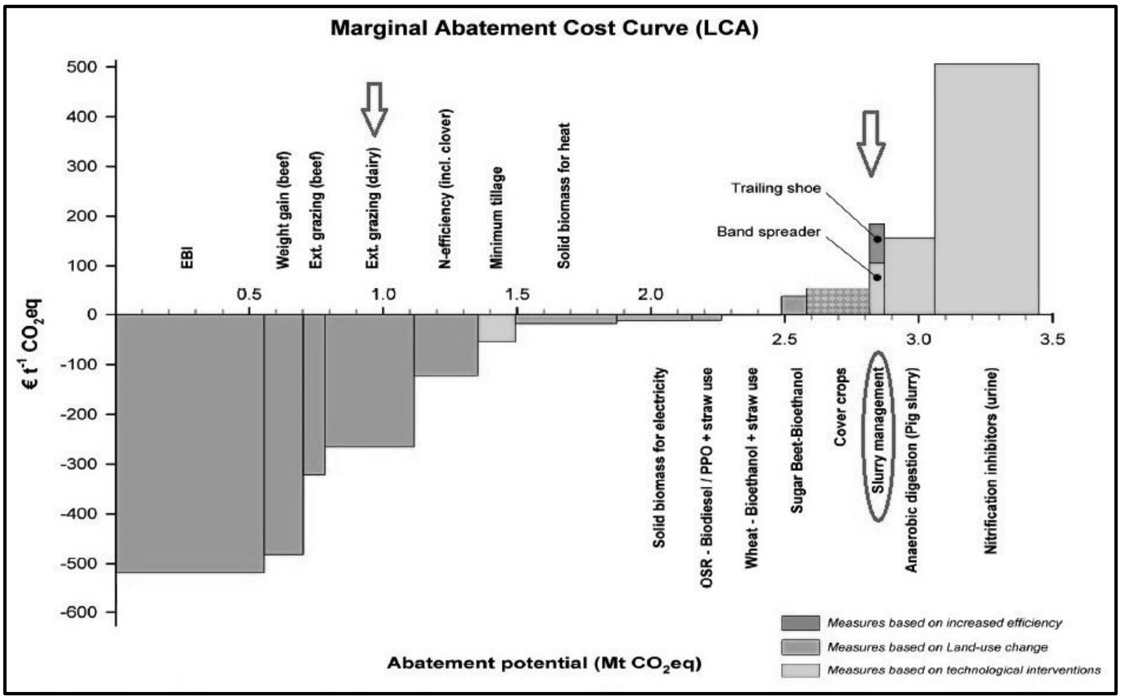

Figure 1: Marginal Abatement Cost Curve (LCA) for Irish Agriculture. Source: Schulte and Donnellan (2012).

Conclusions

Manure management plays an important role in GHG emissions reduction. Understanding manure management hotspots and the potential for mitigating them, environmentally and economically, can guide and feed into the development of climate change mitigation strategies and policies, thereby potentially both benefiting farmers and helping Ireland fulfil its EU obligations on GHG emissions.

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A FEASIBILITY STUDY OF A 250KW ANAEROBIC DIGESTION PLANT IN IRELAND

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Abstract

The study showed the feedstock potential in Ireland for small scale anaerobic digestion (AD), listing the benefits of AD as well as challenges and possible solutions. Low or non-existent renewable energy feed in tariffs, and high capital costs were identified as the major barriers to the implementation of small scale anaerobic digestion plants in Ireland. The goal of the study is to assess the viability of a small scale AD plant in Ireland using its feasibility as a model for application in rural electricity generation in Nigeria.

Introduction

Mankind, today, is faced with the problem of rising energy demands and the corresponding environmental issues associated with the use of the limited fossil fuel resources to produce energy (Amigun et al. 2012). Anaerobic bacteria produce biogas when organic substances are subjected to oxygen free environments (Amigun *et al.* 2012; Wang 2014). An anaerobic digestion (AD) or biogas plant is a controlled, zero oxygen environment carefully put together to harness this bioconversion process (Petersson and Wellinger 2009; Lou *et al.* 2012). Amongst the many benefits of anaerobic digestion are reduction in greenhouse gases emissions and carbon savings, production of renewable energy as well as effective management of wastes (Lou et al. 2012). According to Klavon & Lansing (2010) the majority of the over 30 million small scale digesters in the world generally use manure as feedstock and can be found in developing countries such as China and India. Small scale anaerobic digesters do not have a generally accepted definition although they are a viable tool if the farmer intends to achieve less dependence on the unstable prices of energy, through the production of renewable energy while solving the problem of managing the waste generated from daily farm operations and by effect, contribute to the effort of the country to reach its renewable energy target (enerpedia 2015).

Researchers (Berardino *et al.* 2008; Klavon and Lansing 2010; Ciotola *et al.* 2011; Budiarto *et al.* 2013; Moss *et al.* 2014; Wang 2014) have enumerated the potentials, benefits, problems and possible solutions of small scale anaerobic digestion. Appels et al. 2011 reported the research trends of anaerobic digestion and stated its feasibility both in large and small scales, however, advocating that further mathematical models are required in order to ensure optimized digestion systems. Lukehurst & Bywater 2015 stated that small scale AD provides an efficient and cost effective system for managing slurries from dairy farms. In their report, they identified the relationship between incentives, energy prices and capital cost and the development of small scale AD. They concluded that small AD installations offer a win-win situation for farmers and policy makers as it serves as an income source for the farmer, helping to offset some of the operational costs for the farm while mitigating greenhouse gas emissions which is a win for policy makers. Wang 2014 stated that climate and the variable nature of feedstock as well as the lack of education of biogas users pose a hurdle for the widespread implementation of small scale biogas plants.

The objective for this study is to assess the feasibility of small scale anaerobic digestion in Ireland considering the feedstock, challenges and possible solutions aiding the development of a 250kW AD plant and its potential application in Nigeria

Feedstock Potential

The amount of biogas produced is dependent on the type and amount of feedstock which is digested (Petersson and Wellinger 2009). Feedstock most readily available is in Ireland includes farmyard manure and food waste from households (which is part of the organic fraction of municipal solid wastes) (Stambasky 2016). Other feedstock for small scale anaerobic digestion includes animal fats and waste oils, energy crops (such as maize silage, *Miscanthus*, beet, wheat etc) and agricultural wastes (Appels et al. 2011).

Table 1: Methane yield of selected feedstock (SEAI 2010)

Organic material	% of Fresh Material (FM)	Biogas production m^3/tonne FM	Electricity production kWh/tonne FM	kW/tonne FM day
Cattle slurry	8	20.5	41.8	1.7
Pig slurry	4.5	11.5	23.5	1.0
Chicken litter	40	126.0	257.3	10.7
Food waste	20	110.0	224.6	9.4
Maize	32	200.6	409.6	17.1
Grass	25	116.9	238.6	9.9

To use biogas for energy production, it is important to know the amount of feedstock required to produce the desired amount of biogas for use in the CHP. The feasibility of any scale of biogas depends on the availability of the required amount of feedstock to produce biogas for the desired scale (Wang 2014). Manure is mostly used because it is cheap however since it has a low biogas yield, it is usually co-digested (Appels *et al.* 2011; Wang 2014).

Table 2: Realistic AD feedstock available in Ireland by 2030 (Stambasky 2016)

Realistic AD Feedstock available in Ireland in 2030

Feedstock	Share of total (Table 1) [%]	Quantity 1000× [tpa]	ODM[a] 1000× [tpa]	Biogas [mil. m^3/a]	Energy [TJ]	Energy[d] [ktoe]
OFMSW	60	492	138	65	2,322	55
Slurries, manures	33	4,438[b]	3,551	1,758	34,643	827
Grass	7.46	11,529	3,551[c]	2,187	42,340	1,011

[a]) ODM: Organic Dry Matter; equals to (dry matter minus ash)
[b]) Dry Matter
[c]) Optimal Slurry-Grass ratio has been investigated and evaluated in reference X.
[d]) 1 ktoe = 41.868 TJ
tpa – tonnes per annum

Challenges & Solutions

Anaerobic digestion in Ireland irrespective of scale is troubled by several challenges which affect its viability and feasibility irrespective of the feedstock potential which is currently available in the country. In the 2011, the Irish joint committee on communications, energy and natural resources listed costs, renewable energy feed-in-tariff, public permissions and planning, education of farmer as key barriers to the development of anaerobic digestion in Ireland (Nolan et al. 2011). Other literature list several other problems of small scale anaerobic digestion such as long payback periods, pipeline leakage, construction failures, low biogas production (Wang 2014). Stambasky in 2016 enumerated some policy changes which would be help solve some of the challenges listed above which are:

1. Provision of support necessary to aid generation of electricity from anaerobic digestion (making grid connections easier, increased subsidies and grants to lower starting capital costs for small scale anaerobic digestion)

2. Incentivising the use of agricultural wastes (such as manures) as substrate for AD (using Germany as an example)
3. Introduction of incentives for renewable heat from AD and biomethane injection into national gas grid
4. Grandfathering incentives, allowing investors to qualify with or without the legislative instruments in place
5. Collecting and processing food waste from households and commercial outfits separately as feedstock for AD thus guaranteeing feedstock supply for AD developers.

Conclusions

In conclusion, Ireland has the capacity to produce up to 20% of its energy demand using a number of 250kW anaerobic digesters while scoring wins in the reduction of greenhouse gas emissions as well as efficient manure management which is currently a concern for the country(Nolan *et al.* 2011; Stambasky 2016). Given Ireland's AD feedstock potential, it offers a more steady low energy carbon source unlike wind energy which is unstable and intermittent in supply (Nolan et al. 2011). Incentives and policy changes serve as key drivers to the further development of small scale anaerobic digestion in Ireland, hence making it more attractive for farmers and investors alike (Nolan *et al.* 2011; Stambasky 2016). At the end of the study, it is expected that the feasibility and viability of 250kW anaerobic digesters for electricity generation in Ireland as well as in Nigeria is demonstrated.

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MECHANICAL TESTING METHODOLOGY OF PLASTIC BOTTLE RECOVERED PET MATERIALS

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Abstract

Mechanical properties of materials are crucial to their suitability and potential for functional uses. A proposed method for the mechanical testing of orientated plastic bottle recovered PET material is outlined with a view to enable their assessment for additional uses as products or materials. Our method is presented, tested and discussed below. Our results indicate a potential for consistent mechanical testing of varied sample preparation and degradation methods.

Introduction

The current human period has been already referred as the plastic age (Cózar et al. 2014). The use of these materials has increased in the past decade mostly due to their preferred material characteristics: light weight, long durability, low cost and ease of manufacture. However, the intense consumption and rapid disposal of plastic materials has led to the generation and accumulation of plastic waste. This waste material is a global problem, affecting all areas of the planet, with the most impact exhibited in marine environments. Plastic's low density, and high durability, with plastic bottles lasting hundreds of years (Gregory et al. 2003) in the natural environment makes them a significant threat to marine ecosystems. These materials impact these ecosystems in a number of ways, including accumulating in the stomachs of marine animals (Eerkes-Medrano et al. 2015), collecting other marine pollutants (Ivleva et al. 2017) and generating polymer micro particles (Andrady 2011). Due to these recurring issues, marine plastic quantities, and the influx of further quantities, has become one of society's major environmental problems.

To quantify this problem, a study published in 2015 (Jambeck et al. 2015) demonstrated that between 4.8 and 12.7 million metric tonnes of plastic waste (very roughly equivalent to 500 billion plastic drink bottles) from 192 coastal countries around the globe entered the marine environment in 2010 alone. However, those numbers are not entirely reliable because the study excludes the plastic material which is already in the ocean and the plastic material which gets lost or is dumped in the sea, via the global fishing, shipping and transport industries. In order to counteract this problem, the Printastic project was founded in Ireland (UCD) in 2015. This project aims to reuse and repurpose plastic waste materials through their utilisation with low tech and innovative solutions. This approach to the problem will not only enable local communities to deal with their plastic waste, but also help stop the flow of the plastic into the ocean while also removing plastic material from marine environments. In order to fully understand the properties of both marine and household recovered plastic materials, a mechanical assessment of the recovered PET (polyethylene terephthalate) material will be undertaken as part of the proposed thesis project.

This paper will present the methods proposed for the mechanical testing of recovered PET bottle materials, the effect of sampling variation due to inherent manufacturing methods and the expected and preliminary results of those tests.

Materials and Methods

Testing Standards

As this is the first time that this specific type of test is carried out, there is no reference for the methods of testing the materials. To perform the test the ISO standard 'ISO 527-3-1995: Plastics - Determination of tensile properties - Part 3: Test conditions for films and sheets' were used.

Sample preparation

The procedure of creating the samples consisted of the collection of a standardized bottle (Green PET bottles, 2 liters of capacity, No Corrugations as seen in Figure 1a), removal of the top (from the shoulder) and the bottom from the bottle (Figure 1b), resulting in a curled flat sheet consisting of the main body of the bottle (Figure 1c). Different testing scenarios where considered in terms of the cutting method, heat treatment and orientation of the samples in the bottle. In Table 1 the different scenarios are presented below.

Figure 1 a. Complete Bottle, **b.** Top and Bottom Removed and **c.** Curled Flat Sheet

Table 1. Proposed Testing Scenarios.

Cutting method	Laser
	Manual
	Guillotine
Heat treatment	Yes
	No
Orientation	Vertical
	Horizontal
	45 degrees

The cutting method is referred to the method used to cut the samples from the plastic sheet. The shapes of the samples or specimens used in the tests are as follows:

- For the laser cut samples, specimen type 5. Figure 2a.
- For the manual cut samples, specimen type 5. Figure 2a.
- For the guillotine cut samples, specimen type 2. Figure 2b.

Specimen type 2 was used to aid in the preparation of reliably reproduced samples utilizing the guillotine cutting method, reducing the impact of human error during the cutting process.

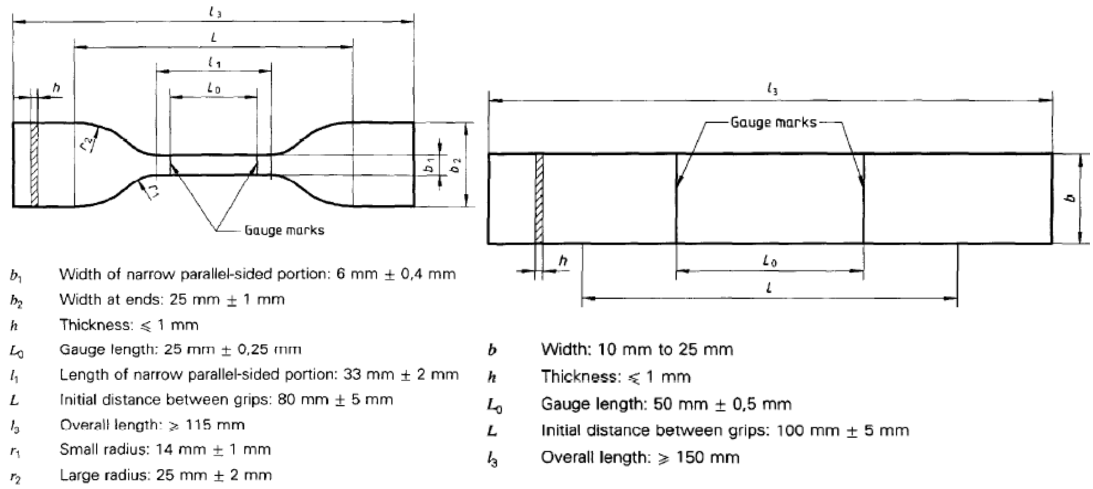

Figure 2 a. Specimen type 5, **b.** Specimen type 2. (ISO 527-3,1995)

The heat treatment of the samples consisted of the heat pressing of the plastic sheets in a heated bed press, normally used in the thermal image transfer process, completed over two intervals of 20 seconds at 100° C. This process resulted in the strengthening and shrinking of the plastic sheet material.

In terms of orientation, due to the manufacturing process of the bottles, injection stretch blow molding (ISBM), the molecules of plastic are aligned in a vertical orientation along the body of the bottle (Billon *et al.* 2014). It is expected that this will have a significant influence in the testing and will be a determine factor in the results and strength characteristics of the bottle samples.

Testing methods

An Instron tensile test machine was used in the tensile testing of the prepared samples, with the testing speed selected according to the ISO standard discussed above (Selected testing speed = 50 mm/min). The thickness and width of the samples was measured before the tests and all the specimens were recorded. Five samples of each variable were tested in this initial testing phase.

Results and Discussion

Once the tensile tests are carried out the results will be analysed. The results of the tests are given in force versus extension and this information should be convert to a stress – strain graph. This is done by using the following equations:

$$s = F/A_0 \qquad \text{(Eq. 1)}$$

$$e = \frac{\Delta L}{L_0} \qquad \text{(Eq. 2)}$$

Where:

- s is the stress (MPa).
- F is the force measures (N).
- A_0 is the is the initial cross-sectional area of the gage section (mm^2).
- e is the strain (mm).
- ΔL is the change in gage length ($L - L_0$) (mm).
- L_0 is the initial gage length (mm).

The expected results after the presented calculations should be similar to those seen in Figure 3. Figure 3 show the results of a test run of samples of laser cut heat treated vertical samples.

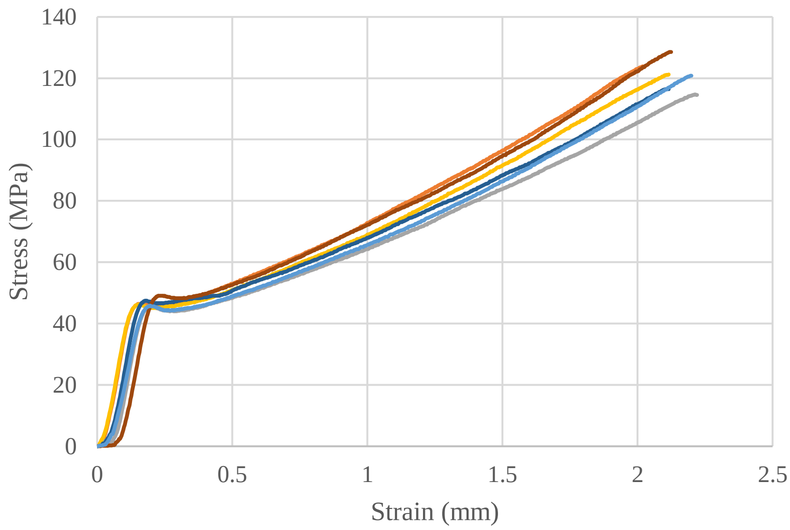

Figure 3. Expected results.

Conclusions

The proposed testing methodology presented above will give insight into the mechanical quality of recovered PET bottle materials. The proposed testing results will act as a baseline for comparison to environmentally degraded PET bottle materials (artificially degraded to act as a simulation for marine environmental degradation), allow the quantification of the effect and potential for marine recover PET bottle materials for reuse and upgrading into additional products or materials. The initial test run results indicate that the proposed methodology could be used to consistently determine the mechanical properties of the desired materials.

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Nanoparticles—Where do they go?

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Abstract

Under different environmental conditions, the interaction between silver nanoparticles (nAg) and the environment varies. This study designs several groups of experiments to assess nAg's movement in surface water, which is the most common way for nAg to enter the natural environment. The study looks at the influence of different values of pH, volumes of oil and temperature. The study then looks at providing an assessment of human exposure to nAg under these environmental conditions. Based on a method that calculates the removal rate of nAg in water samples, this study adopts a factor as a comparison basis using the particle attachment α.

Introduction

Silver nanoparticles (nAg) are widely used in medical and cleaning products because of its antimicrobial and antibacterial functions. But their fate after use is still unknown due to a lack of tracking and analysis (Gondikas, 2014). This limitation has led to unknown human exposure risk, which has come to attention in recent years (Wiesner, 2009; Bernhardt, 2014 and Gottschalk, 2011). Standard absorption tests usually use a batch equilibrium method to model the fate of pollutants, such as OECD 106 Adsorption-desorption. However, this method is not appropriate for NPs because the NPs are not expected to reach the equilibrium in natural environmental systems (Hendren, 2015 and Praetorius, 2014). When nAg goes into the water, a collision process happens between it and the background material due to the water movement. The collision process causes the nAg to end up in three parts. One is dissolved in the water, one is still suspended in the water, and the last proportion of nAg attaches with background materials. The likelihood of this attachment is called attachment efficiency α. As an alternative of the traditional way of testing the fate of pollutants, the attachment efficiency α is a factor analysing the interaction between NPs and natural environmental system, by assessing the attaching process when NPs collide with environmental background materials (Lauren, 2014 and Lecoanet, 2004). The natural environmental conditions are changing significantly temporally and spatially. Different environmental conditions can affect the collision process between nAg and background materials in waters, and further influence the human exposure level. In this study, three basic environmental factors are designed as the independent values in experiments to simulate some typical environmental circumstances in surface water. The values of pH and temperature are most basic parameters in aqueous environments. Their variations can lead to changes of other parameters in water, such as dissolved oxygen (DO) and biological activity. Luoma (2008) outlined that various environmental parameters govern the speciation of nAg, including pH and temperature. A recent study suggested more research on the kinetics of NP dissolution in complex aqueous environments (Zhang, 2016). Therefore experiments design variations of pH and temperature as independent values in order to figure out their relationships with nAg behaviour in water. Oily wastewater is very common in sewage and can cause lots of environmental problems. To simulate this circumstance, a group of experiments are designed by adding oil into water samples.

The objective of this study is to evaluate the attachment efficiency between nAg and environmental background materials in water and further estimate the human exposure to free nAg under some typical environmental circumstances.

Materials and Methods

Materials and equipment

Smaller nAg has better antibacterial and antimicrobial function and is generally in the diameter of 20 nm. Therefore, the experiments choose the nAg with 20 nm diameter as the experimental subject. To adjust the pH value, HCl and NaOH solutions were used and a pH meter. To adjust temperature, a thermostat water bath and a thermometer was used. A spectrophotometer is used to test the absorbance of suspended nAg.

Silver nanoparticle preparation

2 ml nAg is diluted in 45.5 ppm DI water with 2.5 ml SiO_2, which serves as the background material. Then the water samples are stored under different temperatures in the thermostat water bath. As for the scenario that changes pH values, HCl and NaOH solutions are added in water samples.

Experimental design

The pH values of industrial waste water can vary from 4 to 13. Thus, this study adopts 4, 6, 7, 9, 11 and 13 as the pH values of the batch of water samples. At the beginning of nAg entering waters, the cleaning and medical products are flushed with water that could have higher temperature. But when it goes into the natural surface water, the temperature can be lower depending on the climates and seasons of surrounding environment. Therefore, this study sets 5, 15, 25 and 35°C as the experimental temperature. A dropper is used to add oil droplets into water samples. One droplet is 0.05 ml. To make the volumes of water samples all 50 ml, DI water was added to the correlated volumes. Every scenario has 7 samples that have a series of time aliquots from adding the nAg to entry to the centrifuge. Every sample is placed in the centrifuge tube and can be centrifuge for 20s at 10k RPM.

Table 1: The experimental factors and levels

Factor						
Temperature (°C)	5	15	25	35		
pH	4	6	7	9	11	13
Oil droplet	1	2	3	4		

The samples are then tested in the spectrophotometer: SpectraMax 340 under 405nm wavelength. A calibration curve is made to serve as a reference for checking the correlated concentrations of suspended nAg in samples.

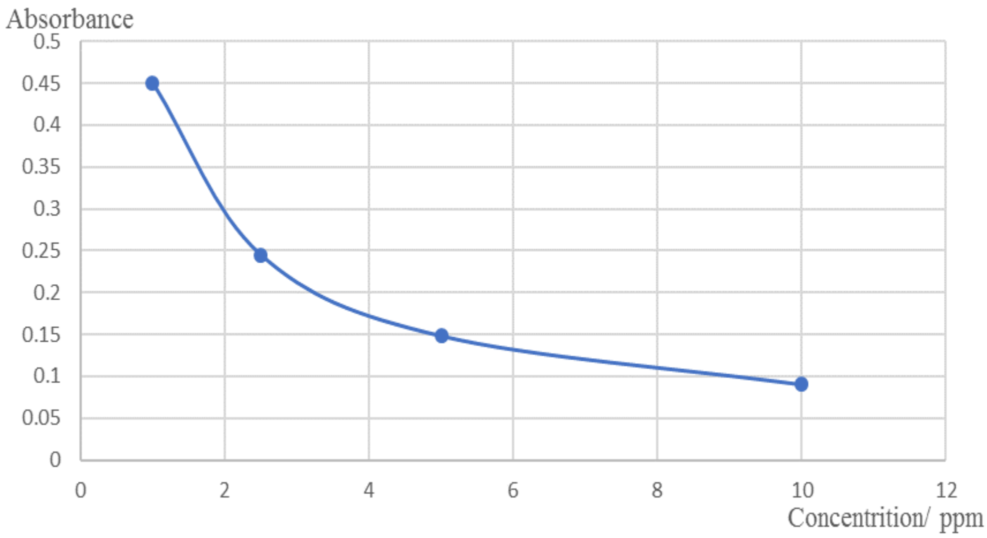

Figure 1: Calibration curve

After we know the concentration c_0 of suspended nAg remaining in water sample, a removal rate curve is made according to the following equation, which is provide by Lauren (2014):

$$\alpha\beta B = \ln\left[r\left(c_0/c\right)+1\right] \quad (1)$$

In this equation, removal rate of nAg in water samples equals the value of αβB. β represents the collision frequency, and B is the concentration of background materials. Based on Lauren's (2014) theory, if we control the mixing condition as the control variable, the value of β multiply B is constant in every environmental scenario. Then the α can be determined.

Results and Discussion

These experiments are still ongoing, preliminary results suggest variation of temperature can influence the likelihood of collision directly. This is in agreement with Michaelides (2015) who states that the thermophoretic velocity, which correlate to the movement intensity, is proportional to temperature gradient. While at the same time, the higher temperature can accelerate the dissolution of nAg. Therefore it is estimated the suspended part of nAg will decrease with the increase of temperature. Liu (2010) proved with a series of experiments that the iron release of nAg from waste of products flushed with water increases with temperature in the range from 0 to 37℃. Combined with the estimation, it is reasonable to deduce that in the natural aqueous environments, the attachment efficiency will have a more obvious increase with temperature.

The surface properties of nanoparticles determine its feature of absorbing oil (Lu, 2017). The existence of oil in water samples can affect the distribution of nAg, which can reduce its likelihood of collision with background material and impact the attachment efficiency.

Conclusion

The kinetics of aggregation and dissolution are the main environmental concerns for silver nanoparticles. The variations of factors in this study can affect these properties by different levels, which induce different collision processes in aqueous environments. The results of the experiments are used to compare the collision processes with the attachment efficiency α. This factor will help to estimate human exposure level under different environmental scenarios.

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IMPACT OF EUROPEAN AND IRISH LEGISLATION ON THE DESIGN OF DAIRY WASTEWATER TREATMENT PROCESSES

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Abstract

The bottleneck for dairy processing expansion is the wastewater treatment plants (WWTPs). They have been built to treat a fixed intake of milk and subsequent milk loss from the various processing lines and now there is a need to modify/upgrade the wastewater treatment plants to allow for the increase in milk intake and associated losses for the various production lines.
Legislation is an element that needs to be considered when designing a sustainable wastewater treatment process. A look at past legislation in Europe highlights the additional parameters/limits that are added to discharge licences during legislation reviews. The wastewater emission limits have reduced concentrations of parameters over time, such as nutrient removal of both nitrogen and phosphorous. The impact of this change in legislation is that in reducing one or both nutrients requires different processes due to the different microbial organisms required for their removal. Each nutrient removing micro-organism also requires a minimum quantity of carbon, along with specific oxygen and temperature conditions that need to be considered in the design.

Introduction

Sustainable development has become a key issue on a global platform (United Nations, 2016). Sustainable development is often assessed in three areas; economics, social and environmental. Research carried out to-date identified the ambiguity of the social aspect of sustainable development. A better division of areas was thought back in 1967 with "The Club of Rome". They set out a number of interdependent components that make up the global system; technical, economic, political, natural and social elements. They identified mankind's failure as focusing on single items "*without understanding the whole is more than the sum of its parts, that change in one element means change in the others"* (Meadows et al., 1972).

For more than 30 years, dairy quotas were imposed on the European Union (EU) Member States. 2015 marked the end of dairy quotas in the EU, allowing dairy farmers in the EU to now expand their stock without any penalties being imposed on them. In the broader scheme of things, it allows EU Member States to better compete for the dairy global market (Donnellan, Hennessy and Thorne, 2015). This is resulting in production/factory expansions within dairy processing facilities. The knock-on effect of this is that the dairy WWTPs currently in place will also need to be upgraded/redesigned to meet the needs of the increase in wastewater being generated from the increased production while also meeting their IED (industrial emissions directive) licence, without which they cannot operate.

The objective of this study is to highlight the trends of industrial wastewater emission limits for the dairy industry in Ireland.

Materials and Methods

This paper concentrates on a review of legislation related to wastewater discharge limits and licences issued by the Irish EPA for processing plants in the dairy sector.

Results and Discussion

Wastewater Characterisation

Dairy wastewater has long been acknowledged as a highly biodegradable wastewater. An analysis of the constituents of raw milk show that milk is made up of 87.5% water, 3.9% fat, 3.4% protein, 4.8% lactose and 0.8% minerals (Tetra Pak, 2015). It is the 13% solids that gives rise to the various wastewater parameters that need to be treated.

The European BREF document for Food, Drink and Milk (FDM) mentions a normal product loss of 0.5 – 1.5% with product loss going as high as 3 – 4% (EIPPCB, 2017) while other literature references 2% total milk loss (Kushwaha, Srivastava and Mall, 2011). This is difficult to determine as each dairy processing facility produces assorted products and uses different cleaning methods and detergents. It is a combination of all activities from intake reception to final product packaging that contribute to the generation of wastewater. The available literature tries to give value ranges of the main parameters noted in wastewater but the values given considerably and are thus not a good indicator for the characterisation of the wastewater generated from the dairy industry (Britz, van Schalkwyk and Hung, 2006). Product loss is not the main contributor to the wastewater. The main contributor to dairy wastewater is the wastewater generated form the cleaning and washing of floors, vehicles and the cleaning in place (CIP) of factory equipment, silos and tanks.

Legislation

The Club of Rome instigated the main components for sustainability that need deeper understanding and their interlinking between each other. It highlighted that all these components need to be considered together when drawing up new policy and promoting new policy initiatives and action (Meadows *et al.*, 1972).

When the first Environmental Action Programme was introduced in the EU in 1973 there were no legally binding provisions. Instead, the EU had general principles that are still relevant and applied to day. The relevant ones being (European Communities, 1973):

- Prevention at source
- Environmental action should be taken at the most appropriate level
- Prevention is better than the cure
- Polluter pays principle

Environmental Protection Agency

The Environmental Protection Agency (EPA) in Ireland is an independent public body responsible for the monitoring and licencing of industrial emissions (Oireachtas, 1992). The main objectives are to regulate and monitor the environment and target/penalise those who do not comply. They provide several public access publications informing and promoting a sustainable environment. They carry out research and provide environmental data to assist in decision making.

BAT - Best Available Techniques Reference Documents

The European Union has brought together a number of the Member States to collect data and exchange information on the major industries and to establish guidance documents on best available techniques and to limit imbalances on the levels of emissions from industrial activities within the Member States. It is intended from the 2010/75/EU directive that these documents will be assessed no later than eight years afterwards. The BAT reference documents are to be the basis for setting permit conditions.

Articles 15 and 16 in the Directive 2010/75/EU gives authorities flexibility in setting emission limits outlined in the BAT reference documents. It allows authorities to set more stringent limits to those in the BAT conclusions. The reason for that is due to the fact that some receiving water bodies are of poor quality and the discharge arising from the industry should not add to the poor quality. The difficulty with article 15 is an industry may not be the only discharge into the water body but could be responsible for possibly rectifying the water body. Article 16 of the same Directive again allows authorities to deviate from the emissions limits in the associated BAT documents on the grounds that the there is a disproportionately high cost compared to the environmental benefits but at the same time it states that "*no significant pollution should be caused and a high level of protection of the environment taken as a whole should be achieved"*(European Parliment, 2010). Article 16 is a matter of interpretation and could be disputed by some industries that are required to install exceptional unit operations to obtain almost drinking water quality from their wastewater stream due mainly to the fact that the receiving water body is of poor quality.

Figure 1 represents six licenced dairy processing plants in Ireland and the reduction of their emission limits over time to the present day. Table 1 represents three licenced dairy processing plants in Ireland and the only currently available BAT conclusion; one is discharging to a river, another to a lake and the third to a sewer. The volume of wastewater to be treated varies significantly from 1,300 – 18,000 m^3/d. The range in final emission limits is representative of the receiving water body, however, it highlights the fact that not all licenced dairy emission limits are being required to achieve BAT conclusions. The unit operations required for the treatment of wastewater to be discharged to the lake are very advanced with almost drinking water quality standards.

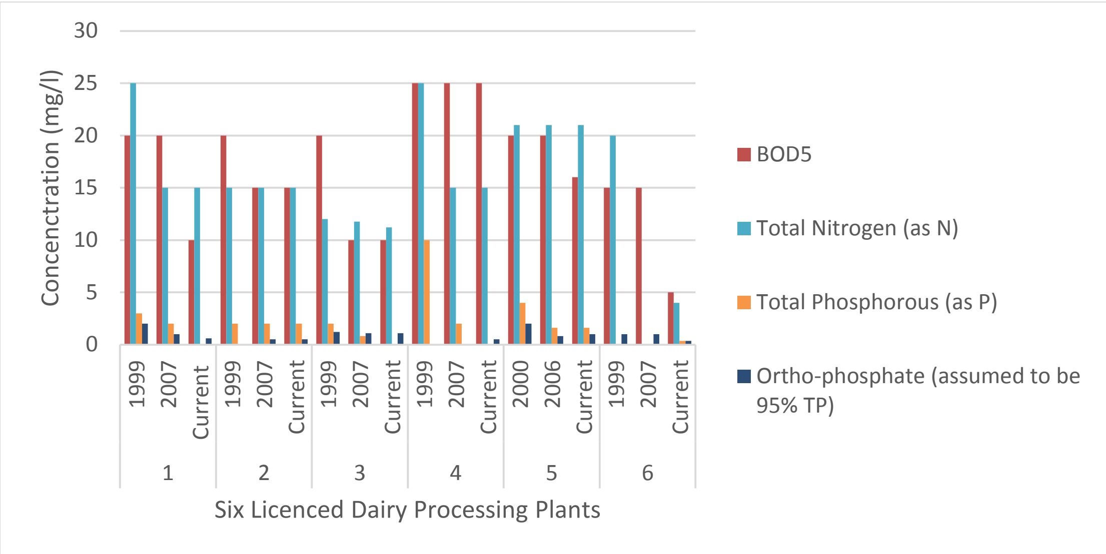

Figure 1: Wastewater emission limit values for period 1999-2017 for six processing plants

Table 1: Comparison of discharge licences to BAT Conclusion

		Discharge to River	Discharge to Lake	Discharge to Sewer	BAT Conclusion*
Volume	m^3/d	18000	1300	4400	
BOD$_5$	mg/l	10	5	2500	
COD	mg/l	76.7		3750	30 - 100
TSS	mg/l	16.7	10	1000	5 – 35
Total Nitrogen (as N)	mg/l	11.2	4		5 - 25
Total Phosphorous (as P)	mg/l		0.35	65	0.5 - 3
Ortho-phosphate	mg/l	1.1	0.35		

*****(European Commission, 2016)

Conclusions

Industries should be aware that new discharge policies could force them to reassess their existing WWTP and require them to redesign it in order that they meet their discharge licence. Industries are currently taking more interest in preventing the pollution from occurring at the source and researching new developments to reduce/reuse wastewater generated.

In terms of the "polluter pays" principle, the polluter should not be solely responsible for improving the receiving water body that it discharges into when there could be unmonitored emissions also discharging into the same water body that could also be contributing to the poor water quality of the water body.

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OPTIMIZATION OF WASTEWATER TREATMENT IN THE DAIRY INDUSTRY

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Abstract

Dairy industry wastewater contains many pollutants which results in the treatment of large quantities of water. These industries discharge wastewater which is characterized by high COD, BOD, nutrients, and organic and inorganic contents. Such wastewaters, if discharged without proper treatment, severely pollute receiving water bodies and disrupts complete ecosystem. Conventional treatments like trickling filter, anaerobic sludge blanket reactor, wastewater stabilization pond, aerated lagoons have problems of high maintenance cost, labour cost and disposal problem of sludge generated frm the treatment. Optimization of such treatment processes is essential.

Introduction

Of all industrial activities, the food sector is one of the highest water consuming and effluent producing per unit of production. The dairy industry is an example of this sector. The dairy industry is one of the major food industries in Ireland. There are more than 17,000 dairy farms in Ireland, producing 5.4 billion litres of milk per year and milk production in Ireland is projected to increase by 50% by the year 2020. The table below depicts milk products produced in Ireland as per 2013 data.

Table 1: Milk products produced in Ireland (Geraghty, 2013)

Products	Quantity
Liquid milk	479 million litres
Butter	1,52,300 tonnes
SMP	46,900 tonnes
WMP	38,000 tonnes
Whey Powder	1,00,000 tonnes (2011)
Casein	42,000 tonnes (2011)
Cheese (mostly Cheddar)	1,82,800 tonnes

The dairy industry is a major source of wastewater and generates effluents in various processes like pasteurization, homogenization of fluid milk and the production of dairy products. The wastewater generated thus contains BOD, COD, TS, TSS, pH, colour, etc. A typical European dairy factory generates approximately 50 m3 wastewater daily with considerable concentration of organic matter (fat, protein and carbohydrates) and nutrients (e.g. nitrogen and phosphorous) originating from the milk and the milk products (Ashish and Omprakash, 2014). Thus, effluent treatment plants are installed in every industry which helps to reduce the pollution level of wastewater going to be discharged in to the environment from industrial premises. As per Environmental Protection Agency requirements, every industry needs to meet wastewater discharge limits. For effective treatment, characterization of wastewater, treatability aspects and planning of proper units needs to be carried out.

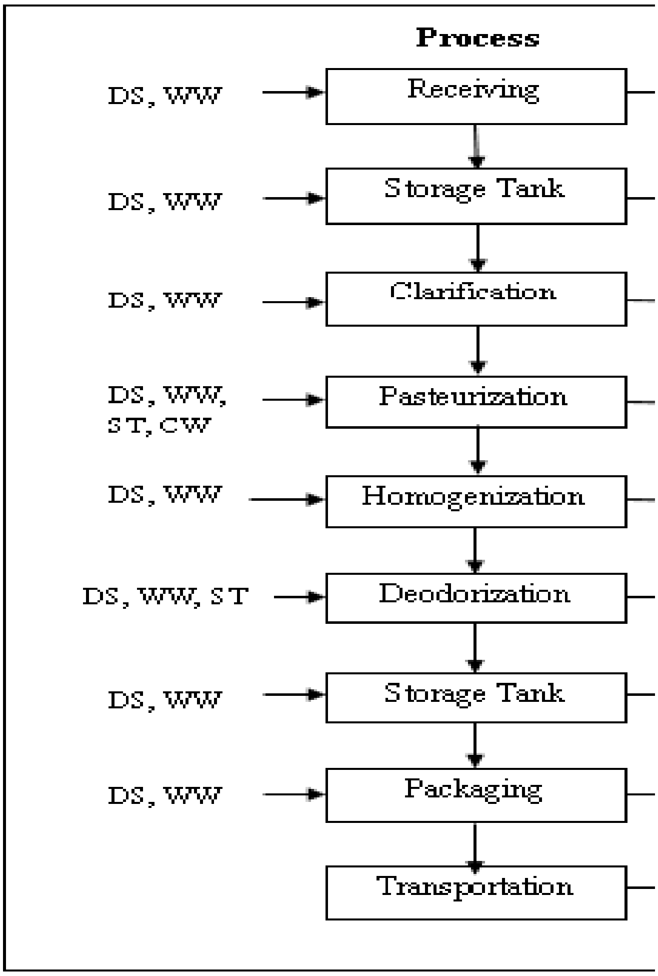
The main objective of this study is to evaluate the most effective and efficient treatment methods for wastewater generated by the dairy industry.

Materials and Methods

In this study, the source of wastewater is the dairy industry and the study area is Ireland. The duration for this research work is two months. This research work involves the data collection of effluent from various dairy industries in Ireland, after which a suitable waste treatment unit is designed. Environmental Protection Agency standards are also taken into consideration while designing the treatment unit. The research is purely carried out comparing various journals and scientific papers and no laboratory work has been carried out in the study.

Results and discussions

Milk is composed of 87.8% water, lactose 4.7%, butterfat 3.5%, proteins 3.2%, and minerals 0.8%, thus, the wastewater contains large amount of dissolved sugars, proteins and fats which is organic in nature and bio-degradable. So, the dairy wastewater is considered as high concentration of organic matter and high BOD. In the dairy industry, some amount of wastewater gets produced during starting, however, most wastewater gets produced during cleaning operations, especially between products changes when different types of products are produced in a specific production unit and clean-up operations. Effluent sources from various units of milk processing is shown in the flow chart below,



DS- Detergents and Sanitizing agents
WW- Wash Water
ST- Steam water
CW- Cooling Water

Figure 1: Effluent sources from various units of milk processing (Bharathi and Shinkar, 2013)

The characteristics of a dairy effluent contain temperature, colour, pH (6.5-8.0), DO, BOD, COD, dissolved solids, suspended solids, chlorides, sulphate, oil & grease. The dairy wastewater also consists of large quantities of milk constituents like casein, inorganic salts, and also the detergents and sanitizers used for washing. Typical characteristics of dairy industry wastewaters reported by various authors are given in table 2.

Table 2: Characteristics of dairy industry wastewaters (Bharathi and Shinkar, 2013)

Waste Type	COD(mg/L)	BOD(mg/L)	pH	TSS(mg/L)	TS(mg/L)
Milk & Dairy Products factory	10251.2	4840.6	8.34	5802.6	-
Dairy effluent	1900-2700	1200-1800	7.2-8.8	500-740	900-1350
Arab Dairy Factory	3383±1345	1941±864	7.9±1.2	831±392	-
Dairy wastewater	2500-3000	1300-1600	7.2-7.5	72,000-80,000	8000-10,000
Whey	71526	320-1750	4.1	22050	-
Cheese Whey pressed	80000-90000	1,20,000-1,35,000	6	8000-11000	-
Dairy industry wastewater	2100	1040	7.8	1200	2500

Dairy wastes are white in colour and usually slightly alkaline in nature and become acidic quite rapidly due to the fermentation of milk sugar to lactic acid. Due to soluble organics, suspended solids, trace organics, dairy effluent is rich in high biological oxygen demand (BOD) and chemical oxygen demand (COD). The suspended matter content of milk waste is considerable mainly due to fine curd found in cheese waste. Decomposition of casein leads to the formation of heavy black sludge and strong butyric acid odours and can characterize milk waste pollution.

As per the BREF documents for food, drink, and milk industries 2006, the treated effluent should meet the following effluent standards:

Table 3: Effluent standards for dairy industries (BREF documents)

Parameters	Concentrations (mg/L) except pH
BOD_5	<25
COD	<125
TSS	<50
pH	6-9
Oil and grease	<10
Total nitrogen	<10
Total phosphorous	0.4-5

In order to meet the standards given in the table 3, a high level of treatment is required. As research is going on, only the expected results have been discussed in the results and the discussion part.

Conclusions

The present study is concerned with the optimization of treatment for dairy industry wastewater. It can be concluded that the wastewater generated is rich in organic matter and hence requires efficient biological treatments like aerobic, anaerobic sludge digestion, activated sludge process and so on. It is also necessary to provide tertiary treatments in order to meet the legal standards. So far, the details about how the dairy industry works is being collected. More work needs to be carried out on other effluents emission and licensing. Designing the treatment plant and meeting the expected results is to be carried out thereafter.

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WASTEWATER TREATMENT OPTIMISATION FOR THE MEAT PROCESSING INDUSTRY

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Abstract

The meat industry is an important sector in Ireland and produces a significant quantity of wastewater. The raw effluent from meat industry contains a high level of biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids and nutrients. To achieve emission standards, these characteristics must be taken into account in the wastewater treatment design. The treatment processes contain preliminary, primary, secondary and tertiary treatment. Various individual and combined systems have been used in the current wastewater management. An overview of the most common applied technologies is introduced in this study.

Introduction

The agriculture food and drink industry is an important industrial sector that accounts for 7.6% of Ireland's economy (DAFM 2016) and it plays a significant role in water consumption issues. Among various kinds of food industries, meat processing industries make up around 32% of Ireland's agricultural manufacturing (Bordbia 2016). The production of meat already becomes one of the top two or three most significant contributors to the world environmental problems. The wastewater from the meat industries contains high levels of the BOD, COD, fat, suspended solid, nitrogen and phosphorus. As the meat industry effluent is regarded as a high-strength industrial wastewater, it must be treated before discharging into the ecosystem.

In recent years, there are several wastewater treatment methods applied to deal with the effluent discharged by the meat industry. Similar to the technologies that are used in municipal wastewater treatment, the methods to deal with the meat industry wastewater also include the preliminary treatment, primary treatment, secondary treatment and sometimes even the tertiary treatment (Bustillo-Lecompte and Mehrvar 2015). The preliminary treatment is the physical process ahead of the treatment management which is used to separate the solid waste and large particles from the raw effluent. The methods after the preliminary treatment are various including the biological treatment, physicochemical treatment, and combined processes. Each method has its own advantages and disadvantages, which will be discussed below.

The objective of the study was to identify the characteristics of meat industry wastewater and analyse different treatment methods.

Materials and Method

The method used in this study is literature review. In this study, the characteristics and standards limits of meat industry wastewater are discussed, according to which, various treatment methods can be compared. All the results will be present in the form of tables.

Results and Discussion

Meat industry in Ireland

The meat industry is one of the main sectors of agriculture in Ireland. Table 1 shows the slaughtering numbers in the meat industry for cattle, sheep and pigs from the Department of Agriculture, Food and Marine (CSO 2015).

Table 1: Livestock slaughtering in Ireland ('000 head) (CSO 2015)

	Cattle('000 head)	**Sheep**('000 head)	**Pigs**('000 head)
April 2014	148.2	210.0	250.1
April 2015	136.3	198.3	268.9

Characteristics and standards of meat industry wastewater discharge

Common characteristics of meat industry wastewater are presented in table 2. The blood from the meat processing and solids break down in the water results in high levels of organics. Other emissions such as nutrients are caused by the breakdown of proteins. According to the Reference Documents on Best Available Techniques in the Slaughterhouse and Animal By-products Industries, the emission levels need be controlled within the range in table 3.

Table 2: Characteristics of meat industry wastewater (Bustillo-Lecompte and Mehrvar 2015)

Parameter	**Range**	**Mean**
BOD_5 (mg/L)	150-4635	1209
COD (mg/L)	500-15,900	4221
TSS (mg/L)	270-6400	1164
TN (mg/L)	50-841	427
TP (mg/L)	25-200	50

Table 3: Emission level associated with BAT for meat industry (European Commission 2005)

Parameter	COD	BOD_5	SS	TN	TP	FOG
Emission level (mg/L)	25-125	10-40	5-60	15-40	2-5	2.6-15

Preliminary treatment

The preliminary treatment aims to remove the solids and large particles from the raw effluent. Typical methods for solid waste removal in wastewater contain screens, fat separators and flotation. At this stage, 50-70% of solid waste can be removed from the wastewater. Moreover, it is possible to collect a large amount of blood in the wastewater which can reduce the BOD level by 25% to 40% (Mittal 2006).

Primary treatment

Primary treatment is sometimes used prior to secondary treatment. Dissolved air flotation (DAF) system is a popular method to reduce the load of FOG, SS and BOD in the effluent. These processed can reduce 75-80% BOD and 70-90% SS (Johns 1995). Other methods such as inclined settlement system or coagulation can achieve similar results.

Secondary treatment

Reducing the organics level remaining after primary treatment is the main focus of the secondary treatment (Bustillo-Lecompte and Mehrvar 2015). Common methods in this stage contain physicochemical treatment, biological treatment and combined processes. Biological treatment is widely used in recent years including anaerobic and aerobic treatment. Anaerobic treatment is highly effective and requires relatively simple equipment when treating high-strength industrial wastewater (Bustillo-Lecompte and Mehrvar 2016). Thus the aerobic treatment is usually applied as post-treatment of anaerobic or physicochemical treatment (Chernicharo 2006). Physicochemical treatment such as the electrochemical (EC) and membrane technology now are becoming interesting alternatives. The EC process is a cost-effective advanced technology to remove organics, colour and adjusts pH in the water, which has advantages such as easy automation, high removal efficiency, short treatment time and low sludge production (Thirugnanasambandham *et al.* 2015). Membrane technology is another alternative which enables the system to reduce the particles, bacteria, microorganisms and organics during operation. In terms of operation and economics, combined processes is a good way to couple the benefits of different technologies to optimize the treatment method. For example, integration of biological and advanced oxidation process (Bustillo-Lecompte and Mehrvar 2016), coagulation and EC combined system(Thirugnanasambandham *et al.* 2015), activated sludge-reverse osmosis combined system(Bohdziewicz and Sroka 2005), etc. Table 4 presents the efficiencies of waste removals of different technologies(Thirugnanasambandham *et al.* 2015) (Bustillo-Lecompte and Mehrvar 2016) (Johns 1995).

Table 4: Performance efficiencies (%) of different technologies from literature review

		TSS	COD	BOD	FOG	TN	TP
Preliminary treatment	Screening	30	55	60			
	Fat separation	yes	yes		yes	yes	yes
1st treatment	DAF	70-90	30-90	75-80	yes		
2nd treatment	Anaerobic treatment		90	88.8			
	Activated sludge	94	89	89.7		81.5	85
	Electrocoagulation	93	84	87	99	yes	
	Membrane system	98	85.8	92.5		90	97.5
3rd treatment	Filtration/coagulation		75			88.8	99.9

Tertiary treatment

Tertiary treatment refers to the removal of nutrients like nitrogen and phosphorus after the secondary treatment. It is the final cleaning step for the treated effluent. Typical operations are filtration, coagulation and precipitation.

Conclusions

Meat industry wastewater is commonly pre-treated by screening, FOG separation, followed by the primary treatment such as DAF. Then, the secondary treatment processes to remove the organics include biological treatment, physicochemical treatment and combined processes. Among them, combined processes have advantages to couple the benefits of different technologies. The final process is the tertiary treatment for nutrient removal.

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LATENT EXISTENCE OF NANOSILVER IN DRINKING WATER SUPPLIES

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Abstract

Engineered nano materials (ENMs) are increasingly utilized in everyday products and processes. Silver nanoparticles (AgNPs) may present a risk to water supplies due to inadequate removal during drinking water treatment process. Levels of drinking water consumption varies over the demographic range which present varying levels of potential exposure. Probabilistic modelling of drinking water treatment removal rates for AgNPs during primary, secondary, and tertiary treatments were performed. AgNP concentrations in finished drinking water were estimated based on literature data on removal rates from bench scale studies. Probability distributions were incorporated to account for the uncertainty in the data. Preliminary results indicate that AgNP exposure in finished drinking water could be in the sub (μg/ L) range.

Introduction

The ever increasing utilization of products and processes incorporating nano enabled particles is elevating concerns in relation to their environmental fate and potential toxicity (Liu *et al.* 2015). While almost any material can be produced in nano form (classed as nano-material with at least one dimension being in the 1-100 nm size range) concerns have been raised in relation to the increasing use of silver nanoparticles (AgNPs) in an array of products. Through the use and disposal, AgNPs can enter waste streams and in particular wastewater networks (Sun *et al.* 2015). Traditional processes used for removal of contaminants in wastewater treatment plants may not be adequate for the complete removal of nano particles (Fu and Wang 2011), resulting in direct particle release during effluent discharges to surface waters.

Fate and behaviour of AgNPs in surface waters are difficult to assess due to the invariably complex nature of natural surface water systems (Figure 1). Their fate is further complicated by the presence of particle surface stabilizers applied to particles to retain stability and uniformity during storage which can inhibit natural removal mechanisms. Coatings can influence the dispersion and mobility of the particles in surface waters potentially resulting in particles persisting for extended periods of time (Simeonidis *et al.* 2015). Surface and ground waters provide the vast majority of drinking water supply sources in Ireland. Once water is abstracted it is subject to water treatment which typically involves coagulation, flocculation, and sedimentation for the removal of contaminants followed by disinfection prior to network distribution and eventual human consumption. While ENMs are a relatively new emerging contaminant, current drinking water treatment processes and plant infrastructure may not be adequate for the removal of ENMs presenting future challenges for entrapment. In particular, the release of Ag^+ ions from AgNPs during particle surface dissolution are known to be toxic to organisms (Simeonidis *et al.* 2015). Human water consumption patterns vary significantly between the differing demographic groups. Ingestion of AgNPs and subsequent risk of ion release may pose a potential direct risk to human health (Chalew *et al.* 2013). Chronic exposure risk from AgNPs remains unclear and as such should be treated as a potential risk to human health that warrants further investigation.

The objective of this study was to assess the development of a probabilistic exposure model for nanosilver in treated drinking water.

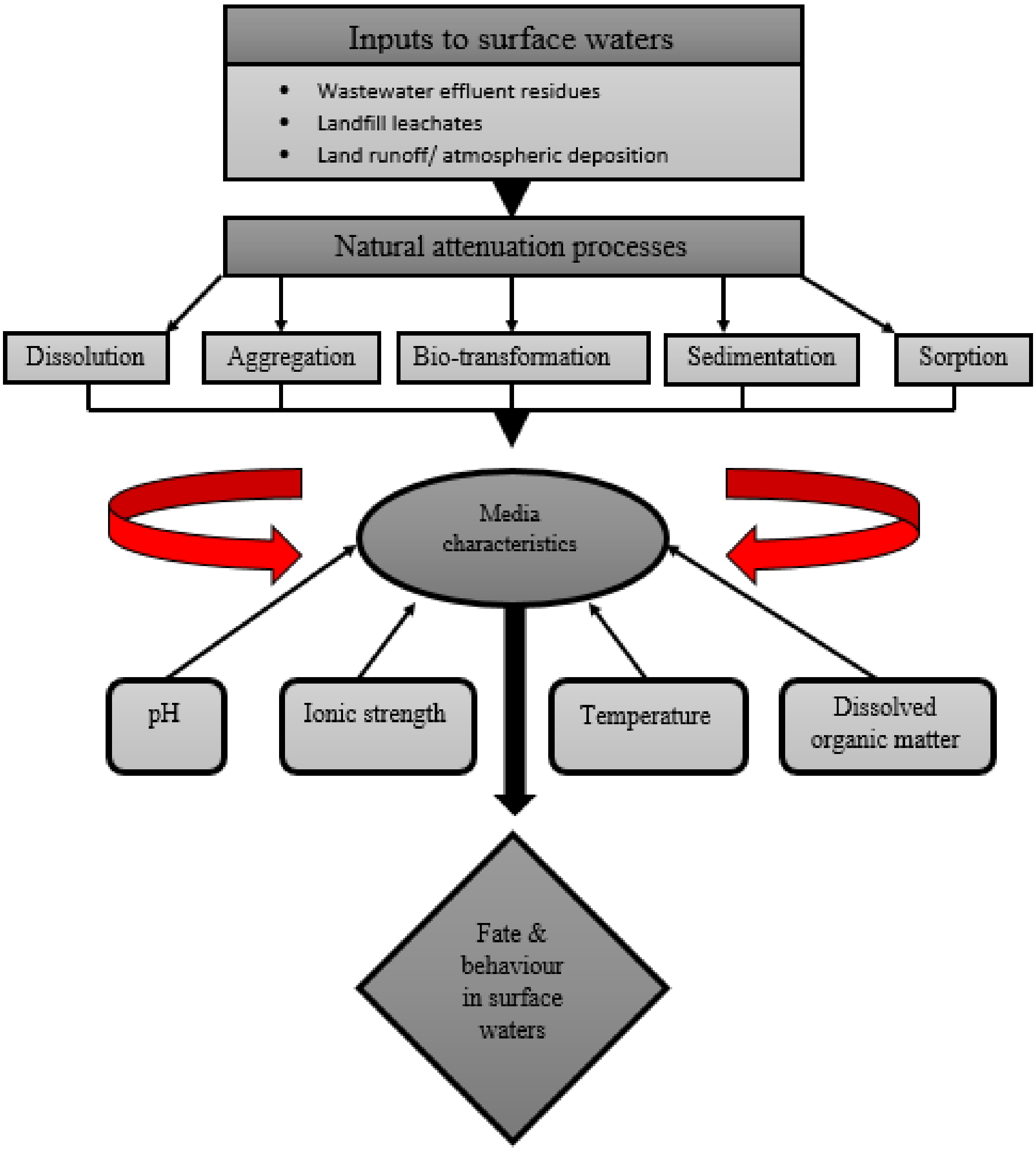

Figure 1. Fate factors in surface waters.

Materials and Methods

A framework probability risk model was developed utilizing Palisade @Risk 7 software for assessing the fate and behaviour of AgNPs through the aquatic environment incorporating potential natural removal mechanisms. Processes of dissolution, aggregation and sedimentation were incorporated as the main natural removal mechanisms. Probability distributions where developed with data sourced through literature on the main processes identified. A base concentration of 0.01 µg/ L was used as a case study and simulated as the surface water input concentration. A mass balance assessment flow was conducted through each natural removal mechanism stage. Data from bench scale studies of attachment efficiencies were collated to estimate aggregation potential of AgNPs with PVP or Citrate coatings. Persisting and available concentrations were determined through a mass balance model accounting for estimated removal fractions by natural processes. Abstracted water concentrations were further modelled through drinking water treatment processes to attain a post treatment concentration (Figure 2).

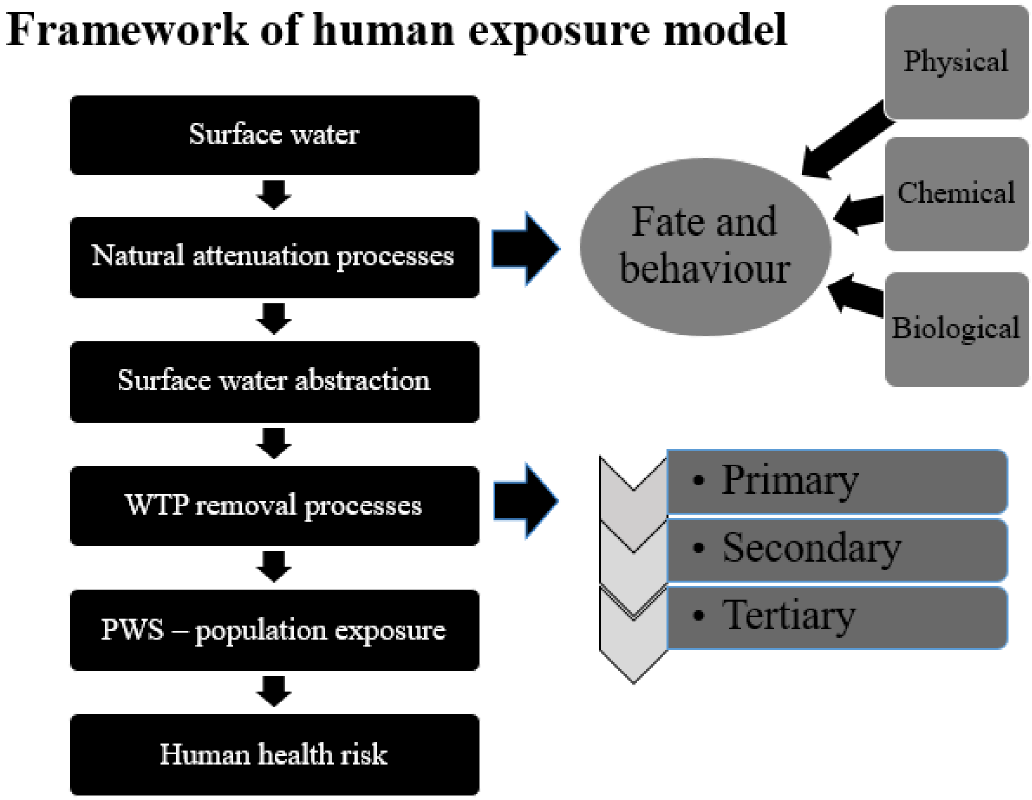

Figure 2: Framework of human exposure from drinking water sourced from surface water.

Results and Discussion

Seasonal data on water parameters were collated from Irish river water studies to represent temporal change. The summer season was selected to represent a worst case scenario as water levels are expected to be seasonally low so concentrations of AgNPs released will likely be more concentrated as the dilution factor will be reduced. Risk analysis was conducted incorporating uniform and triangular probability distributions to account for the uncertainty in the data and variability in the system. Preliminary results from the exposure model (assuming an initial hypothetical case study with 0.01 µg/L entering the surface water) indicated sub (µg/ L) levels of nano silver in surface waters, with a mean value of 4.26 E^{-4} µg/ L (90^{th} percentile range 1.19 E^{-4} - 7.71 E^{-4} µg/ L) and 4.21 E^{-4} µg/ L (90^{th} percentile range 1.14 E^{-4} - 7.69 E^{-4} µg/ L) for citrate and PVP coated AgNPs, respectfully for a scenario representing summer environmental conditions (Table 1). Preliminary results for post treatment drinking water obtained from surface water abstraction for the same season indicated mean values of 4.23 E^{-5} µg/ L (90^{th} percentile range 1.00 E^{-6} - 1.72^{-4} µg/ L) and 4.20 E^{-5} (90^{th} percentile range 1.00 E^{-6} - 1.63 E^{-4} µg/ L) for citrate and PVP coated AgNPs, respectfully (Table 2).

Table 1. Concentration residuals in surface water prior to abstraction

Surface water	
	Mean (5^{th} , 95^{th})
Citrate	
AgNP	**4.26 E^{-4}** (1.19 E^{-4}**,** 7.71 E^{-4})
PVP	
AgNP	**4.21 E^{-4}** (1.14 E^{-4}, 7.69 E^{-4})

Table 2. Concentration residuals post drinking water treatment

Post drinking water treatment	
	Mean (5^{th} , 95^{th})
Citrate	
AgNP	**4.23 E^{-5}** (1.00 E^{-6}, 1.72 E^{-4})
PVP	
AgNP	**4.20 E^{-5}** (1.00 E^{-6}, 1.63 E^{-4})

Conclusions

Surface waters are complex in nature with variable concentrations of organic and inorganic material present, resulting in considerable uncertainty as to the actual fate and behaviour of AgNPs in this environment. Preliminary results from the risk model indicated AgNPs are potentially present and persisting in surface waters. Therefore, AgNPs may subsequently be present during abstraction for drinking water and may present an unknown risk to human health. Drinking water treatment plant infrastructure maybe inadequate for the complete removal of particles in the nano scale. While AgNPs levels were in the sub (µg/ L) range and not likely to present an immediate risk to human health, chronic exposure to AgNPs remains unclear. Increasing utilization of AgNPs will likely elevate AgNP concentrations with as yet unknown risk to human health.

Acknowledgements

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A PRELIMINARY REVIEW OF MANAGEMENT FACTORS AFFECTING NITROUS OXIDE EMISSIONS FROM LIVESTOCK SYSTEMS

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Abstract

Grass based ruminant production systems are a major source of anthropogenic N_2O emissions, resulting from the inefficient utilisation of N by ruminants where 20-40% of N ingested is utilised in milk production and animal growth. The combination of excess N feeding and poor N utilisation lead to the deposition and spreading of high N manure on to pastures. Along with this, additional N is applied in the form of synthetic N fertiliser to increase grass supply to cattle. The inability of pastures to fully utilise the N applied due to excessive loading, poor climate and soil conditions and imperfect timing of application will result in the surplus N being lost in the form of N_2O emissions directly as well as indirectly (NH_3, NO_3) all of which have a detrimental effect on the environment. This review focuses on dietary and synthetic fertiliser mitigation strategies where their strengths and weaknesses are highlighted and compared. The study also investigates the potential of these strategies to be adopted into grass based systems.

Introduction

Nitrous oxide (N_2O) is the third most important greenhouse gas (GHG) where it has a potent global warming potential 298 times higher than carbon dioxide (CO_2) over a 100 year period. Agriculture, particularly ruminant production systems are a large contributor to direct N_2O emissions as well as indirect N_2O emissions such as the emission of ammonia (NH_3) into the atmosphere and nitrate (NO_3) to groundwater and water bodies.

In Ireland, agriculture contributes nearly 90% of the national N_2O emissions with beef and dairy farm systems being the largest contributors. N_2O emissions from livestock systems vary greatly depending on soil conditions, climate, diet, type of excreta, timing of application and the type of synthetic fertiliser. Ruminants have a very poor N utilisation efficiency, rarely exceeding 30% this indicating that approximately 70% of N ingested is excreted where the excess N consumed by the livestock is either excreted onto pasture in dung and urine or is collected during the housing period over winter where it will eventually be spread on to pastures as a means of fertilisation. Of the N excreted on to pasture, over 60% is excreted in urine which is far more susceptible to N loss to the environment than faecal N. In pasture based livestock production countries such as Ireland, it has been reported that 82% of urinary N is excreted on to pastures where 20-30% of the urinary N is leached and approximately 2% is transformed and emitted as N_2O. This makes pasture based livestock systems a key contributor to N loss and a main source of GHG emissions.

To address the concern over N_2O emissions, a number of N_2O mitigation strategies must be investigated to determine if they are effective in reducing N loss and improving the N use efficiencies of pasture based beef and dairy production systems in an attempt to reduce emissions. Therefore this study will review a number of published N_2O mitigation strategies from literature where they will be evaluated for the appropriateness for the use in pasture based livestock production systems typical to Ireland. This paper is a preliminary investigation of N_2O mitigation strategies which will form a basis for a comprehensive evaluation of N_2O mitigation strategies for livestock production systems.

The overall objective of this study is to review the effect of management factors and mitigation strategies on N_2O emissions from pasture based livestock systems using a whole farm model approach.

Materials and Methods

A literature review is currently being compiled using publications available on Web of Science and Science Direct. Google Scholar was occasionally used when specific papers were not available on the research databases above. Key words such as "nitrous oxide from agriculture", "nitrous oxide", "mitigation strategies", "dietary effects on N excretion" and "management factors on N excretion" were inputted into these search tools to gather appropriate literature. The mitigation strategies compiled will be compared and evaluated in respect to the livestock system (beef or dairy production), type of mitigation strategy (dietary or management) and also the effectiveness of the mitigation strategy. This literature review looks at the potential application of mitigation strategies to reduce the N_2O emissions being emitted from Irish beef and dairy production systems. This involves mitigation strategies ranging from farm inputs such as fertiliser and grassland management to mitigation strategies associated with improving the livestock N utilisation efficiency and diet alteration.

Results and Discussion

There are numerous N_2O mitigation strategies published in scientific journals which include grassland management approaches, supplementary feed strategies, fertiliser application and those which use nitrification and/or urease inhibitors.

Dietary Mitigation Strategies

One option is to reduce the N amount being excreted in urine and investigating the effect of increasing the WSC of cattle diet through the use of high sugar grass varieties (Miller et al., 2001). That study found that the increase in WSC content helps to balance and synchronise the C:N ratio in the rumen. This balance means that there will be an increase in the amount of energy used by the microbes present in rumen to synthetize the N into proteins thus reducing the amount of ingested N being transformed into NH_3 gas and consequently urea which would eventually become the source of N in urine.

Table 1: Nitrogen intake and partitioning in dairy cows offered zero-grazed high sugar (HS) and control (Miller et al., 2001)

	HS	Control	s.e.d.	Significance
Nitrogen intake g/day				
Grass	171	181	7.3	NS
Concentrate	109	109	-	-
Total nitrogen intake (g/day	280	290	15.1	NS
Nitrogen output				
Urine (g/day)	71.3	100	5	0.001
Proportion of N intake	0.25	0.35	0.02	0.01
Milk (g/day)	83.3	67.5	4.12	0.01
Proportion of N intake	0.3	0.23	0.012	0.01

In contrast to this, another study (Lee et al., 2002) found that the increase in WSC content of grass and the synchrony of energy and N release in the rumen does not significantly improve the rumen microbial protein synthesis and the flow of non-ammonia N to the small intestines. This proves that that despite the theory showing that high sugar diets improve ruminant N utilisation, animal trials have shown to have an inconsistent increase in N utilisation though they do tend to show that urine N excretion is reduced.

However, it has been stated that diets which are more focused on UN reduction may result in an increase in enteric CH_4 production (Dijkstra et al., 2011). Pollution swapping could be a possible concern if the N intake is reduced and replaced with rumen fermentable carbohydrates, the production of CH_4 will subsequently increase (Miller et al., 2001). To address this issue another study (Gregorini et al., 2016) created an objective to identify diets which have the best compromise between UN, CH4 and milk production (frontier) where if any further reduction in UN is to be made means an increase in CH_4 production. Diets were created for non-lactating and lactating dairy cows where the objective functions were high body weight gain (non-lactating cows), high MS (lactating cows), low urine N excretion and CH_4 emissions for the four periods of lactating. From the diet for each phase of lactation it is suggested that cereal and beet feeds show most commonly in the diets. All the forages offered to these animals have a high fermentable carbohydrate:protein ratio thus showing their potential to increase the N use efficiency. This result is similar to another study (Castillo et al., 2001) which investigated the effects of offering lactating dairy cattle diets of varying energy content consisting of different amounts of fermentable carbohydrates of various types to N balance. However, other work suggests that ruminants which are fed on a high grass/clover pasture diet would not result in the reduction of UN, CH4 and the increase in Milk Solids (MS) (Gregorini et al., 2016). This is controversial due to countries such as Ireland basing their dairy and beef production systems on grass based diets. Conversely, the reasons why these countries utilise grass as their main feed source is due to the well reported positive relationship between profit and grass based systems (Gregorini et al., 2016). However, costs are not always considered in feed trials, so financial viability could be questioned in some cases. The number of possible diets created for the four different stages of lactation address this issue as it is not possible to agree on one dietary option due to the variability in cost and availability of different feed ingredients.

Fertiliser Application Mitigation Strategies

Recent studies have found that N_2O emissions tend to be much higher from NO_3 based fertilisers (e.g. CAN) when compared to urea; emissions are further increased if spread in regions with wet high organic soils. The impact of changing synthetic fertiliser forms from CAN to urea based products as a means of mitigating N_2O emissions from fertiliser application was investigated over three locations across the island of Ireland (Harty et al., 2016). The results showed that changing the N fertiliser type had a significant impact on N_2O emissions where CAN application resulted in an average EF% of 1.5% while the average emission factor for urea application was only 0.4. Though there were substantially more indirect emissions from urea application compared to CAN application the overall N_2O emissions was much lower for urea application. The N_2O emissions from CAN application was far more variable ranging from 0.59 to 3.82 while urea was farm less variable only ranging from 0.24 to 0.63.

The study also examined a combination of mitigation strategies by combining nitrification inhibitors (NI), urease inhibitors (UI) and urea. NI inhibits the nitrification process thus postponing denitrification and therefore the production of N_2O while UI inhibits the hydrolytic action of soil urease, which in turn postpones the hydrolyses of urea to ammonium carbonate and consequently NH_3 gas by blocking sites of urease enzymes. A further reduction occurred where urea+UI had an EF of 0.41, urea+NI had an EF of 0.2 and the combination of urea +NI +UI had an EF of 0.18 (Fig. 1).

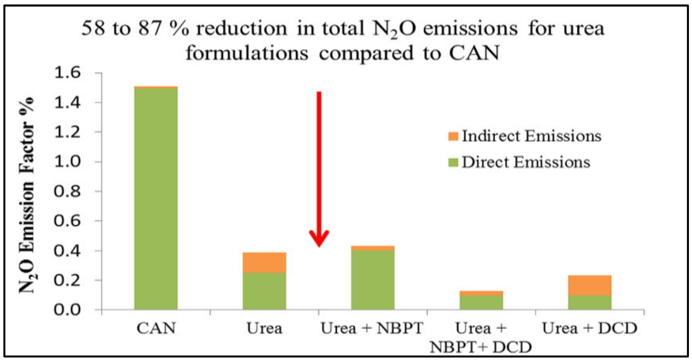

Figure 1: Reducing nitrous oxide emissions by changing N fertiliser use from calcium ammonium nitrate (CAN) to urea based formulations (Harty et al., 2016).

However, though it is clear from the graph above that NI (DCD) and UI (NBPT) are effective in reducing the N_2O EF there is a number of draw backs. Firstly, for these mitigation strategies to be implemented they must be financially viable. Urea + NBPT are commonly found in the EU where though it is more expensive than pure urea it is still cheaper than CAN. The combination of DCD and NBPT with urea showed the best result however the addition of additional inhibitors to urea will have an effect on fertiliser costs where it is advised for economical purposes to only include DCD if a C credit is received for reducing N_2O emissions. There is also concern over the sustained effectiveness of the repeated use of DCD for the reduction of N_2O where it was found that when cattle excreta deposited onto pastures are treated with DCD four and five years consecutively, the long term use did not alter the impact on reducing N_2O emissions when compared to the first application (de Klein et al., 2011). This means that nitrifying bacteria did not adjust from the repeated use of DCD therefore questioning the effectiveness of DCD.

Conclusion

In conclusion this review conducted a study of the different mitigation strategies developed for N_2O emissions from temperate grassland beef and dairy livestock production systems. The study found that there is great potential for the mitigation of N_2O emissions through dietary alteration strategies however the effectiveness of these strategies from animal trials varies greatly. In regards to synthetic fertiliser application and the use of NI and UI, the study found that there is great potential in the use of these strategies to mitigate N_2O from pasture based livestock production systems.

Acknowledgements

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AUTONOMOUS DISEASE DETECTION IN CROPS USING DEEP LEARNING

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Abstract

In crop production, precision agriculture applications seek to deploy different devices and systems to enhance yield and to reduce ecological impacts by optimizing inputs and timing. Large amounts of the world food production are lost through insects, weeds and diseases occurrence in crop fields. Moreover, traditional farming makes use of chemical application without considering local specific factors, such as disease severity and minerals deficiency, which vary within the field. The last years of constant improvement of sensing technologies have generated large amounts of spatial and temporal data that represents an opportunity for the deployment of machine learning systems to assess and improve crop production. Data analysis through machine learning states that computers are capable of identify and quantify patterns taking input data by applying classification, clustering, regression and prediction algorithms. Remarkable applications of machine learning in agriculture cover topics such as diseases and weed detection, canopy cover estimation and yield prediction. This work aims to present first results of the application of a current state-of-the-art approach using deep neural networks to detect diseases in crops, taking as use cases wheat and barley cultures.

Introduction

The increasing availability in rich and complex data for analysis, online and offline, added to the significant progress in algorithms, have made machine learning a popular demand in the last years. This fact relies also on the advances of computational power solutions, offered in an affordable way, as per example, on cloud computing services. These technologies have been applied to precision agriculture in the last decade producing promising results in applications, such as, disease detection in crops. Taking into account the factor that plant diseases relies on upon particular natural elements and that infections regularly show a heterogeneous conveyance in fields, the use of spectroscopy may be considered a valuable resource in identifying disease distribution and severity within crop fields (Franke and Menz 2007). The use of such technologies in addition to new data analytics techniques may be applied to the deployment of local-specific pest management programs. Considering the variability and severity of diseases across the crop fields, by means of targeted pest management programmes, result in reduction of pesticide use and in this way the monetary cost and environmental effect on crop cultivation (Gebbers and Adamchuk 2010). As presented by Sankaran *et al* (2010), limitations of molecular techniques are the time-consuming and labor-intensive and the necessity of an elaborate method, particularly through sample preparation (collection and extraction) to acquire consistent and precise outcomes on plant disease detection. Spectroscopic methods have potential to be employed on rapid detection of plant diseases and in large scale. The evolution of data processing technologies along with developments of geographic information systems opens new opportunities for precision agriculture and plant phenotyping (Mahlein 2016).

The objective of this study is to develop a state-of-the-art application of deep neural networks in order to detect crop diseases in different stages and for different species of plants using as input data, simple RGB images.

Materials and Methods

Database

In order to deploy deep learning architectures, it is fundamental to collect a large amount of images that are used from the training phase to the evaluation of performance. Deep neural network abstract features through the multi layers level by extracting the underlying particularities of each data class. For the sake of the experiment to be successful, a given number of samples with enough discrimination information has to be provided to the network. The images used in this work were downloaded from the internet, where a search for diseases of wheat and barley crops was conducted. Search queries were performed in English, Portuguese and Spanish for the following diseases:

- Barley: Scald, fusarium head blight, net blotch, powderly mildew and rumalaria.
- Wheat: Brown rust, eyespot, fusarium ear blight, mildew, septoria and yellow rust.

Method

Deep learning neural networks have multiple hidden layers that are able to learn increasingly abstract representations of the input data. In computer vision, deep learning convolutional neural network (CNN) have revolutionized the field by producing results with accuracy never seen before.

CNN's are built upon convolutional layers. The layer's parameters are made of a set of learnable kernels (or filters), that take a small receptive field, but spread over the total depth of the input volume. CNN's have basically two phases of operation in the training phase named forward pass and backpropagation. In the forward pass, each filter is convolved over the height and width of the input data, calculating the dot products among the filter entries and the input, generating a 2D activation map of that filter. Given that, the network learns kernels that activate to a determined particular kind of feature at some spatial location in the input data. In the backpropagation phase, the network calculates the partial derivatives of the error, given by a cost function, in relation to all weight and biases of the network. After having the calculation of this gradient of weights, the parameters of the network are updated using a learning rate hyper parameter.

The implementation of the deep learning neural network was due by using an open source deep learning framework, named Caffe (Jia *et al* 2014). Caffe, among others frameworks, offers the advantage of having pre-trained models on large datasets such as ImageNet (Jia *et al* 2009). Using the pre-trained models the weights of neurons of the neural network are already tuned to recognize real word objects of classes presents in a given dataset. In this implementation a fine-tuning approach using the Plant Village Dataset (Hughes and Salathé 2015) was applied.

Fine tuning search for improvement of the efficiency or efficacy of a method or function by creating minor changes to improve or enhance the outcome. In this context the model was re-trained using the Plant Village Dataset for adapting the network to detect crop leaves features.

Every convolutional layer of the network has M maps of equal size, M_x and M_y, and a kernel size K_x, and K_y, is shifted over a determined region of the input image. The skipping factor S_x and S_y define the number of pixels that will be skipped by the kernel in the x and y direction between subsequent convolutions (Ciresan *et al* 2011). The size of the output map can be defined as:

$$M_x^n = \frac{M_x^{n-1} - K_x^n}{S_x^n + 1} + 1,$$

$$M_y^n = \frac{M_y^{n-1} - K_y^n}{S_y^n + 1} + 1,$$

Where *n* indicates the layer. Each map in layer in layer Ln is connected to most M_{n-1} maps in layer Ln_{-1}.

Rectified Linear Units (ReLU) were used in Alexnet (Krizhevsky *et al* 2012) as substitute for nonlinear neurons which results with deep CNNS several times faster to train. This activation function adaptively learns the parameters that are applied to the output of every convolution layer. One ReLU activation is simple defined as:

$$f(z_i) = \max(0, z_i)$$

Results

The system's implementation is shown in the Figure 2. In the training phase the network was adapted to work with the proposed dataset. A new training phase was carried out in order to adjust the parameters of the network to learn the diseases features depicted by images of barley and wheat.

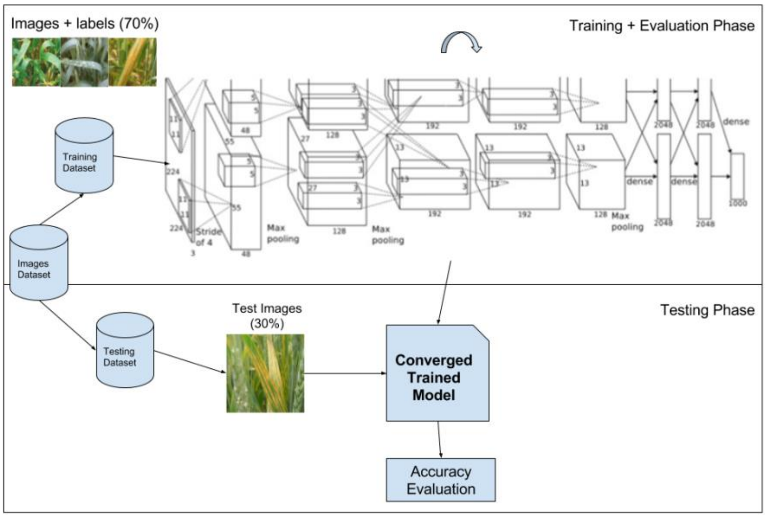

Figure 1. High level schematic of the proposed method showing the training and testing phases of the deep neural network.

This modified version of AlexNet (Krizhevsky *et al* 2012) deep neural network had an overall accuracy of 87% in the test set, using the converged trained model, where each output class corresponds to one of the diseases listed in the dataset. In other words, for each 100 samples presented in the test set, the network was able to classify 87 accurately. The network's parameters can be found in Table 1.

Table 1. Parameters used in the deep neural network.

Input Images size:	224x224
Output Classes:	11
Number of hidden layers:	5
Number of fully connected layers:	3
Number of neurons:	650.000
Number of parameters:	60.000.000
Overall accuracy:	87%

Conclusions

In the literature, a vast range of works in computer vision are found that show good results in the crop's decision detection context. These methods usually rely on the use of handcrafted special features or in the use of hyperspectral imaging, which comes with great cost and is unavailable for the majority of crop growers. In this paper, a new approach using RGB data of simple cameras was proposed by deploying a new trending method of the computer vision community, named deep learning. The deep learning networks are able to extract detailed abstract features directly from data and have been presenting significant results in diverse applications. In the first results of this proposal, an overall accuracy of 87% showed the potential of this approach for crop disease detection. Future work will augment the dataset with diseases in diverse levels and culture and test new neural networks architectures to enhance the result accuracy.

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MODELLING THE EFFECT OF SEASONAL CONDITIONS ON ANTIBIOTIC RESISTANT *ESCHERICHIA COLI* IN RIVER WATER

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Abstract

Antibiotic resistant infections are a risk to human health due to the difficulty in treating this kind of infection. Antibiotic resistant bacteria (ARB) are present in rivers around the world and it is important to gain an insight into how ARB survive in the water environment in order to understand if they are a potential human health risk through this pathway. This paper examines the survival of ARB in river water throughout the different seasons of the year. Data was collected on the different environmental factors (salinity, solar radiation, light extinction coefficient and water temperature) that may effect the ARB survival. Mancini's equation was used to calculate the effect of environmental conditions on antibiotic resistant *Escherichia coli (E. coli)*. Microsoft Excel and the @ risk software were used to create the model. The preliminary results show that in order to achieve a 1 log reduction of antibiotic resistant *E. coli* in river water it took 2.3 days (55 hours) in summer conditions; 2.9 days (69 hours) in spring conditions; 3.3 days (78 hours) in autumn conditions and 4.5 days (108 hours) in winter conditions. This shows that the bacteria will survive longer in winter conditions in comparison to summer conditions. This type of information is useful in creating risk assessment models that investigate the risk to human health from water.

Introduction

ARB are bacteria that were once killed by an antibiotic but can now resist the effects of that antibiotic (WHO 2016). Antibiotics are necessary in treating infections and when they lose their effectiveness this can make medical procedures such as chemotherapy treatment for cancer, organ transplants, surgery such as hip replacements and caesarean sections very high risk for patients (WHO, 2016). Antibiotic resistant infections are difficult to treat and this can sometimes lead to death. ARB are responsible for 25,000 deaths in Europe annually and this is set to reach 10 million deaths globally by 2050 if this problem is not successfully controlled (WHO, 2014).

Research shows that ARB are present at varying levels in rivers around the world and it is unknown the risk they pose to human health from their presence in the water environment (Ash *et al* 2002; Marti *et al* 2013; Iwane *et al* 2001). It is important to identify how ARB can survive in the environment and to identify if they have the same survival characteristics as sensitive bacteria. According to scientific literature bacteria that are antibiotic resistant or bacteria that are sensitive to antibiotics can behave similar to environmental factors (Flint, 1986; Smith *et al* 1974; Rogers *et al* 2011). This model represents a collection of existing knowledge regarding environmental influences. It is important to gain an insight into the survival characteristics of ARB in the environment as this type of information could be useful in creating risk assessment models that can help to gain an understanding of the risk ARB pose to human health. According to Vaz Moreira *et al* (2014) there are still unanswered questions surrounding antibiotic resistance and the risk to human health through their presence in the water environment.

The goal of this study is to estimate the effect of seasonal conditions on antibiotic resistant *Escherichia coli* in river water

Materials and Methods

Data collection
To estimate the decay of ARB in water data was collected on environmental factors such as salinity, water temperature, light extinction coefficient and solar radiation from scientific literature.

Environmental factors were collected to represent seasonal conditions for spring, summer, winter and autumn that are typical of north-western European countries.

Software and model
To account for variability and uncertainty in the environmental inputs, probability distributions were used. Monte Carlo Simulation was used on the model output to characterise for uncertainty and variability in model input data. The model was run for 10,000 iterations. Microsoft excel and the @ risk software (Palisade Corporation, New York, USA) were used to develop the model. For this model it was assumed there were 100 CFU/ml of AR *E. coli* in the river water as the initial starting point before environmental factors were applied.

Mancini's equation
Mancini's equation (Equation 1) was used to model the effect of environmental factors on antibiotic resistant *E. coli* in river water. Mancini's equation is where k is the exponential decay rate of *E. coli* in water (d^{-1}); 0.8 represents the die off in darkness; 0.006 is the salinity related decay; % sea water is the salinity of the river water; 1.07 is the temperature related decay; T is the river water temperature (°C); I_A is the solar radiation (langley/h); et is the light extinction coefficient (m^{-1}) and H is fully mixed water depth (m) (Mancini *et al* 1978).

$$k= \left[0.8 + 0.006 \times (\%\, seawater)\right] \times 1.07^{(T-20)} + I_A \frac{1-e^{-etH}}{et} \quad \text{Equation 1}$$

Results and Discussion

Preliminary results
Preliminary results show that in order to achieve a 1 log reduction of antibiotic resistant *E. coli* in river water it took 2.3 days (55 hours) in summer conditions; 2.9 days (69 hours) in spring conditions; 3.3 days (78 hours) in autumn conditions and 4.5 days (108 hours) in winter conditions (Figure 1). The decay rate (d^{-1}) for the summer, spring, autumn and winter seasons are shown in Table 1. The results show that antibiotic resistant *E. coli* will survive longer in winter conditions compared to summer conditions.

The results show that a longer survival rate in winter conditions could be due to the lower winter water temperatures - according to Ferguson *et al* (2003) bacteria will survive longer in lower water temperatures in comparison to higher water temperatures. It has been reported that at water temperatures of 42°C it took 8.4 hours for *E. coli* levels to be reduced by 90% of the initial starting levels (Selvakumar *et al* 2003). In comparison it took 36 hours at 10°C for the *E. coli* bacteria to be reduced by 90% of the initial starting levels (Selvakumar *et al* 2003). Sunlight intensity is another important factor that can effect the decay rate of bacteria in the water environment. Sinton *et al* 2002 found that in sunlight conditions the reduction in bacterial numbers in fresh water were 10 times greater than when the bacteria were in darkness. In summer sunlight intensity is greater compared to winter conditions and this can lead to a faster decay rate.

Table 1. Mean decay rate of bacteria for each season

Season	Mean decay (d^{-1})
Summer	0.87
Spring	0.72
Autumn	0.35
Winter	0.17

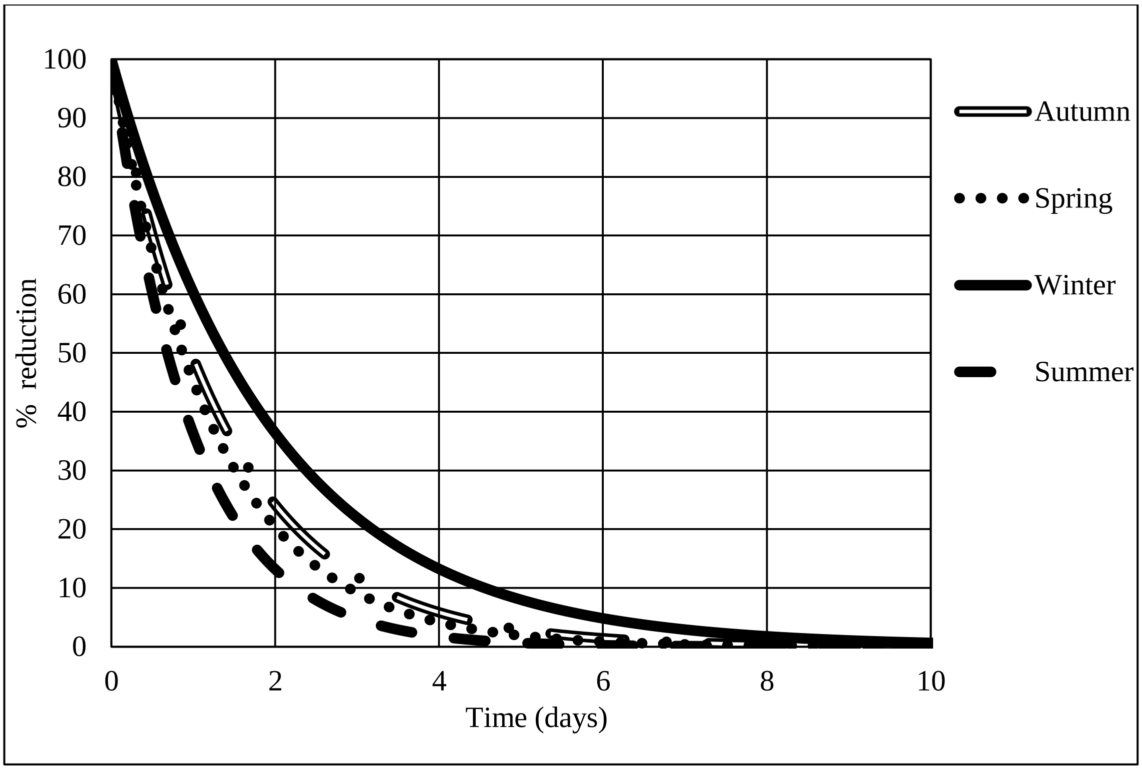

Figure 1. Mean decay rate of antibiotic resistant *E. coli* in river water for each season

Conclusion

Preliminary results show that the antibiotic resistant *E. coli* will survive longer in winter conditions in comparison to summer conditions. The main environmental parameters that are contributing to the difference in decay rates are water temperature and sunlight intensity. This model represents an accumulation of existing knowledge regarding environmental influences and applies this to estimate the decay rate of antibiotic resistant *E. coli* in river water. This paper highlights the importance of taking into consideration the different antibiotic resistant *E. coli* decay rates as a results of the seasonal conditions. This type of information could be useful to inform and improve risk assessment models in predicting ARB levels in rivers for environmental and human health models.

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PRELIMINARY URBAN SEWAGE SLUDGE INVENTORY FOR IRELAND

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Abstract

The current population growth and policies have resulted in an inevitable increase of sewage sludge production. Hitherto, land application of sludge has been considered the most common, economical and beneficial disposal alternative, even though it can make some soils get saturated. In Ireland, application of sludge to land is, by far, the main sludge disposal route. For this reason, a comprehensive inventory of the sludge currently applied to land in Ireland according to source will be performed. This will help to carry out an assessment of the long-term capacity of land for sludge management in Ireland.

Introduction

Sludge management has become a growing environmental challenge due to a steady increase in sludge quantities which is expected to continue in the coming years. This is mainly provoked by the continuous population and house density growth that make industrial works and household sewer connections increase and therefore the sludge production associated with these activities (Ahmad et al. 2016).

In addition to this, the wastewater legislative framework has become more and more stringent in recent decades. For example, the Urban Wastewater Directive (UWWD) has forced EU Member States to collect and secondary treat all wastewaters coming from agglomerations greater than 2,000 p.e. As a result, production of untreated sewage sludge across the EU-15 has increased from 6.5 million tonnes of dry solids (DS) in 1992 to 9.8 million tonnes DS in 2010 (Kelessidis and Athanasios 2012). The UWWD and Waste Framework Directive (WFD) have enhanced sludge re-use because they prohibited dumping of wastewater sludge into waterbodies and set recycling and recovery targets to be achieved by EU members by 2020, respectively. Moreover, it is well known that sludge contains valuable nutrients and organic substances. Hence, after sludge has been stabilised and converted into a biosolid, its land application has become the most common, economical and beneficial disposal option. In Ireland, over 98% of sewage sludge was re-used in agriculture in 2014 (Irish Water 2016).

However, there are many constraints to land application such as metal accumulation in soil and crops, groundwater and surface runoff contamination (Healy et al. 2017). 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. Expansion of the agri-food sector with the Foodwise 2025 Strategy will also generate extra sludge, thus, creating extra pressure to find sustainable strategies for sludge management.

The objective of this project is to compile an inventory of sludge currently applied to land in Ireland according to source to assess the long-term capacity of land for sludge management.

Materials and Methods

Sludge Inventory

Sludge can be defined as an inherent by-product of different domestic and industrial wastewater treatment processes (WWTPs). It is generally a semisolid, odorous and difficult to manage material that contains 0.25 to 12 % solids by weight and it is, by far, the largest and most problematic constituent removed from wastewater treatment plants (Tchobanoglous et al 2003). However, the amount and characteristics of the sludge depend on the type and level of treatment. For example, when biological treatment processes include coagulant addition for enhancing phosphorus removal, they produce larger amounts of inorganic sludge than standard biological processes. Sludge quantities and characteristics are also dependant on the industrial activity. Dairy sludge generally has lower heavy metal, salt, organic toxin and pathogen contents than urban sewage sludge (Conde Suárez et al 2004).

For the development of this study, the performance of a sludge inventory has commenced. It has been focused on the quantification, categorisation, and characterisation of the sludge that can be land applied according to sources. Hazardous sludge coming from pharmaceutical, chemical or any other industry and substances removed during WWTPS (i.e. screenings, grits or scums) that are not suitable for land spreading will not be considered. By contrast, any other waste materials that can be also land applied with the sludge or disposed of in a similar manner, such as paunch and lairage wastes in meat production and abattoir industries, will be included. For the moment, sludge inventory is still ongoing and only data on sludge coming from urban wastewater plants and the agri-food industry has been collected and analysed.

Data Acquisition

Hitherto, the main data resources for the sludge inventory have required records from Irish Water and EPA. Data has been mainly extracted from the IPCC and the Waste Water Discharge Licences (WWDL). The lack of a complete central repository and the use of different units to define the sludge removed from the different facilities presented in the different documents (i.e. tonnes of liquid sludge or DS, sludge volume, etc) greatly hinder the development of sludge quantification. For this reason, a sludge calculation model based on manuals and work experience has been proposed for the urban sewage sludge quantification. It will help to verify and represent sludge quantities and will make it easier to cover data gaps by using a functional unit (i.e. tonnes of sludge per p.e.) previously obtained from a statistical analysis of the results. A similar process will be proposed for other sludge categories in which sludge data is incomplete or not clear.

Figure 1 below represents a diagram of the preliminary proposed urban sewage sludge model. The model is based on a mass balance. Depending on the level of treatment in the plant, the WWTPs have been classified in four different categories described in Table 1. Taking the effluent values from the WWDL, an approximate sludge amount in dry solids is obtained for each of the different wastewater treatment levels. Afterwards it is divided into volatile (V) and inert (IN) compounds. To obtain that approximate sludge amount, standard suspended solids (SS) and biological oxygen demand (BOD) removal rates are applied to each level. Finally, the total sludge generated in the plant is worked out by adding all the sludge amounts generated in each level. When anaerobic digestion (AD) is included in the process, a reduction factor for the volatile compounds is implemented.

Table 1. Wastewater Treatment Plant Categories

Category	Level of Treatment	Description of Activities
A	WWTPs that only have Preliminary & Primary Treatment	Screening, grit removal, FOG removal, first clarification, coagulation and flocculation, etc
B	WWTPs that include activities in A and are provided with Secondary (Biological) Treatment	Conventional activated sludge, SBR, RBC, biofilters, biological nutrient removal, etc
C	WWTPs that include activities in A & B and are provided with Chemical Addition for Phosphorus Removal	Chemical dosing (i.e. ferric chloride and sulfate, aluminum sulfate) for P removal
D	WWTPs that include activities in B or C and are provided with anaerobic digestion	Anaerobic digestion

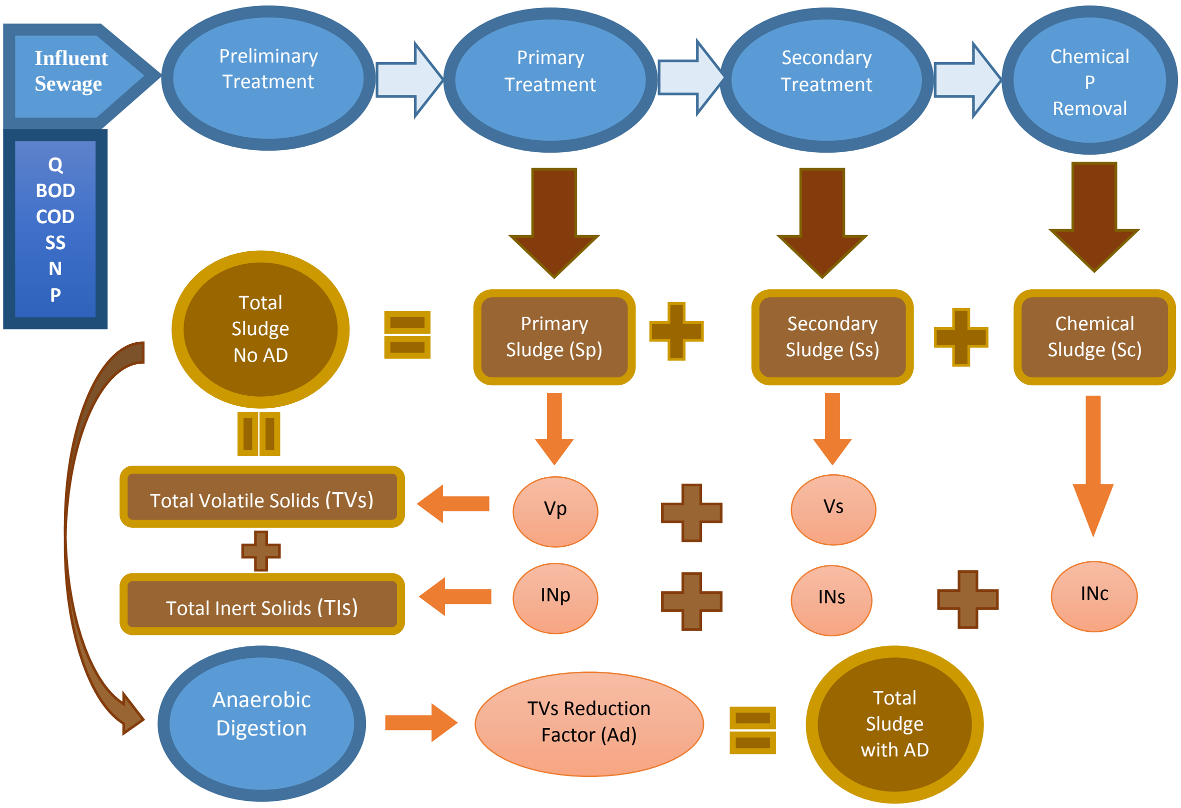

Figure 1. Preliminary Urban Sewage Sludge Model Diagram.

Results and Discussion

This project is at an early stage of development. Data acquisition for the subsequent sludge quantification, characterisation, categorisation, and final disposal location according to source is still ongoing. Nevertheless, by using data collected from the WWDL and implementing the model above described a preliminary quantification for the sludge produced by County Carlow urban WWTPs has been already obtained and is shown in Table 2. A good development of the inventory will facilitate the performance of a GIS multicriteria analysis and the assessment of the long-term capacity of land for sludge management. The inventory will help to spot new areas for sludge land spreading and will make it easier 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.

Table 2. Sludge Produced by Urban Wastewater Treatment Plants located within Co. Carlow

Site Location	Type of Treatment	Design PE	Total Annual Sludge (DS) (tonnes)
Carlow	C	36,000	1559.91
Muinebheag/Leiglinbridge	C	4,000	298.84
Tullow	C	4,000	212.84
Rathvilly	C	2,000	20.26
Rathoe	C	2,000	7.35
Hacketstown	C	2,000	13.55
Fenagh	C	1,500	14.60
Ballon	C	1,200	15.62
Borris	C	1,500	13.37
Myshall	C	800	4.81
Palatine	C	1000	18.48

Conclusions

Since sludge quantities are expected to increase in the coming years and, so far, sludge spreading on land seems to have been the only feasible disposal option, a proper sludge inventory and an accurate assessment of the long-term capacity of land for sludge management are required in Ireland. The proposed model will help to verify and represent sludge quantities and to cover data gaps in the compilation process. Despite the large amounts of assumptions that have been considered, preliminary results for County Carlow show a considerably high accuracy and reliability degree. The real annual sludge produced by Borris WWTP only differs 13.6% from the value obtained in the model.

Acknowledgements

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COMPARATIVE STUDY OF CHEMOMETRIC METHODS USED FOR MID INFRARED SPECTROSCOPIC CALIBRATION OF PHOSPHORUS SORPTION PARAMETERS IN IRISH AGRICULTURAL SOILS

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Abstract

The use of infrared diffuse reflectance spectroscopy (DRIFT) as a rapid and cheap alternative to traditional soil testing methods is explored. Preliminary mid infrared (MIR) calibrations were generated for the following parameters; percentage organic matter (% OM) and pH in water. Two different chemometric methods (partial least squares (PLS) and the Cubist method) were examined for the calibration of % OM and soil pH. According to the RPD performance parameter, both models were excellent for the prediction of % OM, with the PLS model out-performing the Cubist model in validation. The partial least squares model also out-performed the Cubist model in the prediction of pH in water. According to the RPD performace parameter, the soil pH Cubist calibration was excellent, but the validation was only fair. The soil pH PLS model was excellent for both calibration and validation.

Introduction

The effectiveness of the macronutrient, phosphorus, in fertilisers is determined by the ability of a soil to sorb P that has been applied (Forrester *et al.* 2015). Phosphorus sorption capacity of soils is usually determined by the use of batch equilibrium experiments, which generate sorption isotherms. These isotherms can be used to calculate P sorption maxima and P binding energies of soils with differing properties (Nair *et al.* 1984). However, traditional methods for determining these parameters can be time-consuming and uneconomic (Burkitt *et al.* 2002). It has been suggested that infrared diffuse reflectance spectroscopy (DRIFT) could act as a surrogate for some extractive and time-consuming laboratory techniques (Janik *et al.* 1998). Soil organic matter and pH are important parameters to consider when studying P sorption. The mechanisms of P adsorption onto metal (e.g. iron and aluminium) (hydr)oxides have been found to be inner-sphere complex formation and ligand exchange reactions, both of which largely depend on pH. Adsorption occurs through an exchange reaction of aquo and hydroxo ions and metal (hydr)oxides with P. The amount of P adsorbed increases with decreasing equilibrium pH values. Soil organic matter can also affect P sorption. It can sorb to metal (hydr)oxides through the same mechanism as P and disrupt the amount of P sorbed in a competitive manner (Hiradate and Uchida 2004, von Wandruszka 2006). This paper describes how two chemometric methods (partial least squares (PLS) being the most common method used and the Cubist method which is a known alternative (Minasny and McBratney 2008)) for infrared calibration, of percentage organic matter and pH, were compared.

The aim of this experiment was to determine the most appropriate chemometric calibration method for diffuse reflectance infrared spectroscopic (DRIFT) analysis of parameters related to phosphorus sorption dynamics in soil.

Materials and Methods

Data acquisition and modeling

Two hundred and twenty five, first horizon, soil samples were subsampled from an archive of 888 Irish Soil Information System (SIS) samples at Johnstown Castle, Wexford. These samples were already dried at a temperature of 40^{o}C and ball-milled. The samples were scanned in triplicate, in the MIR region of the spectrum, using a Perkin-Elmer Spectrum 400 FT-IR instrument with a DRIFT accessory. Instrument settings were as follows; 16 scans were taken of each replicate, resolution was set at 4 cm^{-1}, data interval was set to 2, y-axis was set to absorbance and the wavenumber range was set to between, 4000 cm^{-1} and 450 cm^{-1}. Once absorbance [log (1/*R*), where *R* is reflectance] of each sample was read in triplicate, spectra were exported as '.csv' files, read into R Studio and averaged. Percentage organic matter (% OM) was measured as the loss-on-ignition of 4 g samples at 500^{o}C. The Irish SIS project provided reference data for the pH in water parameter. The reference data were also read into R Studio as '.csv' files. The spectral data and reference data were both randomly split, 75 % for calibration and 25 % for validation. The pls and Cubist packages were used for modeling in R Studio. Raw spectral data was modeled and no transformations were applied to reference data.

Results and Discussion

Descriptive statistics were calculated for percentage organic matter reference data. The results were as follows; sample size: 224; mean: 14.3; median: 11.1; minimum: 4.3; and maximum: 87.6. Preliminary results were obtained for the calibration and validation (Figure 1, Table 1) of percentage organic matter, using the Cubist and pls packages in R.

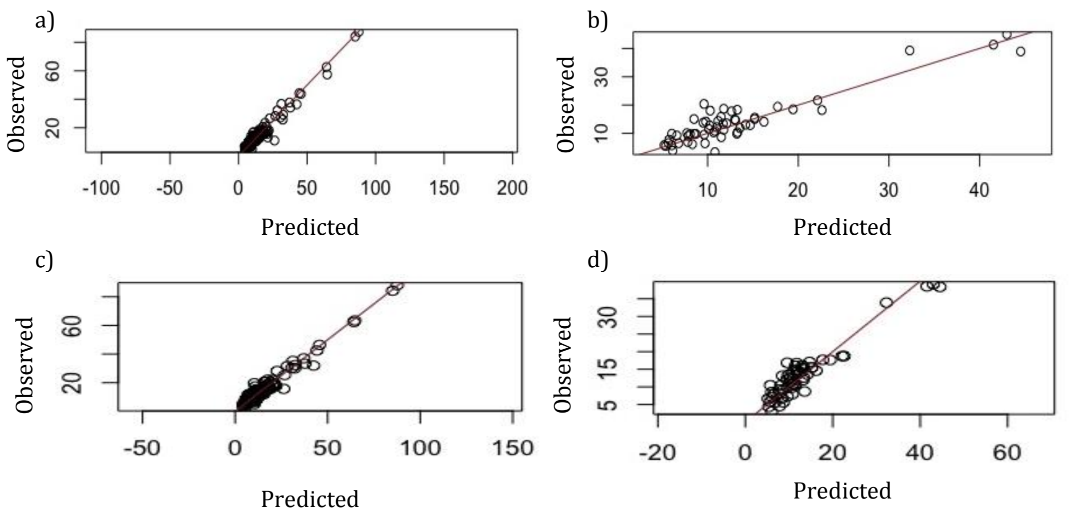

Figure 1. 'Goodness of fit' plots for percentage organic matter; (a) Cubist calibration; (b) Cubist validation; (c) partial least squares calibration; and (d) partial least squares validation

It is clear from all 'goodness of fit' plots in Figure 1, that both the Cubist and pls models fit the percentage organic matter (% OM) parameter well, however a lot of points are concentrated near the base of the prediction lines, indicating that this model could be optimised if focused on mineral soils (i.e. soils with % OM < 20 %) only. This is reiterated by the descriptive statistics for this parameter, where there is a big gap between the median % OM value (11.1) and the maximum value (87.6) of this sample set.

Table 1. Cubist and PLS model summary statistics for percentage organic matter

	R^2	MSE	RMSE	bias	RPD
Cubist calibration (% OM)	0.96	6.30	2.51	0.12	4.83
Cubist validation (% OM)	0.85	11.97	3.46	0.96	2.49
PLS calibration (% OM)	0.96	6.14	2.48	1.23E-13	4.89
PLS validation (% OM)	0.90	7.65	2.77	0.41	3.12

R^2, coefficient of determination; MSE, mean square error; RMSE, root mean square error; bias, the difference of the mean of the predicted versus the mean of the true y values; RPD, ratio of performance to deviation; % OM, percentage organic matter.

Guidelines have been defined to evaluate IR spectroscopic calibrations of soil samples based on R^2 (Nduwamungu *et al.* 2009). According to guidelines associated with R^2: the Cubist calibration of % OM was excellent, Cubist validation was moderately successful, and the PLS calibration was excellent with a successful validation. PLS produced a lower RMSE of calibration and validation. There have also been quality catogories defined to account for model reliability using ratio of performance to deviation (RPD) (Bellon-Maurel *et al.* 2010). According to the RPD performance parameter: both models were excellent for the prediction of % OM, with the PLS model slightly out-performing the Cubist model. The PLS validation RPD was higher by 0.63. Descriptive statistics were also calculated for pH in water. The results were as follows; sample size: 225; mean: 5.8; median: 5.8; minimum: 3.8; and maximum: 8.3. Preliminary results were obtained for the calibration and validation (Figure 2, Table 2) of pH in water, using the Cubist and pls packages in R.

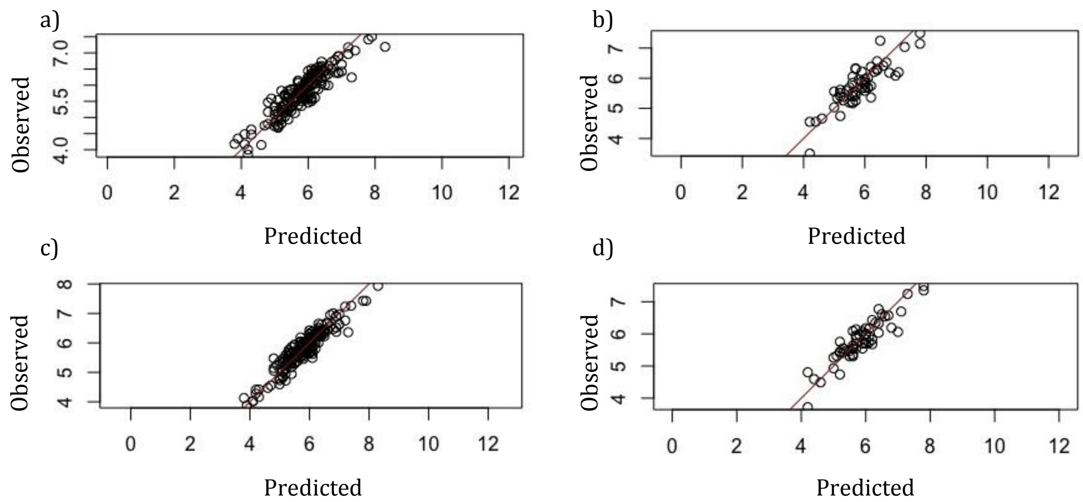

Figure 2. 'Goodness of fit' plots for pH in water; (a) Cubist calibration; (b) Cubist validation; (c) partial least squares calibration; and (d) partial least squares validation

It is clear from all 'goodness of fit' plots in Figure 2, that both the Cubist and pls models fit the pH (water) parameter very well. Overall the PLS model out-performed the Cubist model in the prediction of pH in water. Coefficient of determination was closer to one in both the PLS calibration and validation sets. PLS produced a lower RMSE of calibration and validation. According to the RPD performace parameter: the Cubist calibration was excellent, but the validation was only fair, and the PLS model was excellent for calibration and validation of pH in water.

Table 2. Cubist and PLS model summary statistics for pH in water

	R^2	MSE	RMSE	bias	RPD
Cubist calibration pH (water)	0.82	0.09	0.31	0.04	2.38
Cubist validation pH (water)	0.74	0.15	0.39	0.09	1.93
PLS calibration pH (water)	0.88	0.06	0.25	5.33E-15	2.91
PLS validation pH (water)	0.83	0.10	0.31	0.05	2.44

Conclusions

Partial least squares is the most appropriate chemometric calibration method for diffuse reflectance infrared spectroscopic (DRIFT) analysis of parameters (% OM and pH in water) related to phosphorus sorption dynamics in soil. However, percentage organic matter models could be optimised through use of samples that are less skewed, with respect to percentage organic matter content.

Acknowledgements

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PROCESS MODELING AND OPTIMIZATION FOR LIFE CYCLE ASSESSMENT OF DAIRY PROCESSING

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Abstract

The projected increase in world population to 9.7 billion by 2050 will create more demand for resources such as water, food and energy. To meet this increasing demand for food and to promote competition, the European milk quota system was abolished in March 2015 for EU member states. It is predicted that Ireland's milk production output will reach 7.6 billion litres by 2020, which is a 50% increase relative to the 2009 level. This will create an opportunity and necessity for the dairy processors to expand processing capacity. It is crucial that this expansion should take place in a sustainable manner. This work is developing a life cycle assessment of the Irish dairy manufacturing processes that can be used to evaluate the greenhouse gas emission, water consumption, energy consumption and waste along the entire production chain. As there is a lack of high resolution empirical data, the approach taken is to combine LCA with mechanistic process modeling. SuperPro Designer modelling software will be used to model dairy manufacturing processes and to optimize the process operations with a target to reduce the GHG emission, water consumption, energy consumption and waste generated while remaining cost effective.

Introduction

Globally, the agri-food sector consumed 30% of energy and emitted about 10 Gt CO_2e per year, which was one-fifth of global GHG emissions in 2010 (UN FAO, 2011a). Europe's food sector represented 26% of energy consumption in 2013 and the dairy industry is one of the most energy intensive and water consuming sector of the food industry (EC, 2015). The industry faces enormous challenges when moving towards sustainable production, because of changing climate and strain on the natural resources due to world population growth (Olsson 2013). In future, this will put more strain on resources such as water, food and energy. To achieve sustainable development and to reduce the negative consequences of climate change, the United Nation Conference on Climate Change, COP 21, was held in Paris in December 2015, where more than 190 countries agreed to keep the average global temperature rise to below 2°C from the pre-industrial level. This ambition has serious implications for the dairy industry.

Ireland's milk production had remained stagnant for almost three decades because of milk quota introduced by EU in 1984, however, the quota was abolished in March 2015. This is providing an opportunity for the Irish farmers to increase milk production and consequently, a necessity for the dairy processors to expand processing capacity. It is crucial that this expansion should take place in a sustainable manner if Irish dairy products are to be competitive in a global export market.

The objective of this study is to build mechanistic process models for key dairy manufacturing processes and to conduct life cycle assessment with the aim of identifying best options to reduce greenhouse gas emissions, water consumption, energy consumption and waste generated by processing plants.

Material and methods

Ireland's geographic location, fertile soil, mild climate throughout the year, and moisture containing westerly wind favor a natural grass growth (IFA, 2014). This gives Irish dairy producers an advantage in terms of feed cost over other countries and a position as one of the most highly competitive milk producers in the world (IFA,2014). Ireland has 18,000 dairy farmers and they collectively produced about 5.4 billion liters of milk in 2014 (Irish Farmer Association, 2014), and the industry is an export oriented with 90% of all the dairy productions in Ireland being exported to almost 140 countries in 2014 from a turnover of about € 3.1 billion for the Irish national economy (Irish Dairy Industries Association, 2016). However, grass production is very seasonal and has a peak/trough ratio of 7:1, which makes process optimization a major problem as supply, quality and throughput at plant and at unit operation scale is temporally variable. Life cycle assessment has been widely used to evaluate the environmental impact of European and Irish dairy production (William et al. 2015), but studies focused on dairy processing are far less common. LCA is a holistic assessment to evaluate the environmental impacts associated with all stages of a product life cycle from raw material extraction through processing, use, disposal or recycling with transportation, which requires detailed inventory data to capture mass and energy flow through the system being studied. Its application for process system engineering analysis is not widespread but studies do go back nearly 20 years (e.g. Burgess and Brennan, 2001) and it is used for the assessment of product manufacturing processes during design phase (Leslie Jacquemin et. al., 2012). The only journal paper on Irish dairy process LCA conducted by Finnegan et al. (2015) was based on the data from 12 companies representing 92% of the milk processed in Ireland, but relied on 'averaging', and did not capture unit process level activity. Thus, to use LCA for process plant design and management, it will be necessary to combine it with mechanistic simulation modelling to fill the data gap.

In this study, Gabi software will be use for the life cycle assessment. Life cycle assessment will be conducted by following the standard methodology of ISO 14040 (ISO, 2006 a), ISO 14044 (ISO, 2006 b), ISO 14067, IDF (IDF, 2010) and BSI (BSI, 2011). A gate to gate life cycle assessment (Figure 1) will be conducted which includes all unit operations involved in the manufacturing of dairy products and global warming potential as the main impact category as per IPCC 2007. In the first instance and where available, site-specific unit operations data will be used, and where data are not available, a secondary data source such as the eco-Invent database, literature, and reports will be used. The functional unit will be 'kilogram of product produced'.

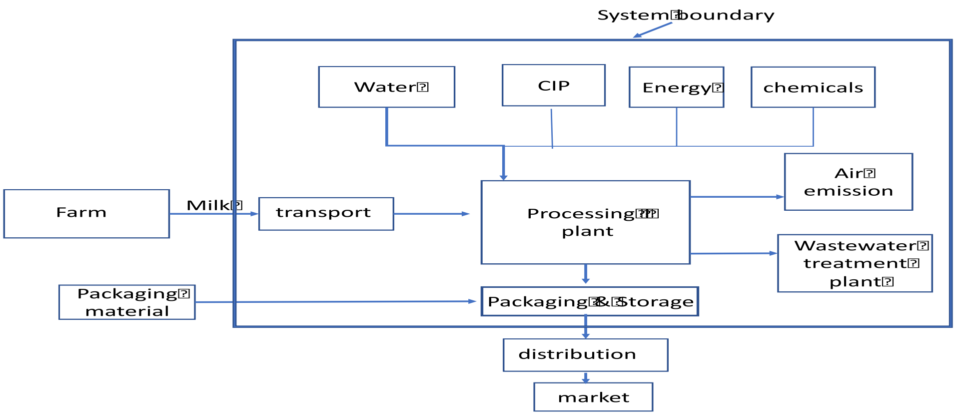

Figure 1. System boundary diagram of the life cycle assessment.

For key unit processes, SuperPro Designer software will be used to develop simulation models to generate more context specific inventory data for the LCA. Sharma et al. (2017)

have used a similar approach for dairy production. Each simulation model will be parameterized, calibrated and validated using empirical data.

To develop the key unit process simulations, the major components of the milk (water, fat, carbohydrate, protein, lactose) and its physical properties (molecular weight, critical pressure, critical temperature, boiling point elevation) will be defined as there is no milk components in the database of the process at present. The thermo-physical properties of the major milk components such as density, specific heat capacity, thermal conductivity, viscosity and thermal diffusivity will be taken from the literature to be incorporate into the model as well. A process flowsheet will be completed by adding streams to the unit operation and specifying parameters describing reaction in which reactants react to form a product.

The processing volume, composition and thermo-physical properties of the feed for each piece of equipment will be initially defined. This will be used to calculate the energy requirement and process parameters for the equipment. This information will be further use for post analysis of the results by performing mass and energy balance and equipment sizing and rating calculations for each of the key unit operations along the production chain (selected from Figure 2). The utility resources such as water, steam, cooling water, cleaning water and electricity associated with each unit operations will be collected from specific Irish dairy plants. Dairy process simulation will be run, followed by optimization to increase the throughput and remove bottlenecks by analyzing planning and scheduling of product manufacturing processes. The activity data will be used as inputs for LCA modelling.

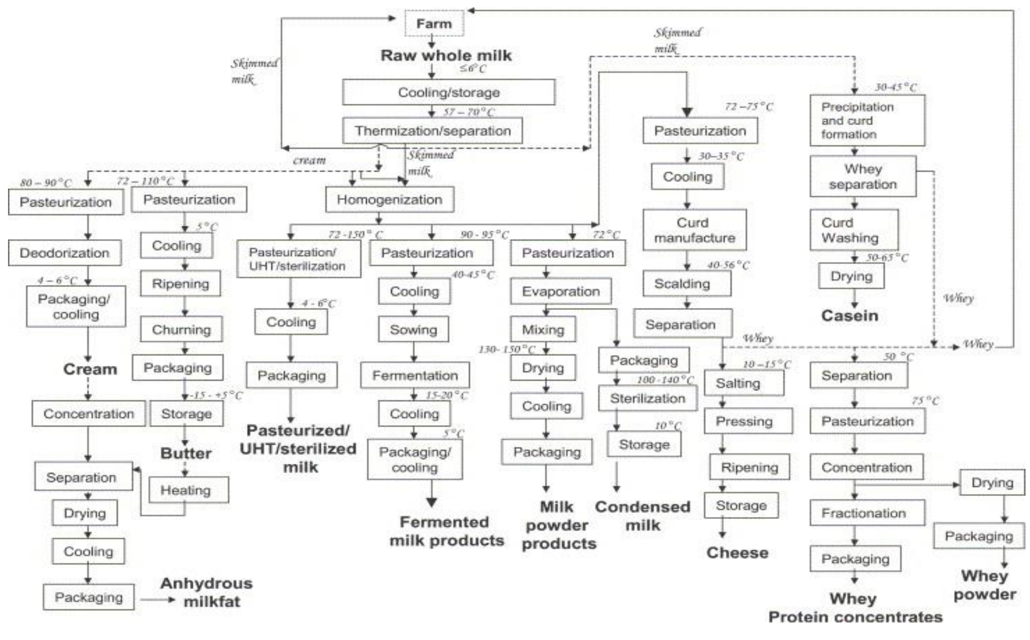

Figure 2. Typical flow diagram of the dairy process operation (Ramírez et. al., 2006).

Result & Discussion

As this study is ongoing, it is difficult to predict the result at this stage. It is expected that this gate to gate LCA study will evaluate the GHG emission, water consumption, energy consumption and waste generate along the entire production chain of the dairy product manufacturing processes. Moreover, the hotspots in the production chain will be identified and optimization for the key unit operations to be modelled using SuperPro Designer. It is expected that this study will identify whether reduction in the GHG emission and resource consumption such as water, energy and waste will be possible. Furthermore, this study is expected to capture the performance of the Irish dairy industry in terms of environmental impacts and resource consumption in processing plants. It is expected that the optimization of process operations will result in throughput increase, less resources consumption, enhance productivity and debottlenecking. Thus, this will not only benefit the dairy processors in financial terms but also society at large because of reducing the climate change impacts.

Conclusion

It is expected that the process model built for the dairy product manufacturing processes and life cycle assessment conducted will result in the evaluation of greenhouse gases emissions, energy consumption, water consumption and waste. Moreover, it is expected that the hotspots in the unit operation chain will be evaluated and optimized for the manufacturing processes in order to reduce GHG emissions, water consumption, energy consumption and waste generated.

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PERFORMANCE EVALUATION OF SUBSURFACE DRAINAGE SYSTEMS IN HIGH RAINFALL AREAS ACROSS SEVERAL EPISODIC RAINFALL EVENTS

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Abstract

Subsurface drainage is one of the most important measures used to maintain or enhance the productivity of agricultural lands on the poorly drained soils. Understanding the variables regulating subsurface drainage flow response to precipitation is critical for making informed decisions on agricultural productivity goals and maintaining environmental protection standards where the transfer of nutrients to surface waterbodies by subsurface drainage systems is a concern.

Introduction

Subsurface drainage is an extensively used water management tool globally, used to reduce water table (WT) depth and drain soils that are seasonally or perennially wet (Williams et al., 2015, Pavelis, 1987). Subsurface drainage is required for economical agricultural production of pasture and crops in many parts of the world (Bowler, 1980, Smedema et al., 2004). The installation of a well-planned drainage system provides a number of benefits (Galvin, 1983, Armstrong, 1986, Ibrahim et al., 2013, Skaggs and Van Schilfgaarde, 1999). While the benefits of subsurface drainage are clear, relative to undrained land, subsurface drainage significantly alters field hydrology (Blann et al., 2009, King et al., 2014). Compared to natural drainage conditions, subsurface drainage lowers water tables, increases sub-surface water movement and reduces surface runoff at the field edge (Radcliffe et al., 2015). Such an influence consequently has a large impact on the control of WT depth, the period of waterlogging (Armstrong, 1986) and also on the fate and transport of sediment and nutrients (Radcliffe et al., 2015). Therefore, characterising the hydrology associated with subsurface drainage is essential to understand nonpoint pollution transport dynamics (Tomer et al., 2003), and from a practical standpoint to aid in future design of drainage systems to provide optimum conditions for agricultural productivity goals (Vidon and Cuadra, 2010). While hydrologic assessments of individual drainage systems exist (King et al., 2014), these studies focus on shallow/tile drainage systems with the influence of additional disruption techniques such as mole or gravel mole drainage not well documented. In addition, studies examining the hydrologic effect of sites with groundwater drainage systems (Cavelaars et al., 1994) are also not well documented. Therefore a comprehensive understanding of the hydrological response of subsurface drainage systems is required to inform on water movement in and out of drained sites and to decipher the principle influencing factors in terms of drainage system response (King et al., 2014).

The objective of this study was to undertake a multi-site field study to compare the performance site-specific subsurface drainage systems in terms of drain discharge response and volume but also WT depth control over several episodic rainfall events.

Materials and Methods

Site description
Seven dairy farms in the south west of Ireland using permanent grassland were selected for this study. An area of the farm that suffered impeded drainage was selected for the installation of a new subsurface drainage system. Each site was characterised and prescribed an appropriate “site-specific” drainage system, which was subsequently installed. Four farms (1,2,3,4) were prescribed a groundwater drainage system (GDS) (Teagasc, 2013), while three farms (5,6,7) were prescribed a

shallow drainage system (SDS) with supplementary measures including mole drainage, gravel mole drainage or subsoiling (Teagasc, 2013). In total 9 drainage treatment were installed on the 7 farms as farms 1 and 7 had additional treatments installed.

Soil physical analysis and classification

A full pedological survey of each farm was carried out using a Dutch soil auger (Approx. 1 per Ha.; Eijkelkamp Agrisearch Equipment BV, Netherlands) and representative profile pits (Approx. 1 per 10 Ha.). Soil characteristics from the auger bore were identified using the Irish Soil Information System (SIS) horizon definitions (Simo et al., 2008). Soil test pits were excavated in areas selected to represent the dominant soils on each farm, using the auger survey as a guide, and to investigate the principal drainage restrictions for the area where drainage systems were installed. From the pits, soil was collected and analysed for physical characteristics (sand, silt and clay %, organic matter %) and undisturbed cores were collected for the establishment of soil bulk density.

Meteorological data

An automatic meteorological station (Campbell ScientificAddress) was installed on each farm to record rainfall (mm), air temperature (°C), relative humidity (%), solar radiation (W m^{-2}), wind speed (m s^{-1}), wind direction, and soil temperature (°C) every 15 minutes.

Flow measurement data

Flow discharge data was measured either by end-of-pipe flowmeters (Water Technology Limited, Togher, Cork) or by calibrated in-stream flumes (Corbett Concrete, Cahir, Tipperary) in tandem with mini-divers (Eijkelkamp Agrisearch Equipment, Giesbeek, Netherlands) which monitored water-head passing through the flume, which was then converted to an open channel flow rate. The flow measuring system selected for each site was dependent on the practicalites of equipment installation particualry in relation to relative invert levels of subsurface and open drains and the geometry of the open drain. Flow rate was recorded automatically every 15 minutes.

Watertable depth

Fully screened piezometers (3 per drained field), HDPE pipes (Eijkelkamp, Agrisearch Equipment, Giesbeek, The Netherlands)) were installed to 2 m below ground level, unless impeded by large stones/bedrock in an upslope, mid-slope and downslope position in each drained field to monitor watertable (WT) depth. Measurements of WT depth were recorded every 15 minutes with mini-divers (Eijkelkamp Agrisearch Equipment, Giesbeek, Netherlands) inserted into the piezometers.

Rainfall event delineation and selection

Rainfall events from the 1/10/2015 to 31/05/2016 period were selected for use in this study. A period of at least 12 hours without rainfall was used to separate one rainfall event from another (Ibrahim et al., 2013, Tuohy, 2015). Rainfall events with less than 5.0 mm total rainfall were excluded from the study as such conditions were not likely to induce widespread flow response from the drainage systems. Thereafter, rainfall events greater than 5.0 mm were selected and categorised (A–D) depending on total rainfall amount. Two rainfall events were randomly selected from each range on each site for inclusion in this study. In total, 72 rainfall events (2 events * 4 ranges * 9 drainage systems) were used to assess how these subsurface drainage system perform during episodic, high intensity rainfall events.

Flow event delineation and antecedent conditions

From the selected rainfall events, flow hydrographs were plotted and examined. A "perceptible rise in discharge" signalled the start of the flow event, while the end of the event was defined as flow returning to pre-event flow levels. Start time was defined as the time between the start of the rainfall event and the start of flow. Peak time was defined as the time between the start of the rainfall event and the time of peak discharge. Lag time was defined as the time between peak rainfall and peak discharge. Cumulative rain at start and peak times was calculated as the cumulative rainfall during the event at start and peak time respectively. Variations in discharge are described using a flashiness index (FI) (Deelstra, 2015).

Results and Discussion

Over the study period several of the drainage systems were successful in maintaining the WT at a depth greater than the 30 cm. The depth of 30 cm is significant as Skaggs and Van Schilfgaarde, (1999) reported that if the water table is within 30 cm of the soil surface, it begins to decrease trafficability, increasing the risk of compaction at the time of field activity and contributing to excess water stress to crops. The results show that for systems 1a, 1b, 2, 3 and 7b, the WT depth was maintained at or greater than 30 cm for 99.7%, 94.1%, 100%, 99.9% and 100% of the study period respectively, while for systems 4,5,6, and 7a WT depth was maintained at or greater than 30 cm for 57.8%, 37.6%, 41.8% and 44.2% of the study period respectively. In general, farms with GDS had a deeper WT depth than farms with SDS. As a result the hydrological response time of start, peak and lag times were affected. In comparing GDS to SDS systems, start time was longer (8.36 h versus 6.34 h), peak time was shorter (29.09 h versus 30.96 h), and lag time was shorter (6.53 h versus 11.22 h). In addition, start, peak and lag times were also affected by total rainfall. In comparing GDS to SDS across increasing rainfall, start time was longer for A events (6.35 h versus 2.90 h), B events (4.48 versus 2.10 h) and D events (13.20 h versus 5.77), while shorter for C events (9.73 h versus 14.58 h). For peak time GDS systems was longer for A (10.2 h versus 6.48 h) and C events (41.58 h versus 29.81 h), while shorter for B (17.70 h versus 23.69 h), and D events (46.90h versus 63.87h) when compared to SDS. While lag time was longer for A (3.17 h versus 1.74) and B (13.40 h versus 3.25) events, while it was shorter for C (0.90 h versus 8.28) and D (8.65 h versus 31.62) events.

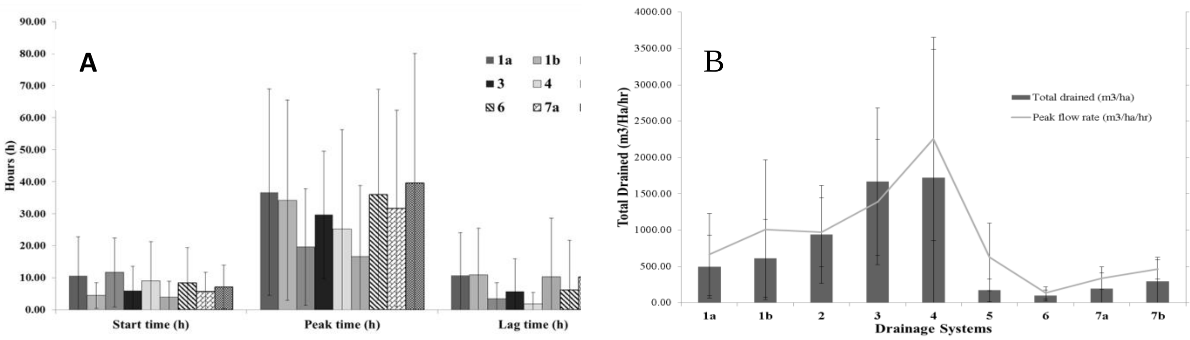

Figure 1. (A) Start, peak and lag times between drainage systems. **(B)** Total drained and peak flow rate from the 9 drainage systems

While the response times varied in treatments and events so did total volume drained. The mean total volume of water drained for all rainfall events across drainage systems 1a, 1b, 2, 3, 4, 5, 6, 7a, 7b was 498.40, 612.03, 940.06, 1666.29, 1722.38, 172.67, 100.45, 192.83 and 294.62 m^3/Ha, respectively. Therefore results shows that GDS drained a higher volume of water from the sites then the volume of rainfall that fell on sites, suggesting groundwater ingress from adjacent areas. However, on farms where two contrasting systems were installed (Farms 1 and 7) greater water volumes were drained as a result of closer drain spacing (1b relative to 1a) or the addition of gravel mole drains and additional subsoiling (7b relative to 7a). In addition SDS drainage systems 5, 6 and 7a removed < 50 % of rainfall that fell on sites. These results from SDS systems correspond well with the proportion of the study period during which WT depth was below 30.

Conclusions

Results show that there is a wide variation in drainage system performance and response. Efforts will now focus on the main influencing factors which dictate drainage response to isolate key predictors of drainage system performance.

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INTENSIFICATION OR EXTENSIFICATION? ENVIRONMENTAL IMPACTS OF IRISH DAIRY FARMS

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Abstract

The aim of the study was to quantify key environmental impacts of a typical Irish dairy farm considering three expansion strategies for increasing milk production. The three strategies were: intensification by increasing stocking rate, intensification by increasing the output per cow and extensification by increasing the land area. System modelling and life cycle assessment were used to assess the environmental impacts. The global warming ranged from 0.96 – 1.26 kg CO_2 eq. per kg energy corrected milk (ECM). The acidification and eutrophication ranged from 3.54 – 7.84 g SO_2 eq. per kg ECM and 2.44 – 3.97 g PO_4 per kg ECM, respectively. The results showed that the best strategy would be intensification of the farm by increasing the output per cow with less environmental impacts for both well and poorly drained farms. Increasing stocking rate of the farm would result in highest impacts for both soil types. The study also showed that there is a scope of increasing milk production from Irish farms with less or equal environmental impacts to baseline.

Introduction

Increasing world population demands increase in animal food products from agricultural land. The Irish dairy industry has the target to sustainably increase milk output by 50% by 2020 (DAFF 2010) facilitated by abolition of EU milk quotas. Milk production in Ireland is mainly grass based. Increased production can be achieved by a combination of expansion in animal numbers and milk production or bringing more land into production. Dairy farms in Ireland are both on well and poorly drained soils. Around 30% of milk produced in Ireland is from poorly drained farms (O'Loughlin *et al.* 2012). Poorly drained soils add complexities to the production systems which reduces productivity and profitability compared to their counterparts on well drained soils (Fitzgerald *et al.* 2008). This necessitates the adoption of a strategy that has the least environmental impact to facilitate sustainable expansion of milk production. Effect of farming intensification on environmental impacts of milk production in Italy has been studied by Bava *et al.* (2014).

Globally dairy production accounts for 3% of total greenhouse gas emissions (O'Brien *et al.* 2014). Life cycle assessment (LCA) is the preferred method to quantify environmental impacts from milk production. This method is increasingly used to quantify environmental impacts of milk production from grass based, confinement milk production systems (Yan *et al.* 2013, Chen *et al.* 2016). LCA studies of agricultural systems are mainly done up to farm gate instead of complete life cycle (O'Brien *et al.* 2012).

Mathematical models are being increasingly used along with experimental research (Shalloo *et al.* 2004). There are a range of dairy farm-scale models. *Dairy_sim* is a dairy simulation models which assess the impact of variation in climate and soil drainage. It is been previously parameterised and tested on well drained and poorly drained dairy farms at different locations in Ireland (Fitzgerald *et al.* 2005, Fitzgerald *et al.* 2008). LCA combined with system modelling has been used by Sharma *et al.* (2016) and Sharma *et al.* (2017) for assessing environmental impacts of typical dairy farms in Ireland with different soil resources and artificial drainage.

The objective of this study was to estimate the environmental impacts of a typical dairy farm on well and poorly drained soil with three expansion strategies to increase milk production.

Materials and Methods

The baseline farm was a 20 hectare (ha) dairy unit supporting 2 livestock units (LU)/ha i.e. 40 dairy cows, producing 5300 kg/cow/yr (Mihailescu *et al.* 2014) on well-drained soil. Three cases were then considered for the expansion strategy. The Irish dairy industry is regulated by Nitrate Directive 91/676/EEC which limits the maximum nitrogen fertilisation of grassland for stocking rates less than or equal to 170 kg N/ha/year. Farmers are eligible to apply for derogation and allows more nitrogen fertilisation and go up to 250 kg/N/ha/yr. The baseline farm works under the Nitrates Directive. In the intensification case 1, the stocking rate was increased to the allowable limit of the Nitrates Directive. Thus in the intensification case 1, the dairy farm area was same 20 ha but supported 2.5 LU/ha or 50 dairy cows, producing 5300 kg/cow/yr. This was a 25% increase in the stocking rate. In the intensification case 2, the dairy unit farm area was same 20 ha with 2 LU/ha, i.e. 40 cows, with 25% increased milk production/cow (6625 kg/cow/yr). For the extensification case 3, a 25% percent increase in land area was considered. In the extensification case, the dairy farm area was 25 ha supporting 2 LU/ha or 50 dairy cows, yielding 5300 kg/cow/yr.

Dairy_sim was used to find optimum management practices for these cases on well-drained and poorly drained soils for a location in Co. Clare (52°N 9°E). An optimum farm is one in which the feed demand was dominated by grass and silage excess was near to negligible (Fitzgerald *et al.* 2005).

LCA was used to estimate the environmental impacts of dairy farms. The goal of the study was to quantify environmental impacts from a grass based dairy system in Ireland with expansion strategies. The LCA model was developed using GaBi 6 software (thinkstep 2014). System boundary was from cradle to grave. Partial inventory for LCA model was derived from *Dairy_sim*. The functional unit was defined as 1 kg of energy corrected milk (ECM). The reference flow of ECM was milk delivered * (0.25 + 0.122 * %fat + 0.077 * %protein) (Yan *et al.* 2013), where fat and protein percentage were 3.94 and 3.4 (Hennessy *et al.* 2013). Foreground processes included milking unit, cattle housing, manure storage, organic and inorganic fertiliser spreading, electricity and diesel use. The background processes included manufacturing and transport of concentrates and fertiliser, replacement heifers. The coproduct (meat) allocation was assumed based on energy and protein requirement (O'Brien *et al.* 2012) to be 12%. Further details of the LCA model is available in Sharma *et al.* (2017).

The main greenhouse gas emissions from a dairy farm are methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3). Enteric methane and methane from manure storage was estimated using 107.2 kg CH_4/cow/yr and 19 CH_4/cow/yr emission factors from O'Mara (2006), respectively. N_2O emissions from manure storage and application were calculated based on IPCC (2006). NH_3 emissions from manure spreading were estimated based of total ammoniacal nitrogen from Webb and Misselbrook (2004). NH_3 emissions from manure storage were taken from Duffy *et al.* (2011). Global warming (GW, kg CO_2 eq.), acidification (AP, g SO_2 eq.), eutrophication (EP, g PO_4 eq.) emission categories were taken for the study.

Results and Discussion

Optimum farm management for the baseline farm and with expansion strategies for both well drained and poorly drained farms (Table 1) indicated that farms on poorly drained soils could only have 6% expansion to work under the policy limits. In case 1 for poorly drained the fertiliser input was very high and it is higher than the permissible limit of the Nitrate Directive.

From the LCA, it was seen that all three expansion strategies will reduce environmental impacts. The emissions were always lower than the baseline farms for well drained soils. For poorly drained farms emissions were lower than the baseline except case 1 (which was equal to baseline). It was estimated that intensification case 2 i.e. increasing the milk output per cow had the least environmental impacts for both well-drained and poorly drained farms. Bringing more land into dairy production will also reduce environmental impacts of milk production from both well and poorly drained farms. The results are similar to Bava *et al.* (2014) who suggested that farming intensification such as increasing milk production per cow, dairy efficiency and stocking density could reduce environmental burden of milk production. The environmental impact values were in range of Yan *et al.* (2013) and Chen *et al.* (2016). The difference in environmental impacts are shown in Figure 1, which shows that the impacts were greater for poorly drained farms.

Table 1. Optimum farm management from *Dairy_sim*

Parameters	**Well Drained**				**Poorly Drained**			
	Baseline	**Case 1**	**Case 2**	**Case 3**	**Baseline**	**Case 1**	**Case 2**	**Case 3**
Farm Size ha	20	20	20	25	20	20	20	21
No of cows	40	50	40	50	32	34	35	34
Stocking rate cows/ha	2	2.5	2	2	1.6	1.7	1.75	1.6
Milk yield kg/cow/yr	5300	5300	6625	5300	5300	5300	5631	5300
Grass Intake (kg DM/Farm)	3336	2756	3442	3336	1822	1851	1880	1822
Silage Intake (kg DM/Farm)	1131	1511	1405	1131	2696	2663	2769	2696
Concentrate (kg DM/Farm)	471	536	549	471	472	460	476	472
Fertiliser N kg/ha	131	179	146	131	197	225	198	197

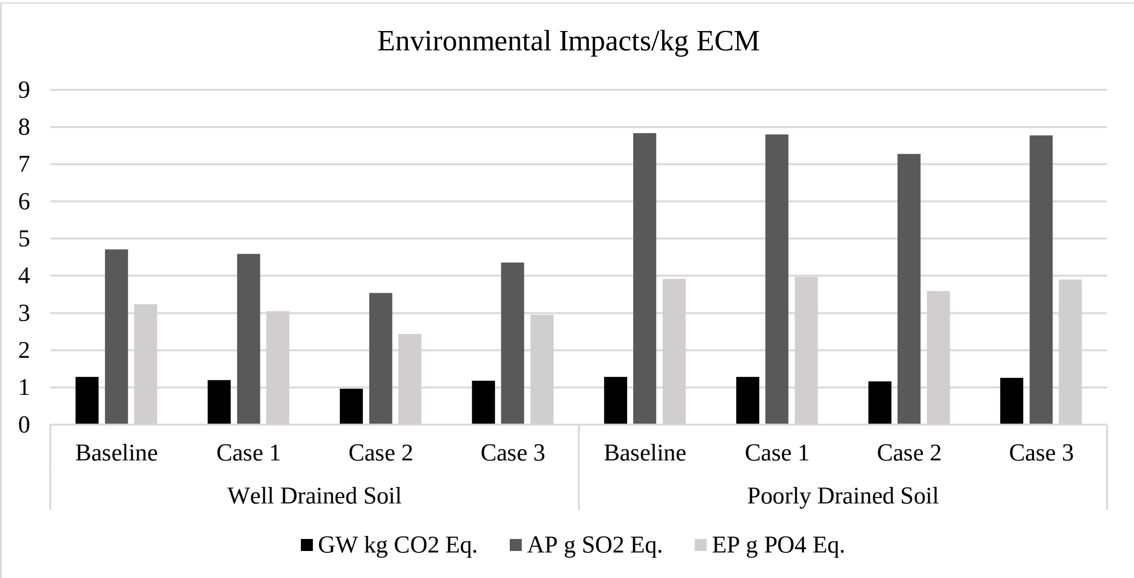

Figure 1. Comparison of environmental impacts of dairy farms on well drained and poorly drained soil with three expansion strategies.

Conclusions

The best strategy would be intensification of the farm by increasing the output per cow with less environmental impacts for both well and poorly drained farms. Increasing stocking rate of the farm would result in highest impacts. For poorly drained farms increasing the stocking rate expansion strategy is not possible as it increases the fertiliser input to greater than the permissible limit. The study also showed that there is scope for increasing milk production from Irish farms with less or equal environmental impacts to their baselines.

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FORMULATING A FUNCTIONAL UNIT FOR DAIRY PRODUCTION LIFECYCLE ASSESSMENT CONSIDERING THE FINANCIAL FUNCTION OF THE PRODUCT

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Abstract

A basic function of dairy farming is to transform nutrients (e.g., feed, fertilizer) into commodities such as milk, endeavouring to achieve profitability with the responsibilities of animal welfare, and the protection of human health (milk hygiene). Life cycle assessment can be used for both economic and environmental impact assessment of dairy farms. Central to this approach is to define a functional unit (FU) for the system. ECM and FPCM are most common FU used in LCA of dairy production. Both approaches express the mass of milk required to provide the same energy as milk with a standardised composition, e.g. 4% fat and 3.3 % protein giving 3.14 MJ/kg. These only reflect a proportion of the economic value of the commodity, which is captured in the financial transaction between supplier and processor. The value of milk to the dairy industry is a function of its composition and the aggregate profit of the product mix manufactured from the milk. In Ireland, the price paid for milk is dependent not only on fat and protein, but also lactose and three key biological contaminant (hygiene parameters). The FU 'base price adjusted milk' BVA is defined by milk quality for processing purposes capturing the value of the economic transaction between farmer and processor (milk pricing) ($BVA_{i.} = V_i * (AP_i/BP)$; where $_i$ is month of lactation, V is volume of milk supplied for month I, AP is actual price paid(€/l) for month $_I$, and BP is base price paid per l milk @ 3.3 % protein and 3.6% butterfat for month $_i$)

Introduction

A basic function of dairy farming is to transform nutrients (e.g., feed, fertilizer) into commodities such as milk and meat, to generate an economic return (Powel *et al* 2008). To do this, dairy production systems need to be able to combine profitability with the responsibilities of animal welfare and the protection of human health (Morgan *et al* 2004). Life cycle assessment can be used for both economic and environmental impact assessment of dairy farms (Yan *et al* 2011). Central to this approach is to define a functional unit (FU) for the system. Both Schau and Fet (2008) and Gerber *et al.* (2010) consider the primary function of livestock products is to satisfy human nutritional needs, especially for protein. Food also has other functions, e.g. to provide energy (Schau and Fet, 2008), but the commodities sold also have the function of providing an income to farm families (Powel *et al* 2008). The simplest FU for dairy production is 1 kg milk (Basset – Mens *et al* 2009) or 1 litre milk (Williams *et al* 2006). Schau and Fet (2008) recommended quality weighted FU that could consider carbohydrate, vitamins, minerals, energy, fat and protein. Most studies only consider fat and the protein content expressed as 1 kg of energy corrected milk (ECM, e.g. Sjaunja *et al* 1990) or 1 kg of fat and protein corrected milk (FPCM, e.g. Thomassen *et al* 2009). Both approaches express the mass of milk required to provide the same energy as milk with a standardised composition, e.g. 4% fat and 3.3 % protein giving 3.14 MJ/kg (IDF, 2015), but with different coefficients, that lead to a slight difference in the final result (1%; Tyrrel and Reid, 1965). The value of milk to the dairy industry is a function of its composition and the aggregate profit of the product mix manufactured from the milk (Breen *et al* 2007). In Ireland, the price paid for milk is dependent not only on fat and protein, but also lactose and three key biological contaminant (hygiene parameters (Carty and Mulligan, 2009).

The objective of this study was to create a FU, defined in terms of both the compositional and the hygiene parameters of milk, which reflect the transaction between the farmer and the processor and to evaluate its use for dairy production LCA compared to fat and protein correction alone.

Materials and methods

A FU capturing the core components, on which the transaction between the farmer and the processor are based, was created. The FU was formulated based on both the compositional and the hygiene components (biological) of milk, where the compositional components were fat and protein, and the hygiene components were somatic cell count (SCC) and total bacteria count (TBC). The FU referred to as 'base price adjusted milk' (BVA) was formulated by multiplying a given volume of milk (V; l) for a given month (i), by the ratio of the 'actual price' paid in cent per litre (AP; c/l) to the 'base price' paid in cent per litre (BP; c/l;) (where BP was base price for 1l milk having 3.3% protein and 3.6% butterfat (as quoted by Glanbia for February 2016 milk supplies). BVA was calculated as:

$BVA_{i.} = V_i \times (AP_i/BP)$ (1)
where $AP = (BP + BV + PV) - P$ (2)
where BV is the butterfat value (€c/l), PV is the protein value (€c/l), and P is the penalty cost (€c/l).

$BV = ((Af - Bf)/0.1)) \times Fd$ (3)
where Af is actual milk butterfat %, Bf is milk butterfat % (3.6%) for payment of BP, Fd is the butterfat differential (€c/l; as quoted by the processor for milk supplies), and 0.1% is the deviation, +/-, from Bf at which Fd is paid.

$PV = ((Ap - Bp)/0.1)) \times Pd$ (4)
where Ap is actual milk protein %, Bp is milk protein % (3.3%) for payment of BP, Pd is the protein differential (€c/l; as quoted by the processor for milk supplies),and 0.1% is the deviation, +/-, from Bp at which Pd is paid.

$P = SCCp + TBCp$ (5)
where SCCp is the penalty cost (€c/l) for 1 L of milk being above a specified threshold for SCC (Table 1), TBCp is the penalty cost (€c/l) for being above a specified threshold for TBC (Table 1).

$BVA_L = \sum BVA_i$ (17)
where BVA_L is an individual farms' BVA for the lactation ($_L$).
An optional conversion can be carried out to enable future comparison between BVA milk and FPCM. To convert BVA (l) to kg of milk a conversion factor of 1.03 as per O'Brien et. al., (2014) can be used.

Results and discussion

Raw milk quality encompasses criteria relating to composition (butterfat, crude protein, lactose, and hygiene (TBC, SCC). While the low fat and protein levels add to processor costs, the inconsistency of these levels can cause problems when marketing and selling products. Fundamentally, when processors cannot produce a consistent product year round, they face major problems selling certain products where consistency of texture, flavour, functionality and year round supply are essential (Shalloo *et al* 2008). Findings from Teagasc (2008) show that a farm increasing milk protein and fat concentrations from 3.33%$ and 3.83 respectively to 3.54% and 4.22% increased profitability by € 11600, €9081 and €13669 at milk prices of 27c/l, 20c/l and 33c/l on on milk sales of 452,586 kg from a 40 ha platform, having a stocking rate of 2.09 lu/ha. These gate prices can potentially be realised as the introduction of the Multiple Component pricing (A+B-C;Geary *et al* 2010) incentivize the farmer to produce more milk solids at farm level, due to the processor having less processing costs (< lactose and <water per kg milk) per kg of milk, C (Shalloo *et al.*2008). SCC is the most important single indicator of milk quality, reflecting the health status of the mammary gland and the risk of non-physiological changes to milk composition (Hamann, 2005). It is also the key component of national and international regulation for milk quality (van Schaik et al . 2002). An udder quarter is considered healthy if it has an SCC < 100,000 cells/ml and is free of mastitis pathogens (Geary *et al* 2013).

Table 1. Hygiene parameter thresholds and price adjustment as per Glanbia 2016

Hygiene parameter	Unit	Price adjustment (cent/litre)
Somatic cell count (SCC)	**Somatic cells /ml**	
	< 300,000	Base price
	301,000 - 500,000	-1
	501,000 - 600,000	-2
	>601,000	-4
Total bacteria count (TBC)	**TBC CFU/ml**	**Points/test**
	< 50,000	5
	51,000 - 75,000	4
	76,000 - 100,000	3
	101,000 - 150,000	2
	151,000 - 300,000	1
	> 301,000	0
TBC points[1]	**Grade**	**Price adjustment (cent/litre)**
10	Standard	Base price
9	2	-0.6
7 - 8	3	-1.4
5 - 6	4	-2.8
3 - 4	5	-5.6
1 - 2	6	-11.2
0	7	-14

[1] Resulting from two tests carried out within the month of supply

Mastitis represents a major economic cost to dairy farmers with losses of up to €190 per case depending on severity (Berry and Amer 2005). At the processor level the occurrence of milk having high SCC concentration (CFU/ml),requires more complex processing requirements, lower cheese and casein yield, shorter shelf life and flavour problems (Shalloo *et al* 2008). These issues impact processor income, costs or both, which indirectly impacts the returns to the farmer in terms of milk price paid (Geary *et al* 2014). Geary *et al* (2014) has estimated that when accounting for the processing sector alone, the Irish dairy Industry with a national average bulk milk SCC (BMSCC) of 252000 cells/ml is losing €19·8 million per annum in net revenue relative to a BMSCC of 100001–200000cells/ml. The positive correlation found between SCC and TBC by Berry et al. (2006) indicated that a reduction in SCC will, on average, be associated with reduced bulk tank milk TBC.

Conclusion

BVA as afunctional unit is a credible alternative to the conventional fat and protein FU that have been used to date. By incorporating SCC and TBC into its formulation, it addresses the animal welfare and consumer protection criteria that the dairy farmer is responsible for when producing milk, and is legislated for through Council Directive 92/46/EEC. While BVA is not an economic FU *per se*, the value economic value placed on a given litre of milk in relation to that of a litre of base price milk is used for quality correction. While the compositional parameters used in BVA formulation are fat and protein, and the hygiene parameters SCC and TBC, BVA calculation has the potential to incorporate the additional compositional parameter lactose, as processors penalise milk of 4.2% lactose and under, and another hygiene parameter in the form of thermoduric bacteria.

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Appendix 1

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

Emmet-Booth JP, Forristal PD, Fenton O. and Holden NM. Evaluation of Visual Soil Structure Assessment Methods for Research and Management Deployment in Temperate Maritime Grasslands and Arable Soils (**PhD**) Research Stimulus Fund as administered by the Department of Agriculture, Food and the Marine.

Liu R and Holden N. Greenhouse gas emissions from homogenization for liquid milk production (**PhD**). CSC-UCD Scholarship Scheme.

Chen Wh and Holden N. Evaluating the impact of Irish dairy farming on human heath: a case study (**PhD**). Smart Integrated Livestock Farming (SILF) project, under ERA-NET scheme "ICT-AGRI.

Murphy E, Curran T, Holden N, Upton J. Improving sustainability through water conservation on dairy farms (**PhD**). Teagasc Walsh Fellowship Scheme.

Kale A and Thomas P. Curran T. Whole farm n flow models and their suitability for temperate pasture-based livestock systems (**MSc**).

Tuffy K and Holden N. Impact of artificial sub-surface drainiage on pasture produc tion, the length of the grazing season and the profitability of milk production on a heavy wet soil (**PhD**). Research Stimulus Fund as administered by the Department of Agriculture, Food and the Marine and Teagasc Walsh Fellowship.

Fahy J and Butler F. Sampling pogrammes for Norovirus in shellfish (**MEngSc**).

Qichen Hao and Butler F. The use of whole genome sequencing to investigate the tempor al and spatial occurrence of microbial pathogens in a dairy processing facility (**PhD**).

Hunt K, Butler F, Doré B, Keaveney S. An assessment of RT- QPCR accuracy in monitoring infectious norovirus in oyster farms (**PhD**).

Li F and Butler F. Efficacy of novel thermal and non-thermal processes to reduc e spore numbers within daiy manufacturing processes (**PhD**).

Henihan L and O'Donnell C. Development of PAT tools for quality and safety improvement in dairy ingredient manufacture for infant formula (**PhD**). Food Institutional Research Measure (FIRM) administered by the Irish Department of Agriculture, Food and the Marine.

Panikuttira B and O'Donnell C. Development of process analytical tools for food processing (**PhD**).

Appendix 2

Profiles of Postdoctoral Research Scholars only includes: Drs, Martínez-González; Gunn, O'Brien; O'Connell; Oldfield; Sosa-Peyton, Sweeney, Yan, Zhao.

José Ángel Martínez-González, BSc, MSc, PhD

Project Title: BIOWATER PROJECT: Theoretical and experimental approaches to unravel the water structure at biomaterial interfaces

Project Leader: Dr. Aoife Gowen

Abstract

This project evaluates the use of Molecular Dynamics (MD) in combination with hyperspectral imaging techniques to provide a deeper understanding of the molecular structure of water at biomaterial interfaces and how this structure is conditioned according to the properties of the biomaterial. MD is a theoretical approach for studying atoms and molecules along a fixed period of time giving a view of the dynamical evolution of the system. MD simulations have many applications, e.g. refine three-dimensional experimental structures from X-ray or NMR (such as proteins or macromolecules) or to understand the growth of thin films. Combining this technique with IR and Raman hyperspectral imaging techniques allow us to obtain a better understanding of the processes that occur in the interfacial zones from a macroscopic and atomic point of view. Additionally, non-equilibrium MD simulations help us to elucidate the key role that water adopts in protein adsorption from the atomic level perspective.

Background, Skills & Qualifications

I obtained my degree in Chemistry from University of La Rioja in 2006. I completed my PhD at the same university in 2013, with a study of the reaction mechanism and kinetics of hepatitis C virus NS3/NS4A protease. In this study I applied several theoretical approaches (QM/MM, EA-VTST, MMPBSA, SCC-DFTB) to elucidate the enzymatic reaction mechanism. From January 2014 to January 2015, I was working in the soft matter field, focusing on the amorphization of silica family derivatives and electronic characterization of these materials at the University Autónoma de Barcelona. Since September 2016, I have been working in the UCD where I have been simulating the interface between silicon based materials with water to characterize the theoretical infrared spectrum of this interface. Recently, I am applying this methodology for the study of the interface between proteins and water.

Recent publications:

Martínez-Gonzalez, J.A.; English, NJ & Gowen, A.A. (2017). *Understanding the interface between silicon-based materials and water: molecular-dynamics exploration of infrared spectra.* The Journal of Chemical Physics. (Under revision)

Mukherjee, S; **Martínez-Gonzalez, J.A.;** Stallard, C.P.; Dowling, D.P. & Gowen, A.A. (2017). *Can ATR-FTIR be Used To Understand The Interaction Between Polymers And Water? A Hyperspectral Imaging Study*. Journal of Spectral Imaging. DOI: 10.1255/jsi.2017.a3

Navarro, J.; **Martínez-González, J.A.;** Sodupe, M.; Ugliengo, P. & Rimola, A. (2015). *Relevance of silicate surface morphology in interstellar H 2 formation. Insights from quantum chemical calculations.* MNRAS, 453:914-924.

Martínez-Gonzalez, J.A.; González, M.; Masgrau, L. & Martinez, R. (2015). *Theoretical Study of the Free Energy Surface and Kinetics of the Hepatitis C Virus NS3/NS4A Serine Protease Reaction with the NS5A/ 5B Substrate. Does the Generally Accepted Tetrahedral Intermediate Really Exist?* ACS Catalysis, 5:246-255.

Martínez-Gonzalez, J.A.; Rodriguez, A; Puyuelo, M.P.; González, M. & Martinez, R. (2015). *Further Theoretical Insight Into the Reaction Mechanism Of The Hepatitis C NS3/NS4A Serine Protease* Chem Phys Letter, 619:97–102.

Lynda Gunn, BSc, PhD

Project title: Whole chain approach to controlling pathogens; Molecular and statistically-based methods for process control of pathogens

Project leader: Prof. Francis Butler

Abstract

The overall aim of the project is to better detect and reduce the number of bacteria in product. This will be achieved using molecular-based methods for investigation of pathogens and spore-forming bacteria and by using statistically-based process control for these organisms. This will require a change in approach from the current culture-based detection methods to new technologies. Existing PCR technology and emerging sequencing technology will be used, to gain better resolution to microbial issues in industry to improve quality control.

Background, Skills and Qualifications

My PhD studies (2010-2014) was based on the investigation of gastroenteritis viruses (rotavirus, coronavirus and bocaparvovirus) in Ireland through the use of molecular and statistical analyses, under the supervision of Dr. Helen O'Shea in Cork IT. This involved the use conventional molecular amplification and sequencing with the computation modelling including phylogenetics and codon substitution model. My previously obtained a BSc [Hons] in Pharmaceutical Biotechnology in 2010 from Cork IT.

Recent Publications

Gunn, Lynda, Collins, P.J., Fanning, S., McKillen, J., Morgan, J., Staines, A., O'Shea, H., 2015. Detection and characterisation of novel bocavirus (genus Bocaparvovirus) and gastroenteritis viruses from asymptomatic pigs in Ireland. Infect. Ecol. Epidemiol. 5. doi:10.3402/iee.v5.27270

Gunn, L., Collins, P.J., O'Connell, M.J., O'Shea, H., 2015. Phylogenetic investigation of enteric bovine coronavirus in Ireland reveals partitioning between European and global strains. Ir. Vet. J. 68, 31. doi:10.1186/s13620-015-0060-3

Gunn, L., Feeney, S. a., Cashman, O., Collins, P. j., Coyle, P. v., O'Shea, H., 2012. Molecular characterization of group A rotavirus found in elderly patients in Ireland; Predominance of G1P[8], continued presence of G9P[8], and emergence of G2P[4]. J. Med. Virol. 84, 2008–2017. doi:10.1002/jmv.23416

Gunn, L., Finn, S., Hurley, D., Bai, L., Wall, E., Iversen, C., Threlfall, J.E., Fanning, S., 2016. Molecular characterisation of Salmonella serovars Anatum and Ealing associated with two historical outbreaks, linked to contaminated powdered infant formula. Food Microbiol. 7, 1664. doi:10.3389/fmicb.2016.01664

Yu, Z., Gunn, L., Brennan, E., Reid, R., Wall, P.G., Gaora, P.Ó., Hurley, D., Bolton, D., Fanning, S., 2016. Complete Genome Sequence of Clostridium estertheticum DSM 8809, a Microbe Identified in Spoiled Vacuum Packed Beef. Front. Microbiol. 7. doi:10.3389/fmicb.2016.01764

Niall O'Brien, BE, M.EngSc., PhD

Project Title: Integrating engineered nanomaterial (ENM) kinetics with environmental exposure modelling

Project Leader: Assoc. Professor. Enda Cummins

Abstract

The "nanoADJUST" project aims to develop expertise in the application of techniques and tools used to characterise and analyse the behaviour of metallic engineered nanomaterials (ENMs) in natural aquatic media and integrate this expertise with environmental exposure modelling and risk management data requirements and processes. Fit-for-purpose analytical methodology shall be developed for quantification of nanoparticle related elemental concentrations in model experiments and natural aquatic environmental matrices. Behavioural indicators or descriptors (i.e. partitioning likelihood distributions) shall also be developed for use in ENM experimental analysis, exposure monitoring and risk assessment. Final reporting for the nanoADJUST project was completed in Jan 2017. I am currently on secondment at Science Foundation Ireland as a SFI Fellow in the Performance Improvement Division.

Background, Skills & Qualifications

My PhD thesis, concerning the development of development of a risk assessment methodology for evaluating ecological dispersion and human health risks from nanoparticles through environmental pathways, was completed in 2010 under the supervision of Dr. Enda Cummins. I obtained a Masters in Engineering Science in the area of renewable fuel production in 2006 and a BE in Biosystems Engineering in 2004, both from UCD. I was funded from 2013-2016 as an EU FP7 Marie Curie International Outgoing Fellow and was based at the Centre for the Environmental Implications of Nanotechnology (CEINT), based at Duke University, NC, USA from Dec 2013-Dec 2015.

Selected Recent Publications

O'Brien, N., Cummins, E. (2016). Environmental Exposure Modeling Methods for Engineered Nanomaterials. In: Senesi, N. and Xing, B. (eds). Engineered Nanoparticles and the Environment: Biophysicochemical Processes and Toxicity.

Geitner, N., Marinakos, S., Guo, C., O'Brien, N., Wiesner, M. (2016). Nanoparticle Surface Affinity as a Predictor of Trophic Transfer. Environmental Science & Technology, 50:6663-6669.

O'Brien, N., Cummins, E. (2011). Nano-functionalized techniques in crop and livestock production: Improving food productivity, traceability and safety. In: Frewer l., Norde W., Fischer A. and Kampers F. (eds). pp.91-106, Nanotechnology in the agri-food sector: Implications for the future.

O'Brien, N., Cummins, E. (2011). A risk assessment framework for assessing metallic nanomaterials of environmental concern: Aquatic exposure and behaviour. Risk Analysis, 31:706-726.

O'Brien, N., Cummins, E. (2010). Ranking initial environmental and human health risk resulting from environmentally relevant nanomaterials. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering 45:992-1007.

Jerome O'Connell BSc, MSc, PhD

Project Title: GeoHub: Radiometric normalisation of image data for vehicle or UAV mounted sensors

Project Leader: Prof. Nick Holden

Abstract
The global market for remote sensing is projected to grow from $8.1B in 2014 to $12.1B by 2019. The move towards integration of remote sensing and other big data sources into day to day decision making in industries like precision agriculture has been clearly demonstrated by large multinational investment. However, several roadblocks (e.g. data quality and consistency and data integration/compatibility) have been identified by industry and academics which is prohibiting the widespread uptake of such data in sectors like agriculture. GeoHub will create a dedicated software solution for maintaining data quality and compatibility for such platforms, thereby facilitating the widespread integration of such data into industries like precision agriculture and natural resources.

Background, Qualifications and Skills
My main research interest lies in the commercial and scientific application of remote sensing in agriculture and natural resources. In particular, the development of image processing tools and software around radiometric correction, image classification, image enhancement and data transfer. I graduated in December 2007 with a Masters in Applied Science in GIS and Remote Sensing in Environmental Management at University College Cork. In addition, I was also awarded a Masters in Forestry from the University of Wales, Bangor in 2005. I completed my PhD in University College Dublin in 2012. The main objective of this research was to create a monitoring protocol for the detection of disturbance in Irish peatlands. In November 2016, I completed a 4 year post doctorate in the University of Leeds on habitat mapping in agricultural landscapes. I am also involved in other collaborations, including work with New York University on conservation agriculture in Malawi and the EU-BON pan-European biodiversity observation network.

Recent Publications
O Connell, J., Bradter, U. and Benton, T. G. 2015. Wide-area mapping of small-scale features in agricultural landscapes using airborne remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, **109**, 165-177.
O Connell, J., Connolly, J. and Holden, N. 2014. A monitoring protocol for vegetation change on Irish peatland and heath. *International Journal of Applied Earth Observation and Geoinformation,* **31**, 130-142.
O Connell, J., Bradter, U. and Benton, T. G. 2013. Using high resolution CIR imagery in the classification of non-cropped areas in agricultural landscapes in the UK. *SPIE Remote Sensing.* Dresden, Germany, International Society for Optics and Photonics.
O Connell, J., *et al.,* 2013. Radiometric normalization for change detection in peatlands: a modified temporal invariant cluster approach. *International Journal of Remote Sensing,* **34**, 2905-2924.

Tom Oldfield, BSc, M.Sc., PhD

Project Title: AgroCycle

Project Leader: Professor Shane Ward

Abstract
Continuing population and consumption growth are driving global food demand, with agricultural activity expanding to keep pace. The modern agricultural system is wasteful, with Europe generating some 700 million tonnes of agrifood waste each year along the entire pre- and post- farm gate food production chain. The AgroCycle project will further develop, demonstrate and validate novel processes, practices and products for the sustainable use of agricultural wastes in applications such as fertilisers, biopolymers and novel chemicals as well as developing technology and policy guidelines for the bioeconomy. The project's holistic approach will also include significant life cycle assessment work to evaluate the environmental performance that is crucial in determining the suitability and sustainability of potential value chains.

Background, Skills & Qualifications
My PhD thesis, regarding the analysis of organic waste was completed in 2016 under the supervision of Professor Nicholas Holden at UCD. This concerned: how life cycle assessment is used to analyse waste management and valorisation pathways, and a number of case studies were underttaken for Ireland, Europe and California. I obtained an MSc in Sustinable Energy and Green Technology from UCD in 20012 and a BSc in International Disaster and Engineering Management from Coventry University in 2008.

Recent publications

Oldfield, T.L., Achmon., Y., Perano K.M., Dahlquist-Willard R.M., Vander Gheynst J.S., Stapleton J.J., Simmons, C.W., & Holden, N.M. (2017). A life cycle assessment of biosolarization as a valorization pathway for tomato pomace utilization in California. J. of Clean. Prod. 141, 146-156.

Ward, S., Holden, N.M., White, E., & **Oldfield, T.L.** (2017). Agriculture. Waste to resource. Report for UK Chief Scientific Officer. In Press.

Oldfield, T.L., White, E., & Holden, N.M. (2016). An environmental analysis of options for utilising wasted food and food residue. J. of Environ. Manage. 183, 826-835.

Amanda Sosa-Peyton, BE, M.Sc., PhD

Project Title: Supply optimisation of novel waste plastic-to-fuel systems in Ireland

Project Leader: Dr Fionnuala Murphy

Abstract

Plastic waste materials are difficult to manage; they contain many different polymers making it difficult to identify the exact composition of the material, they are usually non-biodegradable and highly durable so remain as waste in the environment for a very long period of time. Waste plastic-to-fuel conversion by pyrolysis allows for the recovery of the petrochemical constituents of the polymer which can then be used for different purposes. This aim of this project is to develop a methodology for optimising the supply of plastic waste to a pyrolysis plant in Ireland. The challenge of the optimisation problem is to maximise energy recovery while minimising costs and environmental impacts.

Background, Skills & Qualifications

In 2015 I was awarded a PhD in Biosystems & Food Engineering from University College Dublin. My research project under the supervision of Dr. Kevin McDonnell, aimed at minimising truck transportation costs in order to improve the forest biomass supply chain in Ireland. I developed different decision support tools with commercialisation potential. These tools used digital image processing, geographic information systems and optimisation/heuristic algorithms that dealt with tactical and operational planning issues, namely allocation, routing and scheduling. I also obtained an MSc in World Heritage Management from UCD in 2010, and a BE in Forestry Engineering from Universidad de Los Andes (Venezuela) in 2006.

Recent publications

Trejo, J., Erazo O., **Sosa A.** (2017). *The industrial waste of sawmills as an energetic resource in Venezuela.* Revista Forestal Venezolana (Venezuelan Journal of Forestry). No 59 (1). In Press.

Murphy, F., **Sosa A.,** McDonnell, K., and Devlin, G. (2016). *Life cycle assessment of biomass-to-energy systems in Ireland with biomass supply chain optimisation based on greenhouse gas emission reduction,* Energy (IF 4.159).

Sosa, A., Acuna, M., McDonnell, K., and Devlin, G. (2015). *Managing the Moisture Content of Wood Biomass for the Optimisation of Ireland's Transport Supply Strategy to Bioenergy Markets and Competing Industries*. Energy (IF 4.465). 86, 354-368.

Sosa, A., Acuna, M., McDonnell, K., and Devlin, G**.** (2015) *Controlling Moisture Content and Truck Configuration to Optimise Biomass Supply Chain Logistic in Ireland,* Applied Energy (IF 5.597), 137, 338-351

Joe Sweeney, BSc, MSc, PhD

Project Title: Horizon 2020 AgroCycle

Project leader: Prof. Shane Ward

Abstract
The development and implementation of biosensor solutions, as required by the 'Horizon 2020 AgroCycle' project and its industry partners requires that a computer science, microbiology and biosystems engineering interdisciplinary skill set be implemented. As a leading researcher in the area of whole-cell biosensors, I have created a suite of novel biosensors that will allow end users to accurately and inexpensively determine specific analyte concentrations with the exclusion of all interfering organic acids within their respective fermentation processes.

Background, skills and qualifications
The biosensors that I have created is as a result of the "*Smart Sensing for Hybrid AD reactors*" PhD which I completed in the School of Biosystems Engineering in 2016. This project drew upon my background in both microbiology and computer science; whereby my background in microbiology allowed me to develop the biosensors' biological elements, by implementing suites of novel genetic engineering- and analytical-protocols, while my background in computer science allowed me to create the biosensors' biological-analytical interface from which the concentration of specific analyses could be quantified into by a digital output.

Publication Details

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. Deleting *acs* and *ackA* within an *E. coli* knockout mutant allows for a propionate-biosensor applicable to two-phase ADs to be created. *Enzyme Microb. Technol.* (2017)*

*submitted and under review.

Ming Zhao, BSc, MEnSc., PhD

Project Title: Process analytical technology (PAT) for on-line quality control of dairy products

Project Leader: Prof. Colm O'Donnell

Abstract
PAT encompasses analytical measurements and understanding of chemical, physical and microbiological parameters governing industrial processing. With regard to the dairy industry, critical PAT considerations include quality and authenticity for at-line, inline and on-line monitoring purposes. This project evaluates the potential of spectroscopic techniques combined with multivariate statistical modelling for the prediction of main ingredients and contaminations of infant formula and milk products.

Background, Skills & Qualifications
My PhD thesis, concerning development of PAT tools using a range of spectral and chemometric approaches for advanced process control and adulteration detection in selected beef and dairy products, was completed in 2016 under the supervision of Prof. Colm O'Donnell and Prof. Gerard Downey in UCD. This work involved: spectroscopic techniques (NIR, MIR, Raman, microwave and hyperspectral imaging) with chemometric approaches for in-line, on-line or at-line use in the meat and dairy industry. I obtained an MEnSc in Food and Biosystems Engineering from UCD in 2012 and a BSc in Nutritional Science from UCC in 2010.

Recent publications
Yingqun Nian, **Ming Zhao**, Colm P. O'Donnell, Gerard Downey, Joseph P. Kerry, Paul Allen (2017). Assessment of physico-chemical traits related to eating quality of young dairy bull beef at different ageing times using Raman spectroscopy and chemometrics. Food Research International, 99, 778-789.

Ming Zhao, Carlos Esquerre, Gerard Downey, Colm P. O'Donnell. (2016). Process analytical technologies for fat and moisture determination in ground beef - a comparison of guided microwave spectroscopy and near infrared hyperspectral imaging. Food Control, 73, 1082-1094.

Ming Zhao, Gerard Downey, Colm P. O'Donnell. (2016). Exploration of microwave dielectric and near infrared spectroscopy with multivariate data analysis for fat content determination in ground beef. Food Control, 68, 260-270.

Ming Zhao, Gerard Downey, Colm P. O'Donnell. (2015). Dispersive Raman Spectroscopy and Multivariate Data Analysis to Detect Offal Adulteration of Thawed Beefburgers. Journal of Agricultural and Food Chemistry, 63 (5), 1433–1441.

Ming Zhao, Renwick J. Beattie, Anna M. Fearon, Colm P. O'Donnell and Gerard Downey. (2015). Prediction of naturally-occurring, industrially-induced and total trans fatty acids in butter, dairy spreads and Cheddar cheese using vibrational spectroscopy and multivariate data analysis. International Dairy Journal, 51, 41-51.

Ming Zhao, Gerard Downey, Colm P. O'Donnell. (2014). Detection of adulteration in fresh and frozen beefburger products by beef offal using mid-infrared ATR spectroscopy and multivariate data analysis. Meat Science, 96, 1003–1011.

Mingjia Yan, B.Eng., M.Sc., PhD

Project Title: Mapping and LCA of energy and water

Project Leader: Dr. Nicholas M Holden

Abstract
Life cycle assessment (LCA) is a tool for assessing environmental aspects and potential impacts throughout a product life cycle. This project is aimed to apply LCA to one of the vital industry in Ireland, the dairy processing industry, and assess the energy and water impacts of processing dairy products. The project is funded by the Irish State through funding from the Technology Centre programe.

Background, Skills & Qualifications
My PhD was on the LCA of Irish milk production from farm to national scale. I completed my thesis in 2012 under the supervision of Dr. Nicholas M Holden at UCD and Dr James Humphreys at Teagasc morepark. I obtained an MSc in Ecology from Beijing Normal University in 2008, and a BA in Applied Chemistry from East University of Science and Technology in 2005.

Recent publications

Wiedemann, S, Yan, M-J, Henry, B, Murphy, C. 2016. Resource use and greenhouse gas emissions from three wool production regions in Australia. Journal of Cleaner Production. v 122, p121-132.

Wiedemann, S, McGahan, E, Murphy, C, Yan, M-J, Henry, B, Thoma, G, Ledgard, S. 2015. Environmental impacts and resource use of Australian beef and lamb exported to the USA determined using life cycle assessment. Journal of Cleaner Production, v 94, p 67–75

Wiedemann, S, Ledgard, S, Henry, B, Yan, M-J, Mao, N, Russell, S. 2015. Application of life cycle assessment to sheep production systems: investigating co-production of wool and meat using case studies from major global producers. International Journal of Life Cycle Assessment, v 20, p 463-476

Wiedemann, S, Murphy, C, Yan, M-J. 2015. Resource use and environmental impacts from Australian export lamb production: a life cycle assessment. Animal Production Science. doi.org/10.1071/AN14647

Holden NM and Yan, M-J. 2013. Life Cycle Assessment and Sustainable Food Processing. In Sustainable Food Processing. Tiwari B, Norton T, Holden NM (Ed). Wiley-Blackwell.

Li, D, Watson, CJ, Yan, M-J, Lalor, S, Rafique, R, Hyde, B, Lanigan, G, Richards, KG, Holden NM, Humphreys, J. 2013. A review of nitrous oxide mitigation by farm nitrogen management in temperate grassland-based agriculture. Journal of Environmental Management. v 128, 893-903

Yan, M-J, Humphreys, J, Holden, NM 2013. Evaluation of process and Input-Output based Life Cycle Assessment of Irish milk production. Journal of Agricultural Science (Cambridge), v 151, p 701-713

Yan, M-J, Humphreys, J., Holden, NM 2013. Life Cycle Assessment of milk production from commercial dairy farms: the influence of management tactics. Journal of Dairy Science, v 96, p 4112-4124

Yan, M-J, Humphreys, J, Holden, NM 2013. The carbon footprint of pasture based milk production: can white clover make a difference? Journal of Dairy Science, v 96, p 857-865

Yan, M-J, Humphreys, J, Holden, NM 2011. An evaluation of life cycle assessment of European milk production. Journal of Environmental Management, v 92, p 372-379

Appendix 3

Links to Postgrad Research Activities with YouTube Videos

Taught Masters

Daniel O'Meara (ME Biosystems and Food Eng)
Interview: https://www.youtube.com/watch?v=sVp6CDf8qWo
Presentation: https://www.youtube.com/watch?v=BGKnoNhR75I

Raphaël Menager (MSc Sustainable Energy and Green Technologies)
Interview: https://www.youtube.com/watch?v=l6nDt2aP22c
Presentation: https://www.youtube.com/watch?v=A-K4rXqpgB8

Research Masters

Ronan Dorrepaal
Interview: https://www.youtube.com/watch?v=bRCi_OyDxT4
Presentation: https://www.youtube.com/watch?v=MdcmAIWwJcA

Thomas Wallace
Interview: https://www.youtube.com/watch?v=vNhKpDazAYw
Presentation: https://www.youtube.com/watch?v=6OlMZisw43U

Junior PhD

Sindhuraj Mukherjee
Interview: https://www.youtube.com/watch?v=PcNWyKTOMQs
Presentation: https://www.youtube.com/watch?v=m6pLFQ2Sk1c

Felipe Guth
Interview: https://www.youtube.com/watch?v=FnOI0U6ZQWI
Presentation: https://www.youtube.com/watch?v=eefOza2ScoM

Senior PhD

Rachel Clarke
Interview: https://www.youtube.com/watch?v=Qzu3kAjc2GA
Presentation: https://www.youtube.com/watch?v=I5Q8Vfc-FjI

David Kelleghan
Interview: https://www.youtube.com/watch?v=2Uj6TpGZH3k
Presentation: https://www.youtube.com/watch?v=y6bqPdqZnlQ