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BIOSYSTEMS ENGINEERING

RESEARCH REVIEW 14

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FOREWORD

The Fourteenth Annual **Research Review** describes the ongoing research programme in Biosystems Engineering at University College Dublin. 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 five awards for presentational excellence at the Fourteenth Annual **Biosystems Engineering Research Seminar** held in University College Dublin on **Wednesday 11th March 2009**.

The four 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; and
- a photographic record of the full-time staff who assisted in project supervision and administration.

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.

ENDA CUMMINS and TOM CURRAN 3 May 2009

*MEngSc1, MSc1, MAgrSc1 = Research Masters (Mode 1)

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Prediction of consumer assessment of beef palatability from features of *longissimus dorsi* colour and marbling features and surface texture features

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Abstract

Beef palatability has been previously investigated with digital imaging systems using trained sensory panels to simulate public perception. However, the closest approximation of public perception is a consumer panel. Thus previously successful image analysis methods were repeated on a new set of samples where a consumer panel judged palatability. Accurate modeling of beef likeability with regression models proved possible (r^2 = 0.86). Modeling of some other important palatability measurements proved encouraging (tenderness r^2 = 0.76, juiciness r^2 = 0.69, flavour r^2 = 0.78). A basis has been found for expanding the computer vision approach into consumer panel judgments of palatability.

Introduction

Computer vision systems offer an encouraging alternative to manual expert grading of the type implemented by the United States Department of Agriculture (USDA, 1997). Advantages of computer vision systems are objective, rapid, consistent and non-invasive predictions of palatability (Jackman, Sun, Du and Allen, 2009). Many of the benefits of computer vision in food quality assessment are further analysed by Sun (2008) and Du and Sun (2004).

Many imaging systems handling digital images of fresh beef have been developed in recent years to yield predictive models of palatability (Li, Tan, Martz and Heymann, 1999; Tian, McCall, Dripps, Yu and Gong, 2005; Jackman, Sun, Du, Allen and Downey, 2008a; Jackman *et al*, 2009; Jackman, Sun and Allen, 2008b). The method of Jackman *et al* (2008b) appears to be the most encouraging.

Thus the three palatability indicators of LD muscle colour, marbling and surface texture are used for prediction. Texture is computed from the Cb greyscale of high magnification images with the symmetric modified Daubechie wavelet. Genetic algorithms search for the best model subsets.

Consumer panels follow a similar procedure to sensory panels in that a sample from a duplicate cut of beef is served up and an opinion is offered on the palatability attributes. The average opinion of the panel is taken as the beef sample's palatability. Consumer panels differ in that the panelists are not trained to recognize palatability traits. To compensate for this a much larger number of panelists are used.

Thus the current objective is firstly to investigate if the methods successfully developed for predicting sensory panel assessments of palatability can be successfully applied to consumer panel assessments. Secondly to develop accurate predictive models of a range of consumer panel palatability measurements.

Materials and methods

Sample Preparation
Thirty four beef carcasses were prepared according to the procedures described previously (Jackman *et al*, 2009) except that some carcasses received electric shock stimulation and some carcasses were hung from the hip bone. Cuts from the striploin were excised 2 days post-slaughter. One cut of the striploin was used immediately for image analysis at

both high and low magnification. A consumer panel analyzed a duplicate cut that was aged for 14 days (period of ageing includes the 2 days after slaughter).

Image acquisition and processing
The image acquisition system is the same system used by Jackman *et al* (2008a, b). The images acquired from each sample were a single normal view image of the whole steak ribeye and 5 high magnification images of spots on the ribeye muscle.

A segmentation algorithm split the normal view images into background, LD muscle and marbling. Segmentation was not required for the high magnification images.

Fifteen colour features were extracted from the normal view LD muscle image (mean, standard deviation, skewness, kurtosis and interquartile range of red, green and blue) and 7 marbling features from the marbling image (mean, standard deviation, skewness, kurtosis and interquartile range of fleck size along with overall fleck area density and overall fleck number density).

Texture features were computed from the high magnification images. Texture features computed were from the symlet transform as previous research by Jackman *et al* (2008a) identified the symlet to be the best wavelet type. In pursuit of a simplified approach to texture characterisation 3 orders (3rd, 5th & 7th) of the symlet transform were applied at full decomposition on each image to provide the required characterization of texture.

Sensory property evaluation
A consumer panel determined the overall likeability, tenderness, juiciness and flavour of the 14 days aged duplicate cut. Steaks were grilled and served to consumer panels using the procedure described by Watson, Gee, Polkinghorne and Porter (2008). Consumer panel data differs notably from expert panel data acquisition as a much larger panel is used and palatability is scored on a continuous scale. From the consumer panel data, mean values of tenderness, juiciness, flavour and likeability were computed.

Data processing
Application of 3 orders of the symlet transform at full decomposition yielded 111 variables per 512 x 512 size image. Each texture variable was standardised before further use (the mean feature value over the 5 images was standardised). Incorporating the 22 colour and marbling features (also standardised) made the total number of variables considered 133. The same genetic searching method described by Jackman *et al* (2009) was used to search for the best regression models. Squared and Interaction terms based on the linear model were considered by the same genetic algorithm. Algorithm settings are given in Table 1.

Table 1: Genetic Algorithm parameters

Parameter	Setting
Population	100
Generations	100
Creation	Customised
Fitness	Rank
Selection	Stochastic uniform
Elitism	1%
Crossover	70%
Mutation	Gaussian (scale & shrink = 1)
Crossover	Scattered
Migration	Forward (20% cut, interval =20)
Hybrid func	No
Fitness func	Not vectorised
Cond num	1000

All models must meet by 3 criteria. Firstly the regression equation does not have any eigenvalues near zero. Secondly the regression equation does not predict a random variable and thirdly the PLSR error curve does not have obvious local maxima on the way to the minimum point. The software package Unscrambler (Camo, Woodbridge, NJ, USA) can perform these tests. Some manual elimination of equation variables may be required to meet the 3 criteria.

Results and discussion

Modelling Likeability

Model result is given in Table 2. as an r^2 value, indicating the proportion of beef overall likeability variance accounted for by the model and by the ratio of model error to response variable standard deviation (RRR). The model was validated by full cross validation. The model crucially meets the benchmark of accuracy set by Shiranita, Hayashi, Otsubo, Miyajima and Takiyama (2000) of an r^2 value of 0.8. It however does not meet another important benchmark of a RRR of less than one-third set by Jackman *et al* (2008a; 2009).

Table 2: PLSR model results.

	Like	Tender	Juice	Flav
r^2	0.86	0.76	0.69	0.78
Factors	11	12	13	12
RRR	0.38	0.51	0.57	0.49

As found in previous analyses (Jackman *et al*, 2008a, b, 2009) texture terms dominate the model. Also as found previously linear terms dominate the model. Model terms are given in Table 3. The model met the 3 stability criteria.

Table 3: Model variables.

Like	Tender	Juice	Flav
v_{3-3}	h_{8-3}	v_{7-5}	h_{3-3}
v_{5-3}	v_{5-3}	d_{5-5}	d_{3-3}
v_{6-5}	v_{8-3}	d_{7-5}	v_{7-5}
d_{7-5}	d_{3-3}	h_{4-7}	d_{1-5}
h_{9-7}	d_{5-3}	h_{6-7}	d_{2-5}
v_{4-7}	v_{6-5}	h_{8-7}	d_{5-5}
v_{7-7}	d_{7-5}	v_{4-7}	d_{6-5}
d_{5-7}	h_{7-7}	d_{5-7}	ap_{9-5}
Mean G	v_{4-7}	d_{9-7}	h_{7-7}
Mean B	v_{7-7}	Std B	h_{9-7}
Skew R	d_{5-7}	Kurt B	d_{5-7}
$d_{7-5}*h_{9-7}$	Mean B	Iqr G	d_{6-7}
Mean B*Skew R	skew R	Iqr B	d_{7-7}
		$h_{4-7}*d_{9-7}$	$d_{3-3}*d_{2-5}$

Notes: for x_{m-n}: ap = approximation, d =diagonal, h =horizontal and v = vertical, m = decomposition level, n = wavelet order; R =red, G = green and B= blue.

Modelling other palatability measurements

While the most complete measurement of palatability in a consumer panel test is overall likeability, the other measurements of tenderness, juiciness and flavour are important. These are the 3 most important aspects of palatability (Warriss, 2000). Results for these measurements were computed in the same manner as for likeability with model results in Table 2. None of the models reached any of the benchmarks for accuracy but tenderness and flavour came close to an r^2 value of 0.8.

Similar to likeability texture terms dominated the models; this was also found previously (Jackman *et al*, 2008a, b, 2009). Also linear terms predominated with at most one non-linear term. The model terms are given in Table 3. As with likeability each model passed the 3 stability tests.

Summary

The results obtained have shown that the computer vision methods developed using trained sensory panel palatability data have transposed well to consumer panel palatability data. The likeability model was not as good as the corresponding acceptability model (Jackman *et al*, 2008b) but did use much fewer factors. Achieving accurate models proved difficult with only one model reaching an accuracy threshold. Thus the model results should be viewed as an encouraging basis for further research.

Similar to a lot of previous research surface texture has proven to be the most powerful palatability indicator with 44 of the 54 model variables being purely texture terms. Colour has again proven to be the second most powerful with 10 of the 54 model variables being a colour term. Marbling has again shown to be the weakest palatability indicator with none of the 54 model variables being a marbling term. The addition of non-linear terms has like in previous research proved to be of little benefit with only 4 of 54 terms being non-linear.

Conclusions and future work

The results showed that consumer opinion of beef likeability can be accurately modeled with color, marbling and surface texture features. Other important measurements of beef palatability could not quite be modeled as accurately. The methods developed for predicting sensory panel assessment of palatability have transposed well onto consumer panel data.

A more advanced non-linear analysis than adding squared and interaction terms might lead to some more improvement. Neural networks may be suitable and have been successfully previously (Li *et al*, 1999; Tian *et al* 2005). Although there appears little evidence of strong non-linearity. More promising options would be parallel data such as Near Infra Red (NIR) data. Research by Park, Chen, Hruschka, Shackleford and Koohmaraie (2001) has demonstrated that NIR data can be useful for indicating tenderness. Hyperspectral data is also another alternative worth consideration.Re-interpretation of panel results where a histogram of opinions is treated as the result rather than just using the linear sum of the panel's opinion could offer better insight.

Acknowledgements

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References

Du, C.-J. & Sun, D.-W. (2004). Recent developments in the applications of image processing techniques for food quality evaluation. *Trends in Food Science & Technology,* 15(5): 230-249.

Jackman, P., Sun, D.-W., Du, C.-J., Allen, P. & Downey, G. (2008a). Prediction of beef eating quality from colour, marbling and wavelet texture features. *Meat Science*, 80(4): 1273-1281.

Jackman, P., Sun, D.-W. & Allen, P. (2008b). Prediction of beef palatability from digital image features. *Proceedings of the 2008 CIGR International Conference on AGRICULTURAL ENGINEERING XXXVII*, 31st August-4th September 2008, Iguassu Falls City, Brazil.

Jackman, P., Sun, D.-W., Du, C.-J., & Allen, P. (2009). Prediction of beef eating qualities from colour, marbling and wavelet surface texture features using homogenous carcass treatment. *Pattern Recognition,* 42(5): 751-763.

Li, J., Tan, J., Martz, F.A. & Heymann, H. (1999). Image texture features as indicators of beef tenderness. *Meat Science,* 53(1): 17-22.

Park, B., Chen, Y.R., Hruschka, W.R., Shackleford, S.D. & Koohmaraie, M. (2001). Principle component regression of near-infrared reflectance spectra for beef tenderness prediction. *Transactions of the ASAE,* 44(3): 609-615.

Shiranita, K., Hayashi, K., Otsubo, A., Miyajima, T. & Takiyama, R. (2000). Grading meat quality by image processing. *Pattern Recognition,* 33(1): 97-104.

Sun, D.-W. (ed) (2008). *Computer Vision Technology for Food Quality Evaluation*, Academic Press / Elsevier, San Diego, California, USA, 583 pp.

Tian, Y.Q., McCall, D.G., Dripps, W., Yu, Q. & Gong, P. (2005). Using computer vision technology to evaluate the meat tenderness of grazing beef. *Food Australia,* 57(8): 322-326.

Warriss, P.D. (2000). *Meat Science: An introductory text*. Wallingford: CABI Publishing. pp. 106-130.

Watson, R., Gee, A., Polkinghorne, R. & Porter, M. (2008). Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture,* 48: 1360-1367.

CHARACTERISATION OF VISUAL TEXTURE OF PORK HAM IMAGES USING NORMALISED LACULARITY

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Abstract

Image analysis techniques are capable of extracting descriptors of the visual and non-detected visual textural patterns from ham slice surfaces. These descriptors allow analysis and interpretation with precision and objectivity for the quality grading of hams. This paper investigated the potential usefulness of the fractal normalised lacunarity metric, using binary images of pores/defects and fat-connective tissue structures, as a quantitative descriptor of visual texture in ham slice images.

Introduction

An important goal for the characterisation of visual texture in biological materials, using computer vision technology, is the quantification of spatial patterns. These patterns are often complex, exhibit scale-dependent changes in structure, and are difficult to identify and describe. Consequently, the use of normalised lacunarity has been applied to tackle this problem. Lacunarity quantifies the degree of translational invariance of the analysed objects, with low values of lacunarity indicating high levels of such invariance. It should be noted that the meaning of the term "visual texture" is completely different from the usual meaning of texture in foods, and is defined as the spatial organisation of intensity variations in an image at various wavelengths. Ham slices in general have complex and inhomogeneous colour surfaces and their textures do not contain any detectable periodic or quasiperiodic structure. Instead, they exhibit random but persistent patterns that result in a cloudlike texture appearance. These inhomogeneities can be attributed mainly to formulation, presence of pores/defects and fat-connective tissue, and colour variations. Thus, for objective characterisation, image analysis techniques need to take into account the high variability in colour and texture appearance. A second-order metric such as lacunarity is, in theory at least, able to characterise these images better, providing information about the spatial distribution of their intensity pixels. Numerous algorithms for estimating lacunarity have been implemented for a variety of images. Lacunarity computation using the gliding box algorithm has the advantage of the large sample size that usually leads to more consistent statistical results. Furthermore, lacunarity is suitable to describe the spatial distribution of real datasets, because translational invariance is also a property of non-fractal sets. This is an advantage over fractal dimension, and has been commonly used as a texture descriptor of images that often exhibit limited self-similarity. Moreover, translational invariance is highly scale dependent, so lacunarity is considered a scale-dependent measure of heterogeneity. **The objective of this paper was to investigate the potential usefulness of the fractal normalised lacunarity metric, using binary images of pores/defects and fat-connective tissue structures, as a quantitative descriptor of visual texture in ham slice images.**

Materials & Methods

Three pork ham qualities; high yield ham (A1, low quality), medium yield ham (A2, intermediate quality), and low yield ham (A3, premium quality) were manufactured in Dawn Farm Foods (Co. Kildare, Ireland), using different muscle sections and different percentages of brine solutions (wet curing by injection). Images were acquired immediately after slicing (200 slices per quality). A colour calibrated computer vision system (CVS)

as described by Valous, Mendoza, Sun, & Allen (2009) was used for image acquisition. The software package MATLAB (MathWorks, USA) was used for image processing and fractal computations. Due to the large variations in size and shape among the three ham qualities, the images were subsequently cropped in the central region to produce 256x256 pixel images. For the lacunarity analysis, cropping allowed better scrutiny and interpretation, and also kept computation times manageable. The segmented binary images of pores/defects and fat-connective tissue (Valous et al., 2009) were the input for the lacunarity computation. The algorithm analyses the deviations from translational invariance of the image's intensity distribution using gliding box sampling (Pendleton, Dathe & Baveye, 2005). In this method, a square structuring element or moving window of side length b is placed in the upper left-hand corner of the ham slice image of side length T (pixels), such that $b \leq T$. The algorithm records the number or "mass" m of pixels that are associated with the image underneath the moving window. The window is then translated by one pixel to the right and the underlying mass is again recorded. When the moving window reaches the right-hand side of the image, it is moved back to its starting point at the left-hand side of the image and is translated by one pixel downward. The computation proceeds until the moving window reaches the lower right-hand edge of the image, at which point it has explored every one of its $(T - b + 1)2$ possible positions. Thus, to calculate lacunarity, the number of empties is added to the mass counted. Since the size of the analysed images is 256x256 pixels, the code computes the values of lacunarity for each value of b between $b_{min} = 1$ and $b_{max} = 256$, with a step size of 1. Matlab implementation of the algorithm takes into account the pixel mass-based lacunarity not only of the foreground pixels (structures of pores/defects and fat-connective tissue), but also of the empty boxes (white background or lean of hams). Lacunarity Λ measured with a moving window of side length b, is given by:

$$\Lambda = \frac{\sigma^2}{\mu^2} + 1 \quad (1)$$

where the ratio of σ (standard deviation) to μ (mean) changes with window size which signify that lacunarity depends on the scale (window size relative to image size), as well as the complexity of the image. The normalised lacunarity was computed from the following:

$$\Lambda_{norm} = 2 - \left(\frac{1}{\Lambda} + \frac{1}{\Lambda^c} \right) \quad (2)$$

where Λ^c is the complementary lacunarity (obtained by calculating the lacunarity of the complemented binary image), ensuring a lacunarity measure within the range of 0 - 1 that can be compared independently of image density. Once the computation is complete, normalised lacunarity as a function of moving window b is presented as a 2-dimensional plot, which illustrates the scale dependency of spatial nonstationarity in the image.

Results & Discussion

Figure 1 shows representative images of the three evaluated pork ham qualities (a) as well as a two-dimensional depiction of intensities (enhanced visual texture) in pseudocolor (b) and the corresponding binary images (c) of segmented pores/defects and fat-connective tissue structures (structures presented together). The 2D visualisation of the sliced pork ham textured images in pseudocolor was derived from a 3D surface intensity plot with a viewpoint of 90° (viewed directly from above). The two main enhanced topographical structures are: i) fat-connective tissue; which is depicted as a higher elevation surface feature, due to increased intensity levels (brighter regions), and ii) pores; which are presented as crater-like structures, due to lower intensity values (darker regions). The textured images enhance the differences in appearance among the three ham qualities. It is apparent that differences can be perceived (A2 > A1 > A3) in the spatial distribution of pores/defects and fat-connective tissue, which defines the degree of heterogeneity and complexity of the observed visual texture.

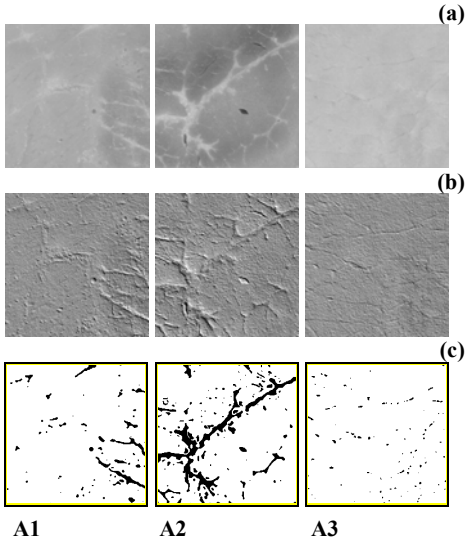

Figure 1. Representative images of the evaluated pork ham qualities: (a) original RGB images, (b) a 2D enhanced representation of image intensities in pseudocolor, and (c) binarised images of pores/defects and fat-connective tissue after segmentation of both structures.

These perceived dissimilarities between qualities emerge due to the differences in the raw material used and on processing conditions, which includes injection of brine, and tumbling. Ham products of higher quality (A3) are manufactured with a low level of brine injection and no tumbling. Tumbling provides an intense mechanical action on the meat (suitable for medium and high-yield hams) resulting in considerable cellular damage, that facilitates extraction of the salt-soluble proteins. This is important to bind the individual muscles together during cooking and leads to changes in the original structure pertinent to the final product texture. The A3 ham which retains the original muscle structure was not tumbled, in order for the meat structure and natural texture appearance to be kept intact. The visual texture of this ham is quite smooth, with characteristic horizontal and diagonal surface fissures. By contrast, lower quality hams (A2) are often structured from several pieces or comprised of different muscle types that can reproduce the entire ham when they are put together before cooking. This also has an effect on the texture appearance and colour of the ham slices. The normalised lacunarity (range from 0 to 1) plots for the binarised ham images are shown in Figure 2 for the whole range of sampling windows (256 pixels).

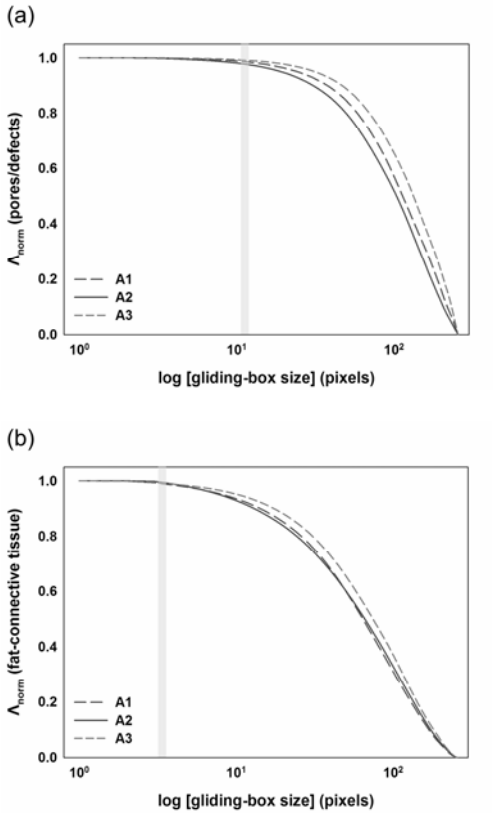

Figure 2. Log-linear plot of averaged values of normalised lacunarity as a function of moving window b for: (a) pores/defects, and (b) fat-connective tissue binary images for the three pork ham qualities.

The three qualities are easily distinguished in the case of the binarised images of pores/defects. Lacunarity plots explicitly characterise the spatial organisation of the image and can measure space filling capacity and heterogeneity. Lacunarity is smaller when the binary image is nearly translationally invariant, being made of "diffuse" clumps separated by smaller empty lacunas, like in the case of the A2 ham. Lacunarity is higher when the image consists of structures in the form of "tight" clumps separated by larger empty gaps. Having this in mind, differences can be perceived (A2 < A1 < A3) regarding the

spatial organisation of structures in the images, with increasing lacunarity towards the premium quality sliced ham (A3). In this sense, the more lacunar A3 images could be called fractally crowded, while lower lacunarity images could be called fractally uncrowded. In addition, the A3 ham (for both pores/defects and fat-connective tissue) has bigger lacunarity values, because the sizes of the structures in the images are distributed over a wider range (not shown). The lower values of lacunarity for the A1 and A2 pork hams relate to the lower deviation from translational invariance. The additional discriminating effect of lacunarity among the three ham qualities is more apparent in the pores/defects binary images, where the curves differentiate the ham qualities better than in the fat-connective tissue images. In the latter, the structures for A1 and A2 seem to have similar but nevertheless distinguishable lacunarity values. Texture appearance is strongly affected by lacunarity due to spatial heterogeneity of the structures. More lacunar images (A3) signify that there are fewer structures in the image, consequently pixel intensity variations are decreased, resulting in a smoother surface. The normalised lacunarity of the binarised fat-connective tissue images for the three ham qualities is relatively similar for small moving window sizes (up to ~5 pixels) and for large moving window sizes (greater than ~190 pixels), but differs in the intervening range. The same applies to the pores/defects images but for different gliding boxes (small: up to ~10 pixels; large: greater than ~240 pixels). For a given structure mass and box size, higher lacunarity indicates greater clumping (A3), so if the gliding box size reaches a characteristic size range of the clumps (gray section in Figure 2), the curve declines more rapidly, however lacunarity decreases more slowly with increasing gliding box size for irregular structures.

Conclusions

The visual texture of pork ham slices reveals a great deal of information about the different qualities and the perceived image roughness. This roughness is encapsulated as spatial variations in geometry and spectral characteristics that occur on a smaller scale. The perceived variations could be due to spatial dissimilarities in directional or spectral scattering characteristics, or due to distributions of structures such as pores/defects and fat-connective tissue. Distinctive topographical features were observed in all three qualities. The visually rougher high and medium yield ham slices (A1 and A2) were cured with increased percentages of brine solutions, comparing to the smoother A3 sliced ham. The results of lacunarity as a descriptor of visual texture indicate the characteristics of space filling capacity and heterogeneity in the images. Normalised lacunarity plots appear more representative for the characterisation of texture appearance, due to the changes of lacunarity over different gliding box sizes. The experimental results suggest that lacunarity has a discriminating effect among the three ham qualities, which is more apparent in the pores/defects binary images, where the curves differentiate the ham qualities better than in the fat-connective tissue images. This investigation confirmed the usefulness normalised gliding box lacunarity as a quantitative descriptor of visual texture in sliced ham images.

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References

1. Pendleton, D.E., Dathe, A., & Baveye, P. (2005). Influence of image resolution and evaluation algorithm on estimates of the lacunarity of porous media. *Physical Review E*, 72(4), 041306.
2. Valous, N.A., Mendoza, F., Sun, D.-W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat Science*, 81(1), 132-141.

CLASSIFICATION OF SLICED PORK AND TURKEY HAM IMAGES BASED ON IMAGE COLOUR FEATURES

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Abstract

Different colour features were extracted and the best features which have a significant effect in the classification of three pork and turkey ham qualities were obtained using Mahalanobis distance analysis as a feature selection method and Linear Discriminant Analysis (LDA) as classifier. The best colour features for pork hams were found to be the Std. deviation of b*, mean of Z and mean of S, while for turkey the best features were the mean of R, mean of V, and mean of X. With these best colour features the classification rates obtained using LDA were found to be 100% and 92.54%, for the pork and turkey hams, respectively.

Introduction

Colour is considered as a fundamental physical property of food products, since it has been widely demonstrated that it correlates well with physical, chemical and sensorial indicators of product quality (Mendoza, Dejmek, & Aguilera, 2006). Colour is the first sensation that the consumer perceives and is used as an indicator for the approval or rejection of a particular food, due to the fact that colour information allows the detection of certain anomalies or defects that food items may have (Du & Sun, 2004). In the meat industry, colour represents a critical factor which is commonly used as a quality index in relation to composition and processing conditions. In the retail sector, the main appearance parameters of pre-sliced hams influencing consumer acceptability and buying decision are not only an attractive and stable colour, but also the colour pattern variations and distributions, as well as the amount and size distribution of other morphological features such as pores/holes (Du & Sun, 2006; Valous, Mendoza, Sun, & Allen, 2009) and marbling or fat-connective tissue (Valous et al., 2009). All these features may occur together and define the final colour or colour appearance of the overall ham surface. It is well known that consumers need first to be entirely satisfied with the colour of a food product, before other quality dimensions become relevant (Chambers & Bowers, 1993). **Therefore, the objective of this study was to evaluate the potential of RGB, HSV, XYZ and L*a*b* colour spaces, and greyscale intensity using a colour calibrated image acquisition system to classify three different qualities of pre-sliced pork and turkey hams, typically consumed in Ireland.**

Materials & Methods

Three pork and turkey ham qualities were manufactured in Dawn Farm Foods (Ireland) and Shalvey Poultry Ltd., (Ireland), respectively, using different muscle sections and different percentages of brine solutions (wet curing by injection). The specifications are given in Table 1. All samples were chilled to 4°C before slicing. To guarantee reproducible colour and quantitative device-independent information from digital images, a colour calibrated computer vision system (CVS) as described by Valous et al. (2009) was used for image acquisition. The software package MATLAB (MathWorks, USA) was used for image pre-processing, segmentation, colour transformations and feature extraction. The black background of the acquired colour images was removed, according to Mendoza et al. (2006), using a global threshold value of 80 in the intensity image histogram. The average and standard deviation values of the segmented pixels in the ham image for each colour scale (R, G, B, H, S, V, X, Y, Z, L*, a*, b*, and Grey) was registered as the colour of the ham slice; hence, 26

colour parameters in total were extracted from each images.

Table 1. Specifications for pork and turkey hams

Ham quality	Muscle types and % brine injection	Processing conditions
	Pork hams	
A1	Silverside PAD (biceps femoris) 50% brine injection	Vacuum tumbled at 1500 rpm for 12 hrs
A2	Topside, Silverside & Knuckle 30% brine injection	Vacuum tumbled at 500 rpm for 5 h
A3	Silverside PAD 12% brine injection	No tumbling, vacuum packed
All pork hams were cooked at 82°C to a core temperature of 72°C.		
	Turkey hams	
A1	boneless turkey roll 40% brine injection	massaged for 10hrs at 4°C, vacuum filled into casings, clipped under vacuum
A2	boneless white turkey breast meat 20% brine injection	massaged for 5hrs at 4°C, filled into turkey crown shaped moulds
A3	turkey breast meat 10% brine injection	massaged for 1 h, vacuum packed in vacuum shrink bags
All turkey hams were cooked to a core temperature of 74°C.		

A1, A2, A3 represents the high, medium and low yield (premium quality), respectively.

Mahalanobis distance was used for obtaining the best colour features among the 26 extracted, while linear discriminant analysis (LDA) was used for classification purposes. The Mahalanobis distance was calculated for each combination of ham qualities (comparing A1-A2, A1-A3, and A2-A3) and the best features were selected depending on how many times the measured distances were found to be the maximum for each colour channel and for all features. The more times a feature obtained the highest value that meant it possessed the highest discriminant power. In this way the best subset was selected from all colour features.

Results & Discussion

Figure 1 shows representative pre-sliced ham images of pork and turkey used in this study. In general, cooked pork hams appear similar, with inhomogeneous colour surfaces and an irregular distribution of fat-connective tissue structures which appears elongated but without any specific orientation. Turkey ham surfaces appear much finer or smoother than pork, and possess a larger degree of colour uniformity. Turkey hams slices are more brittle or fragile as compared with pork. A total of 26 colour features were extracted from both ham types. According to Mahalanobis distance analysis, three colour features each for pork and turkey hams were obtained; these were the std. deviation of b*, mean of Z and mean of S (for pork) and the mean of R, mean of V and mean of X (for turkey). The results are presented in Table 2. For the sake of brevity, only the results for some colour features are shown. Figure 2 illustrates the discriminant power plot of the best features for the classification of different ham qualities.

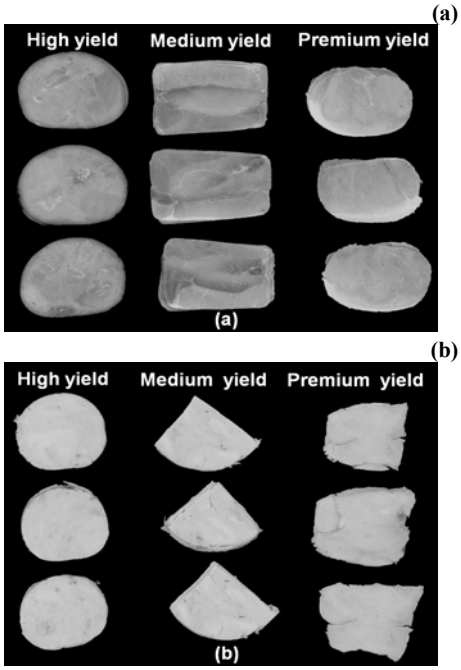

Figure 1. Representative ham images used for quality characterization: a) pork and b) turkey hams.

Table 2. Mahalanobis distance for some colour features among different combinations of pork and turkey ham qualities

*Features	Pork				Turkey			
	Groups/ combinations			# best for 4 larger distances	Groups/ combinations			# best for 4 larger distances
	A1 - A2	A1 - A3	A2 - A3		A1 - A2	A1 - A3	A2 – A3	
R_mean	0.28	30.65	25.06	0	2.41	**36.91**$^{+}$	**20.46**$^{+}$	**2**
G_mean	1.28	51.1	**68.58**	**1**	0.08	12.48	14.58	0
L*_mean	0.27	51.51	59.38	0	0.01	17.24	16.33	0
a*_mean	9.60	17.67	53.33	0	**5.01**	0.76	1.86	**1**
b*_mean	31.73	**113.69**	25.29	**1**	0.03	1.69	1.25	0
H_mean	10.89	0.45	6.87	0	**5.56**$^{+}$	4.15	0.10	**1**
S_mean	4.70	**100.9**	**67.02**	**2**	0.25	1.67	3.21	0
V_mean	0.28	30.65	25.06	0	2.41	**36.91**$^{+}$	**20.46**$^{+}$	**2**
X_mean	0.10	52.85	57.55	0	0.27	**24.09**	**19.22**	**2**
Y_mean	0.67	58.69	**71.96**	**1**	0.00	18.68	18.22	**1**
Z_mean	0.09	**88.33**	**82.7**$^{+}$	**2**	0.04	13.01	11.58	0
b*_std	**104.90**$^{+}$	**122.46**$^{+}$	0.68	**2**	0.85	0.62	0.01	0

Values in bold typeface represent the four largest distances for each combination of hams.

Values denoted with (+) represent the largest distance for each combination of hams

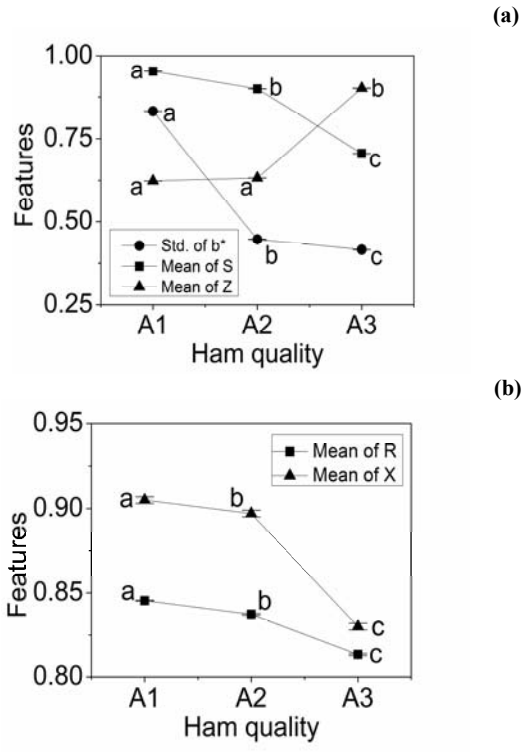

Figure 2. The discriminant power plots of the best colour features for the classification of: a) pork and b) turkey hams. Bars represent the standard errors. Ordinates marked with the same letter for each colour channel indicates that no significant differences exist.

The selected features can be used as descriptors for discriminating amongst different ham qualities. Using these selected best features, the classification for each type of ham was subsequently carried out. Hams were classified using the best colour features with LDA as the selection criterion. The classification results are shown in Figure 3. The three pork ham qualities were correctly classified by 100%. LDA shows that all the three qualities are clearly distinguished from each other. From the outcome, it is deduced that the colour features are robust to completely distinguish the three pork ham qualities. Turkey hams were similarly classified using three best colour features and 92.54% of the cases have been correctly classified. Figure 3b showed that all three turkey ham qualities are almost clearly distinguished from each other with a few overlapping for A1 and A2. A2 gives the lowest classification rate of 90.00% with 8.67% overlapping to A1.

Conclusions

In this study, colour features were extracted from digital images and Mahalanobis distance analysis was used to identify the best feature subset. Subsequently, linear discriminant analysis (LDA) was used to perform the classification of the ham samples, which led to a large score of correctly classified images using only a few numbers of features.

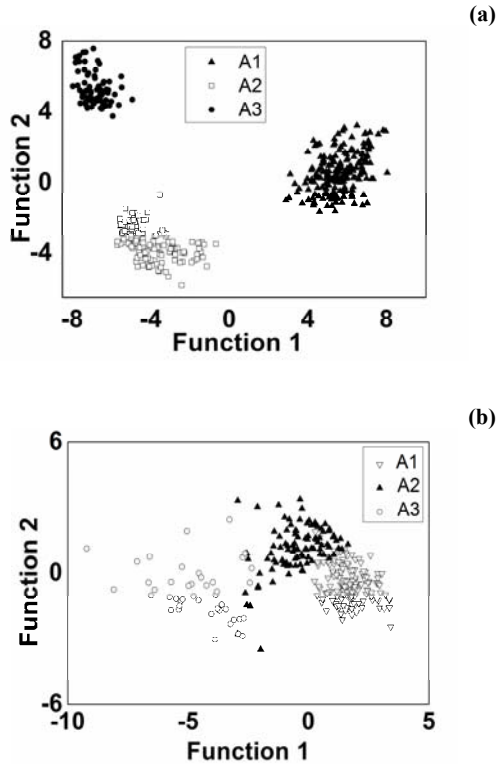

Figure 3. Classification of ham slices using best colour features for: a) pork, and (b) turkey.

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References

Chambers, I.V.E., & Bowers, J. (1993). Consumer perception of sensory quality in muscle foods: sensory characteristics of meat influence consumer decisions. *Food Technology*, 47, 116-120.

Du, C., & Sun, D. (2004). Recent developments in the applications of image processing techniques for food quality evaluation. *Trends in Food Science and Technology*, 15, 230–249.

Du, C.J., & Sun, D.W. (2006). Automatic measurement of pores and porosity in pork ham and their correlations with processing time water content and texture. *Meat Science*, 72(2), 294-302.

Mendoza, F., Valous, N.A., Allen, P., Kenny, T. A., Ward, P., & Sun, D-W. (2009). Analysis and classification of commercial ham slice images using directional fractal dimension features. *Meat Science*, 81(2):313-320.

Mendoza, F., Dejmek, P., & Aguilera, J.M. (2006). Calibrated colour measurements of agricultural foods using image analysis. *Postharvest Biology and Technology*, 41(3): 285-295.

Valous, N A., Mendoza, F., Sun, D.W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat Science*, 81(1): 132-141.

HYPERSPECTRAL IMAGING FOR PORK QUALITY EVALUATION

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Abstract

The spectral technique is one of the most increasingly growing techniques due to its rapidity, simplicity and safety, as well as its ability to measure multiple attributes simultaneously without monotonous sample preparation. Hyperspectral imaging (HSI) is an emerging technology that integrates conventional imaging and spectroscopy to capture both spatial and spectral information from an object. This technology was originally developed for remote sensing applications, and has recently emerged as an important process analytical tool for non-destructive methods with high application for food analysis, in many research and industrial sectors. The food processing industry needs efficient technologies for assessment of food quality in order to save time and money, especially during a crisis. Quality of fresh pork varies greatly. Traditionally, pork quality is classified in various categories based on colour, texture (firmness) and exudation (drip loss). This paper presents a preliminary introduction to the hyperspectral imaging technique. HSI equipment, image acquisition and processing are described; current limitations and possible future applications. In addition, recent advances in the application of hyperspectral imaging to food safety and quality evaluation are reviewed, with a proposal for meat applications.

Objective - The current project aims to establish an identification of different classes of meat presenting different market values according to their quality quantified in terms of chemical composition and physical qualities of the products as well as presence and entity of defects.

Such groups of parameters represent a fundamental set of attributes conditioning the sensory properties of meat and their overall quality in terms of marketable products.

Introduction

Spectral images commonly contain information from several bands with different resolution values. As a result, they expand the capacity to identify or detect subtle or minor features in an object (ElMasry et al, 2008b). Hyperspectral imaging (HSI) is an emerging technique based on the utilization of an integrated hardware and software platform that combines the imaging properties of a digital camera with the spectroscopic properties of a spectrometer able to detect the spectral attributes of each pixel in an image. The imaging technique alone provides a high spatial resolution but with a limited spectral resolution; meanwhile the spectroscopy alone provides high spectral resolution information over both visible and near-infrared spectral regions but with virtually no spatial information. Therefore, the hyperspectral imaging comes to integrate the major features of imaging and spectroscopy for acquiring both contiguous spectral and spatial information from an object simultaneously, which otherwise cannot be achieved with either conventional imaging or spectroscopy (Gowen et al., 2007; Bonifazi & Serranti, 2008). HSI technology was first developed for military and satellite remote sensing applications. Multispectral imaging, on the other hand, is implemented for acquiring spectral images at selected discrete narrow wavebands (often less than 10) that would be more useful than conventional broadband imaging technology for detecting certain physical, biological, and/ or chemical features from the product. Research on applications of hyperspectral imaging for food quality and safety inspection has been studied for the last 8 to 10 years. One major factor that limited the industrial applications of hyperspectral imaging for food inspection is the hardware speed needed for an efficient acquisition and analysis of a huge amount of data collected. In consequence, the technology was initially used as a research tool to assist in identification of key wavelengths for real-time multispectral imaging implementation (Lu & Park, 2008).

In recent years there have been growing interests in this technology from researchers around the world. HSI has evolved rapidly as computers became faster and more powerful, and it has now entered a new stage of industrial applications for real-time inspection of food and agricultural products. During the past decade, there has been a

significant increase in the number of peer reviewed journal articles and conference papers published annually on hyperspectral and multispectral imaging for food or other applications. Several optical companies are now marketing complete hyperspectral imaging systems for the agricultural and food industries.

The utilization of Hyperspectral imaging system for agricultural and food products has been studied because of its power to overcome the limits of visible/near infrared spectroscopic techniques and image processing techniques. This technology has been applied for systems such as quality attributes of strawberry (ElMasry, et al., 2007); detecting chilling injuries and bruises in apples (ElMasry et al., 2008a; ElMasry et al., 2009); beef tenderness prediction (Naganathan et al., 2008); food quality and safety control (Gowen et al., 2007); quality and safety inspection (Lu & Park, 2008). Sorting strategies exists but they fail when a higher degree of detection is required when aiming to perform an "early detection" of quality parameters (Bonifazi & Serranti, 2008).

In this study, the potentials of hyperspectral imaging techniques will be exploited for pork meat quality assessment. The general objectives are:

1) Provide a short overview of the basic principle and features of hyperspectral imaging and its hardware and software implementations;

2) Briefly discuss the potential applications and limitations of hyperspectral imaging in quality evaluation of foods and agricultural products

3) To evaluate the potentials of a hyperspectral imaging system in predicting external and internal features of pork.

Components of a HSI system

Hyperspectral imaging systems are normally composed of the following components: objective lens, spectrograph, camera, acquisition system, translation stage, illumination and computer. These components are as shown in Fig. 1.

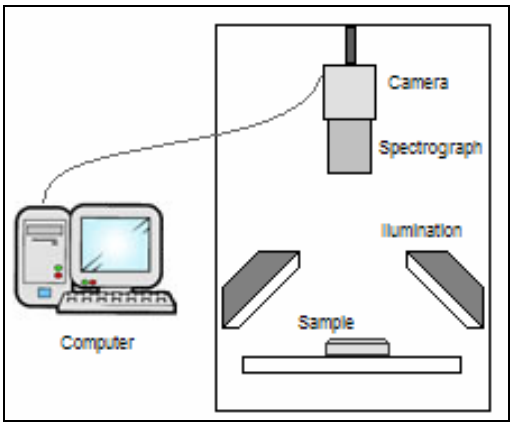

Fig. 1. Components of a Hyperspectral imaging system.

The camera, spectrograph and illumination conditions determine the spectral range of the system. Vis/NIR systems typically range between 400 and 1000 nm, and utilize cameras with Charge Coupled Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) sensors. Longer wavelength systems require more expensive infra-red (IR) focal-plane array detectors with appropriate spectrograph which operates in the IR region.

The sample/target is usually diffusely illuminated by a tungsten halogen lamp. A line of light reflected from the sample enters the objective lens and is separated into its component wavelengths by diffraction optics contained in the spectrograph. A two dimensional image (spatial dimension / wavelength dimension) is then formed on the camera and saved on the computer. The sample is moved past the objective lens on a motorized stage and the process repeated. Two-dimensional line images acquired at adjacent points on the object are stacked to form a three-dimensional hypercube which may be stored on a PC for further analysis (Gowen et al., 2007). Thus, hyperspectral images, known as hypercubes, are three dimensional blocks of data, comprising two spatial dimensions and one spectral dimension (Gowen et al., 2007; Bonifazi & Serranti, 2008; Lu & Chen, 1998). The resulting spectrum acts like a fingerprint which can be used to characterise the composition of that particular pixel.

Meat Quality

Meat tenderness is an important sensory quality attribute for consumer satisfaction. The current meat quality grading system does not incorporate a direct measure of tenderness because there is

currently no accurate, rapid, non-destructive method for predicting tenderness available to the beef industry (Naganathan et al., 2008). Several authors have studied the meat quality evaluation using hyperspectral imaging systems to predict meat composition and quality in order to substitute other commonly used destructive methods.

Quality in pork refers to the factors that influence the processing of both the lean and fat tissues and the consumer acceptability and palatability of both fresh and processed pork products. The preferred method of assessing pork quality is via the direct evaluation of the *longissimus* muscle and the backfat in the same general area. Colour, wetness, firmness, texture and marbling content of the exposed loin eye are the primary lean quality traits. Quality of fresh pork varies greatly. Traditionally, pork quality is classified in three categories based on colour, texture (firmness) and exudation (drip loss). Pork meats that are classified as RFN (Reddish pink, Firm and Non-exudative), have desirable colour, firmness, normal water holding capacity, minimal drip loss, and moderate decline rate of pH. RFN has a normal ultimate pH (5.6-5.8). PSE (Pale pinkish gray, very Soft and Exudative) meats have undesirable appearance and shrinks excessively. These classes of meat have very poor water-holding capacity (WHC), excessive drip loss, and a rapid decline rate of pH (5.5-5.6). DFD (Dark purplish red, very Firm and Dry) meats have firm and sticky surface with high WHC, very little or no drip loss, and very high pH. Usually DFD is caused by long-term stress from improper handling of live animals (National Pork Board, 1999).

Naganathan et al. (2008) proposed the use of visible/near infrared hyperspectral imaging system to predict tenderness of 14-day aged, cooked beef from hyperspectral images of fresh ribeye steaks acquired at 14-day post-mortem. After imaging, steaks, cooked and slice shear force (SSF) values were collected as a tenderness reference. All images were corrected for reflectance. The results indicated that hyperspectral imaging has considerable promise for predicting beef tenderness.

Limitations

HSI is a powerful platform technology for food process monitoring. Currently, however, there are two major barriers to its widespread adoption in the food industry. The first is that, due to the current high purchase cost of HSI systems, there are few commercial suppliers. The second barrier arises from the relatively lengthy times necessary for hypercube image acquisition, processing and classification (Chen et al., 2002). Depending on sample size and image resolution, acquisition time may vary from 2 to 4 min, while processing and classification time are largely dependent on computer hardware and software capabilities. However, it is anticipated that future technological developments in HSI systems for the pharmaceutical industry will promote the manufacture of low cost systems suitable for food industry applications; furthermore, it can be expected that future developments in system components, such as improved cameras, faster hardware, more accurate and efficient algorithms, will reduce processing and acquisition time, enabling real-time HSI quality monitoring systems.

Conclusions

Hyperspectral imaging (HSI) is an emerging method for food quality and safety analysis; the spectral feature allows for the identification of a wide range of complex multi-constituent surface and sub-surface components, while the spatial feature of HSI enables characterisation of complex heterogeneous products. Due to the current high purchase cost of HSI systems, most food related HSI research has been geared towards identification of important wavebands for the development of low cost multispectral imaging systems. However, judging by the continuing emphasis on process analytical technologies to provide accurate, rapid, and non-destructive analysis of foodstuffs, it is likely that imaging systems and particularly hyperspectral imaging will be increasingly adopted for safety and quality control in the food industry, as has already been the case in the pharmaceutical industry. Future developments in HSI equipment manufacture, such as lower purchase costs and improvements in processing speed, will encourage more widespread utilisation of this emerging platform technology.

Acknowledgements

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References

Bonifazi & Serranti, 2008; Hyperspectral imaging applied to complex particulate solids systems. **Proc. of SPIE** Vol. 7003, 70030F, 2008.

Chen, Y. R., Chao, K., & Kim, M. S. Machine vision technology for agricultural applications. **Computers and Electronics in Agriculture**, 36(2), 173-191. 2002.

ElMasry, G.; Wang, N.; ElSayed, A.; Ngadi, M.; Hyperspectral imaging for nondestructive determination of some quality attributes for strawberry. **Journal of Food Engineering,** 81, 98–107. 2007.

ElMasry, G.; Wang, N.; Vigneault, C. Detecting chilling injury in Red Delicious apple using hyperspectral imaging and neural networks, **Postharvest Biology and Technology**, 52, 1–8. 2009.

ElMasry, G.; Wang, N.; Vigneault, C.; Qiao, J.; ElSayed, A. Early detection of apple bruises on different background colors using hyperspectral imaging. **Food Science and Technology-LWT**, 41, 337–345. 2008.

ElMasry, G.; Nassar, A.; Wang, N.; Vigneault, C.; Spectral methods for measuring quality changes of fresh fruits and vegetables. **Stewart Postharvest Review,** 4(4), 1–13, 2008.

Gowen, A. A.; O'Donell, C.P.; Cullen, P. J.; Downey, G.; Frias, J. M. Hyperspectral imaging - an emerging process analytical tool for food quality and safety control. **Trends in Food Science & Technology**, 18, 590–598. 2007.

Lu, R. F., Chen, Y. R. Hyperspectral imaging for safety inspection of food and agricultural products. SPIE Conference on Pathogen Detection and Remediation for Safe Eating, Boston, November 1998.

Lu, R.; Park, B. Hyperspectral and multispectral imaging for food quality and safety. U.S. Department of Agriculture Agricultural Research Service. 2008.

Naganathan, G. K.; Grimes, L. M. ; Subbiah, J.; Calkins, C. R.; Samalc, A.; Meyer, G. E. Visible/near-infrared hyperspectral imaging for beef tenderness prediction. **Computers and electronics in agriculture**, 64, 225–233. 2008.

National Pork Board. Pork quality standard. Des Moines, IA USA. 1999.

Qiao, J.; Ngadi, M. O.; Wang, N.; Gariepy, C.; Prasher, S. O. Pork quality and marbling level assessment using a hyperspectral imaging system. **Journal of Food Engineering,** 83, 10–16. 2007.

Qiao, J.; Wang, N.; Ngadi, M. O.; Gunenc, A. Determination of Pork Quality Attributes Using Hyperspectral Imaging Technique. **Proc. of SPIE** Vol. 5996, 59960M. 2005.

Evaluation of lamb quality by hyperspectral imaging technique

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Abstract

With market expansion, the meat industry needs a rapid, precise, reliable and non-destructive method for fast classification of meat quality. Hyperspectral imaging is a promising analytical technology for non-destructive analysis that incorporates conventional digital imaging and spectroscopy to achieve both spatial and spectral information simultaneously from an object. In this study, hyperspectral imaging techniques will be investigated to evaluate the lamb quality based on different quality attributes from spectral information.

Introduction

In order to reduce economic losses and provide guaranteed quality of meat and meat products to the consumer the meat industry needs to obtain reliable and accurate information about meat quality during the production process. Accurate prediction of meat quality is very important for the success of the meat industry (Tan *et al.,* 2000). Generally, meat quality can be assessed by a specialized expert or by using quality charts and standards. These methods are time consuming and subject to human error and inconsistency. In addition, using laboratory analytical methods for objective evaluation of meat quality can be done by physical and chemical characteristics. However, these analytical methods are time consuming, labour intensive, expensive and destructive. Accordingly, the meat processing industry needs non-contact, non-destructive, rapid, accurate and efficient analytical methods to ensure quality, safety and authenticity.

Hyperspectral imaging is an interdisciplinary field comprising of image analysis, spectroscopy, chemometrics and chemistry. Hyperspectral imaging provides valuable, useful and abundant information on an object and if this information is properly analyzed then it can be used to characterize the object itself. A hyperspectral image consists of several congruent images representing intensities at different wavelength bands.

A hyperspectral image is then a stack of images where each pixel (meaning pixel vector or voxel) represents a spectrum for that specific point. Consequently, the image contains chemical information in every pixel. This information will form a three- dimensional "hypercube" which can be analyzed to determine physical and chemical features of an object (ElMasry *et al.*, 2008). Because of the combined features of imaging and spectroscopy, hyperspectral imaging can be used to detect physical and geometric characteristics such as colour, size, shape and texture through image feature extraction as well as chemical and molecular information such as water, fat, protein, and other hydrogen-bonded constituents through spectral analysis (ElMasry *et al.*, 2008 and Qiao *et al.,* 2007).

Recently, several researches have been working on hyperspectral imaging to assess the quality of meat, fruits and vegetables. For instance- hyperspectral imaging systems have been used to detect contamination in apples (Kim *et al.*, 2002), detection of chilling injury in red delicious apples (ElMasry *et al.,* 2009), early detection of apple bruises (ElMasry *et al.,*

2008), detection of defects and contamination on apple surface (Mehl *et al*., 2004), inspection of poultry carcasses (Chao *et al.,* 2001), detection of contamination in broiler carcasses (Windham *et al.,* 2005), detection of chilling injury in cucumber (Cheng *et al.*, 2004 and Liu *et al.*, 2006), estimation of physical and chemical properties in strawberry (Nagata *et al.,* 2005), determination of moisture, total soluble solid and acidity in strawberry (ElMasry *et al.,* 2007), firmness and soluble solid prediction in apples (Lu, 2004) and determination of pork quality attributes (Qiao *et al.,* 2007).

Some research using hyperspectral imaging has been conducted to evaluate the quality of beef and pork. But the application of hyperspectral imaging to evaluate the quality of lamb is quite limited. **Therefore, the objective of this research is to evaluate the quality of lamb by using hyperspectral imaging.**

Material and methods

Meat samples

Lamb samples is prepared and provided by Ashtown Food Research Centre (AFRC). Animals are usually slaughtered and dressed according to commercial practices. Carcasses are chilled and stored under current commercial conditions. Samples are prepared from different parts of the carcasses. These samples are individually vacuum-packed and stored at 4^{o}C for a period of ageing until the time of analysis. These samples will be used for image acquisition and chemical analysis.

Hyperspectral imaging system

The schematic representation of hyperspectral imaging components is shown in Fig 1. The hyperspectral imaging system consists of a spectrograph, a high performance digital camera, an illuminator, a conveyer and a PC for storing image data.

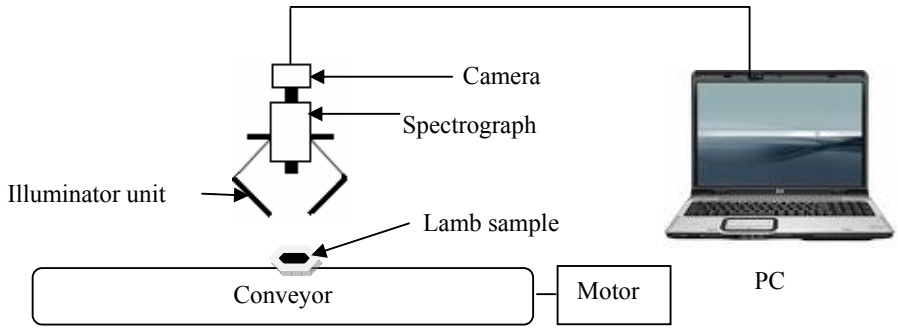

Fig. 1 Schematic representation of hyperspectral imaging system.

Image calibration

The recorded hyperspectral image of the sample is corrected for absolute reflectance with a white and black reference images. The calibrated image (R) can be calculated using the following equation (ElMasry *et al.,* 2009):

$$R = \frac{R_0 - D}{W - D} \times 100$$

Where R_0 is the raw hyperspectral image of the lamb sample, D is the dark current image and W is the white reference image of 100% reflectance. The hyperspectral image can also be expressed in absorbance

(A) by taking logarithms (Geladi *et al.,* 2004):

$$A = -\log_{10}\frac{R_0 - D}{W - D}$$

Measurement of quality attributes

Directly after image acquisition, the fresh lamb samples of different quality, ageing and muscle type will be analyzed for moisture, intramuscular fat (marbling), intramuscular protein, pH and collagen using standard methodology.

Multivariate analysis of data

The spectral data extracted from hyperspectral images is huge and suffers from high dimensionality and co-linearity. Therefore, several pre-processing methods and multivariate strategies should be experienced to overcome these drawbacks. The interactive approach of principal component analysis (PCA) to hyperspectral images and its scores and loadings plots are used to explore the image data. This interactive work has the advantage of bringing an insight into the structure of the data set. Classes in the image can be studied and segmented via score plots, and the connection between spectral features and the raw image channels can be identified by investigating the loadings. When we have reference values for each pixel in the hyperspectral images, PLS regression has shown to be an excellent and efficient tool for modelling the images. The data obtained is analyzed using MATLAB and SPSS software.

Selection of the best models

The best calibration models are usually evaluated by the standard error of calibration (SEC), standard error of prediction (SEP), correlation coefficient (r) and root mean square error estimated by cross validation (RMSECV) between the predicted and measured value. These parameters are defined as follows:

$$SEC = \sqrt{\frac{1}{I_c - 1}\sum_{i=1}^{I_c}(\hat{y}_i - y_i)^2}$$

$$SEP = \sqrt{\frac{1}{I_p - 1}\sum_{i=1}^{I_p}(\hat{y}_i - y_i - bias)^2}$$

$$bias = \frac{1}{I_p}\sum_{i=1}^{I_p}(\hat{y}_i - y_i)$$

Where $\hat{y}_i$ = predicted value in i th sample, y_i= measured value in i th sample, I_c number of sample in the calibration set and I_p number of sample in the validation set.

Conclusion

Meat quality determination by hyperspectral imaging is new research area. There are ample potentials to work on hyperspectral imaging system to extract the spectral information for the evaluation of meat quality. To our knowledge this is the first attempt to implement hyperspectral imaging technique for quality evaluation of lamb.

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Reference

Chao, K., Chen, Y. R., Hruschka, W. R and Park, B. 2001. Chicken heart disease characterization by multi-spectral imaging. *Transactions of the ASAE,* 17 (1): 99–106.

Cheng, X., Chen, Y. R., Tao, Y., Wang, C. Y., Kim, M. S and Lefcourt, A. M. 2004. A novel integrated PCA and FLD method on hyperspectral image feature extraction for cucumber chilling damage inspection. *Transactions of ASAE*, 47(4): 1313-1320.

ElMasry, G., Wang, N and Vigneault, C. 2009. Detecting chilling injury in red

delicious apple using hyperspectral imaging and neural networks. *Postharvest Biology and Technology,* 52: 1-8.

ElMasry, G., Nassar, A., Wang, N and Vigneault, C. 2008. Spectral methods for measuring quality changes of fresh fruits and vegetables. *Stewart Postharvest Review*, 4: 3.

ElMasry, G., Wang, N., Vigneault, C., Qiao, J and ElSayed, A. 2008. Early detection of apple bruises on different background colours using hyperspectral imaging. *LWT-Food Science and Technology,* 41: 337–345.

ElMasry, G., Wang, N., ElSayed, A and Ngadi, M. 2007. Hyperspectral imaging for non-destructive determination of some quality attributes for strawberry. *Journal of Food Engineering,* 81: 98–107.

Geladia, P., Burgerb, J and Lestandera, T. 2004. Hyperspectral imaging: calibration problems and solutions. *Chemometrics and Intelligent Laboratory Systems*, 72: 209–217.

Kim, M. S., Lefcourt, A. M., Chao, K., Chen, Y. R., Kim, I and Chan, D. E. 2002. Multispectral detection of fecal contamination on apples based on hyperspectral imagery: Part I. Application of visible and near-infrared reflectance imaging. *Transactions of the ASAE*, 45(6): 2027-2037.

Liu, Y., Chen, Y.R., Wang, C.Y., Chan, D. E and Kim, M. S. 2006. Development of hyperspectral imaging technique for the detection of chilling injury in cucumbers; spectral and image analysis. *Applied Engineering and Agriculture,* 22 (1): 101–111.

Lu, R. 2004. Multispectral imaging for predicting firmness and soluble solids content of apple fruit. *Postharvest Biology and Technology,* 31 (1): 147–157.

Mehl, P. M., Chen, Y. R., Kim, M. S and Chan, D. E. 2004. Development of hyperspectral imaging technique for the detection of apple surface defects and contamination. *Journal of Food Engineering,* 61: 67-81.

Nagata, M., Tallada, J.G., Kobayashi, T and Toyoda, H. 2005. NIR hyperspectral imaging for measurement of internal quality in strawberries. ASAE Paper No. 053131, ASAE Meeting, Tampa, FL, USA.

Qiao, J., Wang, N., Ngadi, M. O., Gunenc, A., Monroy M., Gariepy, C and Prasher, S. O. 2007. Prediction of drip-loss, pH and color for pork using a hyperspectral imaging technique. *Meat Science,* 76: 1–8.

Tan, F. J., Morgan, M. T., Ludas, L. I., Forrest, J. C and Gerrard, D. E. 2000. Assessment of fresh Pork Color with Color Machine Vision, *Journal of Animal Science,* 78(12): 3078-3085.

Windham, W. R., Smith, D. P., Berrang, M. E., Lawrence K. C and Feldner. P. W. 2005. Effectiveness of Hyperspectral Imaging System for Detecting Cecal Contaminated Broiler Carcasses. *International Journal of Poultry Science,* 4 (9): 657-662.

QUANTITATIVE CHARACTERIZATION OF PORE SPACE MICROSTRUCTURE OF COMMERCIAL BREAD SLICES USING MULTIFRACTAL ANALYSIS

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Abstract

Bread, which is a popular food in the daily diet of humans, was evaluated in relation to the pore-size distribution (PSD) using fractal and multifractal techniques. This paper presents a series of computer algorithms to identify pores of bread samples by converting the colour images into binary, and then, to provide information regarding to the shape and size of pores, as well as, the PSD's using fractal and multifractal dimensions testing different types of loaf of bread. This information is tested to characterize and to distinguish between formulations and qualities of bread by using their images.

Introduction

The bakery industry has seen a revolution in the past 150 years. A high variety of qualities has been produced in an efficient way. It can be said that development of the baking industry is due to market demand that resulted in increased productivity (Mondal. A., 2007) New material and ingredients introduced in bread preparations have generated a constant and impressive progress in bread making. Nonetheless, characterization of the formed microstructures of bread samples is really needed for effective quality control.

Fractal and multifractal techniques measure self similarity of the objects at different scales. These techniques have been applied in various fields; such as processing of medical images, soil science and food analysis, which enlighten us, with useful information about size, shape, area, and distribution of objects on images.

Bread is a porous object, which is made of small pores able to be appreciated by consumers. So, if the pores of bread are magnified over a number of scales, it can be seen that, its distributions are repeating itself in a regular pattern.

The overall project combine an image acquisition technique with advanced image processing methods to characterize the pore microstructure of a variety of bread slices, which enable us to identify quality factors that have great influences on the final bread product. In this project, the pores of bread are examined to evaluate their size and distribution from images using fractal and multifractal approaches and to investigate for bread quality parameters, and their relationships with the microstructure and consumer preferences of bread.

This paper presents the results for image acquisition, pores segmentation, and extraction of morphological features using the computer algorithms developed in the first stage of this investigation. The next stage will be devoted to the implementation of fractal estimations based on the box counting method and multifractal analysis (MFA) based on the generalized dimensions D_q.

The objective of this study is using fractal and multi fractal techniques, to characterize the pore structure of variety of bread slices, in order to identify quality factors that have influence one quality of breads.

Theory

Fractal dimension (D) is measure of a structure that repeated over a range of scale. For fractal objects the number of features with certain size ε, $N(\varepsilon)$, varies as (Posadas et al., 2003):

$$N(\varepsilon) \propto \varepsilon^{-D_0} \qquad (1)$$

where D_0 is the fractal dimension.

Eq. (1) is a scaling or power law which has been used to describe the size distribution of many objects in nature. The box-counting method is used to obtain the scaling properties of two-dimensional fractal objects by a measure with boxes of size ε and counting the number of boxes

containing at least one pixel representing the object under study, $N(\varepsilon)$. This means that the technique does not consider the amount of mass inside a box $N(\varepsilon)$ and is, therefore, not able to resolve regions with high or low density of mass.

Multifractal methods are suited for characterizing more complex spatial arrangement of mass since they can resolve local densities inside each box. In practice, a way to quantify local densities is by estimating the mass probability in the i^{th} box.

$$p_i(\varepsilon) = \frac{N_i(\varepsilon)}{N_T} \tag{3}$$

where $N_i(\varepsilon)$ is the number of pixels containing mass and N_T is the total mass of system.

For heterogeneous and non-uniform system the probability in i^{th} box $p_i(\varepsilon)$ varies (Posadas et al., 2003):

$$p_i(\varepsilon) \propto \varepsilon^{\alpha_i} \tag{4}$$

where α_i is the Lipschitz-Hölder exponent or a singularity strength, characterising scaling in the i^{th} box. The value of α_i varies in at different position in the image. The number of boxes $N(\alpha)$ where the probability has exponent value between α and $\alpha + d\alpha$ is found to scale as:

$$N_i(\alpha) \propto \varepsilon^{-f(\alpha)} \tag{5}$$

where $f(\alpha)$ is fractal dimension of the set of boxes with exponent (α).

Multifractal measures can be characterized through the scaling of the q^{th} moments of P_i distributions in the form:

$$\sum_{i=1}^{N(\varepsilon)} P_i^q(\varepsilon) = \varepsilon^{(q-1)D_q} \tag{6}$$

where D_q is the generalized fractal dimension, which can be written as follow:

$$D_q = \frac{1}{q-1} \lim \frac{\sum_{i=1}^{N(\varepsilon)} P_i^q(\varepsilon)}{\log \varepsilon} \tag{7}$$

The exponent in Eq.(6) is the mass exponent of the q^{th} moment, $\tau(q)$:

$$\tau(q) = (q-1)D_q \tag{8}$$

When q=0, all boxes have weight of unity the numerator becomes $N(\varepsilon)$, and D_q becomes capacity dimension D_0. When q=1, D_1 is called entropy dimension and when q=2, D_2 is called correlation dimension. Entropy dimension D_1 measure decrease in information as the size of box increases, also the correlation dimension D_2 is mathematically associated with the correlation function that determines the correlation of measures contained in a box of size ε.

The D_q spectrum gives indication of the distribution of pores in the image of bread, which may relate to the properties of that material (i.e. ingredients and formulations). The hypothesis of this study is that by determining D_q dimensions it is possible to distinguish between different types of bread. Thus, the result of this study could facilitate identification of the factors (such as formulations and processing conditions) that may have a great influence on quality of breads.

Materials and methods

1. Bread samples

Three samples of breads from a single batch were selected for preliminary analysis. The bread used was a regular white bread (Irish Pride) that is available in the local market in Dublin.

Figure 1: Representative image of bread

2. Image acquisition and processing

Image of samples were captured using a colour calibrated image acquisition system as described by (Valous N.A. (2009)). The images were captured using a resolution of 2048x1538 pixels and stored in JPEG format. Then, they were cropped in the centre of the original colour images to get areas of 500x500 pixels. All computer algorithms were developed in MATLAB (R2008a) to carry out the processes that is shown in Figure 2.

For segmentation of pores, images were converted to gray scale (Figure 2a-b) and after enhancing the contrast of the image, a threshold value to identify pores from the solid mass of the bread image (background pixels) was selected using the '*graythresh*' command implemented in MATLAB. The '*graythresh*' code is based on Otsu's algorithm and assumes that the image contains two classes of pixels, the foreground and background, and then calculates the best possible threshold, to separate those into two classes, so that their combined spread (intra-class variance) is minimal. Then, using *'im2bw'* command the images were converted to binary. The binary images contain '0' which are black pixels and '1' which are white pixels. Black pixels are pores of the image and white pixels are background of the bread. From these binary images a number of morphological features were extracted and they are summarized in Table 1.

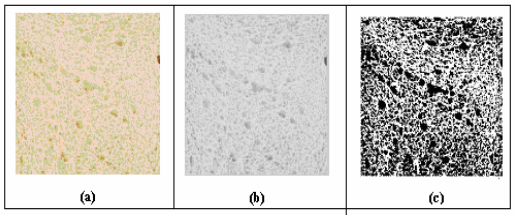


Figure 2: (a) Cropped colour image of a white bread, (b) gray scale image, (c) binary image of bread after processing. Black pixels represent pores and white pixels represent solid mass of the bread.

Result and discussion

In order to carry out fractal and multifractal analysis, images must undergo a series of processes. A summary of these processes are shown in Figure 3. The identification and quantification of pores in the image are necessary to characterize the bulk properties of samples (such as area and size of pores); they are also required for further correlations with fractal and multifractal parameters.

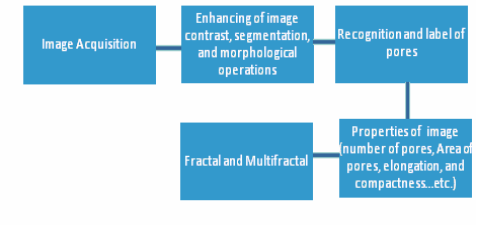


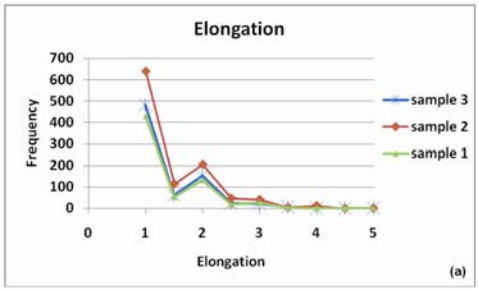
Figure 3: Experimental procedure for analysis of bread samples using MFA.

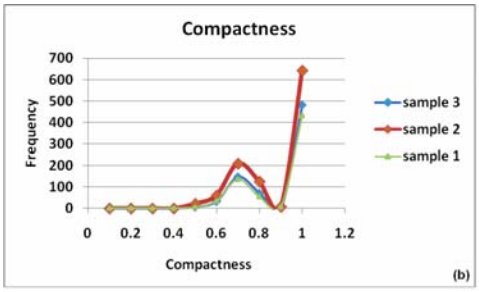
A list of morphological features that can be extracted from the image is presented in Table 1. A brief description for each feature is also presented.

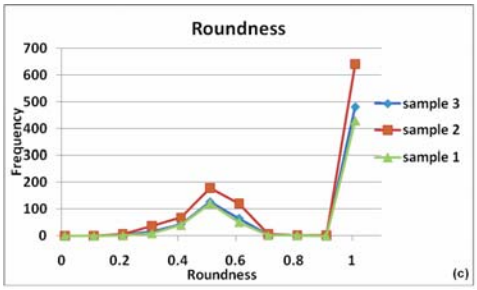
Table 1. Morphological features extracted from binary images of pore structures.

Properties	Description
Area	Number of pixels representing each pore
Major axis length	The longest axis of ellipse
Minor axis length	The shortest axis of ellipse
Elongation	Ratio of major axis length over minor axis length
Compactness	$\frac{\sqrt{\frac{4}{\Pi} \times \text{Area}}}{\text{Major axis lenght}}$
Roundness	$\frac{\sqrt{4 \times \text{Area}}}{\Pi \times \text{Majoraxislenght}}$

The histograms of the extracted morphological properties are present in Figure 4. In Figure 4 the x-axis is the range of the measured property and y-axis is the frequency. The summary of these results are shown in Table 2.







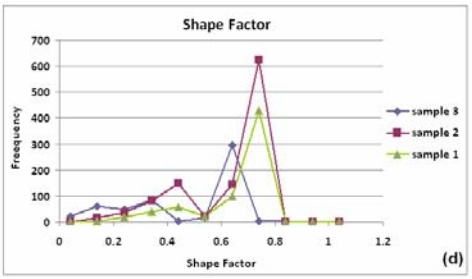


Figure 4. Histograms of selected morphological properties determined from bread pores.

In figure 4, the number of pores in sample 1 was 664, sample 2 was 1070, and sample 3 was 750.

Table 2. Average values of morphological properties of pores using the three bread samples.

Features	Sample 1	Sample 2	Sample 3
All Areas	5.45	18.71	5.05
Elongation	1.35	1.40	1.35
Compactness	0.87	0.86	0.87
Roundness	0.78	0.76	0.78
Shape factor	0.55	0.57	0.60

Table 2 indicated that shape factor of samples has mean value of 0.57. Posadas et al. (2001) suggested three basic pore shapes that were defined based on values of shape factor. If shape factor is less than 0.2, the pore is planer, between 0.2 to 0.5 is irregular, and shape factors greater than 0.5 are round pores (Posadas et al. (2001)). The histogram and average values indicated that pores on bread samples are dominated by rounded shapes. The roundness and elongation histograms confirm that.

Conclusion

To apply fractal and multifractal techniques is necessary to convert the original colour image to binary image before further processing is performed. Also, some information regarding to shape and size of image is required for comparisons and interpretation. Thus, the shape factor, roundness, compactness, elongation and other important properties of image were determined by using MATLAB.

In this preliminary study the implemented computer algorithms for image segmentation and feature extraction have shown to be simple and easy for extracting morphological information from binary images of bread and can be useful tools to characterize and evaluate PSD in a variety of bread formulations and qualities.

The next step is to develop algorithms in MATLAB to determine fractal dimension based on the box-counting method and the generalized dimensions D_q.

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Reference

Mondal.A,Datta,A.K,(2007).Bread baking-A review*, J. Food Eng.*, 86, 465-474.

Posadas.A, Gizmenez.D,Quiroz.R,Protz.R (2003). Multifractal characterization of soil pore system. *Soil Sci. Soc. Am. J., 67,* 1361-1369.

Valous, N.A., Mendoza, F., Sun, D-W. Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced ham. *Meat Sci., 81,* 132-141.

AN INVESTIGATION INTO THE SHAPE PROFILE OF THE AVIAN COMB AS A METHOD OF BIOMETRIC IDENTIFICATION IN POULTRY

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Abstract

This paper investigates avian comb imaging as a biometric based method for the tracking and tracing of poultry. Mature hens (n = 40) were used for this experiment and the initial part of the work consisted of video capturing the set sample. Morphological image processing techniques including dilation and erosion were performed on still images which were obtained from the aforementioned video capture. The purpose of this was to link a template or 'fingerprint' with each bird that was imaged to act as a unique identifier. The second part of the trial concentrates on matching. The Fourier technique of shape characterization was chosen as the preliminary characterization of shape features on the comb profile. The results were analysed using multivariate descriminant analysis and using the pre determined harmonic variables, 129 (80.6%) observations were correctly assigned to the 40 individual groups. This score was increased to 84.4% when the simple comb overlap function was used combined with the Fourier technique.

Introduction

Critical considerations for a secure animal identification and source verification system include: rapid, inexpensive and accurate acquisition of information; security against fraud; humane administration; and easy and rapid transmission, storage and retrieval of data (Marchant, 2002). An animal biometric identifier has been defined by Shadduck and Golden (2002) as any *measurable, robust,* and *distinctive* physical characteristic that can be used to identify or verify the claimed identity of an animal. Biometric labelling systems incorporate biological data and cannot be easily faked, altered or appropriated. Technologies include retinal and iris imaging, facial recognition, nose printing, DNA profiling and immunological labelling (Loftus, 2005). Individual identification of poultry is not generally practised commercially, except in elite breeding stock. Wing-bands and leg-bands have traditionally been used to identify individual birds at elite breeding level, principally for research purposes.

The objective of this work was to investigate whether the avian comb (profile shape) can be considered a distinctive biometric trait of poultry which could potentially allow biometric-based traceability in the poultry industry.

Materials and Methods

The fieldwork and experiments were carried out on a poultry farm in County Monaghan, Ireland. The experiment consisted of video capturing the chicken's comb for a specified period of time. A group of forty 45-week old layer hens were used for this experiment. The birds were labelled and video captured individually using a digital camcorder (Digital HD Video Camera Recorder, Handycam - HDR-FX7E, Sony Inc., Tokyo, Japan) at four different occasions. Still images were obtained from the video images and were saved in bitmap (BMP) format. All image captures were taken in a controlled environment. Light intensity readings were recorded using a luminance meter (Minolta T-10, Minolta Co., Japan) and ranged between 140-180 lux.

Comb extraction process

A number of image processing techniques were performed (Matlab 7.14 (The MathWorks Inc., Natick, Mass, USA) in order to extract the comb profile (Figure 1). The RGB color images (Fig 1.1) were first converted into indexed images (Fig 1.2) consisting of 5-6 colors – in an

indexed image each color has a number associated with it. The comb profile, which is represented by the red color, was then extracted and, the image converted to a binary image (Fig 1.3). Using binary image processing, images were cleaned and any undesired background was eliminated (Fig 1.4). The cleaning process mainly consisted of eroding and dilating the image. The structuring element used was a disk of 4 pixel width.

To allow uniformity the segmented images are rotated and resized to 480x240 pixels (Fig 1.5). These segmented images were used for shape matching.

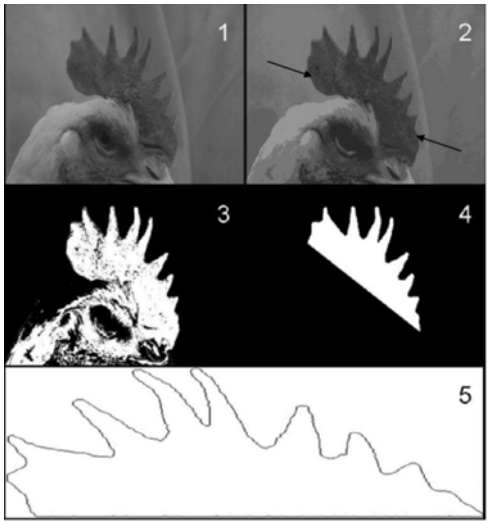

Figure 2. Image processing of a hen comb profile for shape template extraction. (Fig 1.2 demonstrates the points at which the comb was cut)

The Fourier Technique

Fourier descriptors, that are the coefficients of a Fourier expansion of a shape's attributes (outline coordinates or their local trajectories), have been in use for shape quantification in applications spanning various disciplines (Ayalew *et al*., 2009). Being able to detect sharp turns at corners and repetitive patterns are two of their most important features. As a result, the Fourier technique of shape characterization has proved an important tool in various studies, and is chosen in this study for characterizing shape features on poultry combs. There are three variations of the procedure followed in the derivation of the Fourier descriptors of boundary edges. These are the Radial-, Granlund- and Zahn-Roskies Fourier (ZRF), (1972) descriptors. Figure 2 depicts an arbitrary polygon with parameters used for the derivation of the ZRF series. For the definition on this technique please refer to Ayalew *et al*. (2009).

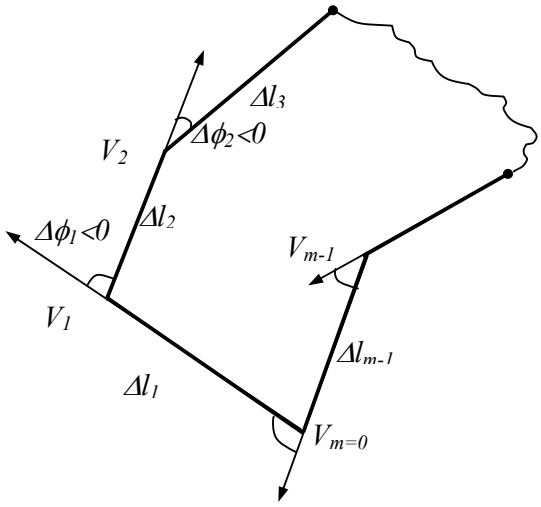

Figure 3. An arbitrary polygon used for the derivation of the ZRF series (redrawn with modification from Zahn and Roskies (1972)).

As the procedure required polygonal approximation of the original comb edge map, the method of Rosenfeld and Johnston (1969) has been used with the smoothing parameter value (m) of 1.1 % of the number of edge pixels resulting in the best approximation to the original comb. Fourier coefficients of the fundamental and successive 48 harmonics were computed, output to a text file for every comb edge map, and statistically analysed.

Statistical Procedure

Stepwise discriminant analysis (SDA) (SAS version 8.2, SAS Institute Inc., NC, USA) was applied to 48 harmonics data set to select the most discriminant Fourier descriptors with sle = 0.05; sls = 0.05. Linear discriminant analysis was performed on the 32 SDA-selected variables to classify observations into the

40 groups with samples from known groups. The cross validation rule was applied to allow more accurate estimation of classification rates within the data sets. One observation of the data was left out at a time and this was used to construct the classification rule. The classification rule was then used to try to classify the observation that was left out. This was repeated for every observation in the data and in this way better estimates of the classification rate were found.

Results and Discussion

From visual inspection, the comb profile from each of the 40 birds that were imaged appeared to be distinctive. The first 48 harmonics associated with the 160 templates (40 birds × 4 replicates) were statistically analysed. The first step involving the stepwise procedure reduced the variable harmonics from 48 to 32. As the total variability was mostly comprised in the 30 first harmonics, ~75%, (Figure 3), they were the most discriminant variables selected by SDA.

Linear discriminant analysis using the 'leave one out method' was then performed on the data set. By applying this multivariate analysis technique, each of the 160 observations was grouped accordingly. Using the SDA-selected variables, 129 (80.6%) observations were assigned to the 40 individual groups.

Mismatch comparisons were investigated and similar comb attributes were discovered from visually comparing templates in addition to the harmonic plot patterns associated with each template.

A final step in improving the matching rate involved a simple overlap of templates using an overlap function that produces a matching score measuring the percentage of common pixels belonging to the comb area present in both images (for further explanation, refer to Barry *et al*., 2007). This was programmed in Matlab (version 7.14, The MathWorks Inc., Natick, Mass.) and was combined with the Fourier technique as a pre-matching stage. In order to build a decision landscape (Gonzales Barron et al., 2007) for this screening test, firstly, each group replicate (4) were compared against a randomly selected basis image producing 160 overlap scores *(ms)*. Secondly, a basis template (replicate A) of each group was compared against a set of 5 random templates (not belonging to the same group). Thus, another set of 200 overlap scores originating from pairs of different templates were produced. Genuine and non-genuine distributions were fitted from the associated histograms of overlap matching scores, and an approximate threshold value was set at 87%., meaning that below this threshold, a pair of samples would be considered as originating from different birds (Figure 4). When the Fourier-based algorithm for shape recognition was applied after the screening test, the correct match rate increased from 80.6% to 84.4%.

Conclusions

A preliminary trial for biometric identification of layer hens has been performed.

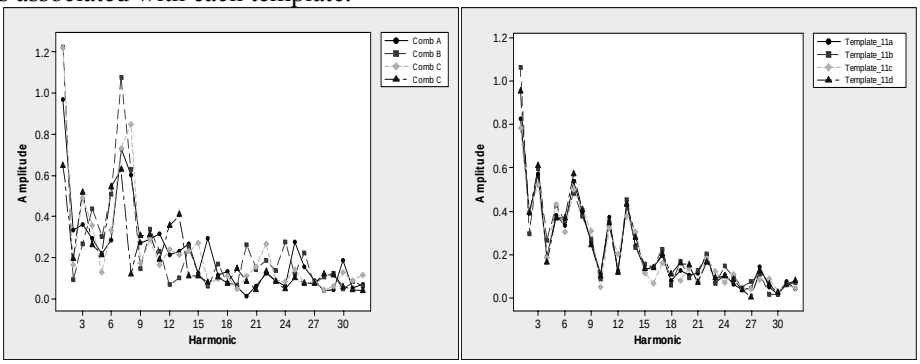

Figure 4. Plot example of harmonics associated with (a) 4 individual hens and (b) replicates of the same hen acquired at 4 different times

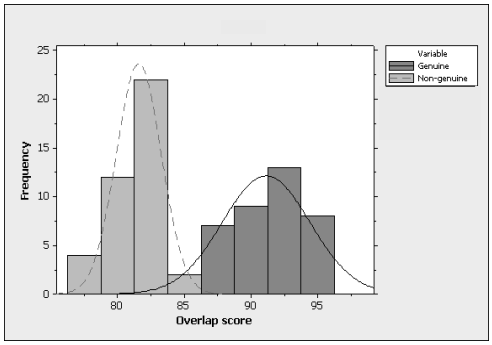

Figure 5. Genuine and non-genuine distributions fitted from histograms of overlap scores (ms) obtained from templates taken from replicates of the same bird and templates taken different birds

Using the Fourier technique, the classification rate was found to be ~81% and when this technique was combined with a screening overlap function, the classification rate increased marginally to ~84%. From the encouraging results of this research, we can conclude that biometric identification of certain types of poultry is feasible, non-invasive, and inexpensive, and has therefore some potential for complementing the traditional means of identification. The fact that broiler chickens' combs only start to develop at slaughtering stage means that this type of identification would be only suitable for more mature poultry. Finally, further research is needed to address problems associated with comb capture and intensive production. It is also recommended that other shape matching techniques such as an improved Fourier method or the Radon transform be assessed with a larger sample size.

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References

Ayalew, G., N. M. Holden, S. Ward. (2009). "Ranking of risk of injury from glass contaminants using Fourier shape measures of fragment outlines." Biosystems Engineering 102(3): 265-273.

Barry, B., Gonzales-Barron, U., Butler, F., McDonnell, K., Ward, S., 2007. Using muzzle pattern recognition as a biometric approach for cattle identification. Trans. ASABE 50(3), 1073-1080.

Gonzales Barron, U., Corkery, G., Barry, B., Butler, F., McDonnell, K., Ward, S., 2007. Assessment of retinal recognition technology as a biometric method for sheep identification. Comput. Electron. Agric. In press.

Granlund, G. H. 1972. Fourier preprocessing for hand print character recognition. IEEE Transactions on computers C-21:195–201.

Loftus, R., 2005. Traceability of biotecderived animals: application of DNA technology. Rev. Sci. Tech. Off. Int. Epiz. 24(1), 231-242.

Marchant, J. M. 2002. Secure animal identification and source verification. JM Communications, UK. Copyright Optibrand Ltd., Colorado, LLC

Rosenfeld, A. and E. Johnston. 1973. Angle detection on digital curves. IEEE Transactions on Computers C-22:875–878.

Shadduck, J. A., and Golden, B. L. 2002. Retinal imaging in secure identification and source verification of livestock. In *Proc. ID/INFO Expo 2002*. National Institute for Animal Agriculture. Illinois. USA.

Zahn, C. T. and R. Z. Roskies. 1972. Fourier descriptors for plane closed curves. IEEE Transactions on Computers C-21(3):269–281.

EVALUATION OF THE EFFECTS OF PERTINENT FACTORS OF UHF RFID APPLICATION IN MEAT SUPPLY CHAIN

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Abstract

The effects of pertinent factors of RFID application have been investigated. The use of linearly polarised reader antennae resulted in better tag detection over larger ranges when tag orientation was consistent, whereas circularly reader antennae resulted in better detection in the case of random tag orientation. Reader antenna placement was also an important factor to consider as an antenna offset lead to a decrease in average coupling (detection) from 62 % to 49 %. Distance between reader antenna and test sample are ideally kept to a minimum as detection rates decreased monotonously from 76 % to 59 % and finally 44 % at 300 mm, 600 mm and 1000 mm. Tag type also proved significant as it varied the average detection rate form 81 % down to 66 % for a variety of designs. Results also revealed that an increase in conveyor speed resulted in a decrease in the number of tags detected from 63 % when stationary down to 50 % travelling at 1 m/s.

Introduction

As a technology RFID has enjoyed incorporation into a variety of applications including animal identification, pharmaceutical product tracking, building access control, toll collection, vehicle immobilisation systems, luggage and asset tracking in the aviation industry, and also waste management and in the mining industries (Keskilammi et al. 2004); (Smith et al. 2008; Smith et al. 2005). Conventional identification methods such as the bar code are used widely, but have some disadvantages: are susceptible to damage in harsh production environments rendering them unreadable; do not have the ability for multiple reads; posses limited data capacity and have a shorter read range (Lahari, 2006).

At its most basic, RFID technology consists of a tag which is attached to the item being tracked and a reader. It enables the wireless transfer of data eliminating the need for direct line of sight between the reader and the tag. When within range of adequate power from the reader, passive UHF tags become activated, and begin to communicate with the reader (Finkenzeller, 2003), by modulating the reflected (backscattered to the reader) signal. The reader demodulates the encoded backscatter signal and presents the unique identification assigned to each tag to a connected computer (Dobkin, 2008, Mc Carthy et al. 2009)

RFID tags are more robust thus making them ideal in hostile production, and logistical operations. Due to its high level of automation this technology reduces product handling thus reducing the potential effects of human error in logistics and associated traceability

The reader is responsible for the launching of an electromagnetic (interrogation) wave via its attached antenna.

However, RFID systems operating in the UHF range are prone to the effects of attenuation and reflection of the propagating electromagnetic wave, essential for coupling, in the presence of metals and moisture resulting in coupling failure (Singh *et al*, 2007).

The objective of this trial was to determine the effects of pertinent factors in the implementation of UHF RFID in the meat supply chain.

Materials and Methods

Materials

The system consisted of a CAEN UHF RFID A-928 development kit, with CAEN RFID V.1.2, Release 2.4.3. interface software, connected to Poynting. Patch-A0003-02 Circular polarised antenna or a HUBER + SCHUNER®. SPA 8090/75/8/0/V Linear antenna. Custom constructed antenna stands provide rigid and reproducible location of antennae. All transponders used were commercially available passive of Class 1 Generation 2 standard. They are listed in Table 1. Test samples analysed constituted (1) Empty carton (2) Muscle (all visible fat removed) (3) Muscle and bone (Muscle covering bone) (4) Muscle and fat (Fat covering muscle) (5) Muscle and fat and bone (Bone covered with muscle covered with fat) and (6) Large muscle (all visible fat removed). Sample weights were kept as consistent as possible at 1 Kg. Each sample type (1 to 6) was replicated three times, with four repetitions of readings carried out per replicate. Movement of the test sample was facilitated with a Belcon Mini (BMG-400-H-4000-90-220V-3ph) variable speed conveyor belt system.

Methods

Each test sample was placed onto the conveyor travelling at 0.5 or 1.0 m/s (dynamic interrogation) or no movement (static interrogation). All test samples were placed into a an empty polyethylene packaging box (1700 mm x 1350 mm x 1250 mm) during interrogation. The test sample had two tags fitted to each of its six faces (12 in total) lying perpendicular to one another. The reader-antenna-to–test-sample centre distance was adjusted alternately at 300, 600 and 1000 mm. The conveyor speed was also alternately set to stationary, 0.5 m/s and 1.0 m/s during interrogation. Test samples were placed at the back end of the conveyor and travelled towards the front and the number of tags detected as the test sample passed the antennae was recorded using both linearly and circularly polarised antennae. Interrogation was firstly carried out with antennae placed orthogonally (left, right and top) around the test sample "no offset" and then where both right and left antenna were adjusted 95 mm up and down the conveyor sides (offset distance). Zero detection rates were recorded and included in data analysis where relevant.

Results and Discussion

Reader antenna polarisation, antenna to sample distance, inlay design, conveyor speed, tag location and orientation all proved significant ($p < 0.0005$) under a GLM analysis of variance (ANOVA) in relation to coupling of the RFID system.

Over larger distances, linearly polarised antennae proved better at coupling (63 % to 53 %) than their circular counterparts, yet circularly polarised antennae proved better with an antenna offset (51 % to 47 %).

As the distance between antenna and sample increased the number of tags detected decreased in all cases with average detection rates at 300 mm, 600 mm and 1000 mm of 76 %, 59 % and 44 % respectively.

In terms of a tag variation AD-612 proved best at coupling (81 % average detection rate) as this may be due to the large surface area covered by its antenna thus not making it ideal for item level traceability due to its size (also *as per* its specification for a carton-level use). This was followed by Rafsec frog, TI-UHF, AD-821 and AD-421 with detection rates of 69 %, 68 % 66 % and 63 %, respectively.

An increase in the conveyor speed resulted in a decrease in the tag detection rate from 63 % when stationary to 52 % at 0.5 m/s, and to 50 % at 1.0 m/s average detection rates.

Strategic tag placement is also important as results showed that tags are most detected when there is a direct line of sight between them and the reader antenna. Results also revealed that tags oriented along the y axis were most detected followed by z oriented tags and finally x oriented were least detected overall.

Reader antenna placement was also an important factor while not proving significant ($p > 0.05$) as an offset of the reader antenna of 95 mm led to a decrease

in the average detection rate from 62 % to 49 %.

Conclusions

It can be concluded that reader antenna is ideally placed as close as possible to the test sample being interrogated. Linearly polarised reader antenna was favoured for coupling over larger distances yet circular polarisation was less dependent on inconsistent antenna alignment. The choice of tag used also determined the coupling capabilities of the RFID system. Dynamic interrogation was also an important factor to consider as an increase in the conveyor speed led to a decrease in the number of tags detected. While not being statistically significant, reader antenna placement is also important as it may also have a negative effect on coupling capabilities. Due to its high level of automation RFID has the ability to increase the integrity of the supply chain. This technology also offers the ability to add value to the supply chain by being able to monitor product conditions during production, storage and distribution of the product.

Acknowledgements

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References

Dobkin, D. M. 2008. The RF in RFID: Passive UHF RFID in Practice. Elsevier Science and Technology, Oxford, UK.

Finkenzeller, K. 2003. RFID Handbook, Fundamentals and Applications in Contactless Smart Cards and Identification. 2 nd Edition. Wiley 2003. page 7.

Keskilammi, M., L. Sydänheimo and M. Kivikoski, 2004. Radio Frequency Technology for Automated Manufacturing and Logistics Control. Part 1: Passive RFID Systems and the Effects of Antenna Parameters on Operational Distance, The International Journal of Advanced Manufacturing Technology, 21(10-11), 769-774.

Lahiri, S. 2006. RFID Sourcebook. Pearsons Plc, IBM Press, NJ 07458

Mc Carthy, U., G. Ayalew, F. Butler, K. McDonnell and S. Ward, 2009. The effects of item composition, tag inlay design, reader antenna polarization, power and transponder orientation on the dynamic coupling efficiency of backscatter ultra-high frequency radio frequency identification, Packaging Technology and Science, in press

Singh, S.P., M. McCartney, J. Singh, and R Clarke. 2007. RFID Research and testing for packages of Apparel, Consumer Goods and fresh produce in the retail distribution environment. Packaging technology and Science. Available at: http://www.interscience.wiley.com. Accessed on 23 February 2008.

Smith, G.C., D.L. Pendell, J.D. Tatum, K.E. Belk and J.N. Sofos, 2008. Post-slaughter traceability, Meat Science, 80(1), 66-74.

Smith, G.C., J.D. Tatum, K.E. Belk, J.A. Scanga, T. Grandin and J.N. Sofos, 2005. Traceability from a US perspective, Meat Science, 71(1), 174-193.

Table 6 UHF Passive tags used for trials

Inlay manufacturer	Model No.	Operating Frequency (MHz)	Communications Protocol	Antenna Dimensions (mm)	Ideal Material/ recommended application
Avery Dennison	AD-821	865 – 868	ISO/IEC 18000-6C, EPC Class 1 Generation 2	72 x 30	edge reading, garment hang-tag, item level
Avery Dennison	AD-612	865 – 928 (wide band)	ISO/IEC 18000-6C, EPC Class 1 Generation 2	140 x 24	RF friendly and reflective contents, Carton level
Avery Dennison	AD-421	865 – 868	ISO/IEC 18000-6C, EPC Class 1 Generation 2	94 x 32	corrugated box labelling, metals and liquids, Pallet and carton level
UPM Rafsec	ANT ID 154_2 (Frog)				
Texas Instruments	RI-UHF-00C02-04	860 – 960	EPC Class 1 Gen 2	89 x 25	

HAZARD IDENTIFICATION AS A FIRST STEP IN MICROBIAL FOOD SAFETY RISK ASSESSMENT OF POULTRY PRODUCTION IN IRELAND

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Abstract:

Microbial food safety risk assessment consists of hazard identification, exposure assessment, hazard characterization, and risk characterization as integrated steps. Hazard identification is the first step in this systematic process of Microbial food safety risk assessment. A hazard identification of foodborne pathogens in poultry meat is described in this study. This work describes a hazard identification process methodology for pathogens in poultry meat. *Salmonella spp., Campylobater jejuni*, *Escherichia coli, Listeria monocytogenes*, *Staphylococcus aureus, Yersinia enterocolitica, Bacillus cereus, Clostridium perfrigens* and *Clostridum botulinum* were identified as main pathogens in poultry meat.

Introduction

Foodborne illness caused by microorganisms is a large and growing public health problem. Most countries with systems for reporting cases of foodborne illness have documented significant increases over the past few decades in the incidence of diseases caused by microorganisms in food, including pathogens such as *Salmonella*, *Campylobacter jejuni* and enterohaemorrhagic *Escherichia coli*. A serious burden of foodborne illness continues to exist in both developed and developing countries (WHO, 2001). To manage food safety risks, it is important to identify which foods, pathogens, or situations lead to foodborne illness, and to determine the magnitude of the impact these have on human health (Lammerding et al. 2000). Microbiological Risk Analysis is a process consisting of three components: Risk Assessment, Risk Management, and Risk Communication, which has the overall objective to ensure public health protection (Codex, 1999). The four steps are shown schematically in Figure 1.

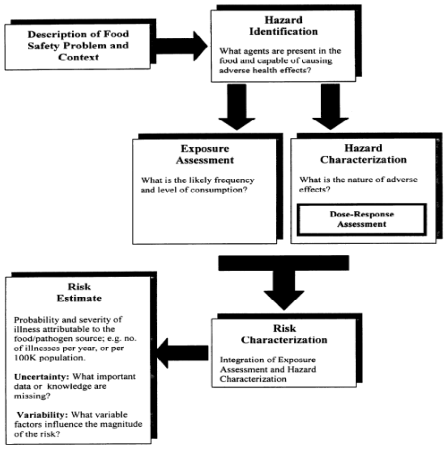

Fig. 1 Steps of microbial food safety risk assessment (Lammerding, 2000)

Hazard identification is the first step in a formal risk assessment. This activity is largely a qualitative evaluation of the risk issue and a preliminary examination of information that is analyzed in more detail in the subsequent steps of the risk assessment process (Lammerding *et al*, 2000). Information on microbial hazards can be obtained from scientific literature, from databases such as those in the food industry, government agencies, and relevant international organizations and through solicitation of opinions of experts. Relevant information includes data in areas such as: clinical studies, epidemiological studies and surveillance, laboratory animal studies, investigations of the characteristics of microorganisms, the interaction between microorganisms and their environment through the food chain from primary production up to and including consumption and studies on analogous microorganisms and situations (Codex, 1999). **The objective of this work is the systematic identification of the microorganisms that are pathogenic hazards in poultry meat in an Irish context. This hazard identification has been made as a preliminary step for a risk ranking of microbial hazards in poultry.**

Methodology

A review of scientific literature taken from relevant and recent publications of scientific journals and texts was done to collect information regarding the identification of biological hazards potentially transmitted to humans by the consumption of poultry meat. This study addressed the main category of poultry produced in Europe, i.e. the indoor reared and finished poultry. A literature search was conducted using: (i) Books related and specialized in Food Microbiology (ii) the ISI Web of Knowledge and Web of Science databases for papers indexed since 2000, (iii) Google website search for official reports published by international organisations (World Health Organization, Food and Agriculture Organization, World Bank, European Commission, Organization for Economic Cooperation and Development). Reports on these incidents have epidemiological data for notable food borne diseases. However, these reports are often lacking in information about the source of the pathogens The papers taken into account had to fulfill the following conditions: (i) to be an original article, (ii) to report the incidence or prevalence of the hazard in human beings or in poultry and meat products, (iii) to be papers concerning about outbreaks and epidemiology studies related with meat, meat products, poultry or poultry products, (iv) to be studies about methods of detection of pathogens in poultry meat.

Results

Nine biological hazards possibly transmitted to humans by the consumption of poultry meat were found (Tab. I): Campylobacter spp., *Clostridium botulinum, Clostridium perfringens, Listeria monocytogenes*, *Salmonella spp., Staphylococcus aureus, Pathogenic Escherichia coli*, *Yersinia enterocolitica, Bacillus spp.*.

Table 1: Pathogenic hazards in poultry and references.

Pathogen & Citations
Salmonella spp. (S. tiphymurium, S. enteritica) Thatcher *et al.,* 1973; ICMSF 1974; Brown, 1982 ; Doyle, 1989; Varman *et al.*, 1991; ICMSF, 1980; Adams *et al*., 1995; Gelinas, 1997; ICMSF, 1998; Davies *et al.*, 1998; Abouzeed *et al.,* 2000; Gorman *et al*., 2002; Soultos *et al*., 2003; W. Blackburn *et al.*, 2003; Jordan *et al*., 2006; EFSA, 2007; Carvajal *et al.*, 2008; Nogrady *et al.*, 2008. Esteban *et al.*, 2008, Bollaerts et al., 2008; Berrang *et al*., 2008.
Campylobacter spp. ICMSF, 1980; Brown, 1982 ; Doyle, 1989; Varman *et al*, 1991; Gelinas, 1997; ICMSF, 1998; Davies *et al.*, 1998; Gorman *et al*., 2002; W. Blackburn *et al.*, 2003; Hussein et al., 2006; EFSA, 2007; Stoyanchev *et al.,* 2007; Reich *et al* 2008; Berrang *et al*., 2008; Esteban *et al*, 2008.
Listeria Monocytogenes Jay, 1996; Doyle, 1989; Varman *et al.*, 1991; Adams *et al*., 1995; Fenlon, *et al*., 1996; ICMSF, 1998; Davies *et al.*, 1998; Capita *et al*., 2000; W. Blackburn *et al.*, 2003; Soultos *et al*., 2003; EFSA, 2007; Lekroengsin et al., 2007; Esteban *et al.*, 2008.
Pathogenic Eschirichia Coli (enterohemorrhagic e.coli) ICMSF 1974; Brown, 1982 ; Doyle, 1989; Varman *et al.*, 1991; Adams *et al*., 1995; Gelinas, 1997; Davies *et al.*, 1998*; Gorman *et al*., 2002; W. Blackburn *et al.*, 2003; EFSA, 2007; Berrang *et al*., 2008; Esteban *et al.*, 2008.
Staphylococcus aureus Thatcher *et al.,* 1973; ICMSF 1974; ICMSF, 1980; Brown, 1982 ; Doyle, 1989; Varman *et al.*, 1991; Gelinas, 1997; ICMSF, 1998, Gorman *et al*., 2002.
Clostridium Perfringens Thatcher *et al.,* 1973; ICMSF 1974; ICMSF, 1980; Brown, 1982 ; Doyle, 1989; Varman *et al.*, 1991; Adams *et al*., 1995; Gelinas, 1997; ICMSF, 1998; Davies *et al.*, 1998;.
Clostridium Botulinum Varman *et al.*, 1991; Adams *et al*., 1995; ICMSF, 1998; Davies *et al.*, 1998;
Yersinia enterocolitica ICMSF, 1980; Brown, 1982 ; Doyle, 1989; Varman *et al.*, 1991; Gelinas, 1997; Davies *et al.*, 1998*; EFSA, 2007.
Bacillus spp. (B. cereus, B. subtilis, B. licheniformis) Thatcher et al., 1973;? Doyle, 1989; Varman *et al.*, 1991; Davies *et al.*, 1998*

* There is very little available information on the new pathogens, Yersinia, Bacillus and E; coli O157:H7

The pathogens listed in Table 1 can be compared with the list of pathogens evaluated by Matagaras et al. (2008). That study considered as potential hazards the following pathogens: *Salmonella spp. Campylobacter spp., Staphylococcus aureus,*

enterohaemorrhagic Escherichia coli (EHEC), *Listeria Monocytogenes Clostridium Perfringens, Yersinia enterocolitica, Bacillus spp. (B. cereus, B. subtilis, B. licheniformis) and* Bacillus cereus and other Bacillus species, and Hepatitis E virus (HEV). These pathogens were considered by the importance of the epidemiological data in the EFSA report 2007. Poultry and pork are the foods most susceptible to contamination with high consumption rates in Europe. The pathogens listed above had the highest outbreaks, illnesses, hospitalizations and death rates in the EFSA report 2007. The next phase of this work is to rank the identified pathogens using several ranking criteria.

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References

Abouzeed, Y., Hariharan, H., Poppe, C., Kibenge, F., 2000. Characterization of Salmonella isolates from beef cattle, broiler chickens and human sources on Prince Edward Island. Comparative Immunology, Microbiology & Infectious Diseases 23, 253-266.

Adams, M.R., Moss, M.O., 1995. Food Microbiology, 160-218.

Berrang, M., Bailey, J., Altekruse, S., Shaw, W., 2008. Presence and numbers of Campylobacter, escherichia coli, and salmonella determined in broiler carcass rinses from United States processing plants in the hazard analysis and critical control point-based inspection models. Journal of applied poultry research, vol. 17, issue 3, 354-360.

Bollaerts, K., Aerts, M., Faes, Christel F., Grijspperdt, K., 2008. Human Salmonellosis: Estimation of Dose-Illness from Outbreak data. Risk Analysis, Vol. 28, No. 2.

Brown, M.H. (Ed.), 1982. Meat microbiology. Unilever Research Laboratory, Colworth house, Sharnbrook, Bedford, UK, 1982. 68-72.

Capita, R., Alonso-Calleja, C., Moreno, B., Camino, M., 2000. Occurrence of *Listeria* species in retail poultry meat and comparison of a culturalrimmunoassay for their detection. International Journal of Food Microbiology, 75–82.

Carvajal, 2008. Effects of Salmonella enterica serovar Enteritidis on cellular recruitment and cytokine gene expression in caecum of vaccinated chickens. Vaccine, Vol. 26 (2008), 5423-5433.

Codex Alimentarius Commission, 1999. Principles and guidelines for the conduct of microbiological risk assessment CAC/GL-30, 1999.

Davies, A., Board, R., 1998. The Microbiology of Meat and Poultry, 161.

De W. Blackburn, C., McClure, P.J., 2002. Foodborne Pathogens, Hazards, risk analysis and control.

Doyle, M.P. (Ed.), 1989. Foodborne Bacterial Pathogens.

European Food Safety Authority (EFSA), 2007. Zoonoses Data Collection Reports. www.efsa.europa.eu/en/science/monitoring_zoonoses/reports.html

Fenlon, D., Wilson, J., Donachie, W., 1996. The incidence and level of listeria monocytogenes contamination of food sources at primary production and initial processing. Journal of applied bacteriology, volume 81, issue 6, 641-650.

Fosse, J., Seegers, H., Magars, C., 2007. Foodborne zoonoses due to meat: a quantitative approach for a comparative risk assessment applied to pig slaughtering in Europe. Medline-International Literature. Veterinary Resources 30 (1), 2008 Jan-Feb.

Gelinas, P., 1997. Handbook of Foodborne Microbial Pathogens, 41-82.

Gorman, R., Bloomfield, S., Adley, C., 2002. A study in cross contamination of food borne pathogens in the domestic kitchen in the Republic of Ireland. International Journal of Food Microbiology, 143-150.

Hussain, I., Shahid Mahmood M., Akhtarb, M., Khan A., 2006. Prevalence of Campylobacter

species in meat, milk and other food commodities in Pakistan. Food Microbiology 24 (2007) 219–222.

Jordan, E., Egan, J., Dullea, C., Ward, J., McGillicuddy, K., Murray, G., Murphy, A., Bradsahw, B., Leonard, N., Rafter, P., S., McDowell, 2006. Salmonella surveillance in raw and cooked meat and meat products in the Republica of Ireland from 2002 to 2004. International Journal of Food Microbiology 112 (2006) 66-70.

Lekroengsin, S., Keeratipibul, S., Trakoonlerswilai, K., 2007. Contamination profile of listeria spp. in three types of ready-to-eat chicken meat products. Journal of food protection, volume 70, issue 1, 85-89.

Limmerding, A., Fazil, A., 2000. Hazard identification and exposure assessment for microbial food safety risk assessment. International Journal of Food Microbiology 58 (2000) 147–157.

Matagaras, M., Skandaris, P., Drosinos E., 2008. Risk profiles of pork and poultry meat and risk ratings of various pathogen/product combinations. International Journal of Food Microbiology 126 (2008) 1–12.

Nogrady N., Kardos, G., Bistyak, A., Turcsanyi, I. *et al*, 2008. Prevalence and characterization of Salmonella infantis isolates originating from different points of the broiler chicken-human food chain in Hungary. International journal of food microbiology 127 (2008) 162-167.

Official Journal of the European Union, 2005. Commission regulation (EC) No 2073/2005.

Olsen, S., MacKinon, L., Goulding, J., Bean, N., Slutsker, L., 2000. Surveillance of foodborne disease outbreaks—United States, 1993–1997. Morbidity and Mortality Weekly Reports 49 (SS01), 1–51.

Reich F., Atanassova, V., Haunhorst E., *et al*, 2008 .The effects of Campylobacter numbers in caeca on the contamination of broiler carcasses with Campylobacter. International Journal of Food Microbiology 127 (2008) 116–120.

Soultos, N., Koidis, P., Madden, R.H., 2003. Presence of *Listeria* and *Salmonella* spp. in retail chicken in Northern Ireland. Letters in Applied Microbiology, Volume 37, Number 5, November 2003 , 421-423.

Stoyanchev, T., Vashin, I., Ring, C., Atanassova, V., 2007. Prevalence of *Campylobacter* spp. in poultry and poultry products for sale on the Bulgarian retail market. Springer Netherlands Publisher.

Thatcher, F.S., Clark, D.S., (Edited and Compiled by) 1973. Microorganisms in Foods. Their significance and Methods of Enumeration.

The International Commission on Microbiological Specifications for Food (ICMSF), of the International Association of Microbiological societies, 1974. Microorganism in Food-2. Sampling for microbiological analysis: Principles and specific applications, University of Toronto Press, 34-36.

The International Commission on Microbiological Specifications for Food (ICMSF), Microbial Ecology of Foods, 1989. Volume 2. Food Commodities, 410 – 457.

The International Commission on Microbiological Specifications for Food (ICMSF), of the International Association of Microbiological societies, 1998. Microorganism in Food-6. Microbial Ecology in Food Commodities, 100 - 102.

Varnam, A.H., Evans, M.G., 1991. Foodborne Pathogens an illustrated text.

Whyte, P., McGill, K., Cowley, D., Madden, R.H., Moran, L., Scates, P., Carroll, C., O'Leary, A., Fanning, S., Collins, J.D., McNamara, E., Moore, J.E., Cormican M., 2003. Occurrence of Campylobacter in retail foods in Ireland. International Journal of Food Microbiology 95 (2004) 111–118.

World Health Organization (WHO), 2007. Executive board eb108/7, 108th session 27 April 2001. Provisional agenda item 7.

SECURING THE CHAIN OF CUSTODY FOR FEED SAMPLES IN THE POULTRY FOOD CHAIN

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Abstract

There is a need to enhance the security of the feed input to the poultry food chain. Because of globalisation, poultry feeds are now sourced on a worldwide basis, and are therefore more prone to contamination, be it inadvertent or malicious. Whether feed samples are taken by independent companies or the competent authority, the chain of custody of that sample needs to be assured. Furthermore, should there be any problem with the sample the need for immediate and effective traceback to the feed of origin is of vital importance. As part of Avian BioTrack, this tamperproof feed sampler coupled with real time traceability technology, seeks to address these issues. Hourly samples were taken by the sampler and weighed, and the results analysed. Significant differences between sample weights from hour to hour confirmed the variation of the production cycle of a commercial feedmill. A reasonable solution would be to set the sampler to collect more than the minimum required and this together with its tamperproof features could indeed provide a viable answer to feed sample security. The feasibility of using the incorporated traceability technologies in an industrial setting, as part of a complete food chain traceability framework, was also examined here with no technical problems exposed, apart from the suggestion of using mobile handheld readers for convenience.

Introduction

In recent years, the introduction of the food chain "farm-to-fork" approach, which acknowledges that the responsibility for the supply of safe, healthy and nutritious food is shared along the entire food chain, has served to highlight the importance of feed safety (FAO/WHO, 2007). The role and importance of animal feed in the production of safe food is recognized worldwide, and events, such as the BSE crisis in the UK, the dioxin crisis in Belgium in 1999, and, even more recently, the pork dioxin crisis here in Ireland, have underlined its impacts on public health, feed and food trade, and food security (FAO/WHO, 2007). Increasingly, the globalisation of trade and industrialisation of food processing have exposed consumers to an even greater number of hazards (Caporale, 2001). Therefore, attention to animal feed safety is essential to ensuring human health. In food processing 100% inspection or analysis is rarely possible or even desirable (Proctor, 1994), as it would be both costly and destructive (Gy, 1998). Therefore sampling to obtain a representative sample is a vital process. A "representative sample" is a sample in which the characteristics of the lot from which it is drawn are maintained (CodexAlimentarius, 2004b) or that can be expected to adequately reflect the properties of interest of the parent population (IUPAC, 1997). Council Directive 70/373/EEC of 20 July 1970 introduced the requirement for uniform methods of sampling and analysis to be used by the authorities of the Member States for carrying out official controls concerning the quality and composition of feedingstuffs (EuropeanCouncil, 1970). Contamination of compound feeds is dependent on a number of factors including human error, production practices and handling procedures in the feed mill, during transport and on farm (McEvoy, 2002). Because of globalisation, poultry feeds are now sourced on a worldwide basis, and are therefore more prone to contamination, be it inadvertent or malicious. Therefore, the need to enhance the security of this part of the food chain is essential. A patented tamperproof sample collection device (see Figure 1 below) has recently been updated

by the Avian BioTrack team, which will allow samples to be collected in a secure manner, especially in 3rd countries, without the continual presence of an official inspector. Attached barcodes/RFID (Radio Frequency Identification) tags will allow automatic identification and capture of data and information relating to the sample and the lot from which it was taken. Samples were collected using an adjustable trier (see Figure 2 below) based on the "dribble" method used in DAFF approved seed certification scheme. **The objective of this research is to assess the feasibility of providing secure, verifiable and traceable feed samples for analysis, and, secondly, to examine how providing such secured samples decreases the risk of contamination to the food chain and therefore risk to the consumer.**

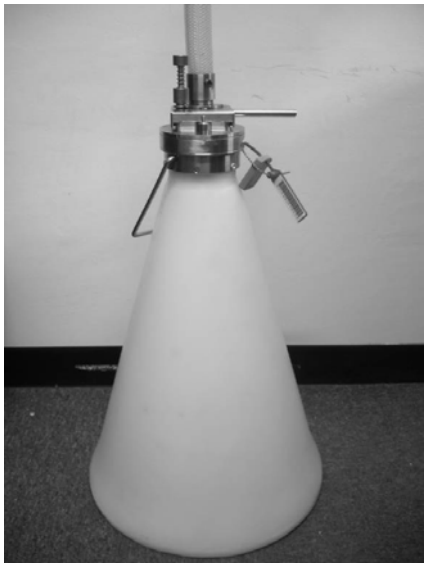


Figure 7: Tamperproof sample collection device

Figure 8: Adjustable sampling triers

Materials and Methods

The selection of the point of sampling on the feedstuff manufacturing line is critical. For best results the trier must be placed cross-flow at a point where there is a vertical flow or chute of feedstuff. This should ideally be at the very end or as close as possible to end of the process. In the present study, the sampling point was selected in consultation with the plant manager one step short of the end process just after drying. At this stage the pellets are fully formed and the sampling process presented minimal disruption to the production. A total of 41 samples were collected from this point and weighed, as previously described (Mc Inerney, 2008), during random 1 hour intervals and the weights recorded. This data was analysed and the results presented below.

Barcode labels and RFID tags encoded with unique identifiers were attached to the device as shown (Figure 1). Information regarding the sample was gathered automatically using these RFID tags and barcodes, onto which, in future, it will be possible to add even further information e.g. chemical analysis, etc. The feasibility of using these e-tracking technologies in an industrial setting was assessed. The sample barcode numbers were encoded with EAN/UPC 13 symbology. Three different passive, UHF EPC1G2 (Ultra High Frequency Electronic Product Code 1 Generation 2) tags were used in this study as follows (Figure 3):

1. Ironside Generation 2 UHF on-metal tag
2. Steelwave Generation 2 UHF on-metal tag
3. Survivor Generation 2 UHF on-metal tag

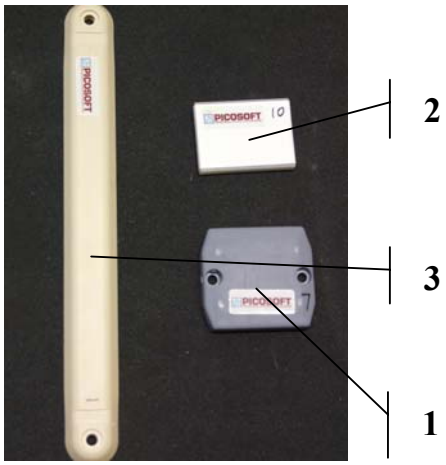


Figure 9: EPC1G2 passive RFID tags

The barcodes and RFID tags were scanned and read following preparation at the lab. They were read again following sample collection at the feedmill, and finally they were read a third time upon return to the lab. This procedure was established to mimic the normal route of official sample collection. This was repeated 12 times in total and the results presented below. A procedure to incorporate sample information into the Avian BioTrack database and to integrate it into the final holistic protocol for complete chain traceability will be developed during the final stage of the project.

The tamperproof features of the sampler were also examined and assessed in an industrial setting and the results presented below. The patented sampler has 3 security features as follows:

1. Unique rotating head design – container is only open to the exterior when the trier is attached in the fill position and cannot pass the lock position without opening and resetting the head.
2. Plastic security tie – this is applied by the official sampler and checked for tampering when the sampler is collected.
3. Official paper stamp – this cannot be removed once in place until the sampler head is removed.

Results and Discussion

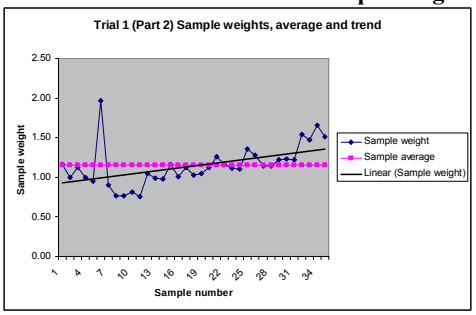
The weights were grouped by "day" and a single outlier omitted from analysis. Using SPSS software in a single factor Analysis Of Variance (ANOVA) (see Table 1 below) the results were analysed and compared. The outcome of the analysis shows that there were significant differences in the production from day to day ($F = 19.1366$, $P < 0.001$). In order to pinpoint where these significant differences were located further multiple comparisons analysis were carried out using the harmonic mean of the groups (due to the unequal size of the groups).

Table 3: ANOVA table of results for tamperproof sampler

Source of Variation	*SS*	*DF*	*MS*	*F*	*P-value*	*F crit*	*%SSTOT*	*%CONFID*
Between Groups	1.5039	6	0.2507	***19.1366***	***1.81505E-09***	2.389394	77.68	100.00
Within Groups	0.4322	33	0.0131				22.32	
Total	1.9362	39					100.00	

From 40 samples, where each one is compared with all the other samples, there were only 6 instances where there was no significant difference between the samples weights collected. Table 2 below shows the variation in sample weights over the period of the trial.

Table 4: Variation in sample weights



Further investigation showed that this variation was most likely due to the variation in production parameters (i.e. production rate, feed recipe, raw materials, formulation, etc.) during and between cycles rather than solely attributed to the sampler. Most feedmills prepare recipes using "least cost formulation" computer software which varies the feed recipe based on the availability and price of the feed raw materials & ingredients. Also production rates vary during and between cycles depending on demand, availability of ingredients and indeed for technical reasons.

However, the sampler's tamperproof features did prove successful in typical industrial feed mill settings. Both the device itself and the protocol for use received positive feedback from the feedmill production manager (non project partner) in terms of security, ruggedness, robustness and ease of use. The possibility of using RFID or barcode e-tracking technology also proved feasible, both applications being user friendly, with no technical problems, no read failures and uncomplicated application.

Assessment of the sampler will now focus on using sampling theory, probability and other statistics to determine if the proposed method (i.e. "dribble" method approved for seed certification) produces a sample statistically representative of the lot and how it compares to accepted methods for feedstuffs (i.e. incremental sampling) (EuropeanCommission, 1976). A risk model will then be developed for the raw materials supply chain which will assess how the use of a tamper-proof sampler could reduce the risk to consumers in this geographically extensive chain, especially with respect to exposure to ingredients originating in countries outside of the EU jurisdiction.

Conclusions

The inherent variability described above in a feedmill production system makes it extremely variable over a period of time and therefore renders the accurate assessment of the ability of the tamper-proof sampler to collect uniform samples that more difficult. Therefore work on this part of the project will now concentrate on the theoretical aspects of sampling statistics and risk model development for the poultry feed chain.

Acknowledgements

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References

Caporale, V., Giovannini, A., Di Francesco, C., Calistri, P., (2001). 'Importance of the traceability of animals and animal products in epidemiology'. *Rev. Sci. Tech. Off. Int. Epiz.*, 20 (2):372-378.

CodexAlimentarius, (2004b). 'General Guidelines On Sampling'. CAC, 1-69.

EuropeanCommission, (1976). 'First Commission Directive 76/371/EEC of 1 March 1976 establishing Community methods of sampling for the official control of feedingstuffs'. In: EU (ed).

EuropeanCouncil, (1970). 'Council Directive 70/373/EEC of 20 July 1970 on the introduction of Community methods of sampling and analysis for the official control of feeding-stuffs '. In: EU (ed).

FAO/WHO, (2007). 'Animal Feed Impact on Food Safety'. Rome: FAO/WHO, 1-74.

Gy, P., (1998). *Sampling for Analytical Purposes*. Chichester, West Sussex: John Wiley and Sons.

IUPAC, (1997). 'IUPAC Compendium of Chemical Terminology'.

Mc Inerney, B., Pacquit, A., Ward, S., , (2008). 'Avian BioTrack: Securing the Chain of Custody for Feed Samples in the Poultry Food Chain'. *Biosystems Engineering Research Review 13*.

McEvoy, J.D.G., (2002). 'Contamination of animal feedingstuffs as a cause of residues in food: a review of regulatory aspects, incidence and control'. *Analytica Chimica Acta*, 473 3-26.

Proctor, A., Meullenet, J-F., (1994). 'Sampling and Sample Presentation'. In: Nielsen, S.S. (ed). Food Analysis: Aspen Publishers, Inc.

DETERMINISTIC AND STOCHASTIC SIMULATION OF A FILED EXPERIMENT ON *SALMONELLA TYPHIMURIUM* PROPAGATION AT PIG FARMS

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Abstract

For the last few years there has been an increasing interest in microbial food safety and some efforts have been put into modelling *Salmonella Typhimurium* at the preharvest part of the pork production chain. Two models were developed, a deterministic one (Soumpasis & Butler, 2009a) taking into account the two-syndrome nature of the disease and a stochastic (Soumpasis & Butler, 2009b), that was based on the deterministic, using the "τ-leap method", developed by Gillespie (2001) as described by Keeling & Rohani (2007) for epidemic modelling. Results show that disease extinctions and their effect on the prevalence of pigs with *S. Typhimurium* can be predicted, while variation of the prevalence is described as a distribution and not as single point estimation.

Introduction

Foodborne human Salmonellosis is the second most frequent foodborne disease. According to the report of EFSA & ECDC (2009) on zoonoses for 2007, 151,995 people were affected in Europe by the bacterium in 2007 compared to 164,011 in 2006. As in previous years, S. Enteritidis and S. Typhimurium were the most frequently reported serovars (81% of all known serovars in human cases). Moreover according to EFSA (2008), the most common serotype of Salmonella from carcass swabs in the slaughter pigs baseline survey, in 13 Member States carried out, in 2006-2007 was S. Typhimurium, while the other serotypes that can pose a risk for human Salmonellosis, were very infrequent. Thus, it is clear that, regarding the risk of human Salmonellosis attributed to pork, the main risk is arising from S. Typhimurium. In addition in the final SALINPORK report (Wong & Hald, 2000), there were results that demonstrated that S. Typhimurium has different shedding and serological response patterns compared to the other serotypes that can be found in pigs.

The objective of this research is, using data from field experiment, to simulate dynamically and stochastically the propagation of S. Typhimurium in pig farms, and to demonstrate the superiority of the latter as part of the risk assessment at the farm level.

Materials and Methods

Data from a longitudinal serological study in France (Beloeil et al., 2003) was used to simulate real farm conditions. This study was focused on three batches of piglets, which were followed from their litter to the end of fattening period, when pigs are harvested and sent to the slaughterhouse. There was no experimental infection, but physical infection and the load of the environment,, the serology of the animals and the situation of the saws regarding Salmonella were monitored during the experiment. The results of this experiment showed that piglets are protected with maternal immunity approximately up to the date that the pigs are moving to the fattening room. For this last part of fattening, the starting conditions of infection, but also the load of the environment during the monitoring period and the culture-positive and sero-positive pigs for the last day were recorded. The mean age of infection of the pigs was calculated from the level of antibodies of the pigs using Cox regression, and it was used in the parameterisation of the model.

Deterministic Model

The deterministic model was constructed following the findings of Fedorka-Cray et al. (1994), which showed the existence of two syndromes, an acute and a sub-clinical, which are distinguished by the different rate and population of shedding the pathogen. Which syndrome will be triggered depends on the load of the pathogen in the environment. The three different compartments of the experiment were representing three different environmental loads, "Negative", "Intermittent" and "Positive". Data from experimental infections was used for the parameterisation of the model. Two different transmission rates were used depending on the syndrome, derived from the mean age of infection calculated from Beloeil et al. (2003), and they represent all the transmission routes of the pathogen, either the faecal-oral or the alternatives (Fedorka-Cray et al., 1995).

The model developed had the two syndromes incorporated, and the acute syndrome was represented by the "Susceptible (S) -> High Infectious (HI) -> Carrier -> Immune" flow and the sub-clinical syndrome by "Susceptible (S) -> Low Infectious (LI) -> Carrier -> Immune" flow. These two syndromes were connected with an "if condition", so when the environmental load of the pathogen becomes above a limit the acute syndrome to be triggered. In order that to be done the concept of Infectious Equivalent (IE) and reduced transmitability factor ε were introduced. ε represents the reduced transmitability that the LI have comparing to the HI class pigs, while IE is the combination of HI and LI pigs, the latter multiplied by ε. Both IE and ε were unknown and were estimated with backwards calculation. For more information about the construction of the deterministic model refer to Soumpasis & Butler (2009a).

Stochastic model

Demographic stochasticity is defined as fluctuations in population processes that arise from the random nature at the level of the individual (Keeling and Rohani, 2007). In this case, whole numbers of animals (integers) are used and individuals experience different fates due to chance. Event-driven approach was used to incorporate demographic stochasticity in the model and more precisely, "τ -leap method", developed by Gillespie (2001) as described by Keeling & Rohani (2007) for epidemic modelling, which offers substantial gains in simulation speed with minor sacrifices in simulation accuracy.

All possible events should be defined and the rate at which each event occurs must be determined. There are 10 events, 5 for each syndrome: The infection of the Susceptible (S) class, the recovery of the High Infectious (HI) class, the recovery of the Low Infectious (LI) class, the recovery for the Carriers (C) class and the loss of immunity (move from Immune (I) class to Susceptible class). A time step was defined to one (1) day, in order to calculate the probabilities of each of the above events to happen in this time step. For small time steps the number of events in each time step is given approximately by a Poisson distribution (Keeling & Rohani, 2007). For more information on the construction of the stochastic model refer to Soumpasis & Butler (2009b).

The model were written in Python programming language v.2.5.2 (van Rossum, 2008) using scipy/numpy libraries (Jones et al., 2001--) for numerical calculations and solution of the differential equations and Gnuplot for the graphical representation of the results. The algorithm for the solution of the differential equations uses "lsoda" from the FORTRAN library "odepack" (Hindmarsh, 1983; Petzold, 1983). R (R Development Core Team, 2008) was used for the statistical interpretation of the results and plotting.

Results and Discussion

The results for the deterministic and the stochastic model are presented in figures 1 and 2 respectively. From the backwards calculation performed, a range of pairs for ε and IE critical limit were found, and the median case of IEcl 0.42 and ε 0.07 was used. Both the deterministic and the

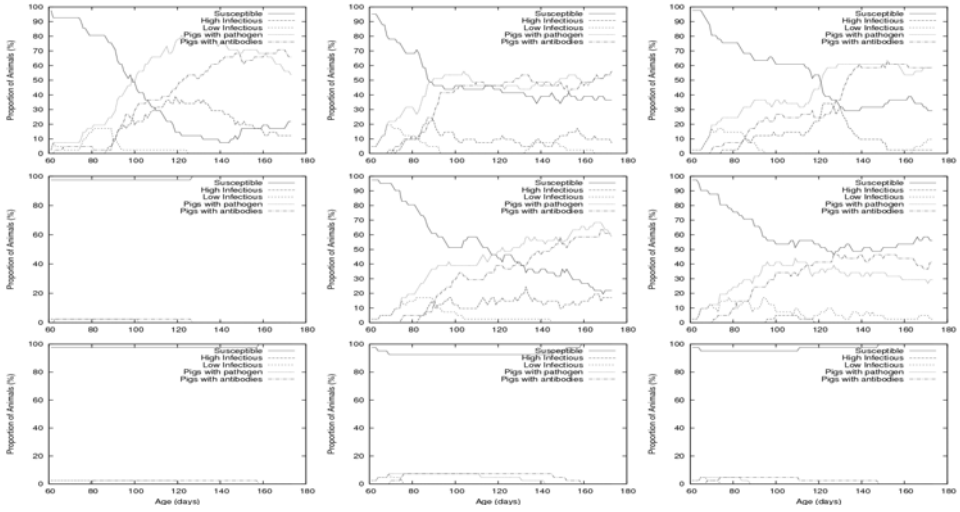

Figure 2 Results of the Stochastic Model for IE critical limit 0.07 and ε 0.42 (9 iterations)

stochastic model results presented are for the intermittent environment. In the deterministic model there is a clear change of the syndrome at day 108, and the forecast for the classes are single point values. For the stochastic model, the results of 9 iterations are presented and it is observed that in some cases there are disease extinctions, while no case is similar to another.

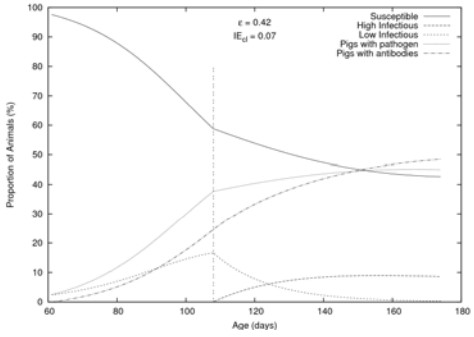

Figure 10 Results of the Deterministic Model for IE critical limit 0.07 and ε 0.42

The effect of this variability is graphically represented at figures 3 and 4, where histograms of HI, LI, Culture-positive and Sero-positive for the last day of modelling period for the "Negative" and the "Positive" environment are presented. The last day of modelling represents the day that pigs go to the slaughterhouse and the histograms are the results of 5000 iterations.

Pigs in HI and LI class are expected to have the pathogen in their intestine and to be caecal or faecal positive, and they constitute a major risk for introducing the pathogen into the slaughtering chain. The Culture-positive pigs are pigs that can carry the pathogen in any of the internal organs where S. Typhimurium can be found, and constitute a minor risk for the slaughterhouse. Finally, the sero-positive pigs are the pigs that can be detected as sero-positive at the national screening tests of the pig farms.

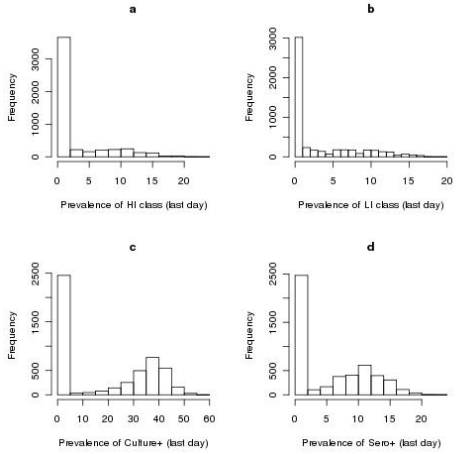

Figure 11 Histograms for a) HI, b) LI, c) Culture-positive and d) Sero-positive for the last day of modelling period (day of slaughter) for the "Negative environment (5000 iterations)

Although the disease extinctions, which are shown by the zero in the two infectious classes, are similar in their quantity in the two different environments, they differ regarding quality. In the case of the "Negative" environment, almost all the extinctions are early extinctions, some which is described by the mean age of extinction which is

close to the beginning of the fattening period. Thus, the cases of big culture- and sero-prevalence are few. On the contrary, for the "Positive" environment, there is a mix of early and late extinctions and the effect on the culture- and sero-prevalence is clear by the higher number of observations of big prevalence.

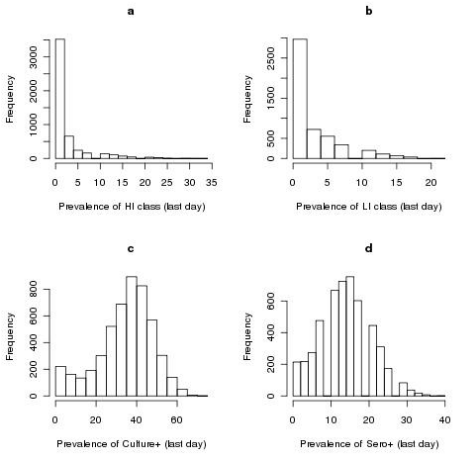

Figure 12 Histograms for a) HI, b) LI, c) Culture-positive and d) Sero-positive for the last day of modelling period (day of slaughter) for the "Positive" environment (5000 iterations)

Conclusion

The results show that demographic stochasticity, when applied to modern pig farming, has the potential for better results, closer to reality, depending on the assumptions made and the data used. It can help the stakeholders to understand better the dynamics of the disease, and try intervention strategies at the critical stages, in order to increase efficiency and to minimise the cost of the strategy applied.

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References

EFSA (2008a). Report of the task force on zoonoses data collection on the analysis of the baseline survey on the prevalence of Salmonella in slaughter pigs, in the EU, 2006-2007, part A. The EFSA Journal, 135:1–111

EFSA & ECDC (2009). The community summary report on trends and sources zoonoses and zoonotic agents in the European Union in 2007. The EFSA Journal, 223:1–215.

Fedorka-Cray P.J.; Whipp S.C.; Isaacson R.E.; Nord N.; and Lager K., 1994. "Transmission of Salmonella-typhimurium to swine." Veterinary Microbiology, 41, no. 4, 333-344.

Gillespie, D. T. (2001). Approximate accelera-ted stochastic simulation of chemically reacting systems. The Journal of Chemical Physics, 115(4):1716–1733.

Hindmarsh A., 1983. ODEPACK, "A Systematized Collection of ODE Solvers." In R.e.a. Stepleman (Ed.), Scientific Computing: Applications of Mathematics and Computing to the Physical Sciences. North-Holland, Amsterdam, Netherlands; New York, U.S.A., IMACS Transactions on Scientific Computing, vol. 1, 55-64.

Keeling M.J. and Rohani P., 2007. "Modeling Infectious Diseases." Princeton University Press. ISBN 978-0-691-11617-4.

Petzold L., 1983. "Automatic Selection of Methods for Solving Stiff and Nonstiff Systems of Ordinary Differential Equations." SIAM Journal on Scientific and Statistical Computing, 4, no. 1, 136-148.

R Development Core Team (2008). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

van Rossum G., 2008. "Python Programming Language". Python Software Foundation, 2.5.1 ed. URL http: //www.python.org/.

Soumpasis I. & Butler F. (2008). A comparison of deterministic and stochastic epidemic models for the risk assessment of salmonella at the pre-harvest level of pork production. In FOODSIM' 2008, pages 80–85. Eurosis-ETI.

Soumpasis I. & Butler F. (2009a). A self-regulated model for Salmonella Typhimurium in pig farms. Under preparation.
Soumpasis I. & Butler F. (2009b). Application of demographic stochasticity in dynamic modelling of Salmonella Typhimurium in pig farms. Under preparation.

Wong, D. L. & Hald T. (2000). Salmonella in pork (salinpork): Pre-harvest and harvest control options based on epidemiologic, diagnostic and economic research - Final report. Technical report, SALINPORK project. Final report Contract no: FAIR1 CT95-0400

A FARM-LEVEL MODEL TO PREDICT ß-GLUCAN LEVELS IN OAT GENOTYPES

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Abstract

Oat β-glucans have health-promoting benefits and consequently are desirable for human consumption. A model was developed during this study using Monte Carlo simulation techniques in order to evaluate the impact of different cultivation stages on β-glucans in oats. A scenario analysis was subsequently developed to look at the impact of different model assumptions and input parameters. The simulated mean β-glucan level in harvested oats grain was 3.56 and 4.31 g/100g for hulled (HO) and naked (NO) oats, respectively. A sensitivity analysis highlighted that genotypic selection was the most important input parameter compared to other inputs in determining the final β-glucan level (correlation coefficients of 0.62 and 0.79 for HO and NO, respectively). The analysis also indicated the importance of a later sowing date without compromising grain quality (correlation coefficients of 0.30 and 0.25 for HO and NO, respectively), while germination and storage factors showed a negative impact on the final β-glucan levels. This study provides a simulation tool to assess critical factors influencing β-glucan content in harvested grain.

Introduction

Oats (*Avena sativa*. L) is an important cereal crop throughout the developing world, and for specialist uses in developed countries, being used for human food (DEFRA, 2003) and livestock feed. The Food and Drug Administration (FDA, 1997) allows health claims associated with phytochemicals, such as β-glucans, present in the oats grain, which has increased human consumption. By incorporating oats β-glucan into various food products,

including breakfast cereals, beverages, bread and infant foods (Flander et al., 2007) it improves the nutritive quality of food and may have positive health benefits (FDA, 1997). β-glucan content is predominately found in the endosperm layers of cereal grains. Unlike barley, oats have a thick layer of cell wall in the sub-aleurone region of the kernel, which contains higher amounts of β-glucan (Fulcher and Miller, 1993). Oat β-glucan is a viscous and soluble dietary fibre component, with potentially positive benefits for human health and nutrition in terms of lowering cholesterol and blood glucose levels (Maier et al., 2000). Variations in β-glucan content are influenced by various genotypic, environmental and agronomic practices.

The objective of this study was to quantify the variability and uncertainty in the level of β-glucans in harvested oats and, through a sensitivity analysis, assess the relative importance various cultivation and management practices have on influencing the final β-glucan levels in harvested oats.

Materials and Methods

Model Methodology:
Data on thirty hulled oat (HO) and naked oat (NO) genotypes were collated from existing scientific and technical literature. In addition, data on the impact of various environmental conditions, agronomic practices and storage factors was collated. Figure 1 representation used to model the cultivation of oats. Monte Carlo simulation techniques were used to model uncertainty and variability using probability distribution functions (PDFs) resulting in an output distribution. The probability distributions used in the model are discussed in the following section and summarised in Table 1. Monte Carlo methods randomly select values from given distributions to create multiple scenarios of a problem. The scenarios developed used the same data as the baseline model except where specified. No fertiliser application was assumed for scenario 1, to assess the predicted influence of fertilisation. For scenario 2, oats grains are harvested on the day of maturity (i.e. growth stage 92) and no storage of the grain was assumed in the scenario

3. The simulation was performed using the parameters and calculations and the model run for 10,000 iterations.

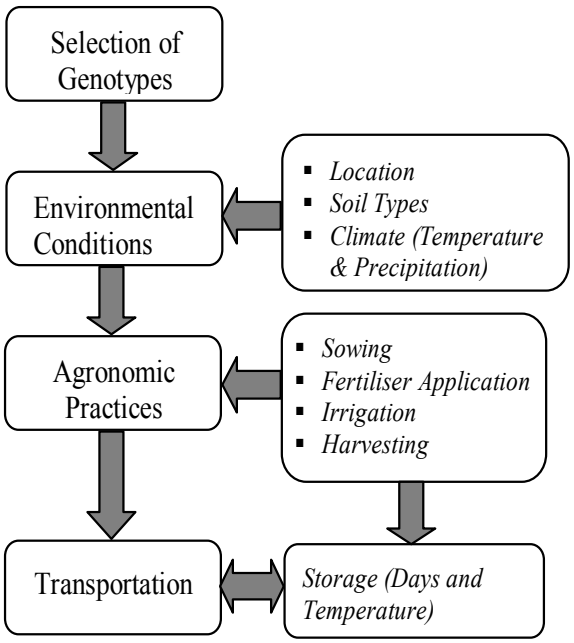

Figure 1. Flow chart representation used to model the cultivation of oats.

Results and Discussion

The baseline model found that the mean simulated β-glucan level in harvested oats grain was 3.56 and 4.31 g/100g for HO and NO, respectively (Figure 2). A sensitivity analysis showed that genotypic selection was the most important parameter in determining the final β-glucan level (correlation coefficients of 0.62 and 0.79 for HO and NO, respectively), when compared to other environmental and agronomical factors. The analysis also indicated that crops sown in the latter part of the sowing season may influence the final β-glucan levels (correlation coefficients of 0.30 and 0.25 for HO and NO, respectively), highlighting the importance of harvesting date. Germination time, storage days and temperature showed a negative impact on the final β-glucan levels (Figure 3). In addition to the baseline model, the scenario analysis also highlighted the impact of fertiliser application, harvest date and storage factors. Scenario 1 showed the β-glucan content was reduced by 3 %, highlighting the importance of fertiliser application, scenario 2 showed β-glucan content was increased about 6% highlighting the importance of harvesting at its maturity, whereas scenario 3 showed β-glucan content significantly increased by 10 % for both HO and NO genotypes, highlighting the impact of storage on the level of β-glucan HO and NO genotypes.

Table 1. Model input distributions to model the predicted β-glucan levels in oats

Symbol	Description	Mean	Distribution	Units
1. Genotypic Data				
HO	Hulled Oats	3.65	Lognormal (3.65,0.047)	g/100g
NO	Naked Oats	4.43	Lognormal (4.43,0.92)	g/100g
2. Environmental Conditions				
L	Location	1	Factor	
SoF	Soil factor	1	Versatile soil	
SpH	Soil pH	1	Factor	
Climatic Condition				
SPr	Precipitation (spring oats)	60	Uniform (min 20, max 100)	mm / month
WPr	Precipitation (winter oats)	95	Uniform (min 40, max 150)	mm / month
ST	Temperature (spring oats)	15	Triangle (min 10, max 20)	^{o}C
WT	Temperature (winter oats)	7	Triangle (min 5, max 10)	^{o}C
Pr	Precipitation (growing period)	95	Discrete ({WPr, SPr}, {0.51, 0.49})	mm / month
T	Temperature (growing period)	7	Discrete ({WT, ST}, {0.51, 0.49})	^{o}C
CF	Climatic factor	0.961	Prediction line, Function of Pr and T	
3. Agronomic Factors				
SDD	Sowing Delay Days	15	Uniform (min 0, max 30)	days
SDF	Sowing date factor	1.129	Fixed factor	days
Fertiliser application				
N	Nitrogen application	97	Triangle (min 40, max 140)	kg/ ha
Fu	Foliar Urea	60	Fixed	kg/ ha
FF	Fertiliser factor	1.028	Prediction line, Function of N and Fu	kg/ ha
Irrigation				
IF	Irrigation factor	1	Fixed factor	
Germination				
GTime	Germination Time	1	Exponential, beta 1.33	days
GTemp	Germination Temperature	10	Fixed value	^{o}C
GF	Germination factor	0.952	Prediction line, Function of GTime and Gtemp	
4. Storage				
SDays	Storage days	90	Uniform (min 0, max 365)	days
STemp	Storage temperature	12	Triangle (min 5, max 20)	^{o}C
SF	Storage factor	0.865	Prediction line, Function of SDays and STemp	

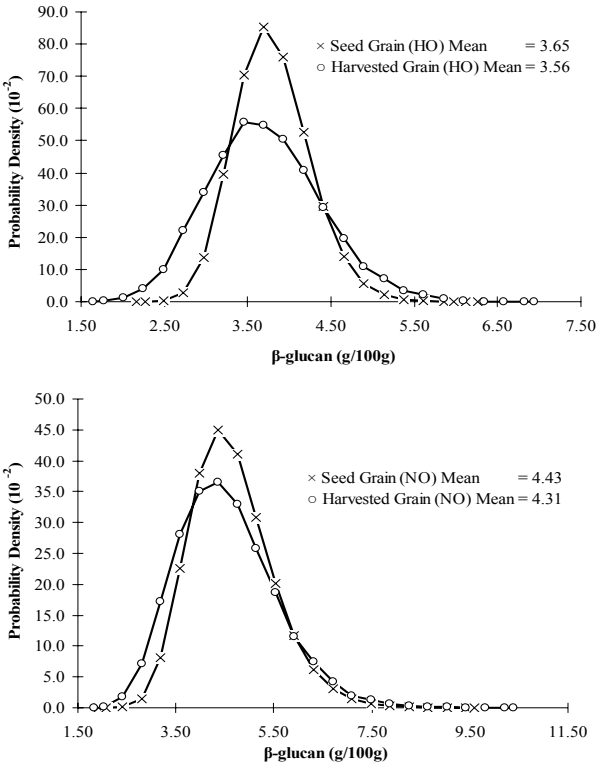

Figure 2. Simulated probability density of β-glucan in oat genotypes

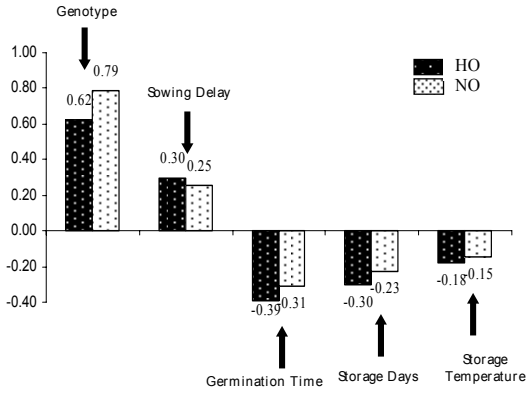

Figure 3. Sensitivity analysis for level of β-glucan in harvested oat genotypes

Conclusions

This study represents a preliminary effort to model various cultivation and storage conditions and their effects on β-glucan content in harvested oats grain. This is a novel approach to predict and assess the level of β-glucan content in oats grain. The model indicated a mean level of β-glucan in HO and NO of 3.56 g/100g and 4.31 g/100 g, respectively, which is within the range of reported values found in the literature. The scenario analysis highlights the importance of agronomic practices such as harvesting date and storage of harvested grains, although they are not as effective as the genotypic selection in effecting β-glucan content. This study also helps to assess the impact of uncertainty in the input parameters and thereby help to identify optimisation techniques.

Table 2. Different simulated scenarios in comparison with baseline model

Model / Scenarios	Input summary of scenario analysis	β-Glucan level in harvested HO (g /100g)	β-Glucan level in harvested NO (g /100g)
Baseline	Baseline model	3.66	4.44
Scenario 1	No fertiliser application	3.55 (-3.1)[a]	4.31 (-3.0)
Scenario 2	Harvesting on physiological maturity	3.79 (3.3)	4.60 (3.4)
Scenario 3	No storage	4.06 (10.7)	4.92 (10.7)

Acknowledgements

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References

Flander, L., Salmenkallio-Marttila, M., Suortti, T., Autio, K., 2007. Optimisation of ingredients and baking process for improved wholemeal oat bread quality. LWT-Food Science and Technology, 40, 860–870.

Food and Drug Administration (FDA), 1997. Final rule for food labelling: Health claims; Oats and coronary heart disease. Federal Regulations, 7, 62, 3584–3681.

Fulcher, G. R., Miller, S. S., 1993. Structure of oat bran and distribution of dietary fibre components. In: Oat bran. Wood, P.J., Eds.; American Association of Cereal Chemists: USA.

Maier, S. M., Turner, N. D., Lupton, J. R., 2000. Serum lipids in hypercholesterolemic men and women consuming oat bran and amaranth product. Cereal Chemistry,77, 297–302.

DEFRA., 2003. Department for Environment, Food and Rural Affairs, Statistics on Raw Materials Usage in the Production of Animal Feedstuffs by GB Retail Compounders, http://www.defra.gov.uk/esg/Excel/hstcomps.xls

RISK PROFILE: SALMONELLA IN POULTRY FOR THE UNITED ARAB EMIRATES

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Abstract
Codex defined a risk profile as the description of the food safety problem and its context developed for the purpose of identifying those elements of a hazard or risk that are relevant to risk management decisions. The UAE poultry production in 2005 is approximately 34,800 tons. In 2006 The United Arab Emirates imported 436,259 kg of life poultry and more than 187,000,000 kg of frozen poultry from around the world. This paper details a risk profile that was carried out for Salmonella spp arising from the consumption of poultry in the UAE. The risk profile developed a simple two way classification to identify the high risk categories arising from local production and from imports from neighbouring countries. Arising from this classification, national surveillance strategies should be prioritised to address these high risk groups.

Introduction
Any risk profile usually covers the production-to-consumption food. It consists of the hazard, exposure to the hazard, adverse health effects, public health surveillance information, control measures, and other information relevant to risk management decision-making (Kiermeier, 2005).

Salmonella spp. is one of the major and most common causes of foodborne illness worldwide. The incidence of foodborne infections caused by Salmonella spp. has increased dramatically during the past few years. In the U.S.A., salmonellosis is estimated to affect 1.4 million people each year, and 95% of the cases are foodborne. (Tunung, Chai, Usha, Lesley, Cheah, Patrick, Farinazleen, Fatimah, Malakar and Son, 2007). In UAE, the Dubai Health Authority reported there were 54 cases of Salmonella food poisoning, comparing 0.8 percent of all reported infectious disease cases in 2006 (UAE Interact, 2009). Over 2500 Salmonella enterica serotypes are recognized and all are capable of producing disease in humans (WHO/FAO, 2002).

The main objectives of this paper are (I) to make a risk profile of Salmonella in poultry products that are produced and imported to UAE. (ii) Review all food laws / regulations that are issued by the Abu Dhabi Food Control Authority and make any recommendations for the control and statistical sampling of poultry imports.

Materials and Methods

Data in relation to the volume of poultry products produced and imported into the UAE was assembled from various sources. With regard to regulations, this paper depended on Abu Dhabi Food Control Authority (ADFCA) food law No.2 (2008), ADFCA regulation No.2 (2008) risk-based approach for the control of imported foods via borders of the Emirate of Abu Dhabi, ADFCA regulation No.4 (2008) documents and health certificates for imported food, and ADFCA regulation No.5 (2008) Food Sampling for Official Control. In addition, this paper relies on UAE Standard No. 322 / 1995 of Cold Chicken and UAE Standard No. 986 / 1999 of Frozen Chicken.

Micro data were assembling from following studies: Salmonella in poultry meat Canary Islands, Spain. This study follows ISO 6579 recommendation to analyze for Salmonella in chicken samples. Salmonella was isolated from 16.5% of all chicken samples. With regard to country of origin, the isolation total percentages were 15.2% for France, and 7.4% for the United States (Hernandez, Sierra, Rodriguez-Alvarez, Torres, Arevalo, Calvo, and Arias, 2005).

In a separate study, a survey took place in Washington, D.C. area from June 1999 to July 2000. A total of 825 samples of retail raw meats (chicken, turkey, pork, and beef) were tested for the presence of *Escherichia coli* and *Salmonella*. Only 25 (3.0%) of the retail meat samples tested were positive for *Salmonella* (Zhao, Ge, Villena,

Sudler, Yeh, Zhao, White, Wagner and Meng 2001).

Results and Discussion

Table 1 Production of Poultry Meat in the UAE in (1000 tons)

Actual 2005		Expected 2015	
Qty	Per Capita (kg)	Qty	Per Capita (kg)
34.8	7.95	130.23	22.87

Source: Freiji (2005)

It is clear from table 1 that poultry industries in UAE produced 34,800 tons in 2005and expected to be 130,230 tons by 2015.

Table 2: Imports of fresh and frozen poultry meat (2006)

Country	Qty kg	Qty %
BRAZIL	146,373,499	77.98%
SAUDI ARABIA	11,422,608	6.09%
FRANCE	7,339,798	3.91%
USA	6,990,922	3.72%

Source: Radi (2008)

The highest four countries that exports frozen and fresh poultry to UAE are illustrated in table 2. 78% of imported frozen poultry was only from Brazil, followed by Saudi Arabia (6.09%) then by France and USA 3.91% and 3.72% respectively. Brazil, France and USA imported only frozen poultry and products, while Saudi Arabia imported fresh and frozen poultry and products.

With regard to consumption of poultry meat, it is clear from table 3 that UAE people consumed 184,530 tons in 2005 and predicted to be 263,860 by 2015.

Table 3 Poultry Meat Consumption in the UAE in (1000 tons)

Actual 2005		Expected 2015	
Qty	Per Capita (kg)	Qty	Per Capita (kg)
184.53	42.13	263.86	46.34

Source: Freiji (2005)

Production and consumption of poultry in UAE is increasing due to the following factors: Rise of local population; health and food safety concerns with red meats due to international problems with BSE; Foot and Mouth disease, dioxin, cholesterol and related cardiac problems; compared to red meats and fish its lower cost; expansion of the Hotel Restaurant and Institutional (HRI) sector; and increase in the transit population, a population segment that is expected to continue on its current expansion path for the next several years.

The year 2007 was the last survey done by Abu Dhabi Food Authority to assess the level of Salmonella contamination in raw fresh and frozen chicken that produced in
UAE and imported to UAE (see table 4).

Table 4 Salmonella test of frozen and fresh chicken, 2007

Origin	Total No. of Samples	Fit	UN-Fit	% Un-Fit
UAE (Fresh)	8	7	1	12.5
S.ARABIA (Fresh)	64	60	4	6.25
BRAZIL (Frozen)	33	33	0	0
FARANCE (Frozen)	14	14	0	0

Source: ADFCA, 2007

The table shown all samples from Brazil and France is negative for salmonella contamination. Only UAE and Saudi Arabia samples are positive for salmonella 12.5% and 6.25% respectively. All positive salmonella samples are fresh products.

Figure 1 risk level of imported and local poultry products

	Frozen	Fresh
Imported	Brazil S. Arabia France USA (Low Risk)	S. Arabia (High Risk)
Local		UAE (High Risk)

Figure 1 summaries the risk level of imported and local produce products. As a result of this figure there is some recommendation. Firstly, UAE food control bodies should make more approach for fresh poultry products that imported from Saudi Arabia and that produce from local industries because of high risk level. On other hand, frozen products should easy access to local market because they are low risk. Secondly, The current inspection procedures of imported food should add Electronic Pre- notification step, in this stage ADFCA or any food control bodies in UAE should check the history of the company or any new international information if there is any past violation; ban information infectious disease such as Newcastle disease, Avian influenza or any epidemic. In addition, checking the presence of any food hygiene certificates such as HACCP to sure safety of the product. Furthermore, ADFCA should implement normal, tighten and reduce inspection when the product entry the borders and sampling procedures should based on the risk level of the products (see Figure 2*)*.

Conclusion

From above data that the United Arab Emirates production rate and consumption rate of poultry products is increased; therefore, the risk of food consumption is increased. So food inspection bodies' needs to change their traditional inspection systems by risk based systems. Regards to statistical sampling of poultry imports, there will be further research focusing on implementing new sampling procedure.

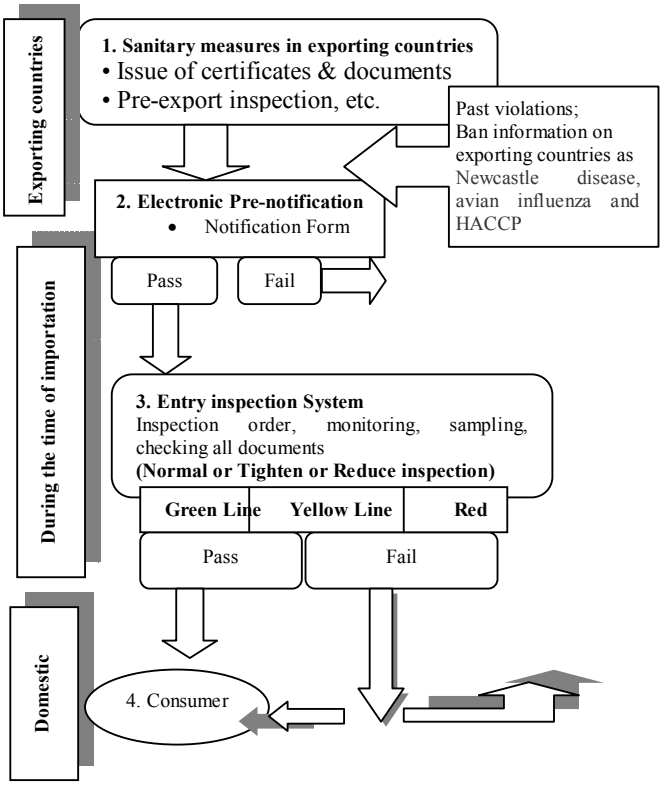

Figure 2 Flow chart of imported process of chicken products to the Abu Dhabi

Source: Results of Monitoring and Guidance Based on the Imported, Foods Monitoring and Guidance Plan for FY (2005)

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References

Abu Dhabi Food Authority (ADFCA) (2007) Annually Report Laboratories Department, Microbiology Section.

Abu Dhabi Food Authority (ADFCA) (2008) Food Law No. 2. Accessed from http://www.adfca.ae/en/Legislations/Default.htm

Abu Dhabi Food Authority (ADFCA) (2008) Regulations No. 2 Risk-based approach for the control of Imported Foods via Borders of the Emirate of Abu Dhabi. Accessed from http://www.adfca.ae/en/Legislations/Default.htm

Abu Dhabi Food Authority (ADFCA) (2008) Regulation No 4 Documents and Health certificates for imported food. Accessed from http://www.adfca.ae/en/Legislations/Default.htm

Abu Dhabi Food Authority (ADFCA) (2008) Regulation No. 5 Food Sampling for Official Control. Accessed from http://www.adfca.ae/en/Legislations/Default.htm

Emirates Standardization and Metrology Authority (ESMA) (1995) UAE Standard No. 322 Cold Chicken. Accessed from http://www.esma.ae/

Emirates Standardization and Metrology Authority (ESMA) (1999) UAE Standard number 986 / 1999 Frozen Chicken. Accessed from http://www.esma.ae/

Freiji, M. (2007) the Poultry Industry in the Arab World Present & Future, FAO

Hernandez, T., Sierra, A., Rodriguez-Alvarez, C., Torres, A., Arevalo, M. P., Calvo, M., and Arias, A. (2005) Research Note: *Salmonella enterica* Serotypes Isolated from Imported Frozen Chicken Meat in the Canary Islands. Journal of Food Protection. Volume 68, Issue 12: 2702-2706

Kiermeier, A. (2005) Food Safety Risk Profile Service. Accessed from http://www.sardi.sa.gov.au/__data/assets/pdf_file/0004/45049/CS_Risk_Profile.pdf

Radi, M.S (2008) Current Situation and Future Prediction of Commercial Exchange of Live Animals, Meats and Eggs in UAE. UAE Ministry of Environment and Water Report
.

Results of Monitoring and Guidance Based on the Imported, Foods Monitoring and Guidance Plan for FY (2005). Accessed from http://www.mhlw.go.jp/english/topics/importedfoods/dl/6-4.pdf

UAE Interact (2009) Tainted peanut butter batch not available in UAE. Accessed from http://www.uaeinteract.com

WHO/FAO (2006) Food Safety Risk Analysis A Guide for National Food Safety Authorities Paper 87, ISSN 0254-4725

WHO / FAO (2002) Risk assessments of Salmonella in eggs and broiler chickens. Dennis Kunkel Microscopy, Inc. Accessed from http://www.fao.org/docrep/005/y4392e/y4392e00.htm

Zhao, C., Villena, B. G. J. D., Sudler, R. Yeh, E., Zhao, S., White, D.G., Wagner, D., and Meng, J. (2001) Prevalence of Campylobacter spp., Escherichia coli, and Salmonella Serovars in Retail Chicken, Turkey, Pork, and Beef from the Greater Washington, D.C., Area, AEM p. 5431-5436, Vol. 67, No. 12

IMPLEMENTATION OF SAMPLING PLAN AND APPLICATION OF MICROBIOLOGICAL CRITERIA FOR *CRONOBACTER SAKAZAKII* IN IRELAND

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Abstract

The Microbiological Criteria (MC) is a set of parameters used to determine whether a specific lot of food is acceptable or not. These parameters are the microbial test protocol and its sensitivity, the confidence level that an unacceptable lot will be detected, the number of samples to be taken and the number of positive samples that are allowed before rejecting the lot. Criteria applied to *Cronobacter sakazakii* (absence of the organism in 10 g) are based on two-class sampling plans. The probabilities of "accepting or rejecting the lot" were calculated based on two contamination levels of *C. sakazakii* in PIF detected by two Surveys carried on in Ireland.

Introduction

Cronobacter sakazakii represents a significant risk to the health of neonates. Although, the organism natural habitat is currently unknown, molecular typing methods have identified PIF as a source and vehicle of neonatal infection.

Published studies in the scientific literature (Muytjens *et al.*, 1988; Nazarowec-White and Farber, 1997; FDA, 2003; Heuvelink *et al*., 2003; Kress *et al*., 2004; Leuschner *et al.*, 2004; Iversen and Forsythe, 2004; Santos, 2006; Kim *et al.*, 2007; Torres-Chavolla *et al.*, 2007) and unpublished studies provided to FAO/WHO in response of a call for data (FAO/WHO, 2006) report the contamination of *C. sakazakii* in PIF with a frequency of 0–92% with cell numbers of between 0.22 and 1.61 CFU/100g in positive batches (Santos, 2006).

The recovery of *C. sakazakii* from numerous locations in powdered milk production facilities (Kandhai *et al.*, 2004a,b), suggests that contamination of the final product occurs via the environment of the processing facility (Drudy *et al.*, 2006a; Mullane *et al.*, 2006).

Although studies have epidemiologically linked contaminated PIF to neonatal infection, no report exists to conclusively link *C. sakazakii* recovered in the manufacturing environment to the final PIF product (Mullane *et al.*, 2007). As Ireland supplies 15% of PIF in the world, monitoring the contamination in the manufacturing environment, along the production chain and in the final product using an appropriate sampling plan represents an important first step in reducing the risk of contaminating PIF product.

The objective of this study is to consider some statistical aspects, as the probability of accepting and rejecting a lot, of two surveys conducted in Ireland to detect the contamination of *C. sakazakii* in PIF.

Materials and Methods

The introduction of legislative microbiological criteria for foods (Official J L338 (2005) 1) has increased the exposure of enforcement and industrial laboratories to the need to test multiple food samples for organisms, such as *C. sakazakii* in PIF. For this organism the attributes sampling scheme is adopted, where the sample results are qualitative (sample indicates presence or absence) and the lot is rejected if any samples are positive.

Recently studies on monitoring of *C. sakazakii* were conducted in Ireland and reported 7 positives in 276 samples and no positives in 719 samples (Mullane *et al.*, 2007; FSAI, 2006). True prevalence is estimated (2.9 and 0.14% for the first and second survey respectively) from apparent prevalence using the Bayesian approach based on beta (1, 1) and assuming the microbiological analyses without error,

thus considering sensitivity and specificity equal to 1 (Fig 1).

The assumptions and the method used to calculate the probability of accepting or rejecting a lot are the ones adopted by WHO risk assessment model for *Enterobacter sakazakii* in powder infant formula (http://www.mramodels.org/esakmodel/ESAKRAModelWizard.aspx) and full described in "Overview of a Risk Assessment model for *Enterobacter Sakazakii* in Powder Infant Formula (Paoli &Hartnett, 2006).

The level of contamination between and within lots is assumed to be log-normally distributed, while the distribution of the organism in the sample follows a Poisson process, with the intensity given by the random lognormal concentration where the sample is taken. Thus, the number of organisms (and any other statistics of the sampling) is derived from the Poisson Lognormal distribution (PLN).

The probability of obtaining at least one positive result can be calculated from $P > 0 = 1- \exp(-C \times s)$ given a sample size of s grams and a concentration in the powder of C per gram. Using this, the concentration in the product can be estimated from C= ln [1- P>0] / S where C is the concentration (per gram), $P > 0$ is the probability of recording a positive sample, and s is the samples size (grams). In this study lots were simulated using the Montecarlo software @Risk and tested against the microbiological criteria established in the EC 2073/2005 (absence in 10 g, 30 samples per unit). Calculation of rejection rates requires three measurements: the mean log concentration (MLC) of *C. sakazakii* across all lots of PIF (cfu/g), the between-lot standard deviation (σb) across all PIF lots, and the within-lot standard deviation (σw) for individual PIF lots. MLC values of -2.53 and -3.85 log (cfu/g) are calculated for the first and second survey respectively. Furthermore, values ranging from 0.4 to 2 for the between lot variability and values from 0.02 to 2.2 for the within lot variability are adopted and simulated.

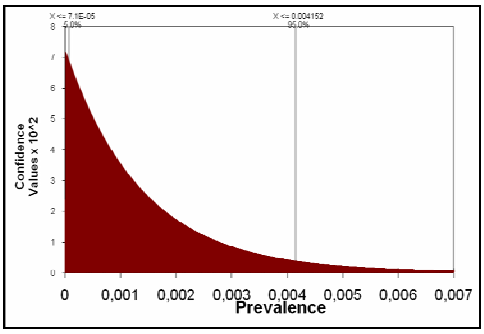

Fig. 1 Uncertainty around prevalence data 0:719, Mean 0.14% (FSAI, 2006).

Results and Discussion

The probabilities of lots rejected calculated are 58% and 4.1% for the first and second survey respectively.

It is apparent from the results of the simulations (Fig. 2), that increases in the within lot variability for the high positive proportion of 2.9% the probability of rejecting the lot decreases because more chances are that some positive samples are not picked. When the within lot variability decreases, the CFU's among units are more uniform, therefore the probability of rejecting the lot increases. In contrast, decreasing the between lot variability, the probability of rejecting the lot also decreases. When manufacturers attempt to decrease their rejection rates, initial gains may be achieved by reducing the variability between lots, but as the variability between lots decreases, more meaningful reduction in rejection rates will require reducing the mean log concentrations of the lots through the implementation of new practices or technologies.

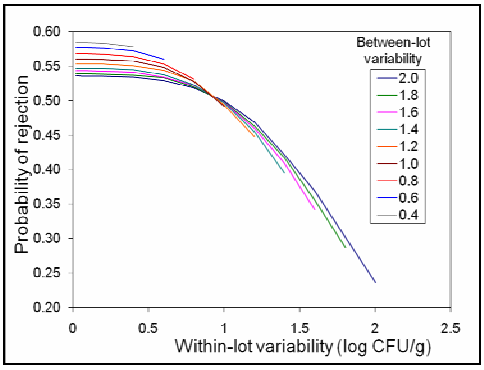

Figure 2. Probability of rejecting a lot with prevalence 2.9%

The results obtained by the two surveys can't be directly compared and some aspects of the sampling and analytical methods used have to be taken into consideration.
Different isolation methods are used to recovery *C. sakazakii* in these two surveys: the mLST and AES method (ISO/DTS 22964), for the first and second survey respectively, and a discrepancies between these and other techniques used to detect *C. sakazakii* have been reported (Iversen &Forsythe, 2007).

Conclusions

Criteria based on presence or absence of *C. sakazakii* are affected not only by the distribution of the organism within the PIF but also by the adequacy, or otherwise, of the test procedures. Hence, there is necessity to use accredited methods with the level of sensitivity and specificity suitable for the intended purpose.
Even then, tests giving negative results on a number of individual replicate samples do not guarantee freedom from the *C. sakazakii*; they merely indicate that the probability for occurrence of the organism in the 'lot' is within certain tolerances. The tolerance will be dependent upon the number of samples tested and, of course, on the efficiency of the method used. However, in the same way that a scheme showing apparent absence of specific organisms cannot guarantee total absence of the organisms from the product, the detection of one or more positive samples could also arise by chance. Hence, PIF products of equivalent quality could be rejected on one occasion yet be accepted on another occasion if only a small number of samples are tested.
The level of uncertainty attributable to sampling is poorly documented. For chemical analyses on foods the uncertainty due to sampling is greater than the measurement uncertainty (Lyn *et al*., 2003) and limited data from Jarvis *et al*. (2007b) indicate that a similar situation may apply to microbiological analyses. Hence, the use of criteria limits that take no account of such variation cannot be considered to be scientifically sound.

References

Commission Regulation (EC) No 2073/2005 (OJ L338, p1, 22/12/2005) of 15 November 2005 on microbiological criteria for foodstuffs http://www.fsai.ie/legislation/food/eu_dos/Food_hygiene/Reg852_2004.pdf

Drudy, D., Mullane, N.R., Quinn, T.,Wall, P.G., Fanning, S., 2006a. *Enterobacter sakazakii*: an emerging pathogen in powdered infant formula. *Clin. Infect. Dis.* 42, 996–1002.

Food and Agriculture Organization-World Health Organization. 2006. *Enterobacter sakazakii* and *Salmonella* in powdered infant formula. Second Risk Assessment Workshop, 16–20 January 2006. WHO, Rome, Italy.

FDA, 2003. FDA field survey of powdered formula manufacturing.

FSAI, 2006. 2nd Trimester National Microbiological Survey 2006 (06NS2): Microbiological Safety Of Dried Infant Formulae and Dried Dietary Foods for Special Medical Purposes Intended for Infants below 6 months of age. http://www.fsai.ie/monitoring_and_enforcement/monitoring/surveillance/national_microbiological_surveillance_2006.aspx?terms=enterobacter+sakazakii

Heuvelink, A.E., Zwartkruis-Nahuis, J.T.M., van der A, H., Wit, B., van Oosterom, R., & de Boer, E. 2003.
Handhavingsactie *Enterobacter sakazakii* in zuigelingenvoeding. Projectnummer: OT 0210 8 p.

Iversen, C., Forsythe, S., 2004. Isolation of *Enterobacter sakazakii* and other Enterobacteriaceae from powdered infant formula milk and related products. *Food Microbiol.* 21, 771–777.

Iversen, C., Forsythe, S., 2007. Comparison of media for the isolation of *Enterobacter sakazakii*. *Applied and Env Microbiol.* 73, 48–52.

Jarvis , B. , Hedges , A.J. , and Corry , J.E.L. 2007. Assessment of measurement uncertainty for quantitative methods of analysis: Comparative assessment of the precision (uncertainty) of bacterial colony counts. *Int. J. Food Microbiol.*, 16, 44 – 51 .

Kandhai, M.C., Reij, M.W., van Puyvelde, K., Guillaume-Gentil, O., Beumer, R.R., van Schothorst, M., 2004a. A new protocol for the

detection of *Enterobacter sakazakii* applied to environmental samples. *J. Food Prot.* 67, 1267–1270.

Kandhai, M.C., Reij, M.W., Gorris, L.G., Guillaume-Gentil, O., van Schothorst, M., 2004b. Occurrence of *Enterobacter sakazakii* in food production environments and households. *Lancet* 363, 39–40.

Kress, C., Estuningsih, E., Hassan, A.A., Akineden, Ö., Schneider, E., Becker, H., & Uslber, E. 2004. Bedeutung und Nachweis von *Enterobacter sakazakii* in Säuglingsnahrung. 45. Arbeitstagung des Arbeitsgebietes "Lebensmittelhygiene" der Deutschen Veterinär-medizinischen Gesellschaft vom 28 September bis 1 Oktober in Garmisch-Partenkirchen, Tagungsbericht.

Leuschner, R.G., Baird, F., Donald, B., & Cox, L.J. 2004. A medium for the presumptive detection of *Enterobacter sakazakii* in infant formula. *Food Microbiology*, 21: 527-533.

Lyn , J.A. , Ramsey, M.H. , and Wood, R., 2003. Multi-analyte optimisation of uncertainty in infant food analysis. *Analyst*, 128, 379 – 388.

Mullane, N.R., Drudy, R., Whyte, P.,O'Mahony, M., Scannell, A.G.M., Wall, P.G., Fanning, S., 2006. *Enterobacter sakazakii*: biological properties and significance in dried infant milk formula (IMF) powder. *Int. J. Dairy Technol.* 59, 102–111.

Mullane, N.R., Whyte, P., Wall, P.G., Quinn, T., Fanning, S., 2007. Application of pulsed-field gel electrophoresis to characterise and trace the prevalence of *Enterobacter sakazakii* in an infant formula processing facility. *Int. J. Food Microbiol*. 116, 73-81.

Muytjens, H.L., Roelofs-Willemse, H., Jaspar, G.H., 1988. Quality of powdered substitutes for breast milk with regard to members of the family Enterobacteriaceae. *J. Clin. Microbiol*. 26, 743–746.

Nazarowec-White, M., Farber, J.M., 1997. *Enterobacter sakazakii*: a review. *Int. J. Food Microbiol*. 34, 103–113.

Santos, R. 2006. Determination of *Enterobacter sakazakii* in powdered infant formula, reconstituted and utensils used in baby's bottle preparation. Poster P1-38. IAFP (International Association for Food Protection), Calgary, Canada, 13-16 Aug. 2006.

Torres-Chavolla, E., Ramírez-Cerda, E., Gutiérrez-Rojo, R., 2007. Isolation and identification of *Enterobacter sakazakii* in infant milk formulas. *Foodborne Path and Disese,* vol 4, n 2.

WHO, 2006. Risk assessment model for *Enterobacter Sakazakii* in powder infant formula http://www.mramodels.org/esakmodel/ESAKRAModelWizard.aspx

Confirmation of food origin claims by Fourier transform infrared spectroscopy and chemometrics: Olive oil from Liguria

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Abstract
The aim of this study was to explore the potential of Fourier transform infrared spectroscopy and chemometrics for confirming the geographic origin of olive oil from Liguria (northern Italy). Authentic virgin olive oil samples (n = 913) from three harvests were collected from Italy, France, Spain, Greece, Cyprus and Turkey - approximately one-quarter of all samples originated in Liguria. Spectra were recorded at room temperature; the analytical challenge was to confirm that an oil which claimed to be from Liguria originated there. Derivative and standard normal variate data pre-treatments were applied to the recorded spectra which were subsequently analysed by principal component analysis partial least squares regression analysis. Prediction models created using samples from all three harvests had sensitivities and selectivities of approximately 0.80.

Introduction
Virgin olive oils are defined as oils obtained from the fruit of the olive tree solely by mechanical or other physical means under conditions that do not lead to alterations in the oil; oils thus labelled must not have undergone any treatment other than washing, decanting, centrifuging and filtration (Codex Alimentarius Commission, 2003). Compared with other edible oils, olive oil is an expensive product typically costing four to five times as much as common edible oils (European Commission); this high market price is due to its highly-prized organoleptic and nutritional properties. The taste and quality of virgin olive oils from different geographical origins varies as a consequence of distinct local agricultural traditions such as olive variety cultivated, oil extraction technique used and oil blending practice (European Commission, 2003). In order to protect the good name of a product, the European Community has set out regulations on the protection of claims relating to geographic indications and designations of origin for agricultural products and foodstuffs (Barjolle and Sylvander, 2002, European Commission, 2006). This means that packaged virgin olive oils produced in defined oil-producing regions may use a protected designation of origin (PDO) or protected geographical indication (PGI) on their labels. Geographic origin is therefore an essential element of olive oil authenticity and food processors, retailers, enforcement agencies and consumers need an independent mechanism to confirm that any given virgin olive oil sample which claims PDO or PGI status actually complies with all relevant specifications (European Commission, 2004).
The aim of this study was to investigate the potential of using FT-IR spectroscopy and chemometrics to confirm the origin of authentic Ligurian extra virgin olive oils using a large set of 913 extra virgin olive oils collected over three harvest periods.

Materials and Methods
Samples
Authentic virgin olive oil samples (n = 913) sourced in Italy, France, Spain, Greece, Cyprus and Turkey were collected from reliable sources soon after olive harvesting over three harvest seasons (2004/2005, 2005/2006, 2006/2007). Immediately after collection, samples were placed in the dark at 4 ^{o}C to minimise any risk of deterioration. After each harvest, oil samples were accumulated at a single location (JRC, Ispra, Italy) and forwarded to Ashtown Food Research Centre by air. Almost one quarter of all samples (n = 210) were from the Liguria region in northern Italy.

Spectral collection took place within 6 months of sample collection *i.e*. FT-IR spectral collection was carried out on a separate occasion for samples from each harvest. Samples were stored in the dark at 4 °C in head space or simple screw cap glass vials in batches of 16 samples from the same region. Three batches were selected at random, removed from chilled storage and placed in a water bath at 25 °C for one hour prior to spectral collection on each measurement day.

Instrumentation

FT-IR spectra were collected on a BIO-RAD Excalibur series FTS 3000 spectrometer (Analytica Ltd., Dublin, Ireland). Instrument control and spectral collection were performed using WIN-IR Pro (v. 3.0) software. Samples were applied to an in-compartment benchmark attenuated total reflectance (ATR) trough plate using a 45 º germanium crystal with 11 internal reflections (Specac Ltd., Kent, UK). One hundred and twenty-eight scans were co-added at a nominal resolution of 4 cm^{-1} with single beam spectra of each sample being collected and ratioed against a background of air. Spectra were recorded over the frequency range 600-4000 cm^{-1}.

Between samples, the ATR crystal was cleaned with Triton X-100 solution (1 % w/w), rinsed with distilled water and dried with soft tissue. All spectra were recorded at room temperature (21 ± 5 ^{o}C) without any nitrogen purge of the sample compartment.

Statistical analysis

Means of the 128 co-added scans for each sample were used for data analysis. Spectra were exported from WIN-IR Pro as GRAMS files (ThermoGalactic, Salem, USA) and imported directly into The Unscrambler (v9.7; CAMO A/S, Oslo, Norway). Data pre-treatments examined were (i) standard normal variate (SNV) (Barnes et al., 1989) and (ii) first and second derivatives using a quadratic Savitzky - Golay method and segment sizes between 5 and 21 datapoints (Savitzky and Golay, 1964). Principal component analysis (PCA) (Martens and Næs, 1991) was performed using The Unscrambler on the entire sample set for preliminary dataset examination.

Partial least squares discriminant analysis (PLS-DA) optimised by leave-one-out cross validation (Roussel et al., 2003) was used to discriminate between Ligurian and non-Ligurian olive oils. Discriminant regression models were created and validated using separate calibration and validation sample sets. Dummy Y-variables were used when creating models; a sample was assigned a value of 0 if it was from Liguria and 1 otherwise. PLS models thus developed were used to predict the value of the Y-variable for each validation sample; given the values of the dummy Y-variables used, an empirical and not entirely arbitrary value of 0.5 was used as a cut-off for identity confirmation with oils with predicted Y-values <0.5 deemed to be from Liguria. Spectra with and without pre-treatments were used to create PLS models. Martens' Uncertainty Test (Martens and Martens, 2000) was used to identify those variables of greatest importance in model development; these variables were then used exclusively to create new models and the prediction procedure was repeated.

Data analysis was done using two approaches. The first approach involved the application of PLS-DA to each of the three harvests individually. In each harvest season, the calibration set comprised two thirds of the Ligurian samples selected at random and an equal number of randomly-chosen non-Ligurian olive oils. The validation set was made up of the remaining samples from that harvest. In the second approach a PLS-DA was performed which included samples from all three harvests in both the calibration and validation sets.

Results and Discussion

PCA

A principal component analysis was performed on the complete frequency range of raw spectral data in. Principal components 1 to 5 accounted for 59, 24, 9, 3 and 1 % of the total variance in the spectral data set respectively. Four oil samples appear to account for a significant amount of this variance as evidenced by

their location at some distance from the main cluster of samples in the PC1 *versus* PC5 scores plot (**Figure 1**). Spectra of all samples (*n*=913) were plotted and three samples showed significant absorption in the region 3000 – 3500 cm^{-1}; absorption in this frequency range is characteristic of water absorption (Stuart, 2004) inferring the presence of water in the samples. A fourth sample exhibited a baseline offset. These atypical spectra originated from the four samples referred to above and, since none of them originated in the geographic region of interest (Liguria), it was decided to leave them out of all further chemometric analyses.

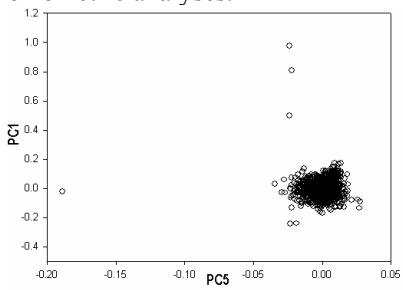

Figure 1. PC 1 *versus* PC 5 from PCA on raw spectral data of all samples (frequency range 3000-2400 cm^{-1} + 2250-700 cm^{-1}).

PLS-DA

The spectra from each harvest were analysed separately in order to determine how well samples from a particular harvest could identify other samples from that same harvest (**Table 1**). The sensitivity of the models for the 2004/2005 harvest ranged between 0.33 and 0.62 while the corresponding selectivities ranged between 0.55 and 0.74. The model with the highest sensitivity (0.62) was created from second derivative spectra with a 9 data point gap and 4 loadings; the selectivity of this model was 0.66. The 2005/2006 harvest had slightly better prediction results than the 2004/2005 harvest with a range of sensitivity values between 0.71 and 0.88 and selectivities between 0.69 and 0.80. The best model had a sensitivity of 0.88 and a selectivity of 0.80. This was based on first derivative spectra with a 13 datapoint gap and 8 loadings. The figures for 2006/2007 were similar to those for 2005/2006. The sensitivity range lay between 0.65 and 0.91 and the selectivity range was between 0.58 and 0.78. The sensitivity of the best model for the 2006/2007 was 0.91 and the corresponding selectivity was 0.77; this model was created using first derivative data with a 21 datapoint gap and involved 7 loadings. Models from one harvest were used to predict the identity of samples from another harvest and when sensitivity was high, selectivity was low and vice versa. These models (results not shown) classified the majority of the samples as being from the one class, (Ligurian or non-Ligurian). The high or low selectivities varied according to the pre-treatment applied so results based on the same calibration and validation samples were inconsistent.

Table 1. PLS predictions (frequency range 3000-2400 cm^{-1} + 2250-700 cm^{-1}) for each harvest

	2004/2005			2005/2006			2006/2007		
Pre-treatment	#L[a]	Sensitivity	Selectivity	#L[a]	Sensitivity	Selectivity	#L[a]	Sensitivity	Selectivity
Raw data	4	0.48	0.59	9	0.85	0.75	7	0.74	0.71
1st derivative									
5 point gap	4	0.57	0.68	5	0.81	0.76	3	0.74	0.73
9 point gap	5	0.43	0.72	5	0.71	0.72	6	0.74	0.70
13 point gap	2	0.57	0.55	8	0.88	0.80	8	0.78	0.77
21 point gap	3	0.57	0.59	10	0.85	0.74	7	0.91	0.77
2nd derivative									
5 point gap	6	0.33	0.71	5	0.85	0.71	3	0.70	0.60
9 point gap	4	0.62	0.66	5	0.77	0.75	7	0.65	0.58
13 point gap	4	0.43	0.67	5	0.77	0.74	8	0.70	0.64
21 point gap	4	0.52	0.64	6	0.85	0.69	11	0.70	0.71
SNV	7	0.48	0.74	9	0.85	0.70	9	0.78	0.78

[a] Number of PLS Loadings

Table 2. Summary of PLS prediction results for samples from three combined harvests

Pre-treatment	# L[b]	Sensitivity	Selectivity
None	11	0.74	0.69
1st derivative			
5 point gap	10	0.73	0.75
9 point gap	12	0.79	0.76
13 point gap	15	0.79	0.78
21 point gap	14	0.71	0.77
2nd derivative			
5 point gap	3	0.59	0.62
9 point gap	3	0.67	0.70
13 point gap	13	0.78	0.73
21 point gap	15	0.75	0.75
SNV	11	0.70	0.72

[b] Number of PLS loadings

It is unlikely that samples from a particular year's harvest will contain all possible variance representative of samples from Liguria so calibration models consisting of Ligurian samples (n = 140) and non-Ligurian samples (n = 140) from the three harvests were used to predict the origin of a separate validation set comprising all remaining samples. Results for this analysis can be seen in **Table 2**. Sensitivities were in the range 0.59 to 0.79 and selectivities spanned 0.62 to 0.78 for models developed using frequencies 3000-2400cm^{-1}+2250-700cm^{-1}.

Conclusions

This study demonstrates the potential of FT-IR spectroscopy with ATR sampling and chemometrics to discriminate between Ligurian and non-Ligurian olive oils from three harvests. The most successful chemometric models (sensitivity and selectivity~0.80) were those derived from datasets which contained samples from three harvest seasons. When models created using samples from one or even two harvests were used to classify samples from a different harvest, the models were unsuccessful. In most cases, models which had high sensitivities had low corresponding selectivities and where selectivities were high, sensitivities were low. A 20 % possibility of a model rejecting a Ligurian sample or falsely accepting a non-Ligurian sample means that this technique may not be a commercially viable stand-alone technique for confirming geographic origin, but the speed and low cost at which measurements can be made suggest that it could certainly be used as a screening technique.

References

Barjolle, D. & Sylvander, B. (2002) Some factors of success for origin labelled products in agri-food supply chains in Europe: Market, Internal Resources and Institutions. *Economies et Société, Cahiers de l'ISMEA, Série Développement Agroalimentaire, N°25, septembre-octobre.*

Barnes, R. J., Dhanoa, M. S. & Lister, S. J. (1989) Standard Normal Variate Transformation and De-trending of Near-Infrared Diffuse Reflectance Spectra. *Appl. Spectrosc.,* 43**,** 772-777.

Codex Alimentarius Commission (2003) Standard for olive oils and olive pomace oils. *Codex Stan 33,* 8.

European Commission Working paper of the Directorate-General for Agriculture: The olive oil and table olives sector.

European Commission (2003) The olive oil sector in the European Union.

European Commission (2004) Regulation (EC) No 882/2004 of the European Parliament and of the Council of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules. *Official Journal of the European Union,* L165**,** 1-141.

European Commission (2006) Council Regulation (EC) No 510/2006 of 20 March 2006 on the protection of geographical indication and designations of origin for agricultural products and foodstuffs. *Official Journal of the European Union,* L 93**,** 12-25.

Martens, H. & Martens, M. (2000) Modified Jack-knife estimation of parameter uncertainty in bilinear modelling by partial least squares regression (PLSR). *Food Quality and Preference,* 11**,** 5-16.

Martens, H. & Næs, T. (1991) *Multivariate Calibration,* New York, John Wiley and Sons Ltd.

Roussel, S., Bellon-Maurel, V., Roger, J.-M. & Grenier, P. (2003) Authenticating white grape must variety with classification models based on aroma sensors, FT-IR and UV spectrometry. *Journal of Food Engineering,* 60**,** 407-419.

Savitzky, A. & Golay, M. J. E. (1964) Smoothing and Differentiation of Data by Simplified Least Squares Procedures. *Anal. Chem.,* 36**,** 1627-1639.

Stuart, B. (2004) *Infrared Spectroscopy: Fundamentals and Applications,* West Sussex, John Wiley & Sons Ltd.

Evaluation of On-line NIR Sensor for Monitoring Curd Moisture Content and Whey Volume during Syneresis

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Abstract

An on-line NIR sensor was used to monitor the course of syneresis during cheese-making with the purpose of developing linear models for predicting syneresis indices, namely curd moisture content, $\boldsymbol{M_c}$, and whey volume $\boldsymbol{Y_w}$. Three series of trials were carried out in an 11 L cheese vat using recombined whole milk. Robust models were developed with an on-line optical sensor for predicting curd moisture content and volume of whey using any of the techniques investigated. The most parsimonious technique for predicting $\boldsymbol{M_c}$ was single wavelength NIR in conjunction with other compositional and technology parameters.

Introduction

Accurate on-line measurement is useful in predictive control in cheese manufacture. Developments in near infrared (NIR) technology can be helpful in monitoring the degree of syneresis in the cheese vat through measuring parameters related to syneresis such as yield of whey, fat, protein and solids in whey and curd moisture, and this technology can be miniaturised to work in the form of on-line sensors. A number of authors have studied the development of near-infrared (NIR) sensors for on-line monitoring of composition of milk, whey or curd (moisture, fat, solids and protein) under different experimental conditions, i.e. pH, temperature, curd stirring speed, calcium chloride, cutting intensity and using different technology, i.e. cheese vat, cutting system, NIR sensor (Castillo et al., 2005; Fagan et al., 2007a, b; Everard et al., 2008; Mateo et al., 2009a).

However, the present study undertook a comparison exercise on the use of an on-line NIR sensor as a tool for predicting syneresis indices during cheese-making.

The objective of this study was to develop linear models for key syneresis indices, i.e. curd moisture content and volume of whey using as sensing techniques a broad spectrum or a single wavelength (980 nm) either alone or in conjunction with other compositional and technology parameters in different experiments for comparison.

Materials and Methods

Three experimental designs were carried out

Three curd stirring speeds and 3 cutting programmes were used to carry out Experiment 1 as described in Mateo et al. (2009a). However, three milk fat levels and three gel firmness levels at cutting were examined to undertake Experiment 2 as described in Mateo et al. (2008); Mateo et al. (2009b). Experiment 3 was carried out using a randomised factorial design with two experimental factors such as milk protein level ($\boldsymbol{PL_m}$) and fat:protein ratio ($\boldsymbol{F}$:$\boldsymbol{PL_m}$). The levels of $\boldsymbol{PL_m}$ were 3.3 and 3.7 g/100 g, while the levels of $\boldsymbol{F}$:$\boldsymbol{PL_m}$ were 0.3, 0.7 and 1.1, giving a total of 24 trials.

Milk preparation
The milk in Experiments 1 and 2 was recombined as described in Mateo et al. (2009a,b). However, the milk in Experiment 3 was recombined from low-heat skim milk powder (Teagasc, Co. Cork, Ireland), distilled water and cream (Dairygold, Co. Cork, Ireland) at 42 ± 0.1 °C while being stirred at 44 rpm. The control of temperature and the cooling of the milk were carried out as described in Mateo et al. (2009a,b).

Milk coagulation, cutting time and gel cutting procedure
The milk in Experiments 1 and 2 was clotted as described in Mateo et al. (2009a,b). However in Experiment 3, on the day of analysis calcium chloride at 2.04 mM was added to the milk. pH was adjusted to 6.7 using HCl (1 M) at 20 ± 0.1°C, and then the milk was heated to 32 ± 0.1 °C.
The following steps, previous and subsequent to cutting the gel, were undertaken as described in Experiments 1 and 2 (Mateo et al., 2009a,b).

Sampling procedure for the curd / whey mixture and measurements of syneresis indices in the three Experiments
In all the Experiments involved in this study, curd and whey samples were removed using a specially designed on-line sampler as described in Mateo et al. (2009a). The curd / whey mixture was separated using a stainless steel sieve and pan (Endecotts Ltd., London, England) with a 75 µm absolute pore size. Curd was removed for curd moisture content analysis and the whey for determining volume of whey at 10 min intervals, from t = 5 min up to t = 75 min (i.e. 8 samples). $\boldsymbol{M_c}$ and $\boldsymbol{Y_w}$ were determined by drying in a convection oven at 102 °C overnight, in triplicate.

Syneresis optical measurements
The large field of view sensor used in the present study was installed in the cheese vat wall for monitoring coagulation and syneresis as described in Mateo et al. (2009a). In the three Experiments, the light backscatter signal ($\boldsymbol{R_t}$ and $\boldsymbol{R'}$) used for predicting $\boldsymbol{M_c}$ and $\boldsymbol{Y_w}$ during syneresis was calculated as described in Mateo et al. (2008); Mateo et al. (2009a).

Results and Discussion

Prediction of $\boldsymbol{M_c}$ & $\boldsymbol{Y_w}$ using linear models
$\boldsymbol{M_c}$ and $\boldsymbol{Y_w}$ were predicted using either of the sensing techniques mentioned above. Comparing the $\boldsymbol{M_c}$ models in Table 1, it was observed that there were differences between the fit of models when the same Experiment was used. However, despite using different Experiments no differences between the fit of the models were found, i.e. models 1.1 and 3.2. In terms of standard error of prediction (SEP) and coefficient of correlation (R), either of the sensing techniques used showed similar prediction accuracy for predicting $\boldsymbol{M_c}$. Although, the best two models developed were model 2.1 (SEP = 0.89 % w/w, R = 0.98) and model 3.1 (SEP = 0.77 % w/w, R = 0.96). In both models, 980 nm wavelength in conjunction with other compositional and technology parameters was the most accurate sensing technique.
Comparison the $\boldsymbol{Y_w}$ models in Table 2, some of the models were equivalent when they were carried out using the same Experiment, e.g. 1.4 and 1.5, and even where different Experiments were used, e.g. 1.4 and 2.5. In terms of R, the best $\boldsymbol{Y_w}$ model was model 2.3 (R = 0.92), although, models 1.4 and 2.5 gave a similar coefficient of correlation (R = 0.91 and 0.91, respectively). The most accurate model in terms of SEP was model 3.3 (SEP = 4.45 % w/w). In general, no significance differences were observed in using any of the sensing techniques mentioned.

Table 1. Comparison of predictive models for curd moisture content, M_c, during syneresis in various studies [1]

Model reference [2]	Parameters in model	Range of milk fat level, %, w/w	Sensing Technique	SEP [5] %, w/w	Correlation coefficient, R	Range of response variable	RER	Number of loadings or parameters in model	No. of data-points, N	Reference
1.1	Light backscatter reflection ratio, time after gel cutting, curd stirring speed, milk fat, curd cutting programme	3.5 [4]	980 nm	1.1 [a]	0.90	10.6	9.6	5	200	Mateo et al. (2009a)
1.2	Light backscatter reflection ratio	3.5 [4]	980 nm	1.5 [b]	0.81	10.6	7.1	1	208	Mateo et al. (2009a)
1.3	Principal components of the spectrum (CV) [3]	3.5 [4]	broad spectrum (189 - 1100 nm)	1.3 [c]	0.86	10.6	8.1	9	216	present study
2.1	Time after gel cutting, light backscatter reflection ratio, milk fat level, cutting time	0 - 5	980 nm	0.89 [d]	0.98	15.76	17.71	4	216	present study
2.2	Principal components of the spectrum (CV) [3]	0 - 5	broad spectrum (189 - 1100 nm)	1.6 [b]	0.92	15.76	9.85	6	216	present study
3.1	Light backscatter reflection ratio, time after gel cutting, fat:protein ratio, milk protein level	1.1 – 4.05	980 nm	0.77 [e]	0.96	11.96	15.5	4	192	present study
3.2	Principal components of the spectrum (CV) [3]	1.1 – 4.05	broad spectrum (189 - 1100 nm)	1.18 [a, c]	0.90	11.96	10.1	4	192	present study

Table 2. Comparison of predictive models for volume of whey produced, Y_w, during syneresis in various studies [1]

Model reference [2]	Parameters in model	Range of milk fat level, %, w/w	Sensing Technique	SEP [5] %, w/w	Correlation coefficient, R	Range of response variable	RER	Number of loadings or parameters in model	No. of data-points, N	Reference
1.4	Milk fat, curd cutting programme, light backscatter reflection ratio	3.5 [4]	980 nm	6.1 [a, b]	0.91	73.5	12	3	200	Mateo et al. (2009a)
1.5	Light backscatter reflection ratio	3.5 [4]	980 nm	6.5 [a]	0.89	73.5	11.3	1	208	Mateo et al. (2009a)
1.6	Principal components of the spectrum (CV) [3]	3.5 [4]	broad spectrum (189 - 1100 nm)	6.4 [a]	0.90	73.5	11.5	5	216	present study
2.3	Time after gel cutting, light backscatter reflection ratio, milk fat level	0 - 5	980 nm	5.2 [c]	0.92	60.1	11.6	3	214	present study
2.4	Light backscatter reflection ratio	0 - 5	980 nm	7.6 [d]	0.82	55.9	7.4	1	216	present study
2.5	Principal components of the spectrum (CV) [3]	0 - 5	broad spectrum (189 - 1100 nm)	5.3 [b, c]	0.91	55.9	10.5	5	216	present study
3.3	Light backscatter reflection ratio, time after gel cutting , milk fat	1.1 – 4.05	980 nm	4.45 [e]	0.87	43.6	9.8	3	192	present study
3.4	Principal components of the spectrum (CV) [3]	1.1 – 4.05	broad spectrum (189 - 1100 nm)	4.9 [c, e]	0.83	43.6	8.9	4	192	present study

[1] Each model shown on this table is a regression model applied to one experiment, i.e. Experiment 1, 2 or 3.

[2] Format m.n, where m means the experiment number; n distinguishes between models for the same experiment.

[3] PLS models with cross-validation (CV).

[4] SD = 0.3 %, w/w

[5] The use of a common superscript indicates no difference in fit, as determined by a F-test for equal variance of the residuals.

Conclusions

The comparison between $\boldsymbol{M_c}$ and $\boldsymbol{Y_w}$ models suggests that an on-line NIR sensor was able to predict curd moisture content and volume of whey using any of the sensing techniques mentioned previously. Although, the most parsimonious sensing technique for $\boldsymbol{M_c}$ was 980 nm wavelength in conjunction with other compositional and technology parameters

Future Work

The future work will apply the technology in commercial cheese manufacture involving different cheese recipes (i.e. type of milk, cooking temperatures, pH and time to drain).

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References

Castillo, M., Payne, F.A., & Shea, A.P. (2005). Development of a combined sensor technology for monitoring coagulation and syneresis operations in cheese making. J. Dairy Sci. 88, Suppl. 1, 142.

Everard, C.D., O'Callaghan, D.J., Mateo, M.J., O'Donnell, C.P., Castillo, M., & Payne F.A.. (2008). The use of colour parameters derived from an online fibre-optic sensor to monitor curd syneresis during cheese-making. J. Food Eng. In press.

Fagan, C. C., Castillo, M., Payne, F. A., O'Donnell, C. P., Leedy, M., & O'Callaghan, D. J. (2007a). Novel online sensor technology for continuous monitoring of milk coagulation and whey separation in cheese making. J. Agric. Food Chem. 55(22):8836–8844.

Fagan, C. C., Leedy, M., Castillo, M., Payne, F. A., O'Donnell, C. P., & O'Callaghan, D. J. (2007b). Development of a light scatter sensor technology for on-line monitoring of milk coagulation and whey separation. J. Food Eng. 83(1):61-67.

Mateo, M.J., Everard, C.D., Fagan, C.C. ,O'Donnell, C.P., Castillo, M., Payne, F.A., & O'Callaghan, D.J. (2009). Effect of milk fat concentration and gel firmness on syneresis during curd stirring in cheese-making. Int. Dairy J. 19(4):264-268.

Mateo, M.J., O'Callaghan, D.J., Everard, C.D., Fagan, C.C., Castillo, M., Payne, F.A., & O'Donnell, C.P. (2009). Influence of curd cutting programme and stirring speed on the prediction of syneresis indices in cheese-making using NIR light backscatter. LWT - Food Science and Technology. In press.

Mateo, M.J., O'Callaghan, D.J., Everard, C.D., O'Donnell, C.P., Fagan, C.C., Castillo, M., & Payne, F.A. (2008). Using light backscatter at 980 nm to determine curd moisture content at various milk fat and gel firmness levels in cheese-making. 2008 ASBE Annual International Meeting.

EFFECT OF PACKAGING FILM TYPE ON QUALITY OF WHITE BUTTON MUSHROOMS (AGARICUS BISPORUS) USING HYPERSPECTRAL IMAGING

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Abstract

Hyperspectral imaging is a novel technique that combines conventional imaging and spectroscopy to acquire both spatial and spectral information from an object. It can also be used to extract some intrinsic chemical and molecular information from a product. In this research, a hyperspectral imaging system operating within a spectroscopic range of 400 – 1000 nm was used to investigate the effect of different packaging films on shelf life of *Agaricus bisporus* mushrooms. Mushrooms were placed in plastic trays, and overwrapped in one of four packaging films (PVC, non-perforated PET, perforated PET with big holes (9 mm diameter) and perforated PET with small holes (1 mm diameter) and refrigerated at 4 °C. Average reflectance spectra of different sample groups were obtained from hyperspectral images recorded after 1, 4, 7, 10 and 14 days storage. Weight loss, Hunter L, a, b values and maturity index were also measured. Partial least square regression (PLSR) was used for. It was found that a 4-wavelength PLSR model could be used to satisfactorily predict important quality parameters from the average reflectance spectra.

Introduction

Hyperspectral imaging technology integrates spectroscopy and imaging capabilities of different sensors to estimate spatially localised physical and chemical properties of an object. This is achieved by constructing a 3-dimensional hypercube, containing 2 spatial and one wavelength dimension. The main advantages of this technique are: minimal sample preparation, simultaneous determination of several constituents, estimation of both concentration and distribution of sample components, robust and easy to use instrumentation. Much research has been published on the application of hyperspectral imaging fruits and meat products (Taghizadeh *et al.*2008).

Mushrooms have a short shelf-life of 1-3 days at ambient temperature and 8-10 days under refrigeration conditions (Burton 1989). Appropriate packaging can delay development and senescence of the mushroom. Hyperspectal imaging has shown potential for mushroom quality evaluation and prediction (Gowen *et al.* 2008). **The objective of this study is to investigate the effect of different packaging films on quality of white button mushrooms (Agaricus bisporus) using hyperspectral imaging technique.**

Materials and Methods

Sample preparation
Two hundred and forty mushrooms were placed in 40 plastic trays (6 mushrooms in each tray) and overwrapped in 4 different films (PVC, non-perforated PET (PET_NH), perforated PET with holes of 9 mm in diameter (PET_BH) and perforated PET with holes of 1 mm in diameter (PET_SH). Samples were evaluated at 5 different time points (day 1, 4, 7, 10 and 14 of storage) and at each time point, 2 packages (i.e. 12 mushrooms) of each film type were analysed.

Hyperspectral imaging system
A hyperspectral imaging systems (DV optics) in the Vis-NIR range (400-1000 nm) has been developed to investigate the spectral characteristics of white mushrooms (Agaricus bisporus). The main components of this system are: objective lens, spectrograph, camera, acquisition system, moving table, and illumination via fiber optic line lights (Gowen *et al.* 2008). Hyperspectral images were obtained in the aforementioned wavelength ranges with spectroscopic resolution of 5 nm. The effective resolution of the CCD detector was 580 x 580 pixels by 12 bits. Hyperspectral images of individual mushrooms were obtained at each sampling point. Average reflectance (R) spectra were calculated for each sample. The first replicate constituted the calibration set (120 samples), while the second replicate made up the validation set (120 samples).

Mushroom quality parameters
Weight loss, Maturity index, L, a and b values are considered as important quality parameters for mushroom.

Weight *loss (WL)*
Weight loss of each package during storage was measured using a mass balance and presented as percentage of weight loss compared to initial weight.

Maturity Index (MI)
The maturity index was assigned to mushrooms based on the extent of cap opening on a 7 point scale (Guthrie, 1984).

Colour
Hunter L, a and b values of individual mushrooms at all experimental days were measured using a Minolta Chromameter (CR-400, Minolta Corp., Japan). Three readings of L, a and b values were obtained from different regions of the mushroom cap and averaged for each sample.

Modelling

To study the effect of different packaging films on quality attributes of mushrooms, analysis of variance (ANOVA) was carried out on the measured parameters for different groupings of the data.
PLSR models were developed to investigate the correlation between reflectance values at certain wavelengths and different quality parameters measured for mushroom samples. The developed models were applied to the calibration set of data using *pls* packaging in R using leave-one-out (LOO) cross validation to estimate the optimal model for correlation of quality parameters to the reflectance values. Root mean square error of prediction (RMSEP) and residual predictive deviation (RPD), which is defined as: Standard deviation / RMSEP, were calculated to select the best predictive model.

Results and discussion

Figure 1 and Table 1 show the effect of different packaging films on the measured quality factors over the storage time. Mushrooms overwrapped in PET_BH had the highest WL among the all samples studied. Also, there was a significant difference in WL between samples overwrapped with PET_BH and samples overwrapped with other films. This could be due to the existence of larger holes on the PET_BH film compared with the other ones. Similar results were obtained for maturity index as demonstrated in Figure 1.

Table 1. Analysis of variance for important quality parameters in mushroom

Weight Loss		Mat index		L		a		b	
Group	P	Group	P	Group	P	Group	P	Group	P
Packages	***	Packages	*	Packages	***	Packages	***	Packages	***
Day	***	Day	***	Day	***	Day	***	Day	***
BH and the rest	***	BH and the rest	*	PVC and the rest	***	PVC and the rest	**	NH and the rest	***
BH and PVC	*	PVC and SH_NH	*	NH and PVC	----	NH and PVC	----	NH and PVC	***
PVC and SH_NH	***	SH and NH	----	NH and BH_SH	***	NH and BH_SH	***	PVC and BH_SH	***

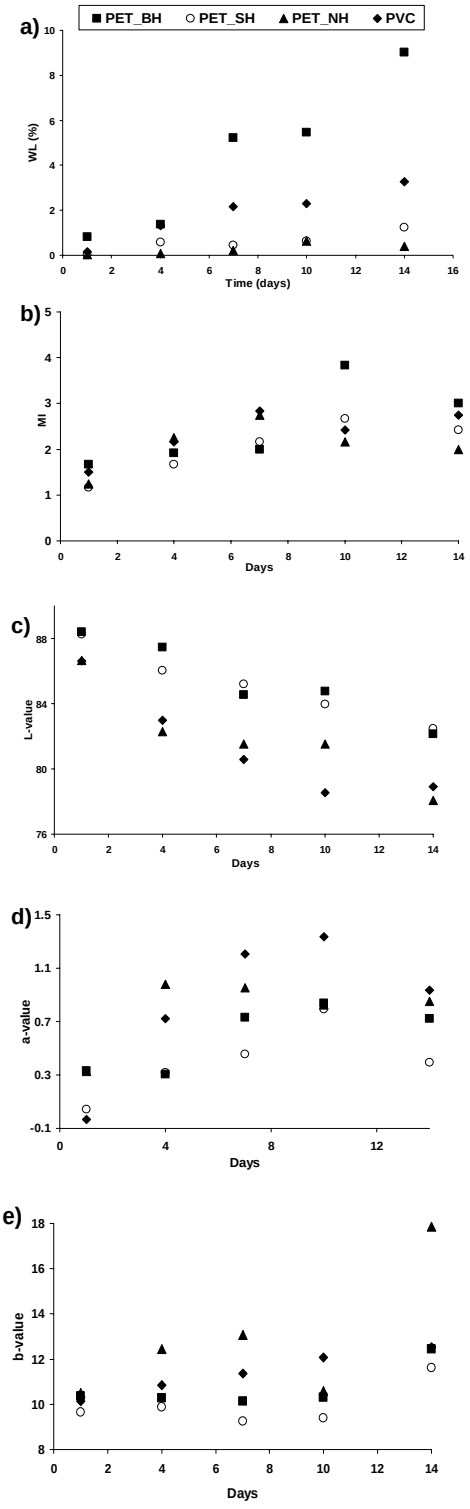

Fig. 1. Effect of different packaging films on a) WL, b) MI, c) L-value, d) a-value and e) b-value

PVC overwrapped samples showed the highest variation in L-value during the storage and their L-value was significantly lower than samples overwrapped with the other films which refers to the poor quality of mushrooms (Figure 1 and Table 1). The lowest a and b values were observed in PVC and PET_NH overwrapped samples, respectively.

Table 2. RPD values for 4-component PLSR models developed for different quality parameters.

Parameter	Calibration set		Validation set	
	RMSEP	RPD	RMSEP	RPD
WL	1.829	1.090	2.706	1.133
MI	0.814	1.189	0.685	1.186
L	1.900	1.877	1.723	2.078
a	0.455	1.435	0.391	1.246
b	0.995	2.159	0.820	2.756

RPD for PLSR models with different numbers of latent variables was calculated for both the calibration and test set (Table 2). It was found that a 4-component PLSR model could perform well with reasonably low RMSEP to correlate the reflectance values of the studied wavelength range to WL, MI, L, a and b values. The best correlation result was obtained for b-value with an RPD of 2.16 and 2.76 for the calibration and validation sets, respectively. The lowest RPD was obtained for WL with the value of 1.09 for the calibration set and 1.13 for the validation set.

Conclusions

Different packaging films showed a significant effect on quality of white button mushrooms during a 2 week storage period. In terms of WL and MI, the greatest deteriorative changes were observed in PET_BH overwrapped samples while the maximum deteriorative changes in L and a values were observed in PVC overwrapped samples. The greatest increase in b-value, which refers to the yellowness of mushrooms and could be a sign of enzymatic browning, was observed in PET_NH overwrapped samples. Generally, PET_SH overwrapped samples showed the best results in term of shelf life during the 2-week period (Figure 2). PLSR models performed well for correlation of reflectance with WL, MI, L, a and b values. Further investigation will be carried out to study the effectiveness of other modelling methods such as PCR and LDA.

Agricultural, Food, and Biological Engineering.

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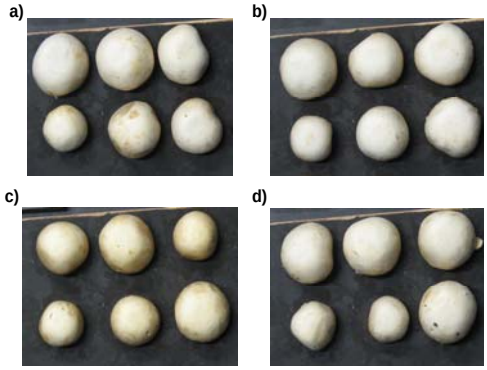

Fig. 2. RGB images of mushrooms overwrapped in a) PET_BH, b) PET_SH, c) PET NH and d) PVC after 2 weeks.

Acknowledgment

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References

Burton, K.S., (1989) The quality and storage life of Agaricus bisporus. Mushroom Science XII. Proceeding of 12th International congress on the Science and Cultivation of edible fungi, Braunschwey, Germany. pp. 683-688.

Gowen, A., O'Donnell, C., Taghizadeh, M., Cullen, P.J., Downey, G. (2008) Hyperspectral imaging combind with principal component analysis for surface damage detection on white mushrooms (Agaricus bisporus). Journal of Chemometrics, 22(3-4), 259-267.

Guthrie, B.D. (1984) Studies on the control of bacterial deteroriation of fresh, washed mushrooms (Agaricus bisporus/brunescens). M.S. thesis, The Pennsylvania state university.

Taghizadeh, M., Gowen, O'Donnell, C., Cullen, P.J. (2008), NIR chemical imaging for the foods industry. Encyclopedia of

WATER ABSORBANCE PATTERN OF PHYSICAL DAMAGE IN MUSHROOMS

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Abstract

Near infrared spectroscopy (NIRS) was used to analysed the water absorbance pattern (WAP) in mushrooms for a better understanding of the mechanical damage. Sequential spectra of 32 mushrooms harvested at two different times were obtained; half of the samples were physically damaged. Damaged mushrooms presented higher concentration of water in superficial layers of the cap since their absorbance was higher. In addition a relevant band appeared at 1510-1518 nm in the damaged mushrooms corresponding to the first overtone of superoxide tetrahydrate, most likely due to oxidative processes triggered by physical damage.

Introduction

The Irish mushroom industry exported 77×103 t with a value of US $136.5 million in 2005 (FAO, 2008). During harvest, transport and handling mushrooms are exposed to mechanical damage that triggers a browning process, which is the main cause of value loss in the market (Mohapatra et al., 2008). Water absorbance pattern (WAP) is defined by the regression vector calculated for a perturbation which activates water absorption bands and provides useful information on the role of water by inducing perturbations in biological systems (Tsenkova, 2007). In this study the WAP of mushrooms was examined to identify the difference in water matrix between undamaged and damaged mushrooms that could be used to develop a method for grading mushrooms based on reflectance in the near infrared range. The most relevant absorption bands could be identified by analysis of the regression coefficients in conjunction with the variable importance in projection (VIP) (Chong and Jun, 2005). **The aim of this work was to study the water absorbance pattern of physically damaged mushrooms.**

Materials and Methods

Mushrooms

Closed cap, defect-free *Agaricus bisporus* strain Sylvan A15 (Sylvan Spawn Ltd, Peterborough, United Kingdom) mushrooms (3 – 5 cm cap diameter) were selected for this study. They were second flush mushrooms grown at the Teagasc Research Centre Kinsealy (Dublin, Ireland) in a manner typical of the mushroom industry, harvested in the normal manner and transported immediately afterwards to the laboratory by car in August 2008 (first repetition) and November 2008 (second repetition). Elapsed time between harvest and delivery to laboratory was approximately 3 hours; special cardboard trays, designed to hold 48 mushrooms by the stem using a metal grid to avoid contact between (a) mushrooms and (b) between the top of mushrooms caps and the tray lid, were used for this transportation.

Treatment

For each repetition of the experiment a subset of 8 mushrooms was subjected to physical damage by controlled vibration (400 rpm) in a plastic box for 10 minutes. , These mushrooms are labelled "damaged" and untreated mushrooms are labelled "undamaged".

NIR spectroscopy

Spectra were collected in reflectance mode using a NIRSystems 6500 instrument (Foss NIRSystems, Denmark) equipped with a remote reflectance fibre optic probe (part number NR 6539-A) over the wavelength range 400 – 2498 nm at 2 nm intervals. Data were recorded in absorbance units (= log 1/R, where R = reflectance), converted to JCAMP-DX

format (*15*), and imported to Matlab (The MathWorks, Inc., USA). Eight undamaged and eight damaged mushrooms were analysed at each time.
Each mushroom was placed upside down on the optical window of the fibre optic probe and both sample plus probe were covered with a black cardboard box wrapped in aluminium foil to exclude stray light ingress. After recording a spectrum, the mushroom was rotated on its vertical axis through 90º and a second spectrum collected; the average of both spectra was used in subsequent chemometric analysis.

Perturbation
After spectra were taken at time 0h mushrooms were left at room temperature conditions (20 ± 2 °C), and sequentially analysed at times 1, 2, 3, and 4 h.

Water Absorbance Pattern
The following spectral pretreatments were applied to the data: Multiplicative scatter correction (MSC); Savitzky Golay second derivative with 15 point gap and second order polynomial smoothing; subtraction of mean time zero spectrum from subsequent spectra from damaged and undamaged groups and individuals as appropriate. Partial least square (PLS) regression models were developed to quantify the weight loss of the samples.

Weight loss
The mass of each mushroom was recorded after spectral acquisition; weight loss was calculated by subtracting time zero mass, and expressed as percentage of time zero mass.

Results and Discussion

Spectra
The spectra of both sample groups (undamaged and damaged mushrooms) are characterised by four peaks associated with the water molecule in the NIR range, with maxima located around 970, 1190, 1450, and 1940 nm (Figure 1). Damaged mushrooms exhibit similar spectra to undamaged mushrooms, but their absorbance values are higher; this increased absorbance indicates that damaged mushrooms have a higher proportion of water in the upper layers of the cap.
As changes in the state of water in food causes variations in the water absorption band located at 1400 nm (Büning-Pfaue, 2003) subsequent analysis were focussed in the range of 1300 to 1600 nm.
Undamaged mushrooms and damaged mushrooms presented similar maxima and minima positions on second derivative of mean spectra (Figure 2) at 1342, 1380, 1408-1410, and 1462 nm which are related to asymmetric stretch (2*ν3), combination of symmetric stretch and asymmetric stretch (ν1+ ν3), (νu)II, and first overtone of O-H...O respectively (Tsenkova, 2007), all of which are associated to the water content.

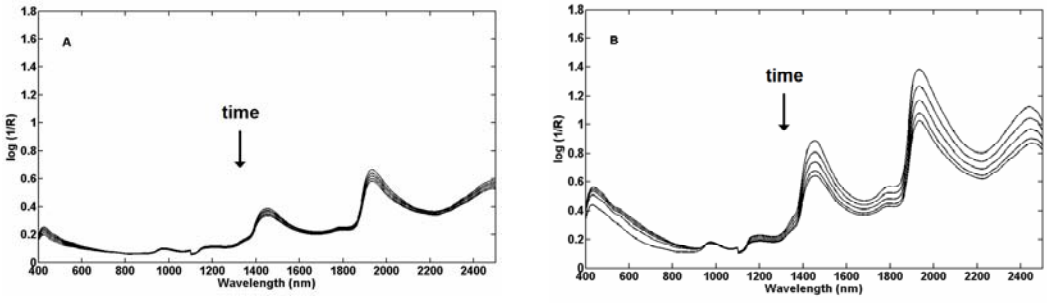

Figure 1. Average spectra at each time of undamaged mushrooms (A) and damaged mushrooms (B).

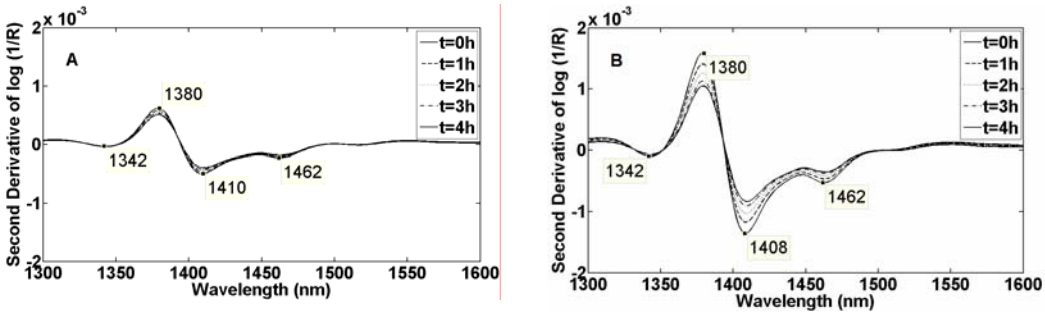

Figure 2. Second derivative of mean spectra at each time for undamaged (A) and damaged (B) mushrooms.

Water Absorbance Pattern

The optimal PLS models to predict weight loss in undamaged and damaged mushrooms was obtained by applying MSC to the spectra, using as a reference the average spectrum for each time. The root mean square error (RMSE) and the R^2 were 0.61% and 0.95 for undamaged mushrooms and 0.74% and 0.94 for damaged mushrooms. The numbers of latent variables were 5 for both models.

The most prominent water bands were selected based on regression coefficients (Figure 3) and influence of wavelength on the model (Table 1) for undamaged and damaged mushrooms and identified according to the assignment of Tsenkova (2007) as presented in Table 2. Damaged mushrooms exhibit a displacement from lower to higher wavelength in the free water band and H-OH bend band compared to undamaged mushrooms; moreover the band 1510-1518 nm related to the oxygen free radicals has a high influence in the model possibly because the oxidative processes triggered by physical damage.

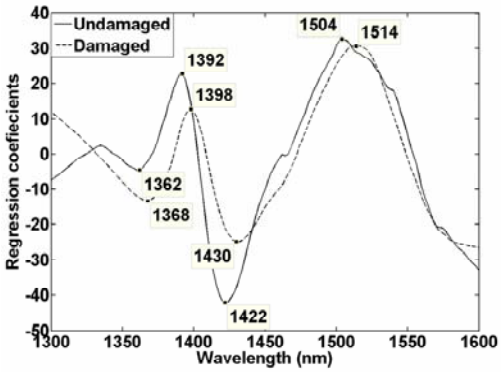

Figure 3. Regression coefficients for weight loss of undamaged and damaged mushrooms for PLS models with 5 latent variables of MSC pre-treated spectra at each time. Undamaged coefficients have been scaled by 5.

Table 1. Highly influent wavelengths on selected PLS models (VIP>1).

Undamaged	Damaged
1300-1310 nm	1300-1324 nm
1388-1488 nm	1386-1460 nm
	1504-1526 nm
	1568-1600 nm

Table 2. Most relevant water bands in undamaged and undamaged mushrooms

Undamaged	Damaged	Assignment
1392 nm	1398 nm	Free water
1422 nm	1430 nm	H-OH bend
	1510-1518 nm	First overtone of superoxide tetrahydrate O_2-.$(H_2O)_4$

Conclusions

The study of water absorbance patterns in the NIR range reveals that: (a) the damaged mushrooms present larger concentration of water in the superficial layers of the mushroom cap than undamaged mushrooms (b) changes in the relationship between water and superoxide tetrahydrate evident in the damaged mushrooms which are not evident in the undamaged ones.

Acknowledgements

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References

Büning-Pfaue, H. (2003). Analysis of water in food by near infrared spectroscopy. Food Chem. 82, 107-115.

Chong, I.-G. Jun, C.-H. (2005). Performance of some variable selection methods when multicollinearity is present. Chemom. Intell. Lab. Syst. 78,103-112.

FAO Statistics Division Faostat http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535.

Mohapatra, D.; Frias, J. M.; Oliveira, F. A. R.; Bira, Z. M.; Kerry, J., (2008). Development and validation of a model to predict enzymatic activity during storage of cultivated mushrooms (agaricus bisporus spp.) *J. Food Eng.* 86, 39-48.

Tsenkova, R. (2007). Aquaphotomics: Aplication of NIR perturbation Spectroscopy for better understanding of water and biology. Workshop at 13th International Conference on Near Infrared Spectroscopy. Vaasa, Finland 16 June.

SHELF-LIFE OF MILDLY/MINIMALLY PROCESSED APPLE DESSERTS

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Abstract
Functional food products are a growing feature in retail outlets, due to increasingly health conscious consumers. This study involved testing processed apple (Bramley's Seedling) puree desserts containing healthy functional ingredients added at levels of 8 (Beneo™ HSI; ORAFTI, Belgium), 5 (apple pomace; Polish Shampion) and 5% (w/w) [alcohol-insoluble-solids (AIS)]. Beneo™ HSI is a prebiotic, while apple pomace and AIS are rich in dietary fibre and help lower cholesterol. Samples were vacuum packed, *sous vide* processed (Barriquand Steriflow retort; P_{90}>10 min), cooled, sieved (1.4 mm mesh), held at 2-4°C, and tested (days 1, 15 and 30) for microbiological stability (TVC), rheological properties (Brookfield rheometer and TAXT2*i* texture analyser), colour (Hunter Lab), pH, titratable acidity, and soluble solids. pH values fell (P<0.001) during storage (3.19, 3.09 and 3.05 on days 1, 15 and 30 respectively). L/b ratios were influenced (P<0.001) by inclusions (lowered L/b ratios) and storage times with the day 30 AIS (3.20) and control (3.12) purees giving the highest L/b ratios. Pomace and AIS purees had higher (P<0.001) consistency values than control or Beneo purees. Shear thinning was observed in all purees. Microbiological stability was maintained in all purees (TVCs <10cfu/g after 30 days).

Introduction
Apples are inherently 'functional' or healthy, i.e. they are a good source of pectin (dietary fibre that also reduces cholesterol), monosaccharides, minerals, vitamins, and various bioactive compounds, such as vitamin C along with phenolic compounds, which are known to act as natural antioxidants (Keenan et al. 2008). A food can be considered 'functional' if demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond that of basic nutrition (Food Safety Authority, 2001). A functional food can be (a) a conventional natural food consumed as part of a normal diet, or (b) a food in which a positive component has been added, or from which a deleterious compound has been modified or removed (Roberfroid, 2000). This study was carried out to exploit opportunities that focus on the importance of health in the diet by developing ready- desserts with added functional ingredients. It embraced the addition of three types of functional ingredients, namely, oligofructose (Beneo HSI™), apple pomace or alcohol-insoluble-solids (AIS). Oligofructose acts as a dietary fibre and prebiotic and is a non-digestible food ingredient that beneficially affects the host by selectively stimulating growth and/or activity of one or a limited number of colonic bacteria, thus, improving host health (Coussement, 1999). AIS remain relatively unused as a food inclusion but have potential functional properties such as the ability to lower serum cholesterol in humans and help modulate late-maturity-onset diabetes. These inclusions, combined with the inherent functionality of apple (Asenjo & Figuerola, 2004; Mayne *et al.*1982) and mild *sous vide* processing (Fagan & Gormley, 2002) should maximise retention of bioactive compounds and produce a value-added, healthy, ready-dessert.

The objective of this study was to produce a apple ready dessert that is healthy and safe over a shelf-life period.

Materials and methods

Protocol for preparation of samples
Purees were prepared from stewed (95°C; 15 min) Bramley's Seedling apple slices (+33% H2O) and inclusions were Beneo HSI™ (8), apple pomace (5), or (AIS 5%w/w). Samples were cooled, sieved (1.4 mm), vacuum packed (200g) and *sous vide* processed (Barriquand Steriflow retort: P90>10 min) and stored (2-4°C) for 30 days. *Sous vide* samples were tested on days 1, 15 and 30.

AIS preparation
Unpeeled, cored Bramley apples were chopped in a robot coupe blixer 4.3000. Ethanol was added to the product to ensure a final aqueous ethanol concentration of 80 % (v/v).The mixture was boiled for 2 min and left standing for 24h. The

AIS was collected, washed with 1L boiling aqueous ethanol (80%) and dried at a temperature below 40°C.

Colour measurement
The colour of the apples was measured using a HunterLab model DP-9000 colorimeter (Hunter Associates Laboratory, Inc., USA). The colour for 5 wedges per replicate was measured and was expressed as a three dimensional L*a*b colour solid.

Rheological measurements
Rheological characteristics (speed rpm, apparent viscosity) of apple puree were measured at 21ºC using a Brookfield viscometer (Brookfield Engineering Laboratory instrument, USA). Approximately 80 ml of puree was placed in a 100 ml glass beaker with a flat bottom. The viscometer was operated at speeds 0.5; 1; 2.5; 5; 10; 20; 50; 100 rpm. Two different spindles (no. 5 and 7) were selected for the measurements depending on the apple purees.

The textural analysis was conducted at 21°C with the TAXT2i, Stable Micro Systems instrument using the back extrusion configuration. Tests were carried out in a cylindrical container (60mm) filled with apple puree, in which a compression disc (50mm) with an extension bar moved at a speed of 1 mm/s, to a distance of 30 mm. Two parameters i.e. maximum positive force of extrusion and the positive area of extrusion were recorded.

pH measurement
pH was measured with an Orion pH meter (Model 420A, Thermo Fisher Scientific, Inc., USA), calibrated with phosphate buffers at pH 4.005 and 7. pH was measured on a homogenous apple puree which was prepared using a blender (Braun Multiquick, Germany). The apple pulp was also used for following physicochemical test.

Soluble solids (SS)
Percentage soluble solids (%SS) was measured using a refractometer (Atago U.S.A., Inc., USA). Approximately 5g of homogenous apple puree was pressed through a porous paper. The residue was transferred onto a prism and SS were measured. The refractometer was calibrated with distilled water.

Measurement of moisture content
About 10g of the sample was added into a previously weighed moisture dish. Samples were dried in a vacuum oven (B-240, Edward High Vacuum Ltd., Crawley, UK.) to constant weight at 70°C and 58 kPa overnight (aprox. 18 hour). The moisture content was determined by weight difference and dry matter was expressed as a percentage of the initial sample weight.

Sensory analysis
Panellists (15 per panel) were asked to mark a 6 cm line with endpoints of 0 (unacceptable) and 6 (very acceptable). The tests were carried out under red light in order to minimize the colour affect of different samples. The samples were presented in small plastic thimbles. Each taster was given 3 coded test samples and five panels were carried out and the results were averaged.

Microbiological assessment

Samples (25g) were microbiologically assessed for on site at the AFRC commercial laboratory. for Total Viable Counts (TVC) using accredited methodologies.

Statistical analysis
Data were analysed statistically by Fischer analysis of variance (ANOVA). Statistical design was 3 inclusions x 3 test days x 2 replicates.

Results and Discussion
Moisture values were lowest ($P<0.001$) in Beneo HSI™ purees (i.e. highest w/w addition of the inclusions) and were also lower ($P<0.001$) on day 30 compared to days 1 and 15 compared to controls. pH values fell ($P<0.001$) during storage (3.19, 3.09 and 3.05 on days 1, 15 and 30 respectively). Soluble solids were higher ($P<0.001$) in Beneo HSI™ purees compared to pomace, AIS and control purees. As Beneo HSI™ is a fructo-oligosaccharide and is used as a sugar replacer, this observation was expected. L/b ratios were influenced ($P<0.001$) by inclusions (lower values) and storage times with the day 30 AIS (3.20) and control (3.12) purees giving the highest L/b ratios. Pomace and AIS purees had higher ($P<0.001$) consistency values than control or Beneo purees. Shear thinning was observed in all purees. Microbiological stability was maintained in all purees (TVCs <10cfu/g after 30 days).

Conclusion

Different nutraceuticals and minimal processing were used to produce a range of healthy apple ready-desserts with a shelf-life of approximately 30 days. Beneo HSI™ inclusions increased puree sweetness and dry matter content. AIS and pomace inclusions increased puree viscosity. Pomace inclusions decreased colour values (L/b ratios) which was undesirable in the final products. pH values decreased during storage due to loss of buffering capacity. Microbiological stability was maintained in all purees throughout the shelf-life period.

Acknowledgements

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References

[1]Gormley, T. R., Keenan, D. F., and Roessle, C. (2008). Increasing functionality of apple products. Horticulture Week. 29/05/2008, 31-33.

[2]Food Safety Authority of Ireland. (2001). Functional Food. Available at: www.fsai.ie/publications/leaflets/functional_food_leaflet.pdf Accessed 24/10/2008.

[3]Roberfroid, M. B. (2000). Defining functional foods. In: *Functional foods, Concept to product.* Gibson, G, R, & Williams, C, M., eds. Woodhead Publishing Limited, Cambridge, England. 9-27.

[4]Coussement, P. A. A. (1999). Nutritional and health benefits of Inulin and Oligofructose *J. Nutrition*. 129: 1412S-1417S.

[5]Asenjo, F., and Figuerola, F. (2004). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chem.* 91(3): 395-401.

[6]Mayne, P. D., McGill, A. R., Gormley, T. R., Tomkin, G. H., Jullan, T. R., and O'Moore, R. R. (1982). *Irish J. Medical Sci.* 151, 36-41.

[7]Tansey, F. S., and Gormley, T.R. (2002). Effect of *sous vide* cooking, with freezing, on selected quality parameters of seven fish species in a range of sauces. *Farm & Food Research*. 12(1): 18-22.

PHYSICOCHEMICAL, SENSORY AND ANTIOXIDANT PROPERTIES OF APPLE CULTIVARS PURCHASED IN AN IRISH SUPERMARKET OVER A PERIOD OF 12 MONTHS

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Abstract
Apples have a good health image and are eaten for a satisfactory sensory experience. Apples are expensive and should be of high quality in order to give consumer satisfaction. Samples of Golden Delicious, Braeburn and Granny Smith apples were purchased in a supermarket on 12 occasions, i.e. monthly, from October 2006 to September 2007. Physicochemical and sensory tests were conducted the day after purchase and sub-samples (±skin) were freeze dried and tested for total phenols (TP) and anti-radical power (ARP) using Folin-Ciocalteau and DPPH methods respectively. Mean values for a range of test parameters in the order Golden, Braeburn, Granny were: flesh pH (3.69, 3.54, 3.43); Hunter L/b (4.23, 4.19, 5.99); Kramer shear force (1.68, 1.55, 2.27 kN/100g); sensory [4.32, 4.15, 3.57; 6-cm acceptability scale; end-points 0 (unacceptable) and 6 (very acceptable)]; ARP (+skin) 0.651, 0.546, 0.796; ARP (-skin) 0.499, 0.482, 0.613 [1/IC50 $(g/L)^{-1}$], TP (+skin) 662, 605, 1107; and TP (-skin) 577, 518, 936 (mg gallic acid equivalents per 100g dry weight).

Introduction
Apples have a healthy image i.e. they are a source of nutrients, non-nutrients (such as dietary fibre), antioxidants and other bioactive compounds that may have a protective effect on health. They also provide a satisfying sensory experience. As apples are expensive, they should be of high quality in order to satisfy consumer demands. This led to the justification for the current study, which observes the changes in quality of supermarket apples over a 12-month period. The cultivars tested were Braeburn, Granny Smith and Golden Delicious as these cultivars are popular sellers in the Irish market place.

The objective of this study was to evaluate quality of apple cultivars in an Irish supermarket over a period of 12 months, depending on their physicochemical, sensory and antioxidant properties.

Materials and methods

Protocol for preparation of samples
Samples of Braeburn, Granny Smith and Golden Delicious apples were purchased in a major supermarket on 12 occasions, i.e. monthly, from October 2006 to September 2007 (inclusive). Samples of 20 apples of each cultivar were obtained in triplicate i.e. 60 apples of each cultivar were tested per month. Samples were tested the day after purchase for moisture content, flesh pH, soluble solids, flesh colour (Hunter Lab), and shear value [Kramer standard test cell; 100g samples (wedges)]. Freeze dried residues were tored in black plastic bags at -20°C for up to four weeks prior to testing for total phenols (TP) and anti-radical power (ARP). Tests were carried out on the skin and the flesh of the apples using the Folin-Ciocalteau and the DPPH methods. Sensory tests for acceptability were conducted monthly using 18-21 tasters per panel.

Colour measurement
The colour of the apples was measured using a HunterLab model DP-9000 colorimeter (Hunter Associates Laboratory, Inc., USA). The colour for 5 wedges per replicate was measured and was expressed as a three dimensional L*a*b colour solid.

Texture measurement
The texture (shear force) of the apple wedges was measured using a T-2000 Texture analyzer (Food Technology Corporation, UK) which was calibrated before use every time. The Lkramer standard test cell (Model CS-1) was loaded with 100 g of apple wedges without cores. The results were expressed as kN force.

pH measurement
pH was measured with an Orion pH meter (Model 420A, Thermo Fisher Scientific, Inc., USA), calibrated with phosphate buffers at pH 4.005 and 7. pH was measured on a homogenous apple pulp which was prepared using a blender (Braun

Multiquick, Germany). The apple pulp was also used for following physicochemical test.

Soluble solids (SS)
Percentage soluble solids (%SS) was measured using a refractometer (Atago U.S.A., Inc., USA). Approximately 5g of homogenous apple pulp was pressed through a porous paper. The residue was transferred onto a prism and SS were measured. The refractometer was calibrated with distilled water.

Measurement of moisture content
About 10g of the sample was added into a previously weighed moisture dish. Samples were dried in a vacuum oven (B-240, Edward High Vacuum Ltd., Crawley, UK.) to constant weight at 70°C and 58 kPa overnight (aprox. 18 hour). The moisture content was determined by weight difference and dry matter was expressed as a percentage of the initial sample weight.

Sensory analysis
A 18-21 untrained taste panel was used to determine the sensory acceptability of the honey infused apple wedges. Each panellist was given a plate containing 2 wedges from each treatment. The taster was asked to mark a 6cm line with endpoints 0 (unacceptable) to 6 (very acceptable).

Extraction of antioxidants
Samples were lyophilised in an A6/14 freeze dryer (Frozen in Time Ltd., York, UK). Prior to extraction, the lyophilised samples were milled to a fine powder using a blender (BL440001, Kenwood limited, Hampshire, UK). Methanol (25 mL) was added to 1.25 g of sample powder, followed by homogenisation for 70 s at 24,000 rpm using an Ultra – Turrax T-25 tissue homogeniser (IKA-group, Saufen, Germany). The samples were vortexed with a V400 Multituve Vortexer (Alpha laboratories, North York, Canada) for 20 min at 1050 rpm and centrifuged for 10 min at 2,000 rpm (MSE Mistral 3000i, Sanyo Gallenkamp, Leicestershire, UK). The supernatant (10 mL) was filtered through 0.22 µm PTFE syringe filters (Phenomenex, Macclesfield Cheshire, UK). Finally the extracts were stored at -20ºC.

DPPH assay
A modified version of the DPPH method (Goupy et al., 1999) was used. A working DPPH solution was prepared by making a 1 in 5 dilution of the methanolic DPPH stock solution. Prior to analysis, serial dilutions of the methanolic extracts of the fruit samples were prepared. 500 µL of diluted sample and 500 µL of the DPPH working solution were added to a micro-centrifuge tube. After vortexing, the tubes were left in the dark for 30 min at room temperature. The absorbance was then measured against methanol at 515 nm in 1 mL cuvettes using a spectrophotometer (UV-1700 Pharma Spec, Shimadzu, Milton Keynes). The antioxidant activity was expressed in mg Trolox equivalent (TE) per 100g dry weight sample.

FCR assay
Total phenolic content of methanolic fruit extracts was assessed using a modified version of the Folin-Ciocalteu assay (Singelton et al., 1999) . Gallic acid was used as a standard and the aqueous gallic acid solution was diluted with distilled water to give appropriate concentrations for a standard curve. For the analysis, 100 µL of methanolic fruit extract or gallic acid standard, 100 µL of methanol, 100 µL of Folin-Ciocalteu reagent and 700 µL of Na_2CO_3 were added into a 1.5 mL micro-centrifuge tube. The samples were vortexed immediately and the tubes were incubated in the dark for 20 min at room temperature. After incubation all samples were centrifuged at 13,000 rpm for 3 min. The absorbance of the supernatant was then measured at 735 nm in 1 mL plastic cuvettes using a spectrophotometer (UV-1700 Pharma Spec, Shimadzu, Japan). The results are expressed in mg gallic acid equivalent / 100 g dry weight (mg GAE $100g^{-1}$ DW).

Statistical analysis
Data were analysed statistically by Fischer analysis of variance (ANOVA). Statistical design was 3 cultivars x 12 months x 3 replicates.

Results and Discussion
Moisture content was lower ($P<0.001$) in Golden Delicious than Braeburn or Granny. Granny was the most acidic (3.43) Braeburn (3.54) was intermediate and Golden (3.69) was the least acidic ($P\leq0.001$). Soluble solids ranged ($P<0.001$) from 13.8 (Golden) to 12.2 (Granny). Hunter L/b ratios (white/yellow) were similar for Golden (4.32) and Braeburn (4.19), whereas Granny (5.99) slices were much lighter with less yellow

(P<0.001). Granny had the hardest (P≤0.001) shear value (2.27) and Braeburn the lowest (1.55 kN/100g). All samples had a good level of sensory acceptability. Golden and Braeburn ranked equally acceptable and both received higher panel scores than Granny. ARP values were Granny (0.796), Golden (0.651), and Braeburn (0.546 1/IC50 $(g/L)^{-1}$) for skin-on samples; and 0.613 (Golden), 0.499 (Braeburn) and 0.482 1/IC50 $(g/L)^{-1}$ (Granny) for skin-off samples. TP values for the skin-on samples ranged from 1107 (Granny), 662 (Golden) and 605 mg gallic acid equivalents/100 g dry weight (Braeburn). Higher TP values were found for samples with skin compared with those in skin-off samples with Granny (936), Golden (577) and Breaburn (512 mg gallic acid equivalents/100 g dry weight). These data highlight the benefits of eating apples with the skin attached. Moisture contents were highest (P<0.001) in March, August and September. pH values were lowest in February (3.48) and highest in September (3.72). Golden was measured the highest for soluble solids of the three cultivars overall. Hunter L/b values were highest between November (5.40) and February (5.23). Granny fruit were firmest on nine of the 12 test dates, with shear values in a range of 1.29 (Golden), 1.13 (Braeburn) and 1.40 kN/100g (Granny) between months. Variations in monthly values reflect the different levels of maturity of the fruit in supermarkets. All samples had a good level of sensory acceptability. Golden ranked highest in 8/12 panels and Braeburn in 4/12 panels. Granny scored lowest in 11/12 panels due to a lack of sweetness and aroma, as well as an ocassional over crisp texture. ARP values for the skin-on samples were highest in September `07 (0.902) and lowest in November `08 (0.3811/IC50 $(g/L)^{-1}$). TP values for the skin-on samples showed the same trend as the ARP with highest values in September `08 (1063) and lowest in November (603 mg gallic acid equivalents/100 g dry weight). This suggest that it is better to consume skin-on apples (Drogoudi et al., 2008, Tsao et al., 2005).

Conclusion

Tests on three apple cultivars purchased on 12 occasions in supermarkets over a one year period indicated a good level of acceptability. Monthly variations in physicochemical properties were due, presumably, to different countries of origin, different levels of maturity, and different durations in storage and channels of trade. Overall, Golden was the most preferred cultivar followed by Braeburn and Granny. However, Granny apples had the highest level of antioxidants, especially total phenols. The difference in antioxidant status between skin-on and skin-off slices is documented and suggests that it is better to consume skin-on apples.

Acknowledgements

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References

Drogoudi, P.D., Michailidis, Z. and Pantelidis, G. (2007). Peel and flesh antioxidant content and harvest quality characteristics of seven apple cultivars. *Scientia Horticulturae,* **115**, 149-153.

Goupy, P., Hugues, M., Boivin, P., and Amiot, M. J. (1999). Antioxidant composition and activity of barley (Hordeum vulgare) and malt extracts and of isolated phenolic compounds. *Journal of the Science of Food and Agriculture*, **79**, 1625-1634.

Singelton, V. L., Orthofer, R., & Lamuela-Raventos, R. R. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in enzymology*, **299**, 152-178.

Tsao, R., Yang, R., Xie, S., Sockovie, E. and Khanizadeh, S. (2005). Which Polyphenolic Compounds Contribute to the Total Antioxidant Activities of Apple? *Journal of Agricultural and Food Chemistry*, **53**, 4989-4995.

Temperature monitoring during cooking of sausages

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Abstract

In this work, the relationships of cooking temperature and bacteria; as well as the relationship of cooking temperature and meat's doneness are going to be observed. Fresh pork sausages (Denny) were fried in a small amount of cooking oil for 7-9 minutes, temperature profile for the different cooking methods were obtained by monitoring the internal temperature of sausages using a thermocouple inserted into the centre of the sausage prior to cooking. Results from the present work showed that the centre temperature of sausage reached 75°C at the sixth minute, and this temperature is enough to destroy bacteria pathogens.

Introduction

The main type of meat product consumed in European market is pork (48.7%) followed by poultry (23.6%) and bovine. (Mataragas *et al*., 2008). Different microorganisms such as Enterobacteriaceae, Salmonella, and Listeria can be found in meat products and in meat facilities which can cause foodborne diseases (Corominas *et al.*, 2007). The foodborne illnesses in humans due to bacterial pathogens and their toxins are well documented worldwide (Hazariwala *et al*, 2002). Foodborne illness imposes a substantial economic and social burden to humans by way of acute morbidity and chronic sequela (Duff *et al*, 2003). Salmonella spp. has been reported by the United States Department of Agriculture Food Safety and Inspection Service (FSIS) as one of the most common causes of foodborne illness associated with meat and poultry products.

Salmonella spp. is not particularly heat resistant and most serotypes are killed by normal cooking conditions (i.e. cooking to a core temperature of 75°C). Many customers do not realize that raw food is a potential threat of bacterial contamination in the kitchen. Thus, they ignore the importance of many basic instructions regarding storage, temperature control, cooking and prevention of cross-contamination (Scott 1992). In order to avoid bacterial pathogens, it is suggested cooking to an internal temperature of 71°C to guarantee microbiological safety (Rhee, *et al*., 2003). Cooking or barbecuing might not achieve this temperature, so people are at potential risk of food poisoning.

The objective of this study is to determine the temperature of sausages during cooking.

Materials and methods

Materials

Fresh pork sausages (Denny) were sourced from local supermarkets and stored at refrigeration temperature (3-5°C). Cooking oil was used to fry sausages in a pan.

Methods

Sausages were fried in a small amount of cooking oil for 7-9minutes according to manufacturer's instructions. Temperatures were measured by thermocouples (Type T) which inserted longitudinally into the sausages. A data logger (Eurotherm Chessel model No. 4180, Eurotherm Recorders. Ltd, West Sussex, UK) was used to record sausage and cooking oil temperature at 15 seconds intervals. (**Fig 1**)

Figure 13: Image of Cooking/Frying Experiment

Results and Discussion

As this trial is in its early stage, only preliminary data is reported here.

Two sausages (Denny) were investigated for this preliminary trial

Fig 2.1

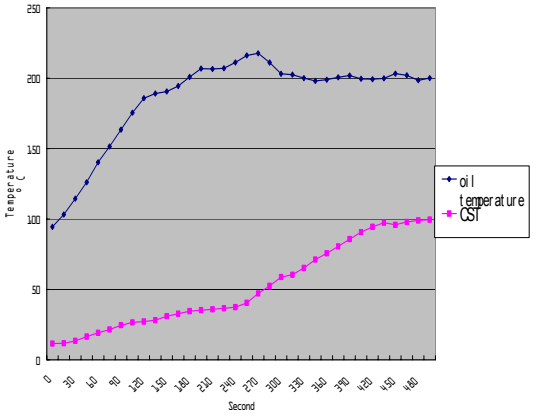

Figure 2: Trends of temperature changes during cooking "Denny sausage"1

As expected, sausage and oil temperature increased with cooking time. By 8 minutes (i.e. manufacturer's cooking guide lines) the sausage temperature had reached 99.53°C and the oil temperature had reached 200°C. The centre temperature of the sausage had reached 75°C by six minutes.

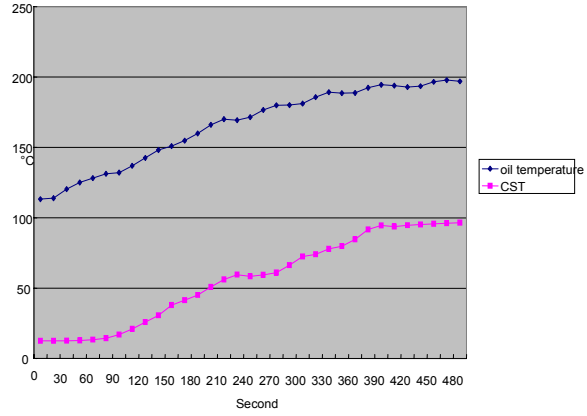

Figure 3: Trends of temperature changes during cooking "Denny sausage" 2

Similar results were found for the 2nd sausage. The maximum cooking temperatures for the oil and sausage were 196.9°C and 96.53 °C respectively. The rate of change is almost the same for the two curves. After 5.75 minutes, the temperature of centre sausage reached to 75°C.

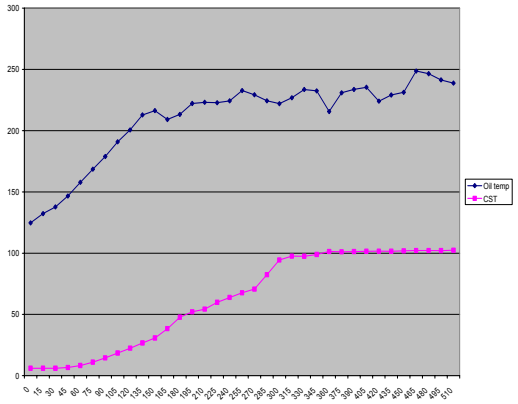

Figure 4: Trends of temperature changes during cooking "Denny sausage" 3

As can be seen from **Figure 4**, the sausage temperature had reached 100.2°C and the oil temperature had reached 200°C. The centre temperature of the sausage had reached 75°C by 5.9 minutes.

This project commenced in January 2009, so it was still in its initial stage

As mentioned above, the *Salmonella* spp. will be killed by cooking to a core temperature of 75°C instantaneously, but actually, during our experiment, it was found that the colour of the sausage was still pink and was not changed from "very rare " to "well-well done" (Lopez *et al.,* 2008) as described by manufacturer's instruction..

According to the manufacturer's instruction, the sausage should be fried for 7-9 minutes. In this experiment, the centre temperature of sausage reached 75°C at the sixth minute, and this temperature is enough to destroy bacteria pathogens. Therefore, cooking sausage for 7-9 minutes can kill the bacteria pathogens completely.

Conclusion and future work

The tests conducted so far in this project have shown that current designs and conditions are satisfactory for observing the temperature change during cooking process. During cooking, the

internal temperature of sausage reached more than 71°C according to the manufacturer's instruction (i.e. frying for 7-9 minutes). The centre temperature of the sausage reached 71°C by six minutes. Therefore, it is sufficient to destroy bacteria pathogens. More practical on other factors must be investigated to confirm these findings, such as using different methods and different heat to cook the sausages.

References

Duff, S.B., Scott, E.A., Mafilios, M.S., and Ackerman, S. J.(2003). *Cost-effectiveness of a targeted disinfection program in household kitchens to prevent foodborne illnesses in the United States, Canada and the United Kingdom.* Journal of food protection bb: 2103-2115.

Scott E.(1996). *Foodborne disease and other hygiene issues in the home*. Journal of Applied Bacteriology 80 (1), pp. 5–9.

FSIS (1998): *Contamination with microorganisms, pathogen Food Safety and Inspection Sever ice*. Washington, D.C. Fed. Regist. 63:1800-1802.

Hazariwala, A. Sanders,Q. Hudson, C.R, Hofacre, C., Thayer, S.G. and Maurer, J. J. (2002): *Distribution of Staphylococci enterotoxin genes among Staphylococcus aureus isolates from poultry and humans with invasive staphylococcal disease.* Avian Diseases 46(1): 132-136.

Corominas L., Garriga M, Martin B. and Aymerich T (2007). *Microbial evaluation of natural contamination sources during the manufacture of fermented sausages, International symposium.* Valencia, 14-15.

López Osornio,M .M , G. Hough, A. Salvador, E. Chambers IV, S. McGraw, S. Fiszman (2008). *Beef's optimum internal cooking temperature as seen by consumers from different countries using survival analysis statistics. Food Quality and Preference*. Volume 19, Issue 1, Pages 12-20.

Mataragas, M .,P.N. Skandamis, E.H. Drosinos (2008). *Risk profiles of pork and poultry meat and risk ratings of various pathogen/product combinations International Journal of Food Microbiology*. Volume 126, Issues 1-2.

Rhee, M., Lee, S.Y., Hillers, V., Mc Curdy, S., & Kang, D (2003). *Evaluation of consumer-style cooking methods for reduction of Escherichia coli O157 in ground beef. Journal of food protection*. 66(6), 1030-1034.

EFFICACY OF ULTRASOUND ON THE INACTIVATION OF YEAST IN TOMATO JUICE: APPLICATION OF WEIBULL FREQUENCY MODEL

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Abstract
The effect of sonication on the resistance of yeast (*Pichia fermentans*) in tomato juice was studied. Tomato juice samples were subjected to sonication at different amplitude levels ranging from 24 – 60 μm at a constant frequency of 20 kHz for different times (2 to 10 min) and pulse of 5 s on and 5 s off at controlled temperature of 25 ^{o}C. Significant reduction ($p<0.05$) was observed at higher processing conditions. The yeast inactivation was found to follow Weibull model with high regression coefficient ($R2>0.98$) and low RMSE (<0.51). Desired 5 log reduction (D5 value) and shape factor was found to correlate exponentially with amplitude level. Results presented in this study show that ultrasound alone is an effective process achieving desired inactivation of yeast in tomato juice.

Introduction
The tomato (*Lycopersicon esculentum*) is one of the most important and widely consumed vegetable crops in the world (Suárez et al., 2008). Yeasts play an important role in the spoilage of fruit juices as they causes loss of nutritive and organoleptic properties (off flavors and odors, smell or taste of alcohol). Majority of spoilage yeasts are *Saccharomyces species*, only 20-30% of wild yeasts belong to other species such as *Candida inconspicua*, *Pichia fermentans* and *Pichia anomala*. Amongst the non-*Saccharomyces species*, *P. fermentans* is a bio-film forming yeast that has been isolated from fruit juices and vegetable (Deak, 2008).
The consumption of tomatoes and tomato based products such as tomato juice is associated with a lower risk of cardiovascular disease. With increased consumer demands for nutritious, safe and chemical free, high quality juice food processors are looking for various alternatives to conventional thermal preservation techniques. Nonthermal processing technologies produces juice with minimal nutritional and organoleptic changes (Gould, 2001). These processing techniques include pulsed white light, high-hydrostatic pressure (Barbosa-Canovas & Gould, 2000), ultrasound (Piyasena, Mohareb & McKellar, 2004; Furuta et al., 2004; Tsukamoto et al., 2004).
Studies showed that ultrasound has been used for microbial inactivation in fruit juices including apple cider (Ugarte-Romero et al., 2006), orange juice (Valero et al., 2007) and guava juice (Cheng et al., 2007). However, no study has reported the ultrasonic inactivation of *P. fermentans* in tomato juice. **The objective of this study was to investigate and describe the efficacy of ultrasound on the inactivation of yeast in tomato juice using the Weibull model.**

Materials and Methods
Yeast strain
The yeast strain (Pichia fermentan, DSM 70090) used in this experiment was supplied by DSM, Derbyshire, UK. The strain was maintained at 4°C on universal yeast agar medium.

Preparation of tomato juice
Fresh tomatoes were purchased from local fruit market (Begley's Marketing Services Ltd., Dublin 7, Ireland) and subsequently stored at 3 ±1 °C and crushed using a domestic juice extractor (Kenstar, Dublin, Ireland). Juice was immediately filtered on a double layer cheese cloth to remove seeds the juice. Tomato juice was sterilised at 110 ^{o}C for 10 min.

Inocula preparation and enumeration procedure
One single yeast colony from a universal yeast agar stock plate was transferred to 10 ml of yeastbroth (sterilised in an autoclave at 121 oC, 15 min) containing yeast extract (Sigma-Aldrich, code Y1625, U.S.A), 3 g of malt extract (Fluka, Sigma-Aldrich, code 70167, U.S.A), 10 g of D-glucose

(Fluka, Sigma-Aldrich, U.S.A) and 5 g of soy peptone (Oxoid Ltd, L0044, Hampshire, UK). The inoculated yeast broth was incubated at 25 °C on a rotatory shaker (200 rpm) for 72 h. The cells were harvested by centrifugation (9000 rpm (10,000 x g), 10 min at 4 ^{o}C) and resuspended in sterile quarter-strength 20 ml ringer's solution (Oxoid Ltd, Hampshire) and tomato juice, resulting in an initial concentration (N0) of approximately 108 CFU/ml.

Ultrasound treatment

A 1,500 W ultrasonic processor (VC 1500, Sonics and Materials Inc., Newtown, USA) with 19 mm probe was used for sonication. 80 mL tomato juice samples were placed in a 100 mL jacketed vessel through which water at 25 ± 1.0 ^{o}C and a flowrate of 0.5 % was circulated. Samples of 1ml of yeast cell suspension were taken at interval of 2, 4, 6, 8 & 10 min at varying amplitude levels of 24, 30, 42, 54 & 60 µm respectively at constant temperature of 25 ^{o}C. The ultrasound probe was submerged to a depth of 2.5 cm into the sample. All treatments were carried out in duplicate.

Viable cell counts and expression of results

At each time point, 1ml of treated sample was transferred aseptically in 6 x 9 ml ringers for dilution (10^{-1} to 10^{-6}). Viable yeast counts were determined by surface plating 0.1 ml of serial dilutions in Universal yeast Agar (duplicate). The agar plates were incubated (Lab Heat) at 30 ^{o}C for 2 days. Cell counts were carried out manually and expressed as colony forming units per ml (CFU/ml)

Weibull distribution model

Models were developed using a two-step procedure. Reaction rate constants were

determined by fitting the experimental data to the Weibull model (Peleg and Cole 1998). In the second step the rate constants were modelled as a function of ultrasound amplitude level (µm).

$$N_t = N_0 \times e^{-\left(\frac{t}{\delta}\right)^{\beta}} \qquad (1)$$

Rearranging Equation 1, yields

$$\log \frac{N_t}{N_0} = -\left(\frac{t}{\delta}\right)^{\beta} \qquad (2)$$

The numerical values of δ and β were used to calculate a desired log reduction. The time required to obtain 5 log reduction (D_{des}) was calculated from model parameters by employing Equation 3.

$$t_d = \delta \times (D_{des})^{1/\beta} \qquad (3)$$

where N_t represents the number of surviving cells at any given time (t, min), while N0 is the initial number of the surviving cells. β is shape factor, δ is decimal reduction time (min). Data fitting was considered significant at a probability level of 95%.

Results and Discussion

Effect of ultrasound on yeast inactivation

Extrinsic control parameters amplitude level and processing time (min) had a significant effect ($p<0.05$) on inactivation of yeasts (*Pichia fermentans*) but the effect was relatively small compared at lower amplitude and processing time. As the amplitude level increased the inactivation rate increased (Figure 1).

Yeast inactivation in sonicated tomato juice samples followed the Weibull model (Equation 1) with R^2 >0.98 (Figure 1). The Weibull model shape factors listed in Table 1. The Weibull distribution corresponds to a concave upward survival curve if β<1 and concave downward if β >1 (Van Boekel, 2002). In this study the yeast inactivation curves were concave downward (β > 1), which can also be seen from Figure 1.

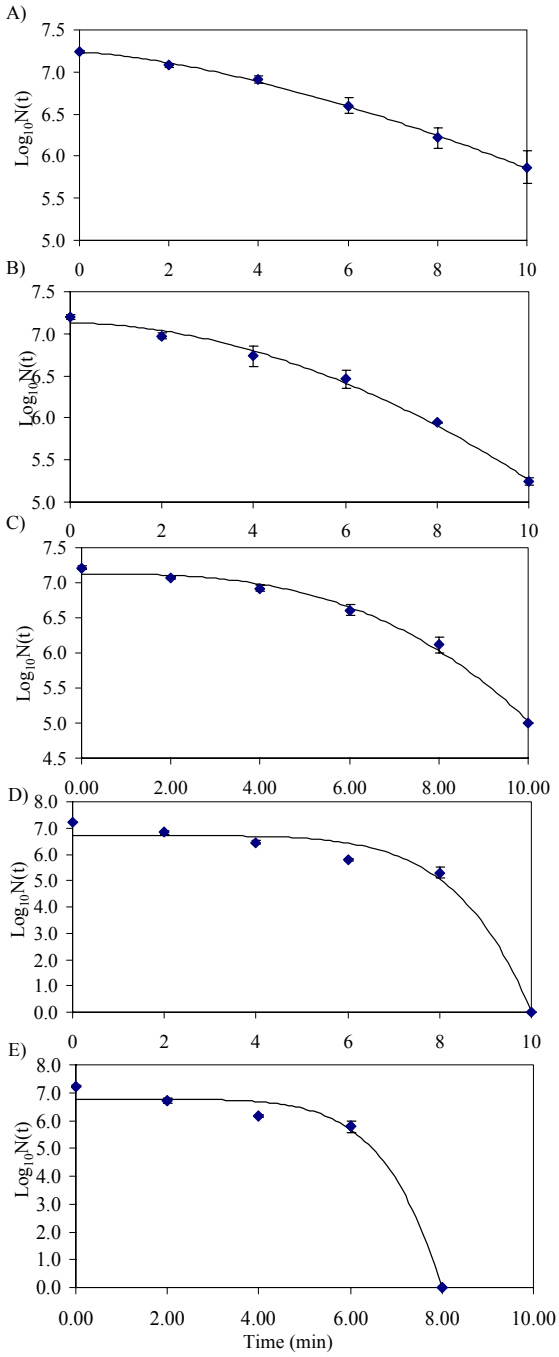

Figure 1. Inactivation of P. fermentans at different amplitude levels as a function of time at various amplitude levels of A (24 μm), B (30 μm), C (42 μm), D (54 μm), E (60 μm).

Downward concavity (β > 1) as observed in this study indicates resistance of yeast cell towards ultrasound at lower treatment time, whereas upward concavity (β > 1) would indicate higher susceptibility of yeast cells towards sonication.

Table 1. Weibull model parameters for various amplitude levels

Amplitude (μm)	β value	D_5	RMSE	R^2
24	1.46±0.79	21.85±1.79	0.031	0.998
30	1.44±0.12	20.50±1.24	0.086	0.990
42	2.05±0.49	16.41±2.65	0.087	0.994
54	3.62±1.04	11.84±3.09	0.519	0.977
60	4.95±0.60	7.51±0.01	0.488	0.986

Guerrero et al (2001) reported the resistance of *Saccharomyces cerevisiae* cells and observed first order degradation kinetics. However, in this study Weibull model best describes the inactivation kinetics. The proposed Weibull model for inactivation kinetics is flexible owing to the inclusion of a shape constant in addition to the rate constant and has been employed to describe microbial, enzymatic and chemical degradation kinetics (Manso, Oliveira, Oliveira & Frias, 2001; Cunha, Oliveira & Oliveira, 1998).

The shape factors (β) were found to correlate exponentially with amplitude level (Figure 2a). Desired 5 log reduction (D5) calculated using Equation 3 was found to decrease exponentially with increase in amplitude level (Figure 2b). These results indicate that yeast cells are resistant to low ultrasonic intensity and are susceptible to higher treatment levels.

The inactivation of microorganisms by ultrasonic waves has been attributed to the cavitation phenomenon. Microbubbles of gas and/or vapour formed within a liquid during the rarefaction cycle of the acoustic wave undergo violent collapse during the compression cycle of the wave. This implosion or cavitation releases large amounts of energy, generating temperatures of 5000 K and shock waves with pressures of several atmospheres (Mason, 1990) and high shearing effects. Consequently the intense local energy and high pressure bring about a localised pasteurisation effect without causing a significant rise in macro-temperature.

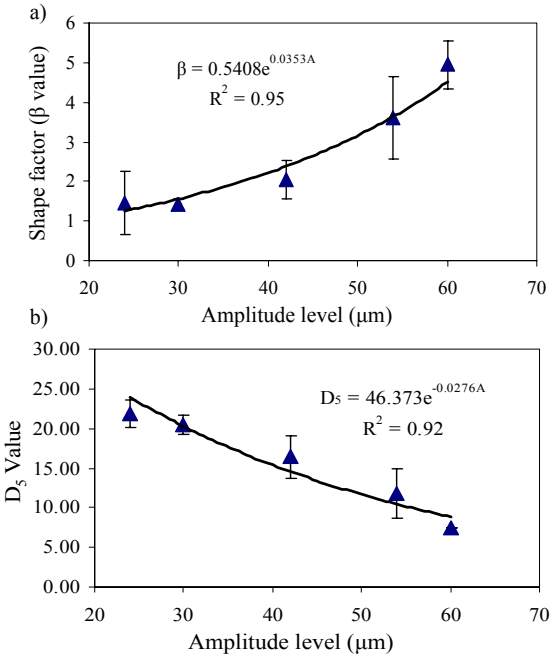

Figure 2. Effect of sonication on a) shape factor (β) and b) D_5 value on yeast inactivation

Conclusion

This study shows that the ultrasound alone at ambient temperature (25 ^{o}C) can achieve desired 5 log reduction. The Weibull model adequately describes the yeast inactivation. Modelling of survival curves of sonicated tomato juice yeast showed good fit with the Weibull distribution.

References

Barbosa-Canovas, G.V.; Gould, G.W. Innovation in food processing. Lancaster, UK: Technomic Pub. 2000.

Cheng, L. H.; Soh, C. Y.; Liew, S. C.; Teh, F.F. Effects of sonication and carbonation on guava juice quality. Food Chem. 2007, 104, 1396–1401.

Cunha, L.M.; Oliveira, F.A.R.; Oliveira, J.C. Optimal experimental design for estimating the kinetic parameters of processes described by Weibull probability distribution function, Journal of Food Engineering 37, 1998,175–191.

Deak, T. Handbook of food spoilage yeasts, Second Edition, 2007.

Furuta, M.; Yamaguchi M.; Tsukamoto T.; Yim, B.; Stavarache, C. E.; Hashiba K.; Maeda, Y. Inactivation of *Escherichia coli* by ultrasonic irradiation. Ultrasonics Sonochemistry 11(2), 2004, 57-60.

Gould, G. W. New processing technologies: an overview. Proceedings of the Nutrition Society. 2001, 60, 463–474.

Manso, M.C.; Oliveira, F.A.R.; Oliveira, J.C.; Frias, J.M. Modelling ascorbic acid thermal degradation and browning in orange juice under aerobic conditions, International Journal of Food Science and Technology 36 (3), 2001, 303–312.

Piyasena, P.; Mohareb, E.; McKellar, R. C. Inactivation of microbes using ultrasound: a review. Intl. J. Food Micro. 2004, 87, 207–216.

Suárez, M. H.; E.M. Rodríguez, E.M.; Romero, C.D. Chemical composition of tomato (*Lycopersicon esculentum*) from Tenerife, the Canary Islands. Food Chemistry, Vol. 106, Issue 3, 2008, 1046-1056.

Tsukamoto, I.; Yim, B.; Stavarache, C. E.; Furuta, M.; Hashiba, K.; Maeda, Y. Inactivation of Saccharomyces cerevisiae by ultrasonic irradiation. Ultrasonics Sonochemistry 11(2), 2004a, 61-65.

Ugarte-Romero, E.; Feng, H.; Martin, S. E.; Cadwallader, K. R.; Robinson, S. J. Inactivation of Escherichia coli with power ultrasound in apple cider. J. Food Sci. 2006, 71, E102 – E108.

Valero, M.; Recrosio, N.; Saura, D.; Munoz, N.; Martıc, N.; Lizama, V. Effects of ultrasonic treatments in orange juice processing. J. Food Eng. 2007, 80, 509–516.

van Boekel, M.A.J.S. On the use of the Weibull model to describe thermal inactivation of microbial vegetative cells. International Journal of Food Microbiology 74, 2002, 139–159.

Effect of different parameters on potato freezing rate with ultrasound assistance

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Abstract

Application of ultrasound to freeze food products is an emerging technology. With assistance of power ultrasound the freezing time of products can be reduced, and food products of higher quality can be obtained. In this study, different parameters, namely, ultrasound power, the position of the product in the ultrasonic tank and the exposure time are considered on the effect of potato freezing time.

Results from the present work showed that the characteristic freezing time is significantly reduced ($P<0.05$) when the sample holder is located at the bottom of the ultrasonic tank, and ultrasound is applied at 34.8 W intermittently for 2 min from 0°C. However, the other parameters had no significant effect for the operating conditions considered in this work though there was a reduction in the characteristic freezing time as compared to that of immersion freezing without ultrasound application.

Introduction

As it is well known, freezing as a method of preservation that has gained widespread attention. Although freezing can prolong the shelf-life of products, to some extent, freezing can alter the texture of food and hence its quality can be reduced. The main cause of this drawback is the formation of large ice crystals during the freezing process. In order to satisfy customers' growing request for high quality food products, many emerging technologies are under research in food processing to improve food quality. In particular, power ultrasound in food freezing process has been proposed and researched recently.

Actually, the application of ultrasound in food process is not very new. Ultrasound can be used to inactivate microorganisms to preserve food products (Harvey & Loomis, 1929); to improve the drying process when it is combined with static pressure (Gallego et al., 1999b) and it also can be used as an analytical tool to determine food material properties (Villamiel & de Jong, 2006b; Vercet et al., 2002b).

Slow freezing generally leads to large ice crystals that could damage cell structure, while rapid freezing can produce small ice crystals that lead to products of better quality. In such case, power ultrasound, a kind of ultrasound wave with low frequency and high intensity, has proved to be extremely useful in crystallization since it can affect both the nucleation and the crystal growth stages of solidification (Mason, 1998; Delgado et al., 2008). The prospect of applying power ultrasound is promising, however, this technology has not been completely expanded at present and further research is necessary.

The objective of this research is to analyze the effect of different parameters on the freezing rate of potatoes frozen by immersion freezing assisted by ultrasound.

Materials and Methods

Sample preparation

Fresh potatoes (79.44% w/w moisture content, wet basis) were bought in a local market and stored at 4 ± 1°C until use. The potato samples were cut into cylinders of 1.8 cm diameter and 2.5 cm height using a cork borer from the middle parenchyma of the vegetable. Each sample was quickly wrapped in tissue paper saturated with water to prevent browning reaction after cutting and kept in a refrigerator at a temperature of 4 ± 1°C to achieve uniform initial temperature until measurements were taken.

Equipment

The ultrasonic bath system (CQBF-1025, 726 Research Institute, China Shipping Company, China) was filled with a mixture of ethylene glycol and water (50%:50% in volume) which was used as coolant. The operation frequency of the ultrasonic tank is 25 kHz and the power range is 0-300W. The ultrasonic tank was well insulated in order to prevent heat losses to the surroundings.

The calorimetric method was used to determine the actual dissipated acoustic power by measuring the rate of temperature increase due to the conversion of ultrasound energy into heat (Ratoarinoro et al. 1995).
An USB TC-08 data logger from Pico technology was connected to a laptop for recording temperatures.

Procedure

A T-type thermocouple was inserted into the center of the sample after taking it from the refrigerator. The potato cylinders were placed in a metal cage, which has four thermocouples to record the fluid temperature during the trials. Special care was taken to position the sample holder in the same place, since intensity of ultrasound might vary with the position in the tank. The temperature of the ultrasonic tank was set at -18 or -20°C.
The time for the centre to transverse the temperature range from the initial freezing point to -7°C or characteristic freezing time was used to characterize the freezing rate (Ngapo et al., 1999).
Ultrasound was applied from 0°C with 30 seconds interval for each 30 seconds/15 seconds ultrasound, because the application of ultrasound generates heat which is negative to freezing. The exposure times were 2 minutes and 1 minute respectively. Different treatments are displayed in Table 1.
Freezing was considered finished when the centre temperature reached -18°C.

Table 1. *Ultrasound treatments*

Treatment	Exposure time(min)	Power level/(W)	Ultrasound application/ intervals(s)	Cage position
A	2	4/(34.8)	30/30	Centre
B	2	5/(78.3)	30/30	Centre
C	1	4/(34.8)	15/30	Centre
D	2	4/(34.8)	30/30	Bottom

Results and Discussion

In a previous work, Li and Sun (2002) found that the freezing rate was significantly enhanced when ultrasound was applied from 0°C at 15.85 W for 2 min in total on stick shape (7.6cm×1.7cm×1.7cm) potato samples. Table 2 shows the results obtained in this work, when potato cylinders (1.8cm diameter, 2.5cm length) were sonicated at 25 kHz for 2 min and 1 min exposure times, at different ultrasound powers levels and for different positions of the sample holder.
It can be observed that when ultrasound was applied at 34.8 W and the sample holder was in the middle of the tank and approximately at 2.5 cm above the bottom of the tank, the average characteristic freezing time was reduced from 7.19 min (control) to 6.83 min and 6.9 min for treatments A (2 min) and C (1 min) respectively, though the reduction was not significant ($P>0.05$) as compared to that of immersion freezing without ultrasound.
No effect was observed at power level 5 (treatment B) and the freezing rates were almost equal to those without the application of ultrasound. At higher ultrasound power more heat is produced by ultrasonic vibration (Sastry et al., 1989), and if this heat cannot be removed quickly due to limitations of the cooling equipment, the temperature of the refrigerating media will increase and might hinder the effect of ultrasound. It is important thus to consider this thermal effect when determining the optimum parameters that can improve the freezing rate.
A significant reduction ($P<0.05$) in the characteristic freezing time was observed for treatment D, when ultrasound was applied at 34.8 W for 2 min in total, with 30 s interval and the sample holder was placed in direct contact to the bottom of the sample. Figure 1 shows typical freezing curves obtained for potato samples frozen under treatment D and without the application of ultrasound, and for an average coolant temperature of -18 C. The sound waves can be absorbed by the fluid medium in which it transmits and converted into heat (Floros & Liang, 1994). Therefore, when the sample holder was set in the middle and at a certain distance from the bottom of the ultrasonic tank, the ultrasonic vibration might have probably been attenuated by the fluid through which it transmits. In addition, the sample holder used in this study was a cage made up with a rather tight and close metal mesh, which could have reduced the fluid flow around the sample and limit also the ultrasound transmission. In contrast, the positive effect of power ultrasound was more

noticeable when the sample holder was located in direct contact to the bottom of the ultrasonic tank.

Further experiments will be carried out to study the influence of the type of material that holds the sample (e.g. glass, plastic, etc) on the ultrasound transmission.

Table 2.*Characteristic time (t_{cf}) for potato samples*

Treatment	Characteristic freezing time(min)
Control (centre)	7.19
Control(bottom)	7.78
A	6.83
B	7.15
C	6.9
D	6.78

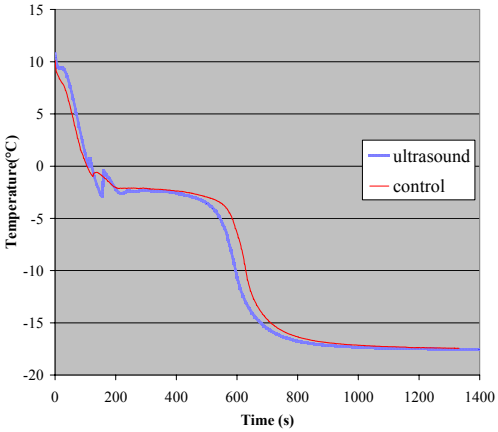

Fig. 1.*Comparison of freezing curves for potato samples frozen in the absence of ultrasound and under treatment D*

Conclusion

The use of ultrasound to assist the immersion freezing of potatoes and the effect of different factors (exposure time, sample holder position, acoustic power and geometry) was researched in this study.

Results showed that for the operating conditions tested in this work, all the parameters had effect on the characteristic freezing time, although was significant ($P < 0.05$) only when ultrasound was applied at 34.8 W from 0°C for 2 min in total, and the sample holder was placed in direct contact to the bottom of the ultrasonic tank.

In the practical point of view, it is important to consider both the enhancing effect of ultrasound on heat transfer and its thermal effect. This technology can be used to freeze other food products.

Acknowledgement

Grateful acknowledgement is made for information and support supplied by my mentor Dr Adriana Delgado and Professor Da-Wen Sun.

Reference

Delgado, A.E.,Liyun Zheng,Da-Wen Sun (2008) Influence of Ultrasound on Freezing Rate of Immersion-frozen Apples, Food and Bioprocess Technology, DOI 10.1007/s11947-008-0111-9

Floros JD, Liang HH (1994) Acoustically assisted diffusion through membranes. Food Technology, December, 79-84.

Gallego JA, Rodriguez-Corral G, Moraleda JCG, Yang TS (1999b) A new high-intensity ultrasonic technology for food dehydration. Drying Technology, 17, 597-608

Hagenson LC, Doraiswamy LK (1998) Comparison of the effects of ultrasound and mechanical agitation on a reacting solid-liquid system. Chemical Engeneering Science, 53, 131-148

Harvey E,Loomis A (1929) The destruction of luminous bacteria by high frequency sound waves. Journal of Bacteriology, 17,373-379

Li Bing, Da-Wen Sun (2002) Effect of power ultrasound on freezing rate during immersion freezing of potatoes, Journal of Food Engineering, 55(3), 277-282

Malcolm J.W. Povey and Timothy J. Mason, T.J. (1998) Power ultrasound in food processing-the way forward. In J.W. Povey and T.J. Mason (Eds.), Ultrasound in Food Processing, 105-126

Ngapo T.M., Babare I.H., Reynolds J., and Mawson R.F. (1999) Freezing rate and frozen storage effects on the ultrastructure of samples of pork. Meat science, 53, 159-168

Ratoarinoro Contamine, F. Wilhelm, A. M. Berlan, J. &Delmas H. (1995) Power measurement in sonochemistry. Ultrasonics Sonochemistry, 2(1), S43-S47

Sastry, S. K., Shen, G. Q., & Blaisdell, J. L. (1989) Effect of ultrasonic vibration on fluid-to-

particle convective heat transfer coefficients. Journal of Food Science, 54, 229–230.

Vercet A, Oria R, Negueruela I, Crelier S, Lopez-BuesaP(2002b)Manothermosonication effects on physical and optical properties of milk. Presented at First Innovative Food Centre Conference' Emerging Technologies for the Food Industry', Madrid (Spain).

Villamiel M, de Jong P (2000b) Influence of high-intensity ultrasound and heat treatment in continuous flow on fat, proteins and native enzymes of milk. Journal of Agriculture and Food Chemistry, 48, 472-478

DEVELOPMENT OF A FARM SCALE SUSTAINABLE NUTRIENT MANAGEMENT DECISION SUPPORT SYSTEM

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Abstract

The approach taken in developing a farm scale Sustainable Nutrient Management (SNM) Decision Support System (DSS) for the agriculture community in Ireland is described. There are 2 main aspects considered, the scientific/technical and the social/political. The main aim in taking this approach is to ensure the uptake and usage of the decision support system in the field.

Introduction

The Canadian Society for Bioengineering (Karmer et al., 2006) did a review on the decision making process for the design, selection and operation of manure management systems. Their findings were environmental considerations are always followed by agronomic considerations. Along with that two types of evaluation practices were evident, overall evaluation of the management system and the second type being one focused on a specific criterion. Few systems developed address whole farm decision making needs. Decisions for farm systems should be based on a three way trade off (1) the technical bio-physical aspects, (2) environmental aspects and (3) economic aspects (Stonehouse et al., 2002).

In 2002, Bob McCown of CSIRO went through the background of DSS's in Agriculture. The field of study evolved from operational research/Management Science and took many techniques for mathematically simulating processes from industry (McCown, 2002a). He highlights a problem seen in the industrial sector the "problem of implementation" and identifies how that same problem also appeared in DSS's in agriculture. They (McCown et al., 2002) then took 6 cases with experiences in building, implementing and designing a combined total of 44 DSS's in Agriculture. The six cases discussed highlight the social/political dimension of DSS development which is usually badly accounted for by system developers who are preoccupied with the scientific/technical aspect. McCown then probes the reasons behind the low use of agricultural DSS by farm managers (McCown, 2002b). It was seen that there was a resistance by family farmers to use systems in which their own decision process is bypassed and the systems designed to serve as a tool in a modified decision process had a greater acceptance. He concludes that expectations of farmer adoption and use of DSS needs to be addressed at the initial stages of DSS development.

Materials and Methods

Scientific/Technical Aspect of the SNM_DSS development

The farm scale sustainable nutrient management decision support system being developed here will address the whole farm decision. The overall decision will be based hierarchically on, no environmental impact followed by maximum utilisation of nutrients. This system develops upon the slurry spreading decision support system which has the fundamental heuristic for the potential of nutrient pollution from slurry spreading (Holden et al., 2007). The economic aspect of the decision will not be part of the DSS at this stage. The heuristics, in drawing from objected oriented components, will enable ease of further development of the system at later stages. The farm herd profile data will be obtained from the Department of Agriculture Fisheries and Food's (DAFF) animal movement identification system (AIMS). The soil moisture deficit (SMD) component will be drawn from the Met

Éireann system which is a 27 minute square area grid over Ireland (Figure 14) The component of the system which will calculate rate of production of slurry on the farm has been evaluated. The nutrient uptake and requirement component will be the next to be developed.

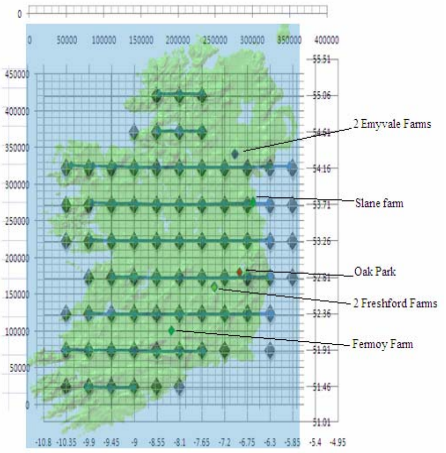

Figure 14. SMD grid over Ireland & 5 site locations

Social/Political Aspect of the SNM_DSS Development

To address this aspect of the system development, a stakeholder user group was formed with the use of a qualitative research approach. Moving from the positivist paradigm towards the interpretative paradigm was a move into unfamiliar territory. The methodology used for the first workshop held this January was a focus group meeting with a set agenda. 10 out of 14 of the group were in attendance; the group was politically diverse throughout the agricultural community in Ireland. The workshop provided a much unanticipated response to the development of the system. A very clear message came across from the group they wanted to know exactly "*how the system was going to end up being used",* for example, "*was it going to be part of legislation?"* An assumption had been made that the system developed based on sound science would be the best system. This scenario disrupted the workshop's set agenda and objectives as the query couldn't be answered there and then. The workshop however still provided good insight into the system development and design. The approach for the next stage is to develop the system taking the input data and have it deliver 2 pieces of advice, the current legislation advice and advice based on the best scientific knowledge available. Going forward a different approach with the stakeholder group will also be taken, action research. This approach "combines inquiry with action as a means of stimulating and supporting change and as a way of accessing the impact of that change" (Burns, 2007). The change here, being the change to the system that will ensure farmer expectations and farmer use of the system being addressed.

Results and Discussion

Scientific/ Technical aspect – A comparison of 3 methods for calculating the rate of production of manure on the farm.

The three methods compared were: Ireland's recommended method (S.I. No. 788 of 2005 – Sch 2 - Table 2), Northern Ireland's recommended method (Guid. Wrkbk Nitrates Action Programme (NI), Part 5-2, Table A) and the USDA NRCS specification for manure production (Part 651 Agr. Waste Management Field Handbook, Ch. 4 , Tables 4-5 and 4-8). The initial data from the 3 sites indicate that Irish Nitrates Directive is the closest to the 3 infield measurements (Figure 15). All Member States of the European Union have regulation based on a minimum storage capacity requirement and that is the figure used for Ireland and N. Ireland. In the USA, there is no such requirement and their figures are based on an actual production. There are significant differences in the calculations between the younger animals; this is swaying the Irish Nitrates directives to be closer to actual observed production at all 3 sites. The USDA figures are swayed by the much higher production rate of the dairy cow and younger animals. The actual figures applied are shown in Table 1. There is more data to be collected from the other farm sites in the project.

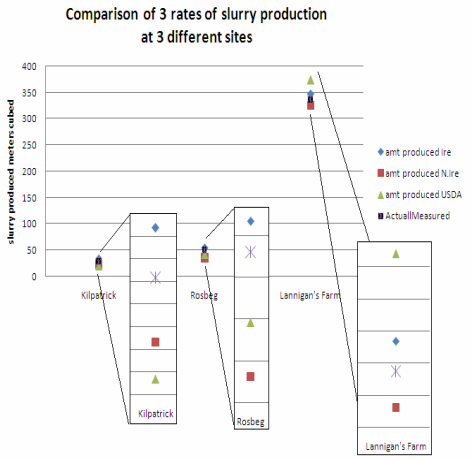

Figure 15. Comparison of 3 sites of actual manure production to 3 different methods of calculation

Table 1. Rates of manure production in 3 different countries for 7 Livestock Types

Livestock type	Irish Nitrates Directive	N.Ire Nitrates Active Programme	USDA ASAE Standards
	m3/day	m3/day	m3/day
Dairy cow	0.047143	0.052857	0.068
Suckler cow	0.041429	0.032857	0.038
Cattle > 2 years	0.037143	0.032857	0.022
Cattle (18-24 mo	0.037143	0.025714	0.022
Cattle (12-18 mo	0.021429	0.025714	0.022
Cattle (6-12 mon	0.021429	0.012857	0.022
Cattle (0-6 mont	0.011429	0.007143	0.0085

Social/ Political Aspect - The 1st workshop with the stakeholder user group.

It was important to form a politically diverse group. Members were selected from the ICMSA, IFA, Irish Farmers Journal, eREPS, ACA consultant, Teagasc consultant and the other members are farmers. The workshops 3 objectives were 1. To ensure the DSS can be easily deployed to the agricultural community 2. To ensure that the system is practical for the farmer while achieving a level of accountability that the Department can stand by. 3. To ensure that the system surpasses the value of the current system that is in use at the present time. After a discussion of the objectives the aim was to go through the system development stage of identification of the system users, their definitions, use cases and user stories. About 40 minutes into the discussion a request for the clarification of the use of the system was requested. This was the most significant learning from the workshop; it drove a clarification of the system aims and goals. The system will perform the functional role required by the DAFF with respect to nitrates regulation – it will inform the farmer how to comply with the legislation. The system will not provide the functional role of the Department of the Environment with respect to the nitrates regulation which is the auditing and enforcing of the compliance. There were many other outcomes from the workshop - there was a very relaxed atmosphere and willingness to engage passionately on this topic; there was scepticism about being listened to as they have not been listened to before. Stakeholders are kept up to date with the system progress and have the opportunity to provide their opinions on all aspects through the use of GoogleDoc's – the group shares a common workspace with the workshop presentations and spreadsheets available for each member to edit.

Conclusions

The object oriented approach to the system development makes it much easier to amend components and to keep the system up to date with adjustments. The use of data from other reliable sources (herd profile data, LPIS data) will reduce the data maintenance aspect and workload of the system. The value in engaging with stakeholders in the initial stages of decision support system development is already evident. Using the action research approach will probably yield a better quality outcome from the inquiry with the stakeholders.

Acknowledgements

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References

Burns, D., (ed.) 2007. Systemic Action Research, pp. 1-194. Policy Press, Bristol.

Holden, N.M., R.P.O. Schulte, and S. Walsh. 2007. A Slurry Spreading Decision Support System for Ireland. A workshop on Decision Support Systems. 25/01/2007 Teagasc Environemtnal Research Center, Johnstown Castle, Co. Wexford.

Karmer, S., C. Lague, J. Agnew, and H. Landry. 2006. Decision-Making process for the design, selection and operation of Manure Management Systems : A Review, pp. Paper No. 06-115 CSBE/SCGAB 2006 Annual Conference. The Canadian Society for Bioengineering, Edmonton Alberta.

McCown, R.L. 2002a. Locating agricultural decision support systems in the troubled past and socio-technical complexity of `models for management'. Agricultural Systems 74:11-25.

McCown, R.L. 2002b. Changing systems for supporting farmers' decisions: problems, paradigms, and prospects. Agricultural Systems 74:179-220.

McCown, R.L., Z. Hochman, and P.S. Carberry. 2002. Probing the enigma of the decision support system for farmers: Learning from experience and from theory. Agricultural Systems 74:1-10.

Stonehouse, D.P., G.W. de Vos, and A. Weersink. 2002. Livestock manure systems for swine finishing enterprises. Agricultural Systems 73:279-296.

Temporally Invariant Clusters for the Relative Normalisation of Multispectral Imagery

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Abstract
Relative normalisation is often the preferred method of radiometric correction when dealing with change detection studies. Temporally Invariant Clusters (TIC) can be used to identify radiometrically stable targets between two images by means of point density mapping of pixel values. TICs typically consist of urban environments, deep water bodies and mature conifer forests. In this study the TIC method was applied to a multi-temporal multi-sourced database of multispectral imagery. Subset areas of interest were used to force the selection of urban and water pixels in the point density plot.

Introduction
The radiance measured by any given satellite sensor in reference to a target object can be influenced by several factors such as changes in illumination, atmospheric conditions, viewing geometry and instrument response characteristics (Lillesand et al., 2004). These variables are compensated by means of radiometric correction. There are two types of radiometric correction: absolute and relative. Absolute correction refers to the use of operational algorithms such as 6S (Second Simulation of the Satellite Signal in the Solar Spectrum). 6S attempts to simulate atmospheric conditions at the time of image acquisition by compensating for atmospheric scattering and absorption of radiation (Vermote et al., 1997). The corrected image consists of the true reflectance of targets at the earth's surface (Hajj et al., 2008). Relative normalisation on the other hand, corrects all images to a base/master image, therefore the reflectance values of objects in the corrected images are relative to the master image. In this study, a multi-temporal multi-sourced database of multispectral imagery is being used to monitor vegetation change on Irish peatlands. After some initial investigations, the Temporally Invariant Cluster (TIC) (Chen et al, 2005) method of relative normalisation was selected. TIC uses a point density plot of two vegetation index images to locate a minimum of two TIC centers using linear regression. TICs need to be temporally stable in relation to spectral reflectance, and typically consist of concrete structures, roads, deep water bodies and mature conifer forests. As the TIC method only uses vegetation index images (e.g. NDVI, EVI, RSR), it reduces the computational effort and data storage required when compared to other methods which correct the whole image, channel by channel. **The objective of this study is to apply the TIC method of relative normalisation to multisource imagery in Ireland.**

Methods
The creation of TICs through a point density plot involves a number of procedures from a number of software programs. Figure 1 outlines the data flow from the multispectral database to the point density plot. The master image was selected on the basis of its spectral quality and its position in the temporal scale of the database. Once selected, the image was converted from DN (Digital Number) scale to at-sensor radiance (Wm^{-2} sr^{-1}) to facilitate cross calibration between sensors. Absolute radiometric correction was then performed on the master image via the 6S radiative transfer code. The remaining images in the database were co-registered to the master image and run though a DN to radiance subprogram.

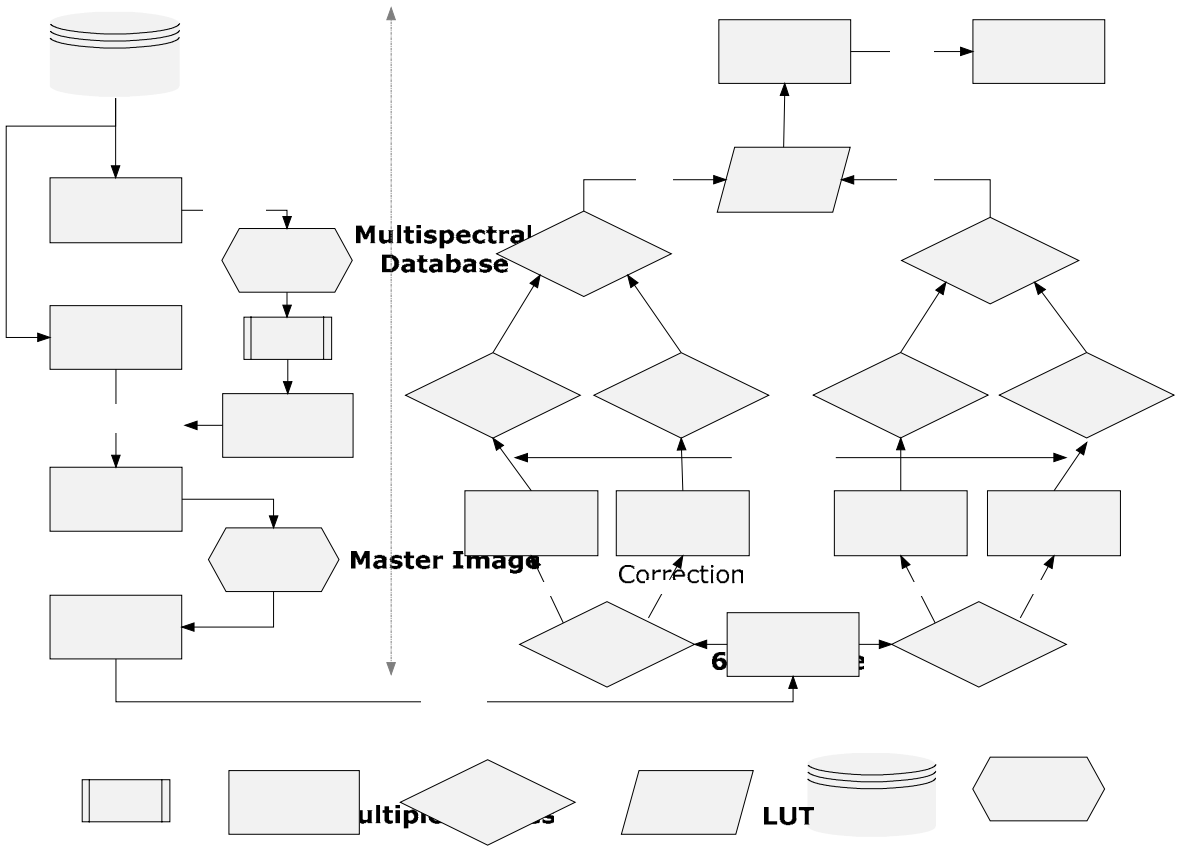

Figure 1. Data flow and procedures for TIC method or relative normalisation. The prefect 1 (water.ndvi.1) indicates data from NDVI image 1, and prefect 2 for NDVI image 2.

This program was created using Erdas Imagine's Spatial Modeler Language (SML), which is useful for automating processes that are beyond the remit of the standard Erdas interface. The resulting NDVI images were then transferred to a GIS (Geographical Information System) (ArcMap™) for point density analysis. In the GIS, the images were subdivided into homogeneous areas of water and urban pixels, to enable the production of distinctive unambiguous TICs in the density plot. Once the clusters were identified in the density plot, an r² regression line (Figure 2) was fitted to intersect with the two TIC centers.

Results

The key to success in the TIC method of relative normalisation is the delineation of unambiguous invariant clusters. In Ireland however, such invariant targets predominantly consist of urban and water pixels. This can make the selection of such targets limiting on a scene by scene bases due to the low density and fragmented nature of urban environments in Ireland.

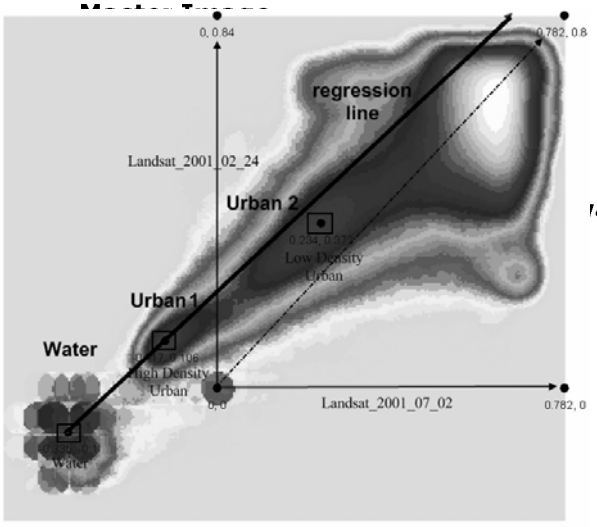

Figure 2. Density plot of subset NDVI images for Limerick.

Initial trials on complete and subset scenes produced a complex density plot, which made it difficult to accurately identify TICs. Urban clusters were elongated with high spectral variability, indicating that vegetation and soil were contaminating the signature.

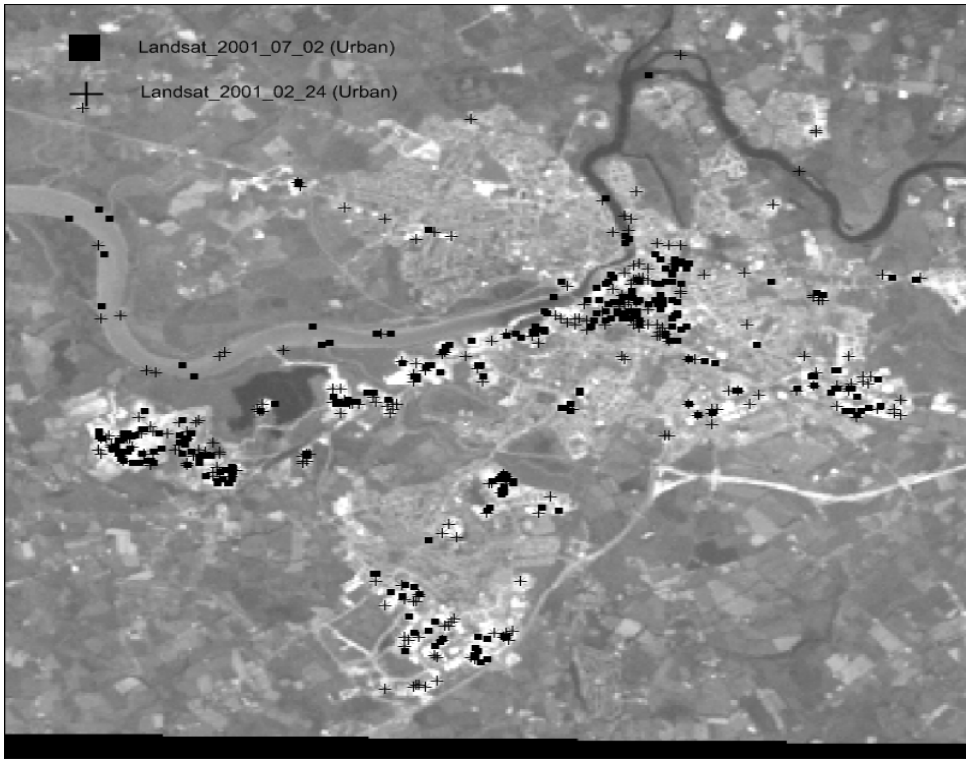

Figure 3. NDVI image of Limerick showing urban pixels identified in the density map for February and July of 2001.

It was decide to run a more subjective approach by extracting homogeneous pixels of urban and water from each image and plotting the resulting NDVI images on a density plot (Chen, personnel correspondence). The location of the TICs would be the same as the previous method, however identification of the TIC centres would be a lot easier due to the reduction in spectral diversity (Figure 2). In figure 2 the TIC Urban 2 consisted of mixed pixels of urban and vegetation (i.e. urban suburbs), and was therefore omitted from the regression analysis. Urban 1 (high density) and water were spectrally unique and allowed for the accurate delineation of the regression line. Figure 3 shows the close spatial correlation and location of selected urban pixels between the February 2001 image and the July 2001 image for Limerick city. The spectral similarity which was identified in the density plot is replicated in figure 3 with the spatial correlation between the urban subsets from the July image as to the February image. Pixels were extracted predominantly from areas of high urban development (e.g. roads, factory roofs, large buildings) justifying this method of water and urban subsets in the creation of a TIC density plot for a complete image.

Conclusion

The TIC method of relative normalisation shows good potential for NDVI images in Ireland. The use of homogeneous subsets gives a more subjective but focused density plot, which facilitates in a useable regression line. Further work needs to be done on the location of suitable urban subsets, where vegetation and soil contamination is minimised.

Acknowledgements

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References

Chen, X., L. Vierling and D. Deering, 2005. A simple and effective radiometric correction method to improve landscape change detection across sensors and across time, Remote Sensing of Environment, **98**(1), 63-79.

Hajj, M., El., A. Begue, B. Lafrance, O. Hagolle and M. Rumeau, 2008. Relative radiometric normalization and atmospheric correction of a SPOT 5 time series, Sensors, **8**, 2774-2791.

Lillesand, T.M., R.W. Kiefer and J.W. Chipman, 2004. Remote sensing and image interpretation, John Wiley & Sons Ltd Chichester, UK, 763 pp.

Vermote, E.F., D. Tanre, J.L. Deuze, M. Herman and J.J. Morcette, 1997. Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: an overview, Geoscience and Remote Sensing, IEEE Transactions on, 35(3), 675-6.

Evaluation of Pesticides risk ranking methods

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Abstract
Chemical ranking systems are used to assess chemical compounds in order to select those that are less harmful to environment and ecosystem health. The review of 14 existing ranking methods showed that they are different in terms of scale, effects and environmental compartments considered. Selection of a given method will thus depend on available data and end user requirements.

Introduction
In agriculture, pesticides are used to control weeds, pathogens (fungi, bacteria, viruses) and animal pests (insects, birds, rodents) which constitute a serious threat for crop yield. In this regard, a large variety of pesticides are known to kill such pests. Unfortunately, the use of pesticides can have potential adverse effects on human health and the ecosystem. Agrochemical compounds are the major contributor of non point-source pollution of water resources (Sharpley *et al.,* 2001); more specifically, pesticides are known to have toxic effects on humans, crops, livestock and wildlife (Schulz *et al.,* 2002). Levitan (2000), identified risks associated with the use of pesticides: unintended adverse effects on target biota, risk of pesticide residues on food, in water, soil and air, pest resistance, disease or loss of food and fibre, harm to natural or agro-ecosystem, cost for pest control. To avoid the negative effect associated with the use of pesticides, it is necessary to assess their risk for the environment. Chemical risk assessment is defined as the process of estimating the likelihood of a pollution event to occur and the consequences of that event (Refsgaard *et al.,* 2007). Hazard Identification which is the first step of chemical risk assessment involves gathering and assessing data on the type of environment and toxicological hazard that may be produced by a chemical. Several chemical or scoring approaches have been proposed to assess the potential hazard of chemicals (Reus *et al*., 2002).
In Ireland, planners and decision makers have no access to tools to minimise the adverse effect of the use of agrochemicals specially pesticides in agriculture.

The objective of this work is to review the existing modelling approaches with the view to identify approaches which are most applicable to Irish conditions

Models evaluation
Fourteen risk ranking models are identified (Table 1) and evaluated according to the following parameters:

1-Objectives or purpose
Various uses have been identified: regulatory action, priority setting, impact assessment, decision aid for farmers, ecolabelling to influence consumers, analytic tool for government, industry (Levitan, 2000; Davis *et al*., 1994; Reus *et al.,* 2002).

2-Scale of interventions
Most of the models are applicable only to the specific sites while others like EYP could be applied at site level as well as regional or national level.

3-Environmental compartments
Fate and behaviour of chemicals depend not only on their physicochemical properties but also on the chemical and physical processes involving in subsequent environmental compartments (air, sol, groundwater, surface water) (IEH, 2004).

4-Effects
Potential effects to the environment and the ecosystem were assessed through the following parameters: bioaccumulation, soil organism and aquatic organism (LC50, NOEC, LD50, NOEL, EC50),

human (LD50 for rat, ADI, Rfd) and bees LD50 for bees.

5-Stage of development
While some models are used in practice, most of the models reviewed are being tested or under development.

6-Score calculation
The scoring approach was based on ''x'' representing a score of 1. A score of each model was obtained by summing up the score of each of their parameters.

The parameter "Purpose" was not scored because this depends on the use of the model.

Table 1: Overview of risk ranking methods

N	Risk ranking models	Acronyms	Reference
1	Environmental yardstick protection	EYP	Reus *et al.,* 1994
2	Hasse Diagram	HD	Reus *et al.*, 2002
3	Synoptic model to evaluate plant protection product	SYNOPS	Reus *et al.,* 2002
4	Environmental performance indicator of pesticides	p-EMA	Reus *et al.,* 2002
5	Pesticide environmental impact indicator	Ipest	Reus *et al.,* 2002
6	Environmental potential risk indicator for pesticide	EPRIP	Reus *et al.,* 2002
7	System for predicting the environment impact of pesticides	SYPEP	Reus *et al.,* 2002
8	Pesticides environmental risk indicator	PERI	Reus *et al.,* 2002
9	Pestscreen	Pestscreen	Juraskle *et al.*, 2007
10	Chemical Hazard Evaluation for Management Strategies	Chems-1	Sawson *et al.,* 1997
11	Chemical scoring and ranking assessment model	Scram	Snyder *et al.,* 2000
12	Chemical Scoring model	CSM	Girando and Fuentes, 2000
13	Environmental risk index	ERI	Alister and Kogan, 2005
14	Risk ranking and identification of chemical hazard	RICH	Baun *et al.,* 2006

Results and Discussion

From Table 1, the following remarks could be made:

- Purpose: most of risk indicators are set for policy makers
- Scale of interventions: these risk indicators are applied directly at field level. Most of risk indicators reviewed were not flexible enough in order to be extended to regional or national level
- Environmental compartments: environmental compartments taken into account were not the same. However, most of these models have included at least 3 environmental compartments. Rarely, some of them were specialised to a specific compartment.
- Effects: human health, aquatic organism and soil organisms were the most common effect taken into account in the model.
- Stage of development: most of risk indicators are at pilot or testing stage.

In total, the highest score were obtained by Environmental Yardstick Protection (EYP) and Pestcreen.

However, it should be noticed that any risk indicator classification is variable and subjective due to the lack of standard agreement about data which has to be incorporated (Maud, 2000). Additionally, all parameters were weighted equally meaning that all environmental components have the same relative importance and this may bias the classification scheme.

Conclusions

Chemical ranking system can be used to assess environmental and toxicological risk. The systems reviewed differed in the methodologies, purpose, scale, environmental and toxicity endpoints. Among the 14 risk ranking systems reviewed, most of them are flexible and could be used with regard multiple environmental compartments, scale and biological effects.

Acknowledgements

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References

Davis, G.A and Sawson, M. (1994) Comparative evaluation of chemical ranking and scoring methodologies.

Haas, C.N., Rose, J.B., and Gerba, C.P. (1999) Quantitative microbial risk assessment. 466 pages.

Juraske, R., Anton, A., Castells, F., and Huijbregts,M.A.J. (2007) PestScreen: A screening approach for scoring and ranking pesticides by their environmental and toxicological concern. Environment International, (33) 886-8896.

Levitan, L. (2000) How ''to'' and ''why'': assessing the enviro-social impacts of pesticides. Crop Protection, 19 629-636.

Reus, J., Leendertse, P., Bockstaller, C., Fomsgaard, I., Gutsche, V., Lewis, K., Nilsson, C., Pussemier, L., Trevisan, M., van der Werf, H., Alfarroba, F., Blümel, S., Isart, J., McGrath, D., and Seppälä, T. (2002) Comparison and evaluation of eight pesticide environmental risk indicators developed in Europe and recommendations for future use. Agriculture, Ecosystems and Environment. 90 (2), 177-187.

Schulz, R., Thiere, G., and Dabrowski, J.M., (2002) A combined microcosm and field approach to evaluate the aquatic toxicity of azinphos-methyl to stream communities, *Environ. Toxicol. Chem.* 21 (10) 2172–2178

Sharpley, R.W., McDowell and Kleinman, P.J.A. (2001) Phosphorus loss from land to water: integrating agricultural and environmental management, Plant Soil. (237) 287–307.

Snyder, E.M., Snyder, S.A., Giesy, G.P., Blonde, S.A., Hurlburt, G.K., Summer, C.L., Mitchell, R.R. and Bush, B.M. 2000 SCRAM: A scoring and ranking system for persistent, bioaccumulative and toxic substances for the North American Great Lakes. Environ Sc & Pollut Res, 7(1)51-61.

Swason, M.B., Davis, G.A., Kincaid, L.E., Schultz, T.W., Bartmess, J.E., Jones, S.L and Goerges, E.L. 1997 A screening method for ranking and scoring chemical by potential human health and environment impacts. Environment Toxicology and Chemistry,16 (2) 372-383.

Oerke, E.C. (2005): Crop losses to pests. Journal of Agriculture Science, (144), 31-43.

O'Sullivan, E. (2004). Cereal diseases and fungicide resistance. In *National Tillage Conference proceedings 2004* (pp. 70-78). Oak Park, Carlow, Ireland: Teagasc Crops Research Centre.

Refsgaard, K., Kovar, E., Haarder and E. Nygaard, E. (2007). *Calibration and Reliability in Groundwater Modelling*. ModelCARE'07,83–88.

Table 1: Comparison of selected risk ranking models

Models	Purpose		Scale of interventions			Environmental compartments				Effects					Stage of development			
	advice to farmers	policy makers	crop or farm level	regional	national	air	soil	surface water	ground water	human health	aquatic organism	soil organisms	bioaccu mulation	bees	under develop ment	pilot /testing	used in practise	Total score
EYP	x	x	x	x	x		x	x	x		x	x	x	x			x	**13**
HD		x	x				x	x	x		x	x				x		**8**
SYNOPS		x	x	x	x	x	x	x			x	x					x	**9**
p-EMA	x		x			x	x	x	x	x	x		x	x			x	**11**
Ipest	x		x	x		x		x	x	x	x					x		**9**
EPRIP	x	x	x			x	x	x	x	x	x	x				x		**11**
SyPEP		x	x					x	X	x.	x					x		**7**
PERI	x		x			x	x		X		x	x	x	x	x			**10**
PestScreen		x	x	x	x	x	x	x		x	x	x	x	x		x		**13**
Chems-1		x		x	x			x		x	x	x	x			x		**9**
Scram		x	x	x		x	x	x		x	x	x	x			x		**11**
CSM		x		x					X	x						x		**5**
ERI		x	x			x	x			x		x	x	x		x		**9**
RICH		x		x				x			x					x		**5**

INTRINSIC VULNERABILITY ASSESSMENT OF GROUNDWATER POLLUTION FROM PLANT PROTECTION PRODUCTS

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Abstract

Plant protection products (PPPs) pose a serious dilemma; although their application contributes to the fight against poverty and diseases, at the same time these agrochemicals represent a significant public health threat. As part of Ireland's commitment to the WFD, the country's groundwater sources and resources have to be properly monitored and specific standards in groundwater quality need to be met. Vulnerability assessment is a methodology that evaluates the likelihood of an adverse event to occur and this information can be useful for pollution prevention and decision-making purposes. Recently, vulnerability assessment has been incorporated in the legislation of the EU and it is the subject of research in many member states. Intrinsic vulnerability assessment considers only the hydrological, hydrogeological and geological characteristics of the area, regardless of the characteristics of the PPPs. This paper provides a review and comparison of the most important methods used in intrinsic vulnerability assessment of groundwater. The comparison showed that the COP index-based method is one of the most suitable methods to be applied in Ireland.

Introduction

The widespread application of PPPs in natural ecosystems has significantly deteriorated their quality and contributed to serious health problems to humans (Suzawa and Ingraham 2008). The concern over groundwater quality prompted the European Union (EU) to establish an effective and up-to-date legislation framework. The most recent regulatory framework has been established in 2000 with the "Water Framework Directive" (WFD 2000/60/EC). According to the aforementioned directive, every country member is responsible for delineating the groundwater bodies within a River Basin District (RBD) and classifying these according to the potential impact from anthropogenic activities. Additionally, for every RBD a river basin management plan (RBMP) has to be produced. The objective of the RBMP is to provide an integrated water management so that all waters (ground and underground) are protected and good status is achieved by 2015. The conceptual basis of groundwater protection schemes is related to the notion of groundwater vulnerability assessment. Vulnerability has been defined by the National Research Council (NRC 1993) as "the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer". Intrinsic vulnerability assessment is performed by combining the available hydrogeological, geological, and hydrological factors of the area of study (Daly et al., 2002). A similar approach has been followed in Ireland where the Irish Groundwater Protection Scheme (DELG/EPA/GSI, 1999) has created maps of vulnerability based on the following data: subsoil permeability and thickness, presence of karst features, and vadose zone thickness for two materials, sand and gravel (Swartz et al., 2004). The disadvantage of the method is that the produced vulnerability maps mainly focus on point sources of pollution neglecting the non-point sources of pollution such as the PPPs (Daly and Warren, 1998).

The objective of this work is to determine the most suitable method for the assessment of groundwater pollution likelihood from PPPs in Ireland.

Materials and Methods

Process

Intrinsic vulnerability is assessed by using a group of methods known as index-based methods. The most frequently used methods are classified into two groups, the Rating Systems (RS) and the Point Count System Models (PCSM) (Gogu and Dassargues, 2000). The outcome of these methods is a categorical or numerical index, which provides a semi-quantitative estimation of intrinsic vulnerability. Different parameters can be used, which are combined by assigning them with a value and consequently by adding or multiplying these values with each other. For PCSM methods, weight coefficients are also applied on the parameters' values to enhance their importance. The process of estimating a vulnerability index is depicted in figure 1.

Description of the Methods

GLA, AVI, GOD, PI, and COP form the group of the RS methods while EPIK, DRASTIC, and SINTACS form the group of the PCSM methods that will be presented in this work. The GLA method is considered suitable for regional scale applications, as it requires data that are already available in most of the European countries (Lamelas et al., 2007). According to Goldscheider (2005), however, the method lacks the efficiency of other methods (e.g. PI) in assessing the vulnerability likelihood of karst areas. AVI is one of the simplest index-based methods, as it requires only two parameters to assess vulnerability. On the other hand, by using a small number of parameters the method neglects significant processes that occur in the soil and vadose zone (Wei, 1998). GOD is another simple method the main advantage of which is that it requires a limited amount of data. A number of studies have reported that GOD produces significantly different results from other methods and overestimates the vulnerability (Lobo-Ferreira and Oliveira, 2004). The PI method is a modified version of the GLA method that focuses on the assessment of intrinsic vulnerability in karst areas (Goldscheider et al., 2005). PI is an advanced method that produces accurate and consistent results. The COP method, which has been developed under the specifications of the COST-620 workgroup, uses the hazard-pathway-target conceptual model to assess groundwater vulnerability (Vias et al., 2006; Daly et al 2002). It is the first method to make extensive use of validation techniques such as tracer tests, hydrographs, and chemographs (Vias et al., 2006; Andreo et al., 2006). EPIK was the first method to focus on the peculiarities of karst aquifers and some of its characteristics have been incorporated in other newer methods (Goldscheider et al., 2005). Its main disadvantage is, however, that it can only be applied to karst areas. DRASTIC has been created by the US Environmental Protection Agency (EPA) and is probably the most frequently used vulnerability assessment method. Many modifications of the method have been created so far to remedy known shortcomings concerning its performance (Guo et al., 2007). However, there are concerns over redundancies with regard to the parameters used (Guo et al., 2007), and it has been reported that vulnerability can be underestimated in fractured bedrock media (Wei, 1998). SINTACS is an adaptation of DRASTIC to the Italian conditions (Civita and De Mayo, 1997). It uses the same parameters as DRASTIC but it has adopted a different rating and weight system. It has been found to be well suited for the conditions of the Mediterranean basin (Corniello et al., 2004).

Results and Discussion

Comparison

The parameters of each method are presented in Annex 1. An estimation of the functionality of the methods is provided in the Total Score column. The Total Score has been calculated with the following formula: Total Score = ΣBasic Parameters

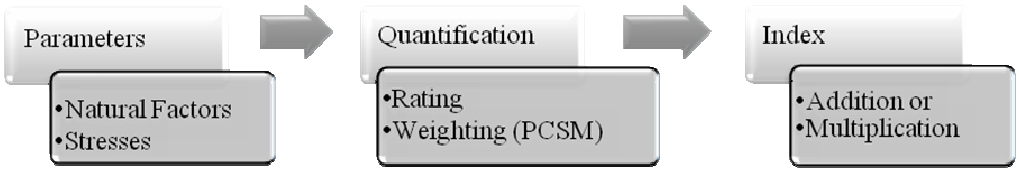

Fig.1 The process of PCSM and RS methods.

– Complexity + Applicability. The sum of the Basic Parameters has been calculated by assigning one point for every X in the Annex 1 and consequently adding these points. To estimate the relative complexity and applicability, a value from 1 to 4 (lower to higher) has been based assigned to each method based on several comparative studies, which are presented in Table 1.

Table 1. Comparative Studies

Order (From the worst to the best)	Study
PI->COP	Andreo et al., 2006
EPIK->DRASTIC->GLA->PI	Neukum and Hotzl, 2007
AVI-> GOD->SINTACS-> DRASTIC	Lobo-Ferreira and Oliveira, 2004
GOD->DRASTIC	Mendoza and Barmen, 2006
GLA->EPIK->PI	Goldscheider, 2005
DRASTIC-> SINTACS->PI->COP	Mustafa and Topkaya, 2007

Results

The Total Score column shows that the COP method is the most advanced technique for the assessment of intrinsic vulnerability. COP incorporates specific parameters for karst systems while at the same time is applicable to all other areas. If it was to be applied in Ireland, however, it would be needed to be modified. In terms of data availability the following datasets could be used: topsoil and subsoil thickness and permeability, vadose zone media, karst features, topography, precipitation, and vegetation. The thickness of the vadose zone is not taken into account in Ireland, as little attenuation occurs in the bedrock due to the flow occurs largely through fissures (DELG/EPA/GSI, 1999). Specific parameters would also need to be revised as the method has been developed to be applied in the Mediterranean conditions (Vias et al., 2006). It would be also useful to explore the possibility of using fuzzy logic to reduce the number of parameters required by the method. Fuzzy logic can preserve more information than other methods and produce comparable results with the use of about 40% fewer variables (Bardossy & Disse, 1993).

Conclusions

This study has compared and evaluated the most advanced index-based methods that are currently available. According to the final index, the highest score is yielded by the COP method and this outcome is in accordance with the findings of other works. It should be noted, however, that vulnerability assessment is a case-specific study, and the appropriateness of a method is largely determined by the available data, the application goals and the needs of the end-users (Civita and De Maio, 2004). In addition, the implementation of more than one method might be necessary as a means to validate the results. Apart from cross-validation, the use of tracer tests and other validation techniques recommended by the COST-620 workgroup should also be considered.

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References

Andreo, B., Goldscheider, N., Vadillo, I., et al. 2006. Karst groundwater protection: First application of a Pan-European Approach to vulnerability, hazard and risk mapping in the Sierra de Líbar (Southern Spain) Sci Tot Environ 357(1-3):54-73

Bardossy, A., and Disse, M. 1993. Fuzzy rule-based models for infiltration. Water Resou Resea, 29(2):373–382.

Civita, M. De Maio, M. 2004. Assessing and mapping groundwater vulnerability to contamination: The Italian ‘‘combined’’ approach. Geofisica Int 43(4):513–532

Corniello, A., Ducci, D., Monti, G.M. 2004. Aquifer pollution vulnerability in the Sorrento peninsula, southern Italy, evaluated by SINTACS method. Geof Inter 43(4):575-581

Daly, D.,•Dassargues, A.,•Drew, D.,•et al. 2002. Main concepts of the European approach to karst groundwater

vulnerability assessment and mapping. Hydrogeol J 10:340–345

Daly, D., and Warren, W.P. 1998. Mapping groundwater vulnerability: the Irish perspective. Geological Society of London 130:179-190

DELG/EPA/GSI. 1999. Groundwater Protection Schemes. Available at: http://www.gsi.ie/Programmes/Groundwater/Projects/Protection+Schemes+Guidelines.htm#categories

Gogu, R., and Dassargues, A. 2000. Current and future trends in groundwater vulnerability assessment. Environmental Geology 39(6):549-559.

Goldscheider, N. 2005. Karst groundwater vulnerability mapping: application of a new method in the Swabian Alb, Germany. Hydrogeology Journal, 13(4): 555-564

Guo, Q., Wang, Y., Gao, X., Ma, T. 2007. A new model (DRARCH) for assessing groundwater vulnerability to arsenic contamination at basin scale: a case study in Taiyuan basin, northern China. Environ Geol 52:923–932

Lamelas, M.T., Marinoni, O., Hoppe, A. et al. 2007. Groundwater vulnerability map for the Ebro alluvial aquifer between Jalo´n and Ginel tributaries (Spain) Environ Geol 53:861–878

Lobo-Ferreira, J.P., and Oliveira, M.M. 2004. Groundwater vulnerability assessment in Portugal. Geofísica Internacional, Vol. 43, Num. 4, pp. 541-550

Mendosa, J.A., and Barmen, G. 2006. Assessment of groundwater vulnerability in the Rıo Artiguas basin, Nicaragua. Environ Geol 50: 569–580

Mustafa, Y., Topkaya, B. 2007. Groundwater Protection: A Comparative Study of Four Vulnerability Mapping Methods. Clean 35 (6), 594 – 600

Neukum, C., and Hötzl, H. 2007. Standardization of vulnerability maps. Env Geol 51(5): 689–694

NRC (US), 1993. Ground Water Vulnerability Assessment:Predicting Relative Contamination Potential Under Conditions of Uncertainty. 224 p

Swartz, M., Misstear, B.D.R., Daly, D., et al. 2003. Assessing subsoil permeability for groundwater vulnerability. Quart. J. of Eng. Geol. And Hydrol. 36(2):173-184

Suzawa, M., and Ingraham, H.A. 2008. The Herbicide Atrazine Activates Endocrine Gene Networks via Non-Steroidal NR5A Nuclear Receptors in Fish and Mammalian Cells. PLoS ONE 3(5): e2117

Vias, J.M., Andreo, B., Perles, M.J., et al. 2006. Proposed method for groundwater vulnerability mapping in carbonate (karstic) aquifers: the COP method. Hydrogeol J 14: 912–925

Wei, M. 1998. Evaluating AVI and DRASTIC for assessing ground water pollution potential in the Fraser Valley. In: 51st Annual Canadian Water Resources Association Conference

WFD 2000/60/EC of the European parliament and of the council. Establishing a framework for Community action in the field of water policy, Official Journal of the European communities L 327/1 of 22 December 2000, 1–72.

Annex 1. The basic parameters and evaluated functionality of the methods

Method	Type	Basic Parameters																			Functionality		
		Soil					Vadose Zone				Sat. Zone			Water									
		Thickness	Permeability	Effe. Moist.	Texture	Hydr. Condu.	Thickness	Lithology	Confin Cond	Epikarst	Hydr. Condu	Aq Media.	Active Kar	Point Flow	Net Recha	Topograph	Vegetatior	Precipitation	Depth to GW	Complexity	Applicability	Total Score
DRASTIC	PCSM				X	X		X			X	X			X	X			X	2	3	9
SINTACS	PCSM				X	X		X			X	X			X	X			X	3	3	8
AVI	RS	X				X	X				X									1	2	5
EPIK	PCSM	X	X							X			X	X		X	X			2	2	7
GOD	RS				X			X	X										X	1	2	5
PI	RS	X	X	X	X		X	X	X	X		X		X	X	X	X			4	3	12
COP	RS	X	X		X		X	X	X	X		X	X	X		X	X	X		4	4	13
GLA	RS	X		X	X		X	X	X						X					2	3	8

WATER QUALITY RISK ASSESSMENT: ANTIMICROBIAL AGENTS AND ANTIMICROBIAL RESISTANCE

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Abstract

Ciprofloxacin, a commonly prescribed fluoroquinolone (antibiotic), can pose a threat to the environment and human health. Its presence can lead to geno-toxic effects on humans such as Achilles tendon disorders, and the occurrence of resistance to form within its target population- *E. coli*. A risk assessment framework model is presented which can be used to determine the human exposure to ciprofloxacin in the environment and assist in the formation of statutory requirements to help combat any risks identified.

Introduction

Antibiotic consumption in Ireland has been rising continuously (The National disease surveillance centre of Ireland reported increases of antibiotic consumption between 1993 and 2002, of 16.3 to 20.3 DID respectively, where DID is the defined daily dose per 1000 inhabitants per day). Currently the highest persisting antimicrobial residues found in drinking water in Ireland are quinolones and fluoroquinolones (Andreu, 2007). Their wide use can lead to the development of residues in the aquatic environment and sewage sludge and their low concentrations can lead to their presence being 'over-looked'. McGowan *et al*. (2008) reported that Ciprofloxacin, one of the most commonly prescribed antibiotics in Ireland (accounting for 54% of the total consumption of quinolones), has increased; by 97% between 2000 and 2005. Antibiotic consumption has been linked to the formation of antibiotic resistance.

Goossens *et al*. (2005) identified that (in Europe) the levels of antibiotic consumption correlated with the geographical variation of resistance.

The fundamental question is what risk does the trace antibiotics pose for aquatic ecosystems and the risk to human health?

The objective of this project is to create a framework risk assessment model which evaluates the risk associated with antibiotic (ciprofloxacin) consumption, the formation of resistant *E. coli* and the risk of therapeutic failure.

Ciprofloxacin

Quinolones are a family of broad spectrum antibiotics. Ciprofloxacin is a Fluoroquinolone, a subset of quinolones (which have a fluoro group attached to the central ring system). Fluoroquinolones have excellent antibacterial activity, high bioavailability, and a wide spectrum of applications (Stahlmann and lode, 1988). Fluoroquinolones can have many adverse effects on the body including musculoskeletal system defects and Achilles tendon disorders being the most widely reported side effect (in relation with quinolone use) (Huston 1994; Van der linden *et al*., 1999). Fluoroquinoles target DNA gyrase, an essential bacterial enzyme (Crumplin *et al*., 1984; Drlica, 1984). The drugs bind to the A subunit of the bacterial enzyme DNA gyrase thus block DNA replication. This simple action of fluoroquinolones can lead to

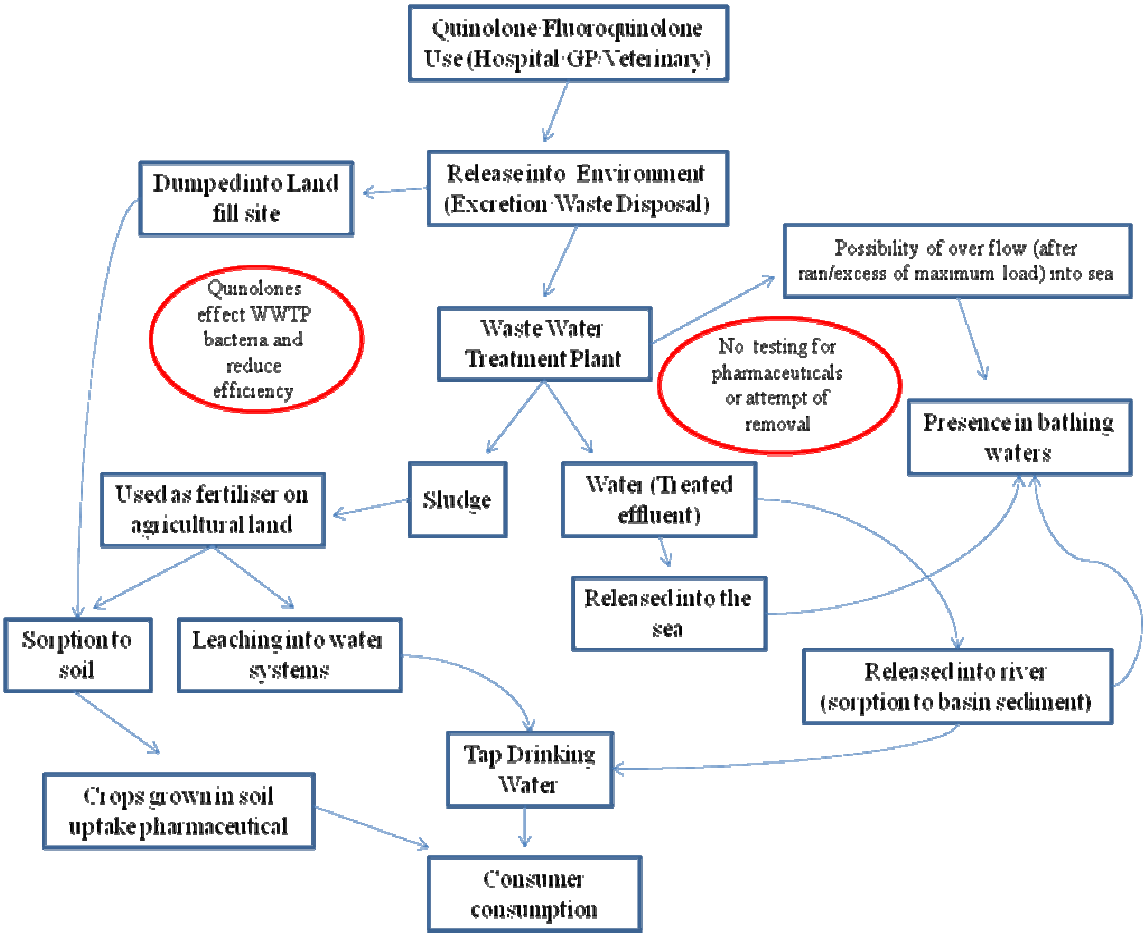

Figure 1: Framework structure for simulating Human exposure to ciprofloxacin resi

the easy formation of resistance, and a single step spontaneous mutation (to high level resistance) could lead to a cross resistance of many fluoroquinolones (Crumplin *et al*., 1984; Hessen and Muytjens, 1984). Therefore the emergence of resistance (Reports of which have been well documented; Kern *et al*., 1994; Llordes *et al*., 1993; Canawati *et al*., 1997) seems very probable if necessary methods are not put into place to reduce this risk.

Methods to reduce the risk of the formation of resistance

A risk assessment model will be created to evaluate the risk associated with antibiotics in the water ways leading to therapeutic failure (i.e. resistance) this will assist the policy makers in the formation of requirements to combat any identified risks.

Wolfson and Hooper (1985) suggest that the only method for determining whether the emergence of bacterial resistance will become a clinical problem is by active monitoring for resistant organisms in clinical studies.

Koschorreck *et al*. (2002) recommend restricted application rates of medicinal products, prolonged sewage storage, limitations to sewage spreading and extensive monitoring of fate and effects after authorisation, as possible mitigation measures.

Giger *et al*. (2003) suggest specialised treatment of hospital waste as a possible method to reduce antibiotic

levels in the aquatic environment. Advanced treatment of hospital waste waters such as; reverse osmosis, activated carbon and ozonation have been shown to reduce or eliminate antibiotics (Huang *et al*., 2001; Sedlak and Pinkstob, 2001). Reduced sludge spreading also is another possible method to reduce the amount of pharmaceuticals entering the water ways, the disposal of sewage sludge into agricultural fields has been totally forbidden in Switzerland since January 2003.

Materials and Methods

Work to date

A literary review is currently being created to review current risk assessment methodologies and to determine international best practice. A model framework was created (Fig 1) for simulating human exposure to Ciprofloxacin resistant *E. coli*. Quinolone/Fluoroquinolone use can lead to its entry into the environment via excretion/disposal. Their presence in the water-ways and sludge allows for *E. coli* exposure; potentially leading to the formation of resistance. The presence of antibiotics in drinking and bathing water, and on agricultural land can lead to human consumption and illness. If a patient becomes ill with resistant *E. coli* and are treated with ciprofloxacin this could cause therapeutic failure. Ciprofloxacin could become ineffective to *E. coli*.

For future work further refinement of the framework will take place and a quantitative risk assessment model will be constructed.

Results and Discussion

Figure 1 above shows the framework model structure developed for simulating Human exposure to ciprofloxacin resistant *E. coli* and stages which will be analysed in the quantitative risk assessment model.

Conclusions

Ciprofloxacin entering the waterways can potentially harm the environment and human health. Their presence can lead to muscular disorders in humans and the development of resistant *E.coli* within the environment; leading to therapeutic failure. A framework model is proposed to facilitate further development of a quantitative risk assessment. Antibiotics in the water ways could pose a major problem if they are not assessed and continuously monitored, and the relevant mitigation measures instigated.

Acknowledgements

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References

Andreu, V., Blasco, C., Pico, Y. (2007). Analytical strategies to determine quinolone residues in food and the environment. *Trends in Analytical Chemistry*. **26**(6):534-556.

Canawati, H. N., El-Farra, R., Seymour, J., Shimashita, J., Dunn, D. and Montgomerie, J. Z. (1997). Ciprofloxacin-Resistant Escherichia coli Emerging in a Rehabilitation Medical Center. *Diagn Microbiol Infect Dis*. **29:**133-138.

Crumplin, G. C., Kenwright, M., Hirst, T. (1984). Investigations into the mechanism of action of the antibacterial agentnorfloxacin. *J. Antimicrob. Chemother*. **13**(Suppl.B): 9-23.

Drlica, K. (1984). Biology of bacterial deoxyribonucleic acid topoisomerases. *Microbiol. Rev*. **48**:273-289.

Giger, W., Alder, A., Golet, E., Kohler, H-P., McArdell, C., Molnar, E., Siegrist, H., Suter M., (2003). Occurrence and Fate of Antibiotics as Trace Contaminants in Wastewaters, Sewage Sludges, and Surface Waters. *Chimia*. **57**:485-491.

Goossens, H. Ferech M. vander stichele R. *Et al*.., (2005). Outpatient antibiotic use in Europe and association with resistance: a cross national database. *Lancet*. **365**:578-587.

Heessen, F. W. A., Muytjens, H. L. (1984). In vitro activities of ciprofloxacin, norfloxacin, pipemidic acid, cinoxacin, and nalidixic acid against Chlamydia trachomatis. *Antimicrob.Agents Chemother*. **25**:123-124.

Huang, C. H., Renew, J. E., Smeby, K. L., Pinkerston, K., sedlack, D. L. (2001). Assessment of potential antibiotic contaminants in water and preliminary occurance analysis. *Water Resour. Update*. **120**:30-40.

Huston, K. A. Achilles tendinitis and tendon rupture due to fluoroquinolone antibiotics. *N Engl J Med*. **331**:748.

Kern, W. V., Andriof , E., Oethinger, M., Kern, I'., Hacker, J., Marre, R. (1994). Emergence of fluoroquinolone-resistant *Escherickia coli* at a cancer center. *Antimicrob Agents Ckemotker.* **38**:681&87.

Koschorreck, J., Koch, C., Rönnefahrt, I. (2002). Environmental risk assessment of veterinary medicinal products in the EU—a regulatory perspective. *Toxicology Letters*. **131**:117–124.

Llordes, M., Xercavins, M., Qunitana, S., Carau, J. (1993). Emergence of ciprofloxacin in *Esckerichia coli.* In: *Program and Abstracts off the 6th European Congress of Clin Microbial lnf Dis.* Abstract 104:28-31.

McGowan, B., Bergin, C., Bennett, K., Barry, M. (2008). Utilisation of Antibiotic Therapy in Community Practice. *Irish Medical Journal*. **101**(9): available at http://www.imj.ie//Issue_detail.aspx?issueid=+&pid=3655&type=papers

Sedlak, D. L., Pinkston, K. E. (2001). Factors affecting the concentrations of pharmaceuticals released to the aquatic environment. *Water Resour Update*. **120**:56–64.

Stahlmann, R., Lode, H. (1988). Safety overview: toxicity, adverse effects and drug interaction, *In* V. Andriole (ed.), the quinolones. Academic Press, London, England. 201-235.

Wolfson, J. S., Hooper, D.C. (1985). The Fluoroquinolones: Structures, Mechanisms of Action and Resistance, and Spectra of Activity in Vitro. *Antimicrobial agents and Chemotherapy*. **28**: 581-586.

Van der Linden, P. D., Van de Lei, J., Nab, H.W., Knol, A. Stricker B. H. Ch. (1999). Achilles tendinitis associated with fluoroquinolones. *Br J Clin Pharmacol*. **48**:433-437.

A PREDICTIVE HUMAN EXPOSURE SCOPING MODEL FOR NANO-FUNCTIONALISED PRODUCTS AND PROCESSES

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Abstract

Risk assessments that explicitly consider the human and environmental exposure potential of nano-functionalised products and processes are required for regulatory frameworks. There is a large range of products commercially available, with many more products and processes in development, awaiting regulatory clarification. A scoping model, Nano-EXP, is presented, which describes potential environmental nano-quantities and behaviours arising from the environmental use of products and processes. Potential surface water nanomaterial quantities are determined for various products, with the following scale from highest to lowest: 1. Groundwater remediation, 2. Exterior paints, 3. Fuel additives, 4. Food packaging.

Introduction

Nanotechnology and nanomaterials are currently being explored and developed for many different industrial uses due to their unique physical and chemical properties (O'Brien and Cummins, 2008). The range of nanomaterials currently available in consumer products includes carbonaceous materials, semi-conductor materials, nano-polymers, metal oxides and zero-valent metals. Those environmentally relevant nano-materials (TiO_2, Ag, Fe_2O_3, CeO_2) and their usage in commercial products and processes (Photo-catalytic paints, anti-microbial coatings, water treatment, bioremediation, fuel additives) are of particular interest when addressing human exposure issues from environmental pathways.

Other potentially hazardous materials have been traditionally controlled through regulation regarding their usage, containment and disposal. In some cases regulation of certain materials was implemented in light of studies highlighting their human or environmental toxicity, as in the case of the synthetic pesticide Dichlorophenyltrichloroethane (DDT), lead in paints and coatings, and asbestos. Until comprehensive fate and toxicity studies have been completed (OECD, 2008) and the relevant nano-specific regulation implemented, responsible industries will be forced to employ a precautionary approach to nanomaterial development to avoid setting a precedent that irreparably damages the image of nanotechnology to consumers or environmental advocacy groups.

Nanomaterial is currently handled, monitored and disposed of as a hazardous material in the vast majority of research and industrial processes (ICON, 2006); however there are currently very little nano-specific data regarding a commercial products usage, containment or disposal. The form in which a nanomaterial is contained within a specific product, its methods of usage and disposal/release, and subsequent treatment upon disposal will be central to assessing and ultimately reducing the potential risk posed by nanomaterials to environmental and human health.

The objective of this study is to predict environmental quantities of nanomaterials resulting from environmentally relevant products and processes, describe their potential behaviour and assess subsequent human exposure potential.

Materials and Methods

The exposure model, Nano-EXP, employs methods of qualitative analysis, developed from food risk management (Ross and Sumner, 2002). In addition, multi criteria decision analysis (MCDA) (Linkov et al.

2007) is used to allow a description of potential environmental behaviours and mechanisms of nanomaterials and the comparison of different exposure end-points (O'Brien and Cummins, 2009). Stage 1 of this model, nanomaterial released to surface water, may be seen in Figure 1.

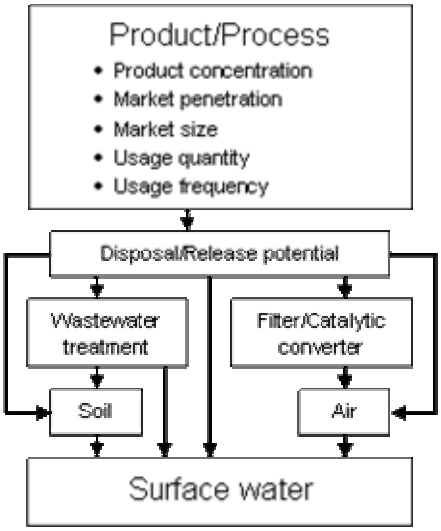

Figure 1: Nano-EXP – Stage 1

Product/process and market characteristics were employed in order to assess the potential nanomaterial quantities that may be released. Their release potential was assessed by means of a release/disposal matrix developed from previous nano-specific studies, as well as metals and chemical studies. Those categorisations of relevance to the case studies examined in this paper may be seen in Table 1. Release potential is determined by means of material form, product/process categorisation and release pathway.

The wastewater treatment descriptors in the model were based on treatment levels commonly associated with Ireland (EPA, 2007a). The effectiveness of these treatment levels on nanomaterial removal was based on particulate, metals and pathogen removal studies and theory. The specific catalytic converter/filter descriptors in the model were based on situations that may be relevant to the filter systems associated with Irish automobiles. The effectiveness of these filter systems on nanomaterial removal were based on previous nanoparticulate studies. There are various levels of uncertainty associated with these treatment factors and this is reflected in the distributions employed in the model (Table 2).

Deposition onto surface waters assumes all suspended material eventually settles, with no movement into or outside of Ireland's boundaries. The fraction of mainland Ireland covered by water is approximately 2 %, however, in this model it is taken as 5 % as it is assumed most nanomaterial release will take place in urban areas, which are generally centred around or close to water bodies, increasing the relative fraction settling onto water.

Leaching from wastewater treatment sludge applied to agricultural land to surface water is determined from a study modelling diffuse-source surface water exposure to "down-the-drain" chemicals (Kannan et al. 2007).

Table 1: Release/Disposal matrix

Phase	C_{pha}	Liquid Suspension	Liquid Suspension	Liquid Suspension	Embedded/Bound
Product/Process	C_{pro}	Paints & coatings	Fuel additives	Bioremediation	Food packaging
Environmental release					
Air	R_{air}	0	$1 - (\Sigma R_3)$	0	0
Drinking water	R_{dri}	0	0	0	0
Surface water	R_{sur}	Normal(24.375,2.964)		Normal(5,0.608)	0
Ground water	R_{gro}	0	0	Normal(10,1.216)	0
Soil	R_{soil}	Normal(24.375,2.964)		$1 - (\Sigma R_4)$	0
Treatment					
Wastewater treatment	R_{ww}	Normal(2.5,0.152)	Normal(0.5,0.061)	Normal(0.5,0.061)	Normal(5,0.608)
Landfill disposal/Recycling	R_{land}	$1 - (\Sigma R_2)$	Normal(0.5,0.061)	Normal(0.5,0.061)	$1 - (\Sigma R_7)$
Specialist disposal/treatment	R_{spec}	0	Normal(0.5,0.061)	Normal(0.5,0.061)	0

Table 2: Wastewater and filter efficiencies

Model descriptor	Model value (efficiency %)
Wastewater treatment	
Preliminary	Normal(25,3.04)
Primary	Normal(50,6.08)
Secondary	Normal(97,5.9)
Secondary and nutrient	Normal(99,6.02)
Filter/Catalytic converter	
Defective	Normal(50,6.08)
Medium	Normal(87,5.29)
High	Normal(92,5.59)
Very High	Normal(99.6,3.03)

The final surface water quantity of a particular nanomaterial is calculated as:

$$Q_{surface\_water} = WW_{sur} + A_{sur} + S_{sur} + P_{sur}$$

Where: $Q_{surface\_water}$ = Total surface water nanomaterial quantity (kg)
WW_{sur} = Material release from WTP's to surface water (kg)
A_{sur} = Material deposition from air onto surface water (kg)
S_{sur} = Material leached from agriculturally applied sewage sludge (kg)
P_{sur} = Material released directly to surface water (kg)

The Nano-EXP model performs 10,000 simulations to ensure a representative sample of input values from the distributions associated with the model inputs. The resulting surface water quantities are represented by probability distributions in order to allow comparison of the potential quantities released to environmental media.

Case Studies

Four environmentally relevant products and processes relating to nano-functionalised exterior paints, fuel additives, food packaging and bioremediation were applied in the model. From the product characteristics in Table 3, the potential surface water quantities were calculated.

Table 3: Product/Process and treatment characteristics

Product/ Process	Exterior paint	Fuel additive	Food pack.	Bio-remed.
Material	TiO_2	CeO_2	Ag	Fe_2O_3
Product conc. (%)	1 - 2.5	0.01 - 0.001	0.1 - 0.01	-
Market penetr. (%)	5 - 10	5 - 10	5 - 10	-
Market size (Tonnes/yr)	20 - 30	200 - 500	10 - 20	-
Usage quan. (kg)	-	-	-	10^5 - 10^6
Usage freq. (yr^{-1})	-	-	-	1
Filter efficiency	-	High	-	-
Wastewater treatment	Secondary			
Freshwater release (%)	91			
Sludge spread (%)	76			

Product and process characteristics were determined from products currently on the market, or literature on nanomaterials in development with commercial applications. Disposal and treatment characteristics were based on typical scenarios found in Ireland (EPA, 2007a; EPA, 2007b).

Results and discussion

The predicted surface water quantities of the nanomaterials investigated may be seen in Figure 2.

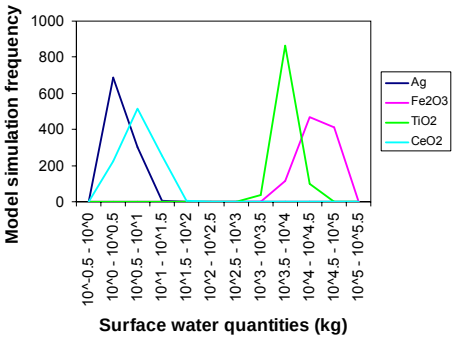

Figure 2: Nanomaterial surface water quantities

A sensitivity analysis indicating the major factors of influence to surface water quantities of TiO_2 from the use of exterior nano-paints may be seen in Figure 3.

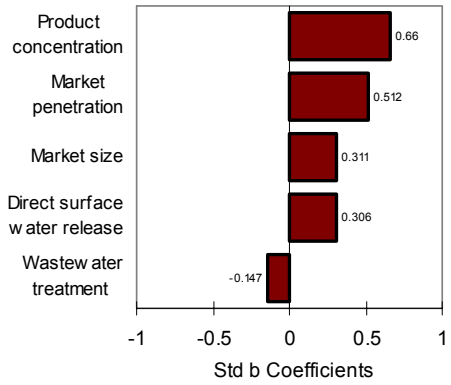

Figure 3: TiO_2 regression sensitivity analysis

From Figures 2 and 3 it may be seen that those products with direct release to the environment, paints and bioremediation, resulted in significantly higher surface water quantities. Those products that undergo some method of treatment, wastewater or filter, as well as those nanomaterials contained in a relatively in inaccessible form (i.e. embedded/bound, suspended in solids), result in relatively lower releases. This is represented by the direct release to surface water and wastewater treatment factors in the regression analysis (Figure 3).

Conclusions

From this initial stage of the Nano-EXP model, it may be seen that treatment upon disposal/release and the form in which a nanomaterial is present in a product or process have a significant effect on potential for release to surface waters. The assumptions made in these exposure points in the model will be critical in determining the accuracy of the model. Surface water quantities must be assessed, in combination with environmental behavioural descriptors, in relation to other "common" pollutants in the environment with adverse environmental or human health effects.

Further research into the fate and exposure to nanomaterials must focus on initial release to different environmental media and a full characterisation of fate in treatment processes. A reference nanomaterial, fully characterised for fate and toxic effects, is required to calibrate the model. This would allow the movement from a relative, comparison model to a fully quantitative environmental management model.

Acknowledgements

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References

EPA, Urban waste water discharges in Ireland, Environmental Protection Agency (2007a), Dublin, Ireland

EPA, National Waste Report 2006, Environmental Protection Agency (2007b), Dublin, Ireland

ICON, A review of current practices in the nanotechnology industry – phase two report: survey of current practices in the nanotechnology workplace, International Council on Nanotechnology (2006), Available from http://cohesion.rice.edu

Kannan, N., White, S.M., Whelan, M.J., Predicting diffuse-source transfers of surfactants to surface waters using SWAT, Chemosphere 6 (2007) 1336–1345

Linkov, I., Satterstrom, F.K., Steevens, J., Ferguson, E., Pleus, R.C., Multi-criteria decision analysis and environmental risk assessment for nanomaterials, Journal of Nanoparticle Research 9 (2007) 543–554

O'Brien, N., Cummins, E., Recent Developments in Nanotechnology and Risk Assessment Strategies for Addressing Public and Environmental Health Concerns, Human and Ecological Risk Assessment 14 (2008) 568–592

O'Brien, N., Cummins, E., Development of a three-level risk assessment strategy for nanomaterials, Nanomaterials: Risks and Benefits, Linkov I., Steevens, J. (Eds.) (2009), Springer

OECD, Series on the safety of manufactured nanomaterials: Number 6. OECD Environment Directorate: Environment, Health and Safety Division (2008), Paris

Ross, T., Sumner, J., A simple, spreadsheet-based, food safety risk assessment tool, International Journal of Food Microbiology 77 (2002) 39–53

PREDICTION OF PATHOGEN LOADS IN IRISH CATCHMENTS USING ARCSWAT

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Abstract
SWAT (Soil and Water Assessment Tool) represents a dynamic modelling system that can be applied to any water catchment and is used to quantify the impact of land management practices on a continuous time basis. Based on input data regarding agricultural practice, demographics and hydrological parameters for the river Fergus catchment, SWAT was run to predict concentrations of *Escherichia coli*. Hydrometric validation results display a very good correlation between observed and predicted data (Coefficient of determination [R^2] = 0.83, Nash-Sutcliffe efficiency [E] = 0.78) and indicate satisfactory simulation of hydrologic processes within the catchment. To date, pathogen predictions have proved variable between observed and simulated figures. Based on recommended values for the quantification of catchment modelling accuracy (Moriasi *et al*., 2007), predictions for *E. coli* can be described as acceptable and satisfactory with the Coefficient of determination (R^2) = 0.68 and the Nash-Sutcliffe efficiency (E) = 0.59. Extensive monitoring is required for such simulations and the current study represents partial validation. However, tentative results indicate potential for pathogen transport modelling. The sensitivity analysis identified the Bacteria partition coefficient (BACTKDDB) as the most important input parameter. In addition it reveals areas where further research is required, particularly in assessing the initial concentration of *E. coli* in human/animal waste. The developed model provides a tool capable of protecting water sources and human health from waterborne pathogens.

Introduction
Management of factors affecting microbial levels in water can act as a progressive method of protecting catchment waters. Surface water sources have long been recognised as being at risk from run-off associated with agricultural activities. Non-point sources of pathogen contamination may result from the manure of grazing livestock, wildlife and manure spread onto land as a fertiliser (Crowther *et al.* 2003; Baffaut 2004).

Point sources of contamination may include animal feedlots, animal housing facilities, wastewater treatment plants (WWTP's) and septic tanks including manure storage areas (Gagliardi and Karns, 2000). Private, trade and agricultural point sources contribute to pollution in many river flows. These tend to receive less scrutiny than WWTP's, and as a result isolated cases of leaky septic tanks or slurry stores can prove significant (Crowther *et al*. 2002).

The ideal microbial catchment model should be capable of simulating four specific factor categories: (a) land use (b) climate (c) topography (d) hydrology. The factors involved and their link to human exposure is illustrated in Figure 1. Water catchment models, such as SWAT, can play a critical role in determining microbial transport in water catchment areas. A recent study highlighted the suitability of SWAT to model Irish conditions and pathogen transport based on available data (Coffey *et al*., 2007).

The objective of this study is to develop a pathogen transport model, using SWAT and ArcGIS (ArcSWAT), capable of simulating criteria affecting

water quality and predicting pathogen loads in Irish catchments.

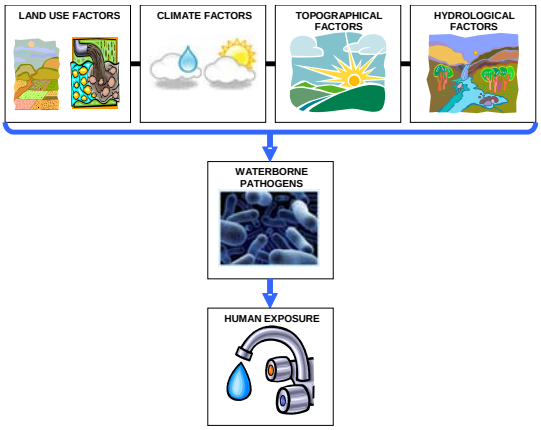


Figure 1. Risk factors affecting human exposure to waterborne pathogens.

Materials and Methods

The study area is based on the river Fergus catchment and focuses on Drumcliff, Ennis, county Clare (extraction point for the Ennis town water supply) [see Figure 2].

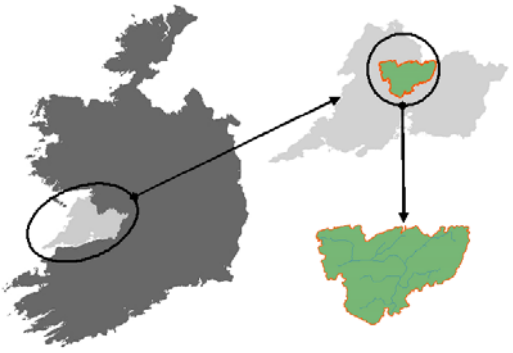


Figure 2. The Fergus water catchment, county Clare.

Manure applied to land as fertiliser (slurry and farm yard manure) and manure deposited from livestock grazing are major bacterial sources in the catchment. The average elevation for the catchment is 68 metres. Annual rainfall ranges from 1200 – 1600 mm [Average = 1401 mm/annum] (Met Éireann, 2008).

Basic data sets required to develop the model included: topography (Ordnance survey Ireland, digital elevation model [DEM]), soils (General soil map of Ireland, 1980), land use (CORINE Land Cover Ireland, 2000), meteorological data (Met Éireann) and agricultural census data (Teagasc/Central statistics office).

Flow calibration was executed using daily flow data recorded by the Office of Public Works from February 2003 to February 2005. Observed bacterial data for use in the model was monitored at Drumcliff by project partners and focused on concentrations of *E. coli*. Sampling was carried out from September 2005 to September 2006 based on when heavy rainfall was predicted for the location.

Scenario

Model simulation was based on the following fixed set up:

a. Bovine livestock graze from late Spring to the end of autumn and are subsequently housed for the remaining period.
b. Sheep are housed for December and January and are outdoors for the remaining months in the year.
c. Manure and slurry produced during housing is stored and used for land fertilisation during the growing season.
d. The timing and frequency of slurry/manure application is fixed for mid spring (prior to grazing) and late Autumn (prior to livestock housing) in line with common agricultural practice in Ireland.
e. 36% of septic tanks within the catchments are failing at any given time.
f. There are 3982 septic tanks in the catchments and 2 wastewater treatment plants (Corofin and Crusheen).

Results and Discussion

Hydrology

For the calibration period (February 2003 – February 2005), model predictions for flow within the catchment fit well with observed data. Validation statistics indicate a very good correlation between observed and predicted flow: Nash-Sutcliffe efficiency index (E) = 0.79; Coefficient of determination (R^2) = 0.82. These results demonstrate that the model is effectively able to simulate the hydrologic processes of the catchment.

Bacteria

To date, *E. coli* predictions have proved variable in comparison to observed data (see Figure 3). Based on model efficiency classification (Moriasi *et al*., 2007), validation statistics indicate a satisfactory correlation for model predictions. The coefficient of determination (R^2) was estimated to be 0.68 and the Nash-Sutcliffe efficiency index (E) was estimated to be 0.59. Results are displayed in Figure 4 and demonstrate that SWAT can be used to assess potential *E. coli* concentrations within the catchment but given the limited number of observed data points, care needs to be taken when interpreting results. However, tentative evaluation suggests satisfactory simulation of *E. coli* is achievable in water catchments.

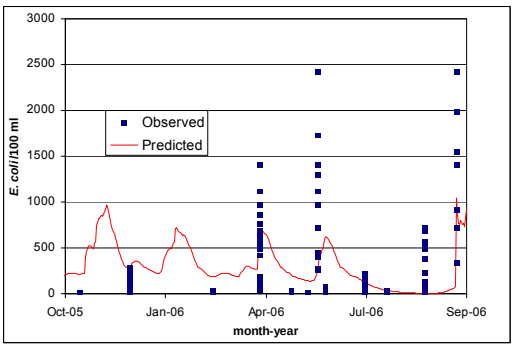


Figure 3. Observed and predicted *E. coli* for the simulation period

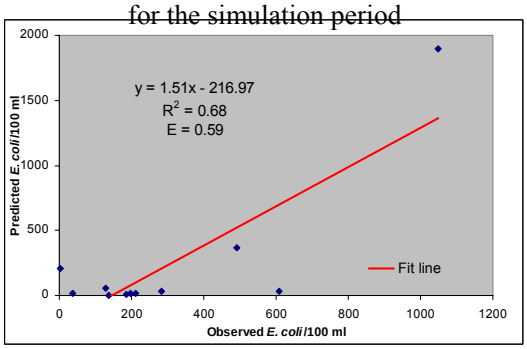
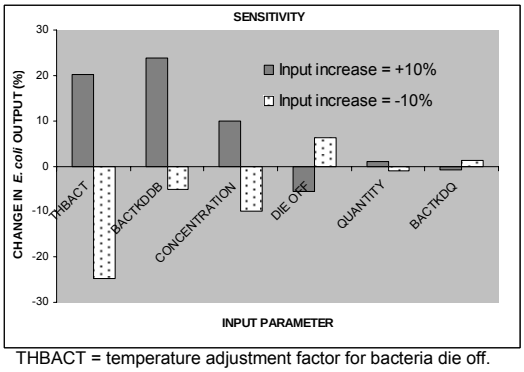


Figure 4. Correlation analysis for *E. coli* ouput.

Sensitivity Analysis

Sensitivity analysis was carried out to assess how certain bacteria input parameters influenced the predicted model output. The analysis was carried out by changing individual parameters by ± 10 % of the initial value (keeping all other input parameters constant) and examining the resulting effect on the predicted *E. coli* concentration by the model. The results of the sensitivity analysis are illustrated in Figure 5. Analysis suggests that the "initial concentration of *E. coli* in human/animal waste" as a real variable to which further research could be focussed to give more accurate information for use in catchment modelling. The high sensitivity of the "bacteria partition coefficient" (BACTKDDB) suggests that the presence of pathogens in solution may lead to greater *E. coli* concentrations at the catchment outlet. This indicates that land management practices, such as manure/slurry application, should be restricted to periods when there is low rainfall so as to prevent a greater number of pathogens being transported in solution.



THBACT = temperature adjustment factor for bacteria die off.

BACTKDDB = bacteria partition coefficient.

CONCENTRATION = initial concentration of *E. coli* in human/animal waste.

DIE OFF = die off factor for *E. coli.*

QUANTITY = quantity of manure applied to land from septic

Figure 5. Sensitivity analysis

Conclusions

Model predictions for flow displayed a very good correlation when compared with observed data. *E. coli* predictions proved variable but did provide satisfactory simulation and follow a similar trend to observed measurements. A sensitivity analysis identified the bacteria partition coefficient (BACTKDDB) as the model parameter that has the greatest influence on model predictions. Despite poor temporal and spatial data available for catchment modelling in Ireland, SWAT can work well in a variety of river basins for many operational purposes. However, it is perceived that model predictions

could be enhanced with more reliable catchment input information. Precise information with regard to fertiliser application (timing, frequency and exact location), septic tank density/hectare, percentage of failing septic tanks, WWTP loading, direct deposition to streams by livestock, specific grazing patterns for livestock and contribution from wildlife would improve overall model reliability. If a larger quantity of validation and observed data were available it is also envisaged that model results could be calibrated to a greater degree of precision. Notwithstanding these limitations, overall results indicate that SWAT can play an important role in determining pathogen transport in Irish water catchments by identifying high risk periods and predicting potential levels of pathogens such as *E. coli*. This can enable catchment protection to be examined.

Acknowledgements
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References

Baffaut C., Benson, VW., 2003. A bacteria TMDL for Shoal Creek using SWAT modeling and DNA source tracking. In Total Maximum Daily Load TMDL Environmental Regulations II. ASAE Proceedings, Albuquerque, NM.

Coffey R., Cummins E., Cormican M., O Flaherty V. and Kelly S., 2007. Microbial Exposure Assessment of Waterborne Pathogens. Human and Ecological Risk Assessment, 13:6, 1313 – 1351.

Crowther, J., Kay D., Wyer, M.D., 2002. Faecal-indicator concentrations in waters draining lowland pastoral catchments in the UK: relationships with land use and farming practices. Water Research. 36, 1725–1734.

Crowther J., Wyer M.D., Bradford M., Kay D., Francis, C.A., 2003. Modelling faecal indicator concentrations in large rural catchments using land use and topographic data. J of Applied Microbio. 94, 962–973.

Gagliardi J.V., Karns J.S., 2000. Leaching of *Escherichia coli* O157:H7 in diverse soils under various agricultural management practices. Appl Environ Microbiol 66:877–83.

Met Éireann, 2008. Shannon airport 30 year averages. Available at: http://www.met.ie/climate/shannonairport.asp

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L.,. Harmel, R.D., Veith, T. L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE. 50(3), 885-900.

WHITE CLOVER FOR IRISH DAIRY PRODUCTION: LIFE CYCLE THINKING

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Abstract

In this paper two theoretical Life Cycle Assessment (LCA) models of Irish dairy units were built with Simapro software. The result shows that the 'grass/clover' system is more competitive with respect to GHG emission per 1 kg energy corrected milk (ECM) than the 'grass/fertiliser' system, but less competitive in land use. The result indicated that white clover has potential to reduce the environmental impact of Irish milk production. Field measurement and farm survey will be used to evaluate the result.

Introduction

There is a growing concern about the effect of GHG emissions on the global climate change. In Ireland, agriculture is the single largest contributor to overall emissions at 26.8% (Environment Protection Agency 2008), and beef and dairy production currently account for 58% of agricultural output at producer prices (Department of agriculture fisheries and food of Ireland), thus the dairy GHG emissions of dairy farms are of considerable importance.

Life Cycle Assessment (LCA) can be used to address agricultural system impacts(ISO 2006; van der Werf et al. 2007). Simapro is a powerful LCA software developed by PRé Consultants (PRé 2007).

The main GHG from agricultural production are CO_2, CH_4, and N_2O. Nearly 80% of the N_2O emissions due to agriculture are related to the use of fertilizers. As a result of the increasing price of fertilizers and the more stringent regulation on N losses from intensively managed grassland, white clover (*Trifolium repens* L.) has received attention for its capacity to fix atmospheric N and make it available for pasture production.

Research based on two farms in the Netherlands (Schils et al. 2005) found that white clover had a marked effect on the GHG emissions. Compared to grass/fertiliser-N system, the indirect emissions on the grass/clover farm were 32% lower per ha and 22% lower per kg milk. Meanwhile, James suggested that the recycling of N from grazed herbage to the soil via the grazing cows was the main cause of lower N-use efficiency (Humphreys et al. 2008), which implies that white clover may not effect significantly on the N loss on farm.

The objective of this paper was to develop a LCA model of two Irish dairy farms (with and without white clover), to assess the potential of white clover for reducing environmental impact, especially GHG emissions.

Materials and Methods

The four parts of LCA methodology were implemented as following:

Goal and scope definition

Two dairy units, one based on permanent grassland and the other on grass/clover pastures, were defined. Their management were taken from Casey and Holden (2005a), while the clover management in 'grass/clover' system was taken from Humphreys and Lawless (2008). Some background data were taken from IPCC default value and the Ecoinvent database in Simapro (Intergovernmental Panel on Climate Change 2001).

Table 1. Characteristics of the two systems

	grass/ fertilizer	grass & clover
Pasture area/ha	39	39
Dairy cows (#)	47	47
N application (kg ha^{-1})	170	90
Milk production (litre cow^{-1})	4822	4822
Clover seeds/kg	0	156

It was assumed that the two systems occupied the same area of (Coulter et al. 2002), kept the same number of cows and

other stocks and cows produce the same amount of milk.

The system boundary was defined at the dairy unit at farm. For resources coming from outside of the farm, eg. concentrate feed, fertilizers, only their production and transportation were included in the inventory. Infrastructure was not included as it was assumed to be the same in the two systems. The life cycle of the system is shown in Fig. 1. Mass allocation between milk and meat (96.6% and 3.4%) was used to divert some burden to the co-product meat (Cederberg and Mattsson 2000).

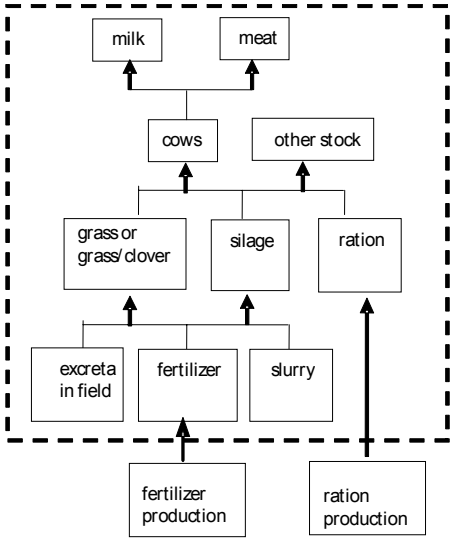

Figure 1. The conceptual model of the dairy unit (dotted lines indicate system boundary)

Inventory analysis

Only GHG emissions associated with milk production were assessed. The functional unit (FU) was defined as 1 kg energy corrected milk (ECM), determined as:

$$ECM = 0.25 * M + 12.2 * F + 7.7 * P$$

Where M is the mass of milk (kg), F is the fat (kg) and P is the protein (kg). The average density, fat and protein content (1.03 kg L-1, 3.9% and 3.2%) were used (Casey and Holden 2005a).

Impact assessment

The mid-point method, 'IPCC 2001GWP 100a' in Simapro method library was used to assess the environmental impact per FU, which defined that the Global Warming Potential (GWP) of CO_2 (with a time span of 100 years) as 1, of CH_4 as 23, and of N_2O as 296. The total emissions of GHG were determined as follows:

$$\text{GHG effect} = \sum GWP_i \times m_i$$

Where m_i is the mass (in kg) of the emitted gas (Heijungs et al. 1992). The total impact was expressed as kg CO_2 eq (equivalents) per FU.

Interpretation

Comparison between the two systems was made by the emissions per FU and a Monte Carlo simulation was used to evaluate uncertainty. The end-point method, Eco-indicator 99 (H) with normalization/weighting set Europe EI 99 H/A was used for the Monte Carlo simulation.

Results and Discussion

Emissions per FU

The emissions per FU are shown in Fig. 2. The 'grass/clover' has 9.5% lower airborn emissions per FU, and 8.2% lower total emissions per FU than the 'grass/fertilizer' system. The total emissions include negative indicators 'raw material: CO_2, in air', and thus are lower than airborn emissions.

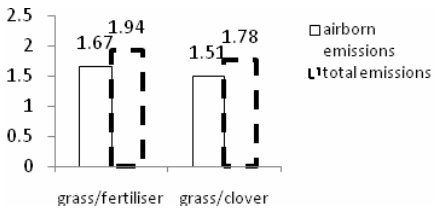

Figure 2. total and airborn emissions (kg CO2 eq. per FU) of the two systems

The 'fertilizer' process accounts for most of the total missions (20.7% in 'grass/fertilizer'), which reflects the differences between the systems: the amount of fertilizers used in 'grass/fertilizer' was 170 kg/ha, while in 'grass/clover' 90 kg/ha.

In Fig. 3 the contributions of the three GHG are shown. Since main sources of N_2O in agriculture activities are associated with fertilizer use, N_2O contributes the most to global warming. The demand for clover seeds in 'grass/clover' has little impact on that.

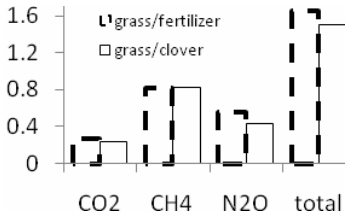

Figure 3. contributions to global warming, kg CO2 eq per FU.

Monte Carlo simulation

The effect of uncertainty of in data was evaluated by running the Monte Carlo simulation (Fig. 4). Some of the ranges of emission factors were taken from literature (Casey and Holden 2005b). The result shows that in the 'land use' category, 'grass/fertilizer'(A) is significantly better competitive than and 'grass/clover' (B), which implies that the additional land use for clover seeds is significant. There is no significant difference in 'climate change' category but 'grass/clover' is slightly more competitive.

Comparison with literatures

Direct comparison (kg CO_2 eq per FU) with the literature is difficult with different characterization factors and impact categories are used. For example, Casey and Holden (2005a) adopted that GWP of CO_2 (with a time span of 100 years) is 1, of CH_4 is 21, and of N_2O is 300, and so does Ciderberg and Matteson (Cederberg and Mattsson 2000). However, in the IPCC 2001 GPW 100a method, not only are the characterization indicator defined differently (1, 23, and 296), but also other emissions are included, such as 'carbon dioxide, fossil', 'methane, biogenic'. A critical analysis of approach is required.

In this paper the two systems only have 8.2% difference in total emissions per kg ECM, which is considerably lower than the 22% indicated by Schils et al (2005). This is probably a result of small difference between the management of the two theoretical systems. However, it is also because Schils et al (2005) took into carbon sequestration into account, which brought negative emissions of 0.47 and 0.41 kg CO_2 eq per FU in grass/fertilizer and grass/clover system, respectively.

One of the concerns with white clover is that the emissions associated with it may not be necessarily lower, since the recycling of N from grazed herbage to the soil via the grazing cows was the main cause of lower N-use efficiency (Humphreys et al. 2008), and there is potential risk that when the fixed N becomes available to grass, it is also exposed to leaching to the ground water, which may result in eutrophication. Meanwhile, if the clover content in the grassland is considerably higher, there is a risk of N_2O and NH_3 volatilization (Schils et al. 2005). However, early stage of experiment in Solohead implied that there were no significant difference in N_2O or NH_3 emissions between grass/fertilizer and grass/clover pasture, and leached N was also low (McNamara 2008).

In this theoretical study it was assumed that although the two systems differ significantly in fertilizer use, they still can reach the same output of milk with the same number of dairy cows, pasture areas and all the other input such as silage and concentrate feed. According to research on Moorepark (Hmphreys and Lawless 2008), this can be achieved by careful management. However Schils et al (2005) also found that grass/clover was less productive.

Conclusions

The result shows that the 'grass/clover' system is more competitive than the 'grass/fertilizer' system in total GHG emissions per FU, but less competitive in land use.

Acknowledgements

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References

Casey, J. and N. Holden (2005a). "Analysis of greenhouse gas emissions from the average Irish milk production

system." Agricultural Systems **86**(1): 97-114.

Casey, J. and N. Holden (2005b). The Relationship between Greenhouse Gas Emissions and the Intensity of Milk Production in Ireland, Am Soc Agronom.

Cederberg, C. and B. Mattsson (2000). "Life cycle assessment of milk production—a comparison of conventional and organic farming." Journal of Cleaner Production **8**(1): 49-60.

Coulter, B. S., W. E. Murphy, et al. (2002). A survey of fertilizer use in 2000 for grassland and arable crops, Teagasc, Johnstown Castle Research Centre, Wexford, Ireland.

Department of agriculture fisheries and food of Ireland. from http://www.agriculture.gov.ie/index.jsp?file=agproduction.xml.

Environment Protection Agency (2008). Ireland's national greenhouse gas emissions inventory for 2007, EPA headquaters.

Heijungs, R., J. B. Guinee Â, et al. (1992). Environmental life cycle assessment of products, part I, Centre of Environmental Science, Leiden University, the Nethrelands.

Humphreys, J. and A. Lawless (2008). Moorepark dairy research update, a guide to management of white clover in grassland. M. Dairy production research centre, Moorepark dairy production research centre.

Humphreys, J., K. O'Connell, et al. (2008). "Nitrogen flows and balances in four grassland-based systems of dai production on a clay-loam soil in a moist temperate climate." Grass and Forage Science **63**(4): 467-480.

Intergovernmental Panel on Climate Change (2001). Climate change 2001: the scientific basis. I. P. o. C. Change, Cambridge University Press, Port Chester, NY, USA.

ISO (2006). Environment management -- Life cycle assessment -- Principles and framework.

McNamara, K. (2008). personal communication.

PRé (2007). Simapro 7.1, Pre Consultants B.V. Plotterweg 12, 3821 BB Amersfort. The Netherlands www.pre.nl.

Schils, R., A. Verhagen, et al. (2005). "A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems." Nutrient Cycling in Agroecosystems **71**(2): 163-175.

van der Werf, H. M. G., J. Tzilivakis, et al. (2007). "Environmental impacts of farm scenarios according to five assessment methods." Agriculture, Ecosystems & Environment **118**(1-4): 327-338.

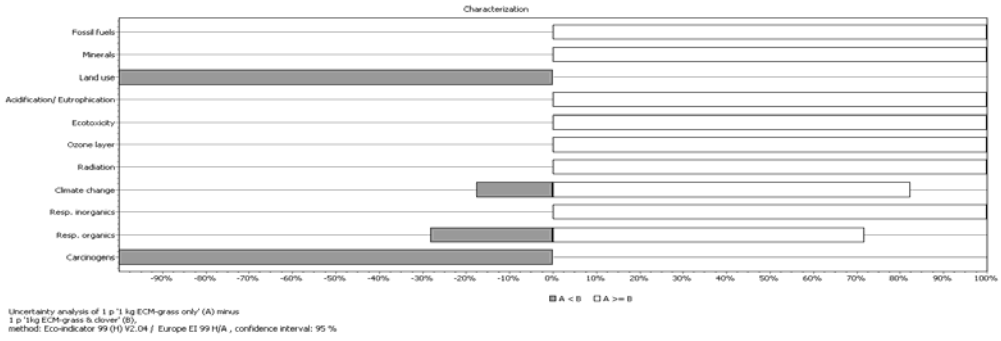

Figure 4. Monte Carlo simulation result

Use of Recovered Food Nutrients (Biomers) from Food By-Products to Boost Soil Organic Matter

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Abstract

The application of organic matter to soil to replenish the nutrients lost through agricultural production has been used for decades to restore the productivity of the growing environment. As a result of the EU Landfill Directive (1999/31/EEC) restricting the amount of organic waste that can be sent to landfill, application of organic wastes to the land has become an area of interest as an alternative treatment for biodegradable waste. This project, however, investigates the use of organic waste as a substrate for soil microbiota and the subsequent application of microorganisms to the soil.

It is anticipated that organic wastes can be used to induce the metabolism of autochthonous nutrient sources in the soil environment by *Trichoderma longibrachiatum*, a fungus that occurs naturally in soil, rather than applying the organic waste directly to the soil to restore productivity levels. Upon fine-tuning this method, it is envisioned that application of the fungus will become a standard protocol in agricultural production systems to accelerate degradation of organic material in the soil, thus returning nutrients to the soil at a faster rate than is currently experienced.

Introduction

The EU Landfill Directive (1999/31/EEC) has imposed strict limits on the amount of organic waste that can be sent to landfill in European Union member states (Roche, 2006), and alternative means of waste handling are encouraged. Rather than applying organic wastes directly to the soil, such as in composting, in this and a parallel study organic waste is used to support the growth of an inherent soil fungus and induce its degradation of cellulose in the soil. The organic wastes of interest are production line by-products and finished products that failed to meet quality requirements of a readymade pizza company, and starch separated from water used in the preparation of vegetables for the catering industry. The presence of starch infers high levels of biological oxygen demand (BOD) and suspended solids in the wash water, making it unsuitable for discharge directly to the sewerage system. Pre-treating the water by removing the starch reduces the suspended solids and BOD, making it more suitable for discharge (Kiely, 1997).

Soil organic matter has two major components: that which is decomposed rapidly and that which is decomposed more slowly (Allison, 1973). The actively decomposed portion plays an important role in aggregation and binding of soil particles and influences soil structure (Troeh and Thompson, 1993; Lickacz and Penny, 1985). The less-readily decomposed portion supplies nutrients to soil flora and fauna (Tan, 2000; Lickacz and Penny, 1985). The degradation of organic matter returns nutrients to the soil, therefore increasing the rate of degradation may improve the availability of nutrients for higher organisms, thus improving the soil's productivity.

The two waste streams will undergo analysis to determine which is more suitable to support *T. longibrachiatum*, and the effect of fungal application to the soil environment will be assessed. The impact on the soil will be determined through changes in the soil's physical and chemical parameters, including infiltration rate, bulk density, soil strength, organic matter content, NPK content, and pH.

The objective of this research is to determine the effect of application of

***Trichoderma longibrachiatum* to soil to develop a model that can be used to predict the impact of fungal application to soil environments with differing growth characteristics.**

Materials and Methods

Waste Streams

A literature and technology review has been conducted to determine the most suitable technology for separation of starch from the wastewater generated in the preparation of vegetables. The quality of the separated starch is a key determinant of the removal technology to be implemented in this project, as its quality will decide whether the starch can be reused as a feedstock for another sector, e.g., paper production, or if it should undergo alternative treatment along with other organic wastes. BOD analysis (dilution method using a Winkler titration, Golterman *et al*., 1978) was also carried out on the wastewater to determine the level of suspended solids in the water before removal.

Proximate analysis according to AOAC methods (AOAC, 2000) was conducted to determine the nutritional composition of the solid waste stream to assess its suitability as a substrate for *T. longibrachiatum*. An elemental analysis will also be conducted to assess the presence and concentration of essential elements in the organic waste, which should provide for successful growth of indigenous soil microflora and the expression of the enzymes involved in the metabolism of organic matter in the soil environment, e.g. nitrogen is essential for the degradation of cellulose by soil fungi, and its absence restricts the extent of cellulose degradation (Moore-Landecker, 1996).

Soil tests and T. longibrachiatum

A parallel research study will determine the optimal growth substrate for *T. longibrachiatum* using samples from the waste streams and comparing the resulting growth with that seen on commercial substrates. When the ideal treatment of the fungus has been determined for optimal growth, the fungus will be applied to soil boxes (0.6m l x 0.6m w x 0.45m h) with different levels of organic matter incorporation (0t straw ha^{-1}, 3t straw ha^{-1}, and 10t straw ha^{-1}). These boxes will be used to determine the impact of fungal application and cellulose degradation on soil with different slopes (Figure 1). The success of the application will be assessed on the basis of improving the productivity of the environment. This will be determined by measuring changes in the chemical and physical characteristics of the soil, focusing on infiltration rate, hydraulic conductivity, soil structure (bulk density and porosity), soil strength, organic matter content, NPK content, and pH, among others.

Results and Discussion

Waste Streams

As a result of the literature and technology review a centrifugation system has been installed in the industrial setting to remove suspended starch from the wastewater prior to discharge to the sewerage system. It was decided that centrifugation was the most suitable system with regard to cost, size of equipment and scalability for potential future expansion.

BOD analysis has been carried out on water entering the processing system ("clean" water) and on water leaving the centrifuge to determine if the separation system removed starch particles to a sufficient degree allowing discharge to the sewerage system. The results of the BOD analysis indicate that the centrifuge is satisfactory in producing sufficiently "cleaned" water for discharge. The BOD of water leaving the centrifuge is 18.0 mg/l 0_2. This BOD value is below the limit imposed by the Urban Wastewater Treatment Directive (91/271/EEC) of 25 mg/l O_2 (Zabel *et al*., 2001) and so it is concluded that this centrifugation system is suitable for its setting.

The organic waste obtained for proximate analysis consisted of bakery waste, finished product readymade pizzas that

Figure 1: Soil boxes used to determine impact of fungal application to various soil/straw combinations at different slopes.

failed quality control, and fruit and vegetables that had failed quality control. The waste pizzas were analysed as separate entities to determine the nutritional composition of each variety, thus due to the large number of different samples the results generated are too extensive to be included in this report. There are no results to report yet relating to the elemental composition of the organic wastes.

Soil tests and T. longibrachiatum

Results from the parallel study on the growth of *T. longibrachiatum* on differing substrates indicate that the recovered starch produces a higher level of microbial proliferation than commercial starch due to the "impurities" included in the recovered starch. It is anticipated that recovered starch will be used to support fungal growth for application to soil.

Table 1: Initial condition of soil used for determination of the effect of application of *Trichoderma longibrachiatum*

Characteristic	Initial Level
Bulk Density	0.66 g cm^{-3}
Porosity	76 %
pH	7
Organic Matter content	4.25%
Nitrate-N concentration	26.13 kg ha^{-1}
P concentration	16.8 kg ha^{-1}
K concentration	285.6 kg ha^{-1}

Tests on the soil to establish changes in the physical and chemical parameters chosen for analysis are underway. Preliminary trials to determine the effect of fungal application to soil containing 10t ha^{-1} of chopped barley straw have begun. *T. longibrachiatum* has been applied in a liquid medium to soil boxes, which will be compared with boxes with the same level of straw incorporation but without fungal application.

It has been determined that the soil contained in the boxes in this study is a clay/clay loam, and has an initial organic matter content of 4.25% and a pH of 7. The nitrate-nitrogen concentration is ~26 kg ha^{-1}, the phosphorus concentration is ~17 kg ha^{-1}, and the potassium concentration is ~285 kg ha^{-1} (Table 1). The initial bulk density is ~0.66 g cm^{-3} and porosity is ~76 %. At this early stage in the soil box investigation there are no definitive results to be reported relating to the effect of application of fungus to soil.

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References

Allison, F.E., (1973) *Soil Organic Matter and Its Role in Crop Production*. Elsevier Science Publ., New York, USA

Association of Official Analytical Chemists (AOAC) (2000) *Official Methods of Analysis of AOAC International*. AOAC International, Gaithersburg, USA

Golterman,H.L., Clymo, R.S., Ohnstad, M.A.M. (1978) *Methods for Physical and Chemical Analysis of Fresh Waters.* Blackwell Scientific Publications, London, UK. 2nd edition

Kiely, G. (1997) *Environmental Engineering*. McGraw-Hill Book Company, Boston, USA

Lickacz, J., Penny, D. (1985) *Soil Organic Matter* Agdex 536-1, Alberta Agriculture, Food and Rural Development, Canada

Moore-Landecker, E. (1996) *Fundamentals of the Fungi*. Prentice-Hall, Inc., New Jersey, USA

Roche, D. (2006) *National Strategy on Biodegradable Waste*. Department of the Environment, Heritage and Local Government, Dublin, Ireland. Available at http://www.environ.ie/en/Publications/Environment/Waste/WasteMangement/FileDownLoad,1442,en.pdf

Tan, K.H. (2000) *Environmental Soil Science*. Marcel Dekker, Inc., New York, USA. 2nd edition

Troeh, F.R., Thompson, L.M. (1993) *Soils and Soil Fertility*. Oxford University Press, New York, USA 5th edition

Zabel, T., Milne, I., McKay, G. (2001) Approaches adopted by the European Union and selected member states for the control of urban pollution. *Urban Water* **3**: 25-32

CALIBRATION, TESTING AND EVALUATION OF A SUSTAINABLE NUTRIENT MANAGEMENT DECISION SUPPORT SYSTEM

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Abstract

The nitrate directive has placed limits on slurry spreading by applying a winter spreading ban which represents an effort to manage nutrients in order to improve water resource protection. This allows little flexibility for farmers to account for their own environment in terms of the dynamics of soil / weather interaction. A decision support system (DSS) will allow a sustainable nutrient management (SNM) based farm-economy by delivering to farmers, advisors and other stakeholders a scientific method of nutrient management that is driven by individual farm criteria, weather and other environmental factors. The development of a land classification method related to soil drainage classes will tailor the system to individual farms based on characteristics such as soil physical properties and topography. The SNM-DSS will provide advice founded on a scientific basis and could improve slurry utilization and water protection. This work will address two crucial issues: calibration of the model (the forecasting of critical soil water deficit thresholds of when to spread or not); and the testing of the model (does its advice improve spreading management).

Introduction

Slurry spreading in Ireland is restrained by a ban period during winter due to large amount of slurry production and wet weather conditions. Pollution risk is increased in areas where abundant rain falls and cattle must be housed. Rainfall is the main factor of interest regulating safe spreading slurry. Water transports nutrients from the soil to groundwater and rivers. Thus, nutrients will be underused and will cause pollution. A previous study has developed a decision support system, based on a soil moisture deficit model, which evaluates whether water will be available for nutrient transport from field to other locations (Holden and al., 2007). This project will further develop the idea. While slurry spreading can be managed by controlling nutrient transporting, storage capacity is still a problem in some cases. The DSS will have two driving principles: when there is no risk of storage capacity being exceeded, advice will focus on nutrient utilisations; alternatively, advice will focus on safe spreading and minimum pollution of ground or surface water, when slurry volumes are approaching full storage capacity. The SNM-DSS will be developed theoretically to assign spatially specific advice to farmers, taking into account soil and weather condition, which period is safer for spreading and when nutrients will be better utilized.

This aim of this work is to calibrate, test and evaluate the SNM-DSS. Foremost, a method will be developed to allocate land to drainage classes. Water and nutrient flows are affected by soil characteristics. Afterwards, the SNM-DSS will be run and tested to assess the system performance. The system will be compared with farmer opinion of spreading opportunity (disregarding legislation) and Irish legislation. Hence, advice quality will be estimated and it will also give a way for revisiting nitrate legislation.

Materials and method

Land allocation

A taxonomic key will be developed to assign parcels of land to drainage classes using a scoring system based on field observations. Primary soil texture will be evaluated by hand

evaluation. Soil particles diameters vary from about 2 mm to 0.0002 mm. When soil has a high content of particles greater than 0.02, the soil is sandy and should feel gritty between thumb and fingers. If particles smaller than 0.002 mm predominate, the soil is clayey and should feel smooth and sticky (Landon, 1991). The feel will be supplemented by testing deformation of a ball of soil (MAFF, 1994). A score will be assigned depending on estimated texture class.

The structure is the second most important factor affecting water behaviour into the soil. Relative expression and strength of pedal units will be evaluated using standard field descriptors (Landon, 1991; Brady and Weil, 2007). Bulk density will be measured by a simple bead displacement method.

Water content and behaviour are both good indicators of soil drainage. On the assessment date, soil wetness and plasticity will be evaluated relative to preceding meteorological conditions (rainfall) (Brady and Weil, 2007). Furthermore, short-term infiltration will be measured accounting for previous weather as well by pre-soaking soil and measuring dispersal rate of a fixed volume of water through a fixed diameter cavity at the soil surface. An assessment of field evidence will be given another score. Primarily, either runoff or erosion observations on a sloping field or signs of inundation on a flat field will be evaluated. Special features such as vegetation indicators and field drains will also contribute to the score.

The simple field methods will be evaluated relative to standard laboratory analysis for test sites (texture, stoniness, structure, organic matter content and bulk density). Soil physical properties will also be measured such as hydraulic conductivity (K_{sat}), porosity and soil water retention curve (pF curve). These analyses will be correlated with soil water potential at several soil water conditions, using tensiometers. Saxton and Rawls (2006) developed soil water characteristics equations which report the relationship between tensions or conductivities, and texture, organic matter and structure.

Previous studies have shown that SMD predictions were well correlated with soil water tension at high water contents (Schulte et al., 2005). Tensiometer or tension infiltrometer data will therefore be very useful for field testing of the classification method. If possible field runoff meters will also be used to evaluate the classification system.

Farmer opinion of spreading opportunity

The survey is currently under design. Around 300 farmers will be investigated over a period of 30 days per year. On a weekly basis, a subsample (10-15 farmers) will be randomly chosen and asked two questions. The first question will be: "Do you think you can safely spread on your land (or a suitable part thereof) today", and the second will be: "would you like to spread slurry on your land (disregarding legislation) today (i.e. do you need to empty tanks)". Answers will be compared with the DSS, legislation and actual meteorological data, in order to know how reliable the DSS is (through an advice quality). Each farm will be classified according to the DSS soil classification, as previously described. GPS co-ordinates and farm attributes for each one are required.

Evaluation of farmer diaries and their meaning

Figure 16: Locations for installation of Met Stations and TDRs in counties Monaghan, Meath, Carlow, Kilkenny and Cork.

Seven farms based on seven sites are being monitored on a daily basis. These are: Emyvale Co. Monaghan (2 farms), Slane Co. Meath, Freshford Co. Kilkenny (2 farms), Oak Park O. Carlow and Curtin's farm, Co. Cork (Figure 1). Every farmer is recording their activities on a daily basis and recording whether they think they should be able to spread slurry on a given date. Then, data will be collected and evaluated.

Testing the temporal and spatial recommendations of the SNM-DSS outputs

On each farm there are 2 soil moisture Time Domain Reflectometer (TDR) stations which determine volumetric water content in the soil. There are two probes buried at 10 cm and two buried at 20 cm. The four probes connect to the data logger and record the volumetric water content. Three weather stations are installed in Monaghan, Slane and Kilkenny. Carlow and Fermoy having their own weather station; Met Eireann data will be used. Weather stations record wind speed, wind direction, rainfall, air temperature, relative humidity and net radiation on an hourly basis; these data are downloaded each month. Some additional measurements are taken including the use of a soil compaction meter and portable soil moisture probe to measure moisture at a number of points in the top 10cm soil. These measurements are repeated each month.

Results and discussion

The allocation method should reliably assign land parcels to drainage classes and should be useable by trained advisors. Neither divergence between people nor ambiguity between on field observation should be observed. The boundaries of the classes have to be determined carefully and calibrated. Thus, strong correlation between allocation by field observation and laboratory methods should be seen.

An advice quality index ($AQI = \frac{(TP + FN) - FN}{(TP + FN) + FP}$) comparing the expert knowledge (individual farmer) and field data (TDR, etc...) and DSS outputs will quantify how well the model performs and how helpful the system is. Farmers are aware of pollution caused by slurry. As the DSS will be evaluated in terms of the reliability of forecast and the consequences of following advice, this model should help farmers to make a better utilization of slurry depending on actual meteorological conditions and their soil properties.

The development of intelligent, environmentally responsive tools such as a decision support system for sustainable nutrient management would allow for a proper balance to be struck between production requirements (optimum intensity), economic viability of the enterprise (farm livelihood) and environmental protection (minimum pollution).

If SNM-DSS functions reliably with respect to predicting the soil water status, drainage and runoff, then future research will be proposed to assess the impact the system may have on surface and ground water quality.

Acknowledgment

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References

Brady, N.C. & Weil, R.R. 2007. The nature and properties of soils. 14th ed. Pearson International Edition, Upper Saddle River, New Jersey.

Holden N.M., R.P.O. Schulte and S. Walsh. 2007. A slurry spreading decision support system for Ireland. In N. M. Holden, T. Hochstrasser, R. P. O. Schulte, S. Walsh (editors). 2007. Making Science Work on the Farm. A Workshop on Decision Support Systems for Irish Agriculture. Agmet, Dublin. p 24-33.

Landon, J. Soil chemistry. In Booker Tropical Soil. A Handbook for Soil Survey and Agricultural Land. Evaluation in the Tropics and Subtropics, pp. 118–122. Longmans, London, 1991

Ministry of Agriculture, Fisheries and Food (MAFF), Soil Survey of England and Wales. 1994. Soil texture. Leaflet 895

Saxton, K.E. and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Sci. Soc. Am. J. 70:1569-1578

Schulte R.P.O., J. Diamond, K. Finkele, N.M. Holden, and A.J. Brereton. 2005. Predicting the soil moisture conditions of Irish grasslands. Irish J. Agric. Food Res. 44:95–110

Sisson, J.B., W.L. Bratton, G.W. Gee, J M. Hubbell, J.C. Ritter, and T.G. Caldwell. 2002. Advances in tensiometry for long-term monitoring of soil water pressures, Vadose Zone Journal 1 (2) (2002), pp. 310–315.

CONCEPTUAL DEVELOPMENT OF A SUSTAINABLE NUTRIENT MANAGEMENT DECISION SUPPORT SYSTEM

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Abstract

This project will develop the concept of a farm scale sustainable nutrient management (SNM) decision support system (DSS) focusing on N and P management. The SNM-DSS will be developed from an existing slurry management DSS (developed by the Agmet Group), based on a 1D SMD model, in conjunction with a number of stand-alone nutrient management support tools developed by Teagasc. Consideration will be given to farm nutrient balance, timing of nutrient application and safe nutrient application. The DSS will have two driving principles: when there is no risk of storage capacity being exceeded, advice will focus on nutrient utilisation; alternatively, advice will focus on safe spreading and minimum pollution of ground or surface water, when slurry volumes are approaching full storage capacity.

Introduction

Concerning the protection of water against pollution caused by nitrates from the agricultural sector, the European Council Directive of 12 December 1991 was adopted with the objective of reducing water pollution. Ireland's national nitrate action programme was given statutory effect by the European Communities (Good Agricultural Practice for Protection of Waters) which were made on 19 July 2006. Implementation of the Action Programme is supported by an enhanced package of financial supports for farmers by the Department of Agriculture, Fisheries & Food (DAFF) and by the cross-compliance inspections carried out by that department. In Ireland, agriculture contributes significantly to the eutrophication of Irish rivers and estuaries with 70% of phosphorus loads and 82% of nitrogen loads (Environmental Protection Agency, 2004; Stapleton *et al.,* 2000). The loss of nutrients from farms, and the subsequent transport to water, has been the subject of numerous studies in Ireland as well as in the European Community. Land spreading of artificial fertilisers and animal manure plays a predominant role in the loss of nutrients if it is not carried out according to the Good Agronomic Practices.

The aim of this project is to further develop the SMD model at the heart of the Sustainable Nutrient Management Decision Support System. It will predict for a given parcel, the fate of gravity moveable water in terms of run-off and leaching proportions.

Materials and Methods

Shulte at al. (2005) developed a hybrid SMD model. The hybrid SMD model is simple by necessity because it works on a national scale by categories of soil.

Given a standard meteorological condition, a field is subjected to Precipitation (ppt^{n}) and Evaporation (Ep). The difference between these two events determines Net rain (mm). When Net rain is negative, soil is defined as drying. Otherwise if net rain is positive, soil will be wetting. The amount of soil water present in a field is calculated as Soil Moisture Deficit (SMD). It is defined as the amount of water that must be added to soil to restore it to field capacity. Field capacity (FC) is the amount of soil water held in soil after excess water has drained away by gravity and downward movement has stopped, which usually takes place within 2–3 days after rain or irrigation in soils of uniform structure and texture.

Every time that soil moisture content exceeds field capacity, runoff or leaching can occur. If slurry or artificial fertilizers

are spread in these conditions then the excess water can transport nutrients away from the field so that it becomes a source of pollution.

The Hybrid model for soil moisture deficits, categorises the differences in drainage regimes between different soil types in Ireland into three distinct soil drainage classes: *well-drained soils*, which never exceed field capacity; *moderately drained soils*, can exceed field capacity and have free moveable water able to drain away in 24 hours bringing the land to field capacity; *poorly drained soils* which need more than 24 hours to return to field capacity.

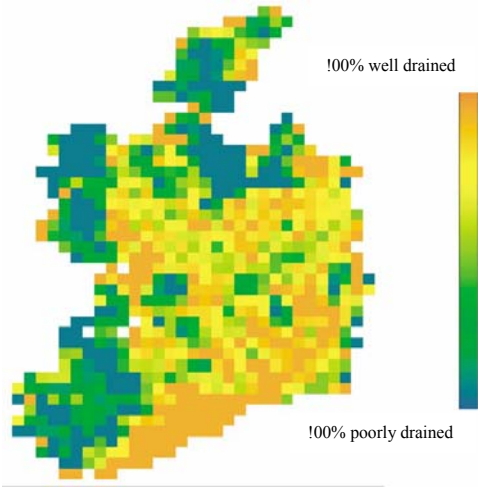

Figure 1. Indicative drainage map of Ireland based on the drainage capacity of the dominant mineral type of each soil association (Schulte et al., 2005).

The SMD model is a water mass balance model with a daily time step, calculating SMD from the cumulative balance of precipitation, evaporation and drainage:

$$SMD_t = SMD_{t-1} - Rain_t + ET_t + Drain_t$$

Where SMD_t and SMD_{t-1} are the moisture deficits (SMD) on day t and $t–1$, respectively (mm). *Rain* is the daily precipitation (mm/day), an input variable of the model, ET_t the daily actual evapotranspiration (mm/day), and *Drain* equals the amount of water drained daily (mm/day) by percolation and/or overland flow.

The approach to this research will start from these concepts going forward in to develop the following points:

The fate of gravity moved water

Infiltration rate will be analyzed by tension infiltrometer studies and laboratory experiments as a means of quantifying the proportion of leaching vs run-off.

Spatial context of the SMD model (one dimensional vs two dimensional model)

In the Hybrid model for the soil moisture deficit, as soon as field capacity is exceeded, water starts to drain. Any water in excess or any precipitation in excess of drainage rate is termed "drainage" but whether it is runoff or leaching is not defined. If the soil is saturated it is assumed that all excess water becomes runoff.

When $SMD = -10$ *(saturation)*

If $ppt^n > Drainage$

then *Run-off*

With saturated soil or near saturated, it is most likely that water will run off if there is a slope, but in a flat situation water cannot move laterally.

On slopes it is expected that water will move as run-off or as sub-surface run off (it can infiltrate and move parallel to the surface), but some proportion will leach.

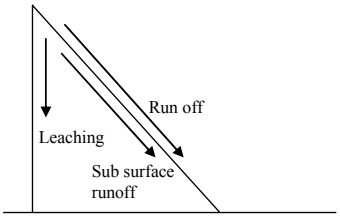

Figure 2. Scheme of expected water movement on slope.

If lateral flow occurs then water balance down slope is effected thus:

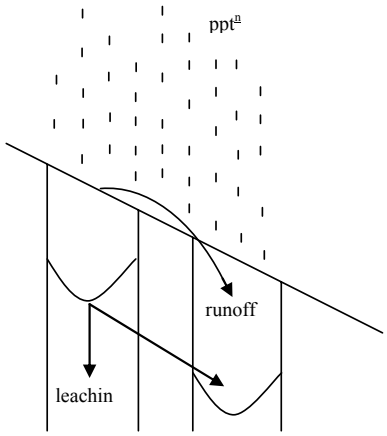

Figure 3. Scheme of expected water balance down slope.

In this condition soil moisture deficit will be calculated as following:

$SMD = ppt^2 - Ep - Drainage + Inflow$

To create a 2D version of the model, it can be integrated with a digital terrain model. Starting from the highest elevation, SMD will be calculated and excess water it will be moved down on the lowest adjacent area (pixel) adding it to the soil water. Using rainfall distribution, soil type and slope, soil water deficit and surface water movement for small catchments can be calculated.

Results and Discussion

In the slurry management DSS, the one dimensional model is reformulated in terms of source (slurry spread), transport vector (free water available to transport nutrient) and target (surface or ground water), (Holden et al., 2007).

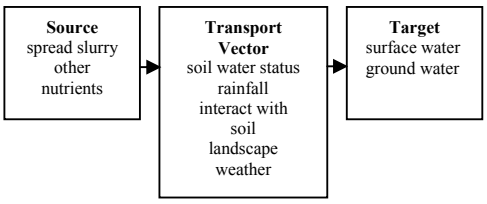

Figure 4. The conceptual model of nutrient pollution following slurry spreading.

The one dimensional model predicts the risk of a transport vector occurring in the field at a given time, location and soil type. If there is no transport vector connecting the source with the target there will be no pollution problem. It will therefore be possible to carry out safe spreading.
In other words if the soil is of a water content drier than field capacity, the chance of there being a transport vector, i.e. free moveable water that can move nutrients to cause pollution, is negligible. If the soil is wetter than field capacity, then the risk of pollution can occur.

Conclusions

With no gravity moveable water available there is little risk of pollution. The success of the method used in this study is highly connected to the correct partitioning of the amount of water that moves vertically versus the amount that moves laterally into the soil.

References

Holden Nicholas M. (2001). Agro-Metereological Modelling-Principles, Data and Applications. Agmet, Dublin.

Holden N.M., Hochstrasser T., Schulte R. P. O., S. Walsh (2007). Making Science Work on the Farm. A Workshop on Decision Support Systems for Irish Agriculture. Agmet, Dublin.

Brady Nyle C., Weil Ray R. (2008). The Nature and Properties of Soils. Pearson Education, New Jersey.

Shulte R.P.O., Diamond J., Finkele K., Holden N.M. (2005). Predicting the soil moisture conditions of Irish grasslands. Irish Journal of Agricultural and Food Research 44: 95-110

Shulte R.P.O., Richards K., Daly K., Kurz I., McDonald E.J., Holden N.M. (2006). Agriculture, metereology and water quality in Ireland: a regional evaluation of pressures and pathways of nutrient loss to water. Biology and Environment: Proceeding of the Royal Irish Academy, 106B, 117-133.

ESTABLISHMENT OF AN OPTIMUM HARVEST WINDOW AND PRE-HARVEST TREATMENT OF *MISCANTHUS GIGANTEUS*

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Abstract

It is apparent that Miscanthus will play a vital role throughout Ireland and Europe as an alternative to fossil fuels in years to come. However, little is known about the drying habits of Miscanthus prior to harvesting, therefore it is necessary to establish the correct time of year and method of harvesting in order to achieve optimal biomass fuel quality. Different possibilities exist with respect to harvesting techniques, for example one option is to cut the crop and leave it on the ground prior to collection while direct cut/collection in one pass is the alternative option. Early indications from this study suggest an increase in moisture content in the crop that has been cut and left in the field when compared to that which is left standing and sampled directly (control).

Introduction

Over the last number of years Miscanthus has generated a lot of interest and gained a strong reputation as being an environmentally friendly substitute for rapidly depleting fossil fuels. Miscanthus is a perennial grass that produces cane-like stems and is likely to be suitable for combustion in mixed feedstock boilers (Nixon *et al.,* 2003). In terms of Miscanthus harvesting there are a number of areas that need to be addressed as Miscanthus is such a new crop. Harvesting of Miscanthus typically takes place in February/March/April (Bassam *et al.,* 2003). This is when the moisture content of the crop is at its lowest after leaf senescence has taken place over the course of the winter. There are a number of issues that need to be addressed however in relation to harvest window and harvesting techniques. Finding the optimum time to harvest the crop is essential in order to achieve maximum yield of high quality biomass

(Lewandowski *et al.,* 2002). Coupled with this, finding a cost effective method of harvesting is also key to ensure maximum biomass is being collect from the field. The main factor that determines harvest window is crop moisture content. This is very much dependent on weather. There are a number of options available to the grower with regards to harvesting. These include cutting the crop and placing the biomass material in a swath prior to collection, direct cutting and chipping of the crop or direct cutting and baling of the crop. Each of these techniques have their advantages, and moisture content, quality of biomass and amounts of biomass losses that occur can vary significantly depending on the system employed. This study hopes to establish the optimum time to harvest the crop in order to achieve maximum crop yield potential as well as optimum biomass quality with respect to harvest time and harvest technique. **The objective of this study is to determine the optimum time and method to harvest Miscanthus in order to achieve maximum biomass quality and highest possible biomass yield.**

Materials and Methods

The following experiments were conducted in the Teagasc Crops Research Centre, Oak Park.

Experiment 1
Moisture movement within the plant
This experiment was set out to gain an understanding of how the moisture content varies within the Miscanthus cane over the course of the winter through to harvesting. It was carried out by taking samples of the crop from the Miscanthus stand,

measuring the moisture content in the top, middle and bottom of the cane. A sample of ten canes was taken from the Miscanthus stand on a weekly basis. The leaves were removed and the canes were then divided into top, middle and bottom sections. The samples were then weighed, oven dried and re-weighed in order to determine the moisture content of three plant sections. The results from this trial were then plotted on a graph so a direct comparison could be drawn between the moisture contents of the top, middle and bottom sections of the cane.

Experiment 2

Optimum harvest window and technique

This experiment was carried out to establish the optimum time to harvest the Miscanthus throughout the months January, February and March. It incorporates harvest times with a number of harvest treatments. The plot is divided into four blocks, each representing one replicate. Each block is then divided into three treatments, and each treatment is then subdivided into four sub-treatments. The three treatments used in this trial are cut in January, February, and March. The four sub-treatments are then applied which are:

1) Leave cut biomass material flat on the ground
2) Leave cut biomass material in a swath on the ground
3) Remove cut biomass material and place in a glasshouse for the duration of the trial
4) Leave biomass uncut in the field (control).

Figure 1 below is a plan of the layout of the Miscanthus stand and the distribution of the treatments being used. In the plan of the Miscanthus stand, each block represents a replicate of the experiment, each strip represents a treatment, and each square represents a sub-treatment. The cut material is then removed from the stand and placed on the clearance so that the standing crop doesn't create a factor of error by sheltering the biomass material, while sub-treatment three is removed from the field and brought to the glasshouse.

Results and Discussion

Experiment 1

When this experiment began in October 2008, the moisture content of the plant samples varied between 71% for the top, 63% for the middle and 65% for the bottom as can be seen from the graph below (*Figure 2)*. Initial indications show the general trend for the moisture content in the plant sections was to drop consistently over the course of the trial to date. It can be seen in the graph however that the top portion of the cane fluctuated considerably more than the middle and the bottom, both of which drop gradually with the exception of 3 weeks from week 5 to week 8. It is thought this occurred due to the fact that the top section was more exposed to rain and weather conditions while the middle and bottom were not as severely affected by precipitation. It is also worth noting however the way in which the bottom follows the same drying pattern as the middle, meanwhile the top section varied from week to week, increasing and decreasing in moisture content independent to the middle and bottom. It can be seen from the figure below that by week 15 the moisture content has dropped 14-18% depending on the plant section in question. However this experiment is on-going so final results are expected when the trial concludes in early April 2009.

									Hedge										
		Block 1				Block 2				Block 3				Block 4					
	Treatment	3	2	1	4c	3	1	2	4c	2	3	1	4c	4c	1	3	2		
		Strip A	Strip B	Strip C	Strip D	Strip A	Strip B	Strip C	Strip D	Strip A	Strip B	Strip C	Strip D	Strip A	Strip B	Strip C	Strip D		
		1	3	2	ctl	3	2	2	ctl	2	2	1	ctl	ctl	3	3	1		
N Trial	Clearance	3	1	3	ctl	1	1	1	ctl	3	3	3	ctl	ctl	1	1	2	Clearance	
		2	2	1	ctl	2	3	3	ctl	1	1	2	ctl	ctl	2	2	3		
							Clearance		Field										

Figure 1: Plan of Miscanthus stand

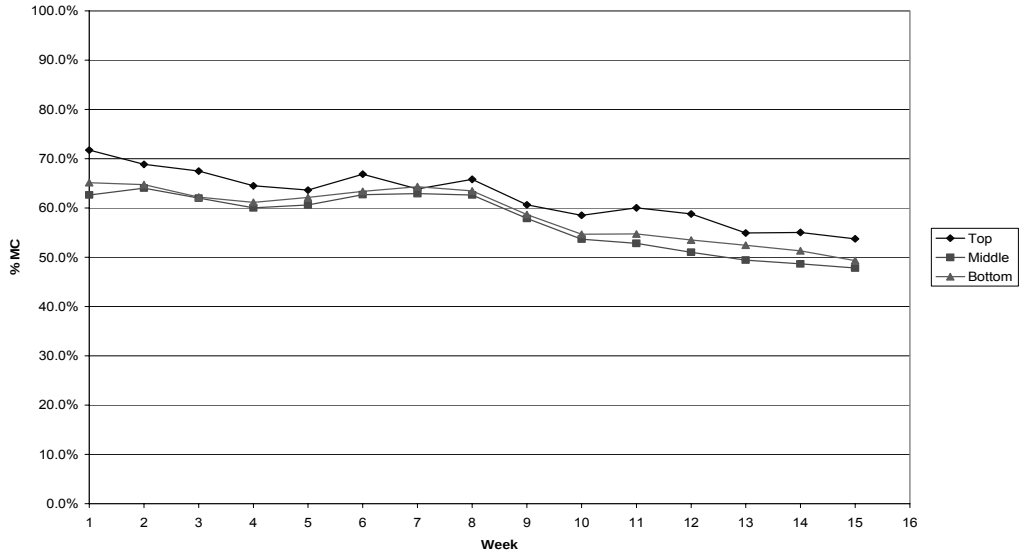

Figure 2: Crop drying data recorded from October 9th 2008 through to harvest in Spring 2009

Experiment 2

This experiment is being carried out to establish the optimum time to harvest Miscanthus throughout the course of the spring, while also establishing if leaving the crop on the field post-mowing leads to an increase in moisture loss from the crop, or in turn results in a reduction in the quality of the biomass material as a fuel. Figure 3 below illustrates the difference in moisture contents that have occur to date. From the graph it can be seen that all four sub-treatments started off at a very similar moisture content, however as time progressed, the moisture content of the material in the glasshouse can be seen to drop significantly every week, while the moisture content of the control has dropped marginally with the exception of one week's results. It can also be observed how the material remaining in the field left both flat and in a swath has suffered a week on week increase in moisture content once harvested until week five when a minor reduction in moisture content can be observed.

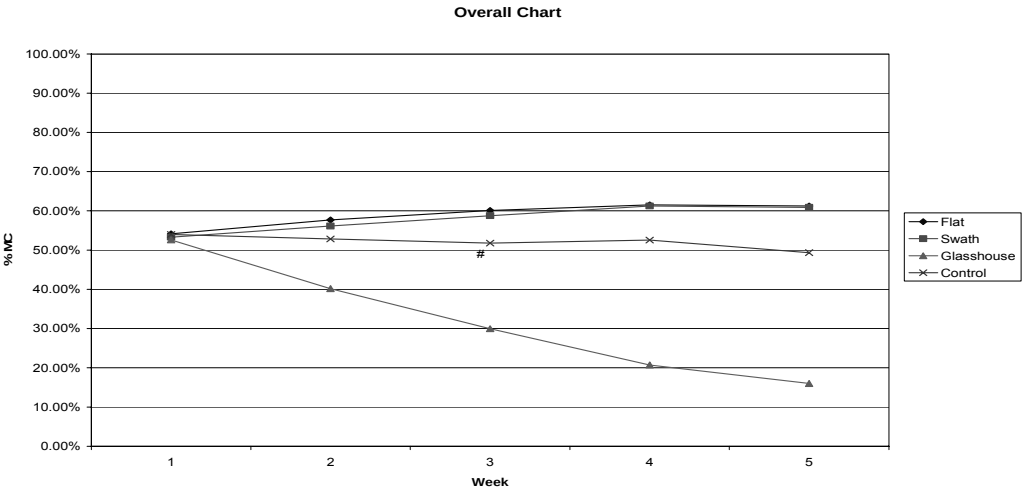

Figure 3: Moisture Content data for Experiment 2

Conclusions

Experiment 1

By the conclusion of this experiment it is hoped that a greater understanding of the drying habits of a Miscanthus crop throughout the winter/spring period will be gained, thus helping the grower to gauge when the crop should be harvested.

Experiment 2

In a similar way to *Experiment 1,* it is expected that *Experiment 2* will help determine the most appropriate time to harvest the crop in order to achieve the best quality biomass possible for use as a fuel. This experiment will also indicate whether it is of benefit to cut the crop and leave it on the ground prior to harvesting at a particular time over the potential harvest window throughout the months of January, February and March. Initial indications from the graph show that in sub-treatments 1 and 2, cutting the crop and leaving it either flat or in a swath under treatment 1 has led to a significant increase in moisture content. The control has shown a minor reduction in moisture content similar to that achieved in *Experiment 1* while the moisture content of the material suffered a significant reduction in moisture content dropping by as much as 10% each week. Therefore, it can be seen from preliminary results that the best drying results from a practical perspective is to leave the crop standing rather than trying to achieve drying by wilting the crop after cutting. These results however are preliminary and whether a significant change in the drying trend occurs under treatments 2 and 3 remains to be seen.

Further Work

The remaining treatments will be carried out on the Miscanthus stand thus allowing all results to be calculated and displayed on the graph, in turn indicating the optimum method and time of harvesting Miscanthus to achieve the lowest possible moisture content. To conclude *Experiment* 2 it is hoped calorific value analysis as well as proximate and ultimate analysis will be carried out on samples of Miscanthus taken from all treatments and sub-treatments in order to establish which treatments result in the best quality biomass fuel.

Acknowledgements

The authors wish to gratefully acknowledge the financial support provided by Teagasc under the Walsh Fellowship Programme for this project.

References

Nixon, P., and Bullard, M., (2003). Optimisation of Miscanthus Harvesting and Storage Strategies.

Bassam, N., and Huissmann, W., (2003). Optimising Harvesting and Storage Systems for Energy Crops in the Netherlands. International Conference on Crop Harvesting and Processing, February 9-11 2003, Louisville ,Kentucky, USA.

Lewandowski, I., and Heinz, A., (2002). Delayed harvest of Miscanthus-influences on biomass quantity and quality and environmental impacts of energy production. *European Journal of Agronomy 19 (2003),* 45-63.

A REVIEW OF BIOETHANOL FISCAL SUPPORT STRATEGIES

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Abstract

Bioethanol is a potentially viable domestic source of transport fuel that can be used to displace petrol, a conventional fossil based fuel, which is thought to have adverse environmental impacts. Bioethanol as a fuel requires fiscal support in order to stimulate demand and encourage supply. The type of fiscal support varies from compulsory inclusion to tax relief to mixes of the two strategies. This paper concludes that both strategies will likely be required to encourage indigenous production and use of bioethanol from the feedstock considered.

Introduction

Bioethanol is an increasingly popular choice as a renewable fuel that can be used to displace fossil fuels which pose significant social, environmental and economic problems. The success of any alternative fuel will be dependent upon how well, economically, it can compare to existing fuels. The three largest producers and users of bioethanol are the US, Brazil and the EU. Each of these regions employs different support mechanisms, feedstocks and tax systems; this results in a wide range of international costs and competitiveness. Ireland too has employed various fiscal supports for biofuels with varying degrees of success. **This paper uses recent trends in commodity prices to investigate how well different fiscal supports would have benefited ethanol producers and suppliers.**

Material and Methods

Commodity price database

A commodities price database was developed that tracks a range of commodities and their variations in value. The database includes energy products such as oil, natural gas and refined products and agricultural commodities such as wheat, corn and rapeseed which can be used as biofuel feedstock. Other commodities such as biofuel co-products like distillers' grains and rapeseed cake are also tracked. The database incorporates exchange rates and conversion tables to convert non euro-zone markets and non-metric units to enable accurate comparisons among internationally traded commodities relevant to biofuel production.

Modelling fiscal support strategies

Within the database, different fiscal support strategies and their impacts on bioethanol economics were determined. The two approaches compared were a compulsory inclusion strategy and a tax reduction strategy. Both strategies have been employed by EU countries. In Ireland, the tax reduction strategy was used in the Mineral Oil Tax Relief MOTR I and II (DCENR, 2007). The compulsory inclusion strategy was initially used to require a 5.75% blend of biofuels by 2010 in line with EU targets but was later reduced to 3% (DCENR, 2008).

Determining feedstock costs

For this study, the use of sugarbeet and wheat as raw materials to produce bioethanol were used. Bioethanol can potentially be produced from other sources such as lignocellulose feedstock but the technology to do so is not yet commercially viable (Deverell et al., 2009). Ethanol from sugarbeet is a favourable feedstock due to the potential to use some of the existing infrastructure left over from the collapse of the sugar industry in 2005. Although, Ireland is not the most efficient producer of sugarbeet due to lower sunshine hours and temperatures compared to other EU producers. Wheat also has favourable characteristics, such as its ability to be stored for long periods and imported from foreign sources if domestic supplies are inadequate or too expensive.

Feedstock costs for the two raw materials sugarbeet and wheat were determined based on their conversion efficiency and market prices over time. While there is no active trade in sugarbeet due to its poor storage characteristics and inability to be internationally traded, its price was derived from raw sugar prices, its nearest equivalent product and the expected sugar content and conversion costs. The cost of wheat as a feedstock was determined based on prices quoted on the Liffe Futures Exchange and expected conversion efficiencies and costs.

Results and Discussion

The impact of tax costs

Based on outputs of the database the economics of bioethanol production based on using either wheat or sugarbeet varied greatly since 2008.

At the beginning of 2008, wheat prices were high which caused bioethanol produced from that commodity to be more expensive than petrol (prices have been adjusted to account for energy contents) (Figure 1). As the year progressed, wheat prices fell dramatically while petrol price fell at a slower rate as did imported bioethanol. The imported bioethanol price is based on prices quoted on the Brazilian mercantile and futures exchange (BM&F) and shipping, handling and duty costs. Bioethanol produced from wheat in Ireland would currently be competitive if VAT (at 21%) was paid, if excise were also due at a similar rate to petrol then at no point over the last year would bioethanol have been competitive. This has been demonstrated by the closure of several prominent bioethanol producing plants in Spain and Germany.

For sugarbeet, the opposite occurred over the past year (Figure 2). In the early part of 2008, sugar prices were low corresponding to a low sugarbeet price that made bioethanol competitive. Rising sugar prices have since made bioethanol from this feedstock with both petrol and imported bioethanol.

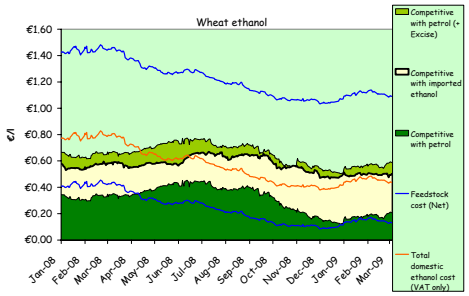

Figure 1. Ethanol competitiveness using wheat as feedstock.

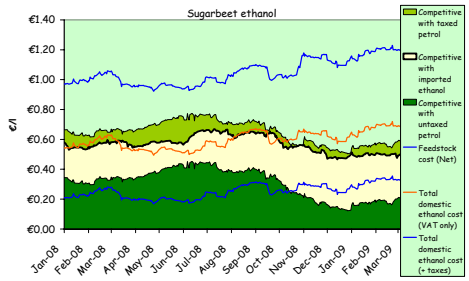

Figure 2. Bioethanol competitiveness using sugarbeet as feedstock.

These two figures clearly show that even favourable tax policies do not ensure the economic sustainability of bioethanol produced from domestic feedstock over extended periods of time.

The impacts of compulsory inclusion

The next question then is what impact would a compulsory inclusion strategy have on fuel costs? Compulsory inclusion, as its name implies requires that bioethanol be blended with conventional fuels at a pre-determined rate. In some instances, compulsory inclusion may result in a blend of bioethanol in all petrol or alternatively higher blends in some of the petrol to meet substitution target. If the bioethanol is cheaper than petrol a compulsory inclusion will benefit users, if bioethanol is dearer it will be to end-users detriment. The potential impact of a compulsory inclusion target on fuel prices was modelled. Based on the market price for bioethanol in the EU and a full compliment of taxes comparable to petrol then lower level blends would have resulted in marginally higher costs for consumers, while a higher E85 blend

would have been a considerably more expensive fuel for end-users (Figure 3).

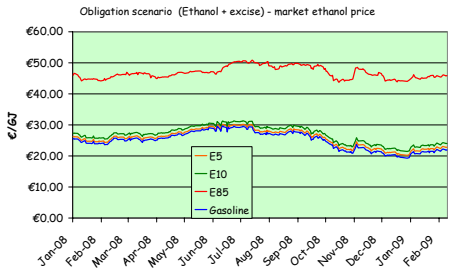

Figure 3. The impact of compulsory inclusion of various bioethanol blends with full tax.

On the other hand, if excise relief and compulsory inclusion were instituted then lower level blends would have had little or no impact on fuel price generally and a slightly beneficial impact more recently. The higher E85 blend would still be a comparably more expensive fuel (Figure 4).

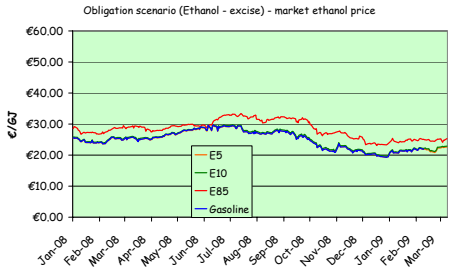

Figure 4. The impact of compulsory inclusion of various bioethanol blends with full excise tax relief.

Conclusions

In conclusion, bioethanol produced from the feedstock considered will require significant, long term supports in order to ensure their economic viability. If bioethanol is to be supported then potentially a combination of compulsory inclusion and a floating tax (excise) rate would be more economical from both an end-user and government strategy viewpoint. The floating tax rate should reflect bioethanol feedstock costs and competitor fuel values such that when competitiveness is low, so too are bioethanol excise rates, where bioethanol is commercially viable it should contribute taxes. Alternatively, to avoid large tax losses, a market based system similar to the US Renewable Identification Number (RIN) market could be employed which would reduce the tax losses and ensure bioethanol can be economically produced, however, this would lead to higher fuel prices for end-users.

Acknowledgements

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References

DCENR, 2007. *Delivering a sustainable energy future for Ireland*, 2007. Available online: www.dcenr.gov.ie/NR/rdonlyres/54C78A1E-4E96-4E28-A77A-3226220DF2FC/27356/EnergyWhitePaper12March2007.pdf.

DCENR, 2008. Available online at: www.dcenr.gov.ie/Press+Releases/2008/Minister+Ryan+proposes+new+target+for+biofuels+in+Ireland.htm

Deverell, R., McDonnell, K. P., Devlin, G. 2009. Potential Bioethanol Feedstock Availability Around Nine Locations in the Republic of Ireland. Energies, 2, 120-133

ECONOMICS OF NON-WOODY BIOMASS AS A FEEDSTOCK FOR PELLET PRODUCTION

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Abstract

The use of renewable sources to aid the reduction of greenhouse emissions and to decrease the dependency on imported energy supplies is increasingly necessary. Agricultural residues and energy crops are a valuable source of biomass. For these crops to be utilised in pellet production the cost of supplying this biomass must be calculated. Depending on the type of biomass, harvest method, storage, drying and transportation used biomass can be supplied at a non-margin base cost of €30 per tonne dry matter. For reduction of transportation costs density of the biomass must be increased.

Introduction

The use of renewable energy sources is becoming increasingly necessary due to the increasing threat of climate change and given that in 2007 Irelands import dependency on energy was almost 90% (McKendry, 2002 and Energy Policy Statistical Support Unit, 2008). In 2004, Irelands greenhouse gas (GHG) emissions were 25% higher than 1990 levels and 13% above the agreed Kyoto limits to be achieved in the period 2008 to 2012. Co-firing energy crop biomass for electricity and heat production can demonstrate substantial national GHG emissions (Styles et al., 2008).

Biomass is CO_2 neutral, not contributing any increase to the CO_2 content in the atmosphere (Pastre, 2002). Production costs for biomass materials have previously been investigated. It is reported that the production cost of cereal straw in 2002 was 28 GBP/t (dry matter – dm) while short rotation coppice (SRC) and miscanthus was 47 and 54 GBP/t dm (€45/t, €75/t and €86/t respectively) (McKendry, 2002 and Euro exchange rates, 2002). It is reported by Styles et al, 2008 that the production costs for miscanthus in Ireland are between €37 – 48/t dry matter while for short rotation coppice willow (SRCW) production costs are €31 – 46/t dry matter. In Denmark the cost for big bales of straw delivered to the pellet plant is €61/t at 15% moisture content (Eubionet – Fact sheet 12).

In considering the production costs of agricultural residues the following costs need consideration: establishment, harvest, storage and transport. Harvesting biomass represents one of the significant cost factors in the production of biomass energy crops (McKendry, 2002). The method of harvest influences both storage and transport costs (Huisman et al, 1997). Transport can account for as much as 70% of total delivered biomass costs (McKendry, 2002). This is due to agricultural residues and energy crops having bulk densities as low as 30 kg/m^3 (Mani et al, 2006). Storage of biomass is generally on farm under plastic or roofed storage. Storage and transport costs are lowest when density of the product is high (Huismann et al, 1997).

The objective of this research is to determine the cost of delivered biomass to the pellet production facility.

Materials and Methods

In determining the cost of biomass delivered to the production facility for pelleting the costs to be considered are biomass production costs, storage, drying and transportation. The biomass under consideration is cereal straws (wheat, barley, oaten and rape) and energy crops (miscanthus and willow).

Biomass production costs

In determining the cost of biomass production costs two approaches can be considered:

1. Crop production costs (Teagasc booklet – Management data for farm planning 2008)
2. Opportunity cost of the biomass

When considering the cost of wheat, barley and oaten straw both costs will be considered from available data (current market value and straw fertiliser value). Existing markets exist for willow and miscanthus hence crop production costs will be considered.

Storage costs

To ensure a year round supply of quality, dry biomass covered storage is essential. For pellet production biomass should be between approximately 12 – 18% moisture content wet basis (m.c.w.b). The storage of cereal straws and miscanthus is best facilitated in bale form either in roofed structures or under reinforced plastic. Willow is generally stored in chip form either in roofed structures or under plastic cover.

Drying costs

When considering agricultural crop biomass many materials can be harvested at less than 20% m.c.w.b. (cereal straws). Drying of other crops can take place in storage by either natural ventilation (miscanthus) or forced ventilation (willow).

Transportation costs

Considering the low bulk density of straw and miscanthus (0.02 – 0.04 dmt/m^3: straw and 0.075 – 0.1 dmt/m^3: miscanthus) baling of the crop is necessary to increase the volume transported (0.11 – 0.2 dmt/m^3: straw and 0.13 dmt/m^3: miscanthus). When transporting baled biomass either an articulated tractor unit with flatbed trailer or an agricultural tractor and flatbed trailer is used. Willow is transported in chip form using either an articulated tractor unit with stepframe tipper or agricultural tractor and high sided trailer.

Results and Discussion

Biomass production costs

The straw market is very changeable and depends on weather conditions and harvestable yields. The price of straw differs slightly from crop to crop. Table 1 details biomass costs. On average straw yield is considered as 60% of grain yield. For miscanthus the harvesting method was mowing and baling while the willow was cut and chopped using a self-propelled harvester.

Table 1: Biomass production costs per hectare and per tonne

Biomass	**Production Cost**		**Opportunity Cost**	
	(€ / ha)	**(€ / t)**	**(€ / ha)**	**(€ / t)**
Wheat straw	70 – 85	16.50	86 – 91	19
Barley straw	100-110	30	64 – 70	19
Oaten straw	100	28	95 – 107	28
Rape straw	-	-		
Miscanthus	534	53	-	-
Willow	865	86.50	-	-

Source: Teagasc Management data for farm planning 2008

Storage costs

For the purpose of these costs the following assumptions were made:

1. Two types of roofed structure are considered:
   - Roofed with no side sheeting (structure 1)
   - Roofed and sheeted 1/3 down the side (structure 2)
2. Two types of cover are considered:
   - heavy duty 1200 gauge plastic
   - Tarpaulin

Willow chip is generally stored on a concrete yard and covered using plastic or a tarpaulin. Mechanical or forced ventilation is necessary to dry the chip and prevent heating as harvest moisture can be

as high as 50% m.c.w.b. Storage costs are described in Table 2.

Table 2: Storage costs for biomass per tonne

Storage Type	Storage Form	Storage Cost (€ / a / t)
Roofed Structure:		
Structure 1	1.2 x 1.2 x 2.4m Bale	1.64*
Structure 2	1.2 x 1.2 x 2.4m Bale	1.75*
Covered:		
1200 Gauge Plastic	1.2 x 1.2 x 2.4m Bale	1.06*
Tarpaulin	1.2 x 1.2 x 2.4m Bale	1.46*
Chip Heap (27 x 14 x 2m)	Chip	1.47*
** Storage costs does not include any sub-base or concrete base*		

Drying costs

In general circumstances natural ventilation of baled biomass over a period of 6 – 9 months is adequate to ensure drying to below 20% m.c.w.b. Where natural ventilation is adequate self heating is not a concern. Drying of willow chips was conducted using forced ventilation at ambient temperature through ducting. Table 3 details the costs incurred in drying willow to on average 20% m.c.w.b.

Table 3: Drying costs for biomass per tonne

Biomass	Storage Form	Drying Medium	Cost (€ / a / t)
Wheat straw	1.2 x 1.2 x 2.4m Bale	Natural Ventilation	Nil
Barley straw	1.2 x 1.2 x 2.4m Bale	Natural Ventilation	Nil
Oaten straw	1.2 x 1.2 x 2.4m Bale	Natural Ventilation	Nil
Rape straw	1.2 x 1.2 x 2.4m Bale	Natural Ventilation	Nil
Miscanthus	1.2 x 1.2 x 2.4m Bale	Natural Ventilation	Nil
Willow	Chip	Forced Ventilation	7
Source: Teagasc Crops Research Centre.			

Transportation costs

A maximum cost of €5.71/t (5GBP/t) is calculated for straw haulage in 1.2 x 1.2 x 2.4m bales (maximum 50km radius). This pelleting company operates a JCB Fastrac with a 12 metre flatbed trailer. Transportation costs per km tonne are detailed in Table 4. The maximum load capacity of 15 tonnes (1.2 x 1.2 x 2.4m bales, average mass 500kg, 30 bales per load) is obtained using a 6x2 tractor unit and flatbed trailer. For chip haulage the maximum load capacity is 9 tonnes using a 6x2 tractor unit and stepframe tipper (50m^3 volume). From previous experience when the travel distance is short (within 50km radius) an agricultural tractor and trailer is most cost effective.

Table 4: Transportation costs for biomass per tonne

Haulage Type	Max Load (t)	€ / km / t	50km (€ / t)
Tractor & 12m Flatbed Trailer	15	0.12	6
6x2 Artic & 12m Flatbed Trailer	15	0.20	10
6x2 Artic & Step frame Tipper	9	0.20	10

Conclusions

Harvest method has an effect on both storage and transport costs as may be seen when comparing these costs for baled and chip material. The lowest cost of delivered biomass to a production facility (base price – no profit margins) is approximately €30 / t for straw, €60 / t for miscanthus and €105 / t for willow chip. Depending on storage method costs vary from €1.06 / t (1200 gauge plastic) to €1.75 / t (roofed structure with 1/3 side sheeted). Using an agricultural tractor and 12m flatbed combination for transport over small distances (less than 50km) is cheaper than articulated haulage (€6 / t compared with €10 / t). The cost of delivered biomass critically depends on material and harvest method, storage and transport option.

Acknowledgements

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References

Energy Policy Statistical Support Unit. (2008). Energy in Ireland 1990-2007. Sustainable Energy Ireland, 51-53.

EUBIONET 2. Fact Sheet 12 – Denmark. Production of big straw bales, straw pellets, transport and storing for power plants and CHP plants. Supply chain for straw pellets to power plants, No 12 (1).

Euro exchange rates. (2002). Official journal of the European Communities. 2002/C 1/02. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2002:001:0002:0002:EN:PDF. Accessed on: 02 February 2009.

McKendry, P. (2002). Energy production from biomass (part 1): overview of biomass. Resource Technology, 83: 37-46.

Huisman, W., Venturi, P. and Molenaar, J. (1997). Costs of supply chains of miscanthus giganteus. Industrial Crops and Products, 6: 353-366.

Management Data for Farm Planning 2008. Available at: Teagasc Crops Research Centre, Oak Park, Carlow, Ireland.

Mani, S., Sokhansanj, S., Bi, X. and Turhollow, A. (2006). Economics of producing fuel pellets from biomass. Applied Engineering in Agriculture, 22(3): 421-426.

Pastre O. 2002. Eubia Pellets for Europe. (2002). Analysis of the technical obstacles related to the production of fuel pellets made from agricultural residues. ALTENER 2002-0120137-160.

Styles, D., Thorne, F. and Jones, MB. (2008). Energy crops in Ireland: An economic comparison of willow and miscanthus production with conventional farming systems. Biomass and Bioenergy, 32: 407-421.

Integrated Assessment of Biogas Technology Options in Germany

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Abstract

The Renewable Energy Policy in Europe is underpinned by: need to limit supply and price volatility for fossil fuels; need for reduction of GHG emissions by using cleaner and locally produced energy, and; need for more competitive energy markets to stimulate innovation technology and jobs. A key energy policy target in Germany is to increase the share of total energy consumption from renewable resources from the current 9.1% to 20% by 2020. Biogas has potential applications in generation of electricity, heating, and as fuel for the transportation sector; with less CO_2 emission compared to fossil fuels, and therefore could provide significant contribution to meeting these targets. Objective of this study are to carry out an integrated assessment of biogas technology deployment in German, with specific focus on multiple feedstock options. The assessment takes into account technical feasibility, environmental, economic and social parameters on common basis of importance. Initial results indicate that National and EU level policy incentives and barriers have significant impacts on potential expansion in utilisation. Technical and environmental performance of biogas technology depends on type of feedstock, conversion technology employed and biogas utilization pathway. In the next stage of the study, energy conversion efficiency and environmental impact criteria for sustainable biogas production systems will be determined.

Introduction

The principal driver for deployment of biogas technology in Germany is to secure a renewable energy resource substitute for fossil fuels. Other benefits include; reduction of GHG emission; potential use of the spent feedstock or digestate as organic fertilizer, and; since the ban on landfilling of organic waste, anaerobic digestion (AD), has also been adopted as a technically viable waste management option. The requisite organic feedstock are renewable, therefore, with the right policy incentives, security of energy supply could be enhanced. The deployment of biogas technology created about 10,000 jobs in 2007 (FvB, 2008), and contributed to economic growth with the increased export of the technology. However, the competitiveness of biogas plants has lately been impeded by concerns about sustainability of biogas production regarding feedstock used and high dependence of biogas technology on government subsidy, due in part, to inefficient operation.

The overall objectives of this project are, to: (1) assess economic and policy drivers determining biogas technology deployment, hence, evaluate the prospects for expanded utilization; (2) evaluate energy efficiency and environmental impacts of biogas production with focus on multiple feedstock, and; (3) develop scope and methods to facilitate comparison between design and the inherent technology options.

Materials and methods

The study is centred upon four specific objectives. Objective 1 covered the prospects for expanded utilization of biogas in Germany. The associated tasks have been completed and the result submitted to the *Energy Policy Journal* for peer review. Objective 1 was aimed at identifying the key factors affecting the complete chain of processes in plant implementation from the planning process, installation and commissioning, to

feedstock supply, and biogas production and utilization (see Fig. 1). A review of biogas production systems in Germany (see Fig. 1) was conducted and the supporting energy policy framework analysed, in order to identify the key incentives and barriers to the potential for expanded deployment. Interviews with industry stakeholders were carried out as part of the technology review, in order to corroborate the pertinent data and observation reported in technical literature. Important policy issues were identified in the plant implementation process, and in biogas production and utilization phases.

Objective 2 is currently in progress and deals with energy audit of biogas production systems. It covers energy balance of biogas systems with focus on multiple feedstock, and comparison of biogas conversion paths to biogas plant location for sustainable operation. Objective 3 will assess the critical design factors impacting on fuel cycle emissions. Objective 4 will focus on potential environmental impacts of replacing selected reference energy generation systems with biogas systems.

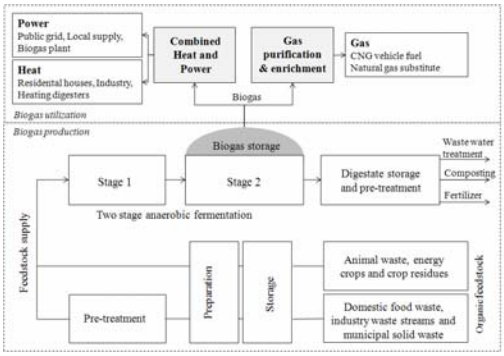

Fig. 1: Biogas production system

The energy audit of biogas systems that is covered under objective 2, considers the system boundary depicted in Fig. 2. The base scenario is developed for evaluation of the energy performance of different biogas systems within the entire life-cycle. All calculations will be based on literature data, practical experience from manufacturer of components, and production statistics from judiciously selected production systems and scenarios. Calculations will be validated by measured data or corroborated with evidence from comparable or equivalent setting from literature survey.

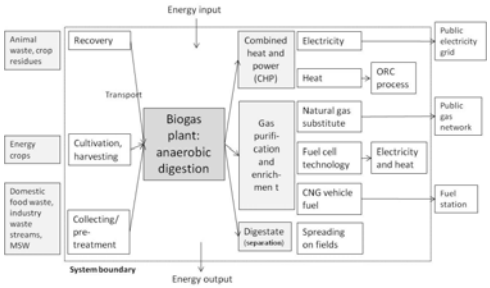

Fig. 2: System boundary biogas systems

Results and discussion

From the concluded objective 1, it was found that the European Environment Agency guidelines focus on environmental protection and sustainable energy supply. Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has implemented this policy goal by setting up a detailed action plan, including; energy efficiency measures, energy management schemes and sustainable practices. The Federal Environmental Agency in Germany identifies biogas technology as important for GHG emission reduction and a sustainable waste management system.

On the implementation process of biogas systems, it was found that both environmental protection and economic considerations are key to plant location. Although all plants conformed to the minimum regulatory standards, in most part, Germany's biogas plants had not adopted the best available technology. In addition, the anaerobic digestion (AD) process was deemed to be optimal in approximately 75% of plants surveyed (FAL, 2005). In light of the unstable feedstock prices and low electricity feed-in tariffs, feedstock flexibility was considered to be important for future subsidy-free biogas plant operation.

Agricultural waste and energy crops were the most suitable feedstock because of their easy availability, optimal characteristics for anaerobic process and ecologically friendly digestate disposal

options. Only about 10% of the available feedstock resource potential of 417.5 PJ per annum is currently utilised (Table 1). Although biogas production from liquid manure has ecological advantages, only 15% of the resource was used.

Biogas yield from corn silage of up to 171 m^3 per tonne of dry matter could be achieved, compared to 20 m^3 for cattle manure; therefore, energy crop feedstock was technically more attractive, although with potential negative ecological impacts for monocultures.

Organic waste from agri-food industry and municipal solid waste (MWS) streams provide attractive feedstock options due to ready availability, high biogas yield, and revenue from gate fees (Table 2). However, regulations require their pre-treatment prior to use, and there is a knowledge gap on co-digestion technology with regards to differences in homogeneity and degradation for the AD process control.

Table 1: Feedstock resource potential in Germany (FNR, 2006)

Feedstock type	Potential PJ/a
Manure with litter	96.5
Crop residues	13.7
Landscape conservation	12.0
Energy crops	236.0
Industrial waste	9.3
Municipal solid waste	12.5
Waste water	19.5
Landfills	18.0
Total	***417,5***

Table 2: Gate fees for waste disposal in Germany (IFAT, 2008; Mathews, 2008)

		Gate fees, €/t
Incineration plant		60 – 350
Composting	Unpacked food waste	35 – 45
	Packed (expired food)[1]	75 – 95
Biogas plant	Municipal solid waste (MSW)	30 – 40
	Waste of industrial sector	25 – 30

[1] Includes pre-treatment costs for the composting process

The cost of pre-treatment prior to AD as a technique for waste disposal was found to be significant and therefore less competitive against alternative disposal methods (e.g. incineration).

Operation efficiency was enhanced by availability of feedstock and entire biogas utilization at point of generation. Upgrading of biogas to natural gas quality could support rapid utilization expansion. Lower transmission losses, possibility for decentralised biogas production (i.e. closer to feedstock source to minimize transportation cost), and potential transmission to expansive market supports this view. Whereas technical capacity was found to be available for such deployment, investment costs were still high, and therefore only economic for large-scale biogas plants.

Objective 2 addresses the evaluation of energy outputs compared to energy inputs in dependence on multiple feedstock used and different conversion paths for biogas utilization. The energy input will be influenced by effort for feedstock preparation and optimal location of biogas system with efficient feedstock supply logistics. The energy output depends on biogas yield of feedstock and innovative conversion technology which focus on subsidy-free operation of biogas systems in Germany. Expected impact of objective 2 is therefore the assessment of energy balances from various biogas systems with high efficiency and sustainability.

Conclusion

Completed tasks under Objective 1 suggest that existing incentives for production and utilization of biogas in Germany are still weak, therefore, may be unable to support expansion. Enhanced policy framework for expanded deployment should support: (1) Optimal plant location for enhanced feedstock supply logistics; (2) R&D for process innovation and plant operator training programmes for efficiency, (3) Higher utilisation of liquid manure resource; (4) Co-digestion of agri-food industry and MSW streams as basis for sustainable

feedstock supply, and as waste management strategy; (5) Maintenance of economic incentives that will encourage plant operators to generate CHP for more efficient plant operation, hence, and develop a utility market for electricity from RR by the introduction of CO_2 tax on fossil fuels; (6) Energy conversion technologies that will generate economic attractiveness even for small-scale biogas plants.

Acknowledgements

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References

Agency for Renewable Resources (FNR) (2006), Guidance - Biogas production and utilisation. Gülzow, Germany.

Federal Agricultural Research Centre (FAL) (2005), Results of the biogas program of measurements. Gülzow, Germany.

German Biogas Association (FvB) (2008), Figures of the biogas branch 2007, available at <www.biogas.org>, visited 2008-08-26, (in German).

International Trade Fair for Water-Sewage-Refuse-Recycling (IFAT) (2008), (personal communication) May 5-9 2008. Munich, Germany.

Mathews, W. (2008), CEO Bruckner Biotec GmbH (personal communication) September 2008. Siegsdorf, Germany.

EXPERIMENTAL INVESTIGATION OF GASIFICATION/CO-GASIFICATION CHARACTERISTICS OF WILLOW, MISCANTHUS, CEREAL STRAW, AND PEAT

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Abstract

This project is aimed at optimising the gasification of three promising biomass fuels for Ireland (willow, miscanthus and cereal straw) and peat in an atmospheric air blown, bubbling fluidised bed gasifier. The effectiveness of co-gasification with wood and optimisation of operating conditions to overcome bed agglomeration associated with straw and miscanthus will be investigated. The experimental data will be used to develop criteria for optimisation of the energy efficiency of biomass gasification process. In addition the scale necessary to reach commercial viability for a combined heat and power plant based on this technology will be determined.

Introduction

By 2020 Ireland aims to meet 33% of its electricity and 12 % heating and cooling requirements using renewable resources [Anonymous I]. Biomass has a high potential to contribute significantly to meeting these targets, but commercially adopted energy conversion pathways are currently limited to the relatively inefficient direct feedstock combustion technologies. This limitation can be overcome by gasification technology, which transforms the solid biomass into gaseous fuel. Miscanthus and willow short rotation coppice are promising energy crops for Ireland, with potential dry matter yields ranging between 16 to 26 $t.ha^{-1}$ [Clifton-Brown JC] and 7 to 11 $t.ha^{-1}$ [Anonymous II], respectively. The corresponding net calorific vales are 17 M kg^{-1} and 18.4 to 19.2 M kg^{-1}, respectively [Pisarek M, Smyth B] The two energy crops can be grown for waste management (bioremediation) while simultaneously supplying energy feedstocks, and can also be grown on spent peat-lands thereby minimising the competition for land with arable crops [Jones DL, Anonymous III]. The significant surplus of cereal straw (estimated at 0.08 to 0.53 million tons per annum) in the farming system in Ireland makes it another promising bioenergy resource [Pisarek M]. Currently, there is limited knowledge on gasification characteristics of these biomass resources. Additionally, gasification of miscanthus and straw can impact negatively on gasifier operation due to bed agglomeration linked to the formation of low temperature melting point eutectics associated with the their ash components. This problem is severe in the case of wood. Co-gasification of agglomeratig biomass feedstocks with wood and reduction in bed temperature are known to reduce the impact.

This work will identify the gasification /co-gasification characteritics of willow, miscanthus, cereal straw and peat. It is envisaged that the inclusion of peat could provide for a more efficient energy conversion pathway than the currently used steam cycle.

Material and Methods

Pilot plant

A pilot plant air-blown, autothermal bubbling fluidised bed (BFB) gasifier illustrated in Figure 1 will be used in this study. The gasifier is situated at the Fraunhofer Institute UMSICHT. It has heating capacity of 100 kW_{th}. The gasifier is insulated to compensate for heat losses and the air preheated to obtain the required self ignition temperatures.

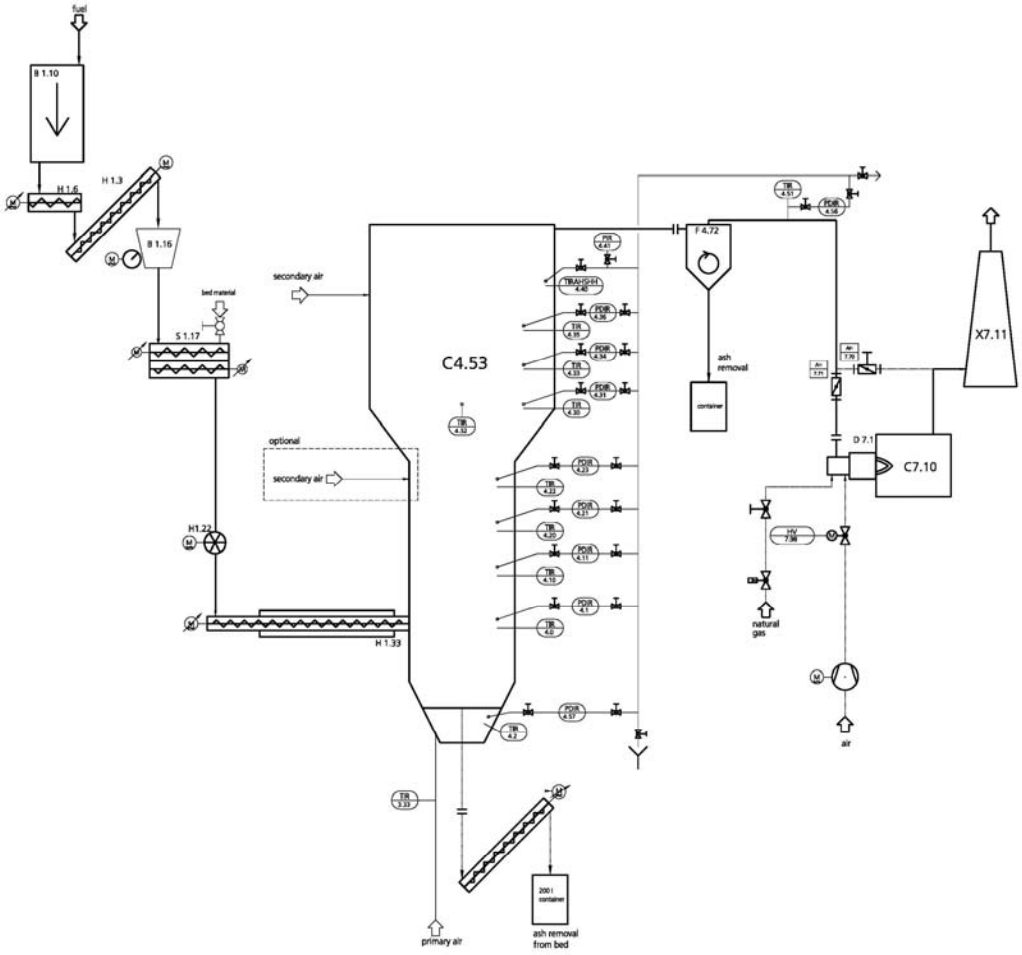

Figure 1: The 100 kW_{th} air-blown BFB gasifier used in this study (Gasifier: C4.53, Feed Augers: H1.6, H1.3, H1.33, Flue Stack: X7.11, Cyclone: F4.72, Combustion chamber: C7.1, Thermocouples denoted by T, Pressure transducers denoted by P).

Fuels

Gasification of untreated wood chips is considered as state-of-the-art, having been successfully demonstrated at industrial scale in many different plants throughout Europe, e.g. Harboøre in Denmark and Güssing in Austria. As such, chipped wood was chosen as the reference fuel. Willow will be used in chipped form. To prevent gasifier bed agglomeration problems, it is intended to co-gasify miscanthus and straw with wood chip. Due to the single feeding mechanism densification of these materials is necessary to achieve similar densities to that of the wood chip. This is in order to avoid separation. Miscanthus and straw will therefore be fed in pelletised form. Crushed peat briquettes will be used as milled peat could cause feeding problems.

Measurements and analysis

Laboratory analysis of the fuels will be conducted to determine water content, ash content, heating value and elementary composition (i.e. C, H, O, N, S). The sintering, softening and flow characteristics of the fuel ash will also be determined. Temperatures and relative pressures at different heights in the gasifier (see figure 1) will be logged. The temperature of the primary and secondary air will be measured along with their flow rates. These values will also be logged with regard to the producer gas (PG). In addition the composition of the PG, specifically, the CO, H_2, CH_4, CO_2, H_2O, O_2 and tar contents will be determined. An

infrared (IR) detector will be used in the measurement of CO, CO_2 and CH_4. O_2 will be measured using an electrochemical cell and H_2 with a thermal conductivity detector. Steam content will be evaluated using a heated sample line and an IR detector. Tars will be collected by absorption sampling in cold traps with acetone solvent and analysed using a mass spectrometer. The heating value of the gas will be calculated from the experimental data. Specific rate of gas generation (m^3kg^{-1} fuel consumed) will also be determined. Initial gasification temperature of 920°C will be set. This operating point has been determined with the adoption of a Ni catalyst for the reforming of tar in the PG to meet the requirements of an internal combustion engine (ICE) and allowing for sufficient catalyst reactivity. The air fuel ratio will then be altered, by varying the air flow rate, to reach the maximum allowable temperature of 950 °C (imposed by materials adopted in the construction of the gasifier) and subsequently the minimum desirable temperature. The lowest temperature is limited by decreasing carbon conversion. Coke build up will be monitored by pressure drop readings which will also determine the minimum temperature point. The optimum operating point will be determined from the tests runs, and the process will be repeated by altering the fuel flow rate to quantify the influence of these two parameters versus that of the equivalence ratio (ER). With miscanthus and straw, the quantity of wood to be co-gasified will be based on the ash sintering and softening data. This quantity will be progressively reduced until signs of agglomeration are witnessed – show by alterations in temperature and pressure readings within the bed.

Results and Discussion

Ash related problems have been identified as a major concern for biomass gasification. It has been highlighted as the main ash related problem with respect to fluidised bed gasifiers, and is linked to their ash contents forming low temperature melting point eutectics. Generally, a highly viscous melt is produced that covers the bed material and causes collation of the bed. The formation of this melt has been associated with reactions between alkali and alkali metals, mainly potassium, and the bed material of silica sand [Arvelakis S]. The Cl and sulphur contents of straws and grasses can be elevated, which has been associated with ash agglomeration, which is more severe for straw [Maniatis K.]. Miscanthus also experiences agglomeration and defluidisation of fluidized beds [Nijenhuis J]. Co-gasification with wood as well as reduction in bed temperature are seen as steps to prevent such ash related problem [van der Drift A]. Since the experimental gasifier is authothermal, temperature will be controlled via the ER. This has been highlighted as a key factor determining the quality of the PG such as the heating value. Generally, there is inverse correlation between heating value and ER [García-Ibanez P, Mansaray KG] but with exception for relatively low ERs when the order is reversed [Natarajan E, Zainal ZA]. This trend has been associated with decreases in combustible gases, predominantly CO. In modelling work carried out by Salzmann R [Salzmann R] the CO content of PG from the atmospheric air gasification of wood, taken as $C_{1.26}H_{0.66}$, at adiabatic conditions was maximised at an ER of ca. 0.36. Due to heat losses this should be higher in our case. Variation of the temperature will also impact on the tar content of the PG. Specifically, the quantity of tar is inversely proportional to temperature, which can limit its use, e.g. a tar limit of 50-100 mg/Nm^3 is given for ICEs [Ising M].

Conclusions

This study will provide a quantified assessment of characteristics and energy conversion potential of willow, miscanthus, cereal straw and peat as promising biomass resources in Ireland. Their performance will be rated against wood – a clean fuel with regard to gasification - as benchmark. The study will investigate operational limits as well as optimal operating conditions. The technical feasibility of overcoming agglomeration problems associated with

ash-product, by co-gasification and process optimisation will be investigated. The experimental data will be used to develop criteria for optimisation of the energy efficiency of biomass gasification process. The commercial potential of this plant with regard to combined heat and power production utilising an ICE will be calculated. The economic analysis will incorporate an appropriate gas cleaning train to meet the requirements of the ICE, specifically with regards to tar.

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References

Anonymous I (2007). Energy White Paper 2007, Delivering a Sustainable Energy Future for Ireland, the Energy Policy Framework 2007 – 2020, Department for Communications, Marine and Natural Resources.

Anonymous II (2009). Planting and Growing Miscanthus, Best Practice Guidelines for Growing Miscanthus Under the Bioenergy Scheme (BES). Department of Agriculture, Fisheries and Food.

Anonymous III (2008). Corporate Social Responsibility Report 2007/2008, Bord na Móna.

Arvelakis S, Gehrmann H, Beckmann M, Koukios EG (2005). Preliminary results on the ash behavior of peach stones during fluidized bed gasification: evaluation of fractionation and leaching as pre-treatments, Biomass and Bioenergy, 28, 331-338.

Clifton-Brown JC, Neilson B, Lewandowski I, Jones MB (2000). The modelled productivity of Miscanthus giganteus(GREEF et DEU) in Ireland. Industrial Crops and Products: 12; 97–109.

Jones DL, Williamson KL, Owen AG (2006). Phytoremediation of landfill leachate, Waste Management 26, 825–837.

García-Ibanez P, Cabanillas A,. Sánchez JM (2004). Gasification of leached orujillo (olive oil waste) in a pilot plant circulating fluidised bed reactor. Preliminary results, Biomass and Bioenergy, 27, 183-194.

Ising M, Unger C., Gil J, Balke U (2000). Gasification of Biomass in a Circulating Fluidized Bed for the Generation of Power and Heat, 1st World Conference and Exhibition on Biomass for Energy and Industry, 5 - 9 June 2000, Sevilla, Spain

Maniatis K. (Unknown). Progress in biomass gasification: An overview, European Commission.

Mansaray KG, Ghaly AE, Al Tawee AM, Hamdullahpur F, Ugursal VI. (1999). Air Gasification of Rice Husk in Dual Distributor Type Fluidized Bed Gasifier. Biomass and Bioenergy, 17, 315-332.

Natarajan E, Nordin A, Rao AN (1998). Overview of Combustion and gasification of Rice Husk in Fluidized Bed Reactors, Biomass and Bioenergy, 5/6, 533-546.

Nijenhuis J, Korbee R, Lensselink J, Kiel JHA, van Ommen JR (2007). A method for agglomeration detection and control in full-scale biomass fired fluidized beds, Chemical Engineering Science, 62, 644 – 654.

Pisarek M. et al (2004). The Review-Biomass Resources and Potentials-Regional Studies and Experiences, Project RENEW.

Salzmann R (2002). Fuel Staging for NO_X Reduction in Automatic Wood Furnaces. Thesis in completion of doctor of technical sciences. Swiss Federal. Institute of Technology Zurich

Smyth B (2007). Optimal biomass technology for the production of heat and power. MEngSc Thesis National University of Ireland, Cork

van der Drift A, Olsen A (1999). Conversion of Biomass, {private} Prediction and Solution Methods for Ash Agglomeration and related Problems. ECN Energy Research Foundation.

Zainal ZA, Rifau A, Quadir GA Seetharamu KN (2002). Experimental Investigation of a Downdraft Biomass gasifier, Biomass and Bioenergy, 23, 283-289.

Wood Gasification for Combined Heat and Power an Analysis and Report

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Abstract

A combined heat and power plant was designed to illustrate, process requirements, product potential and design layout of such a plant. This plant used wood syngas as the fuel. The design was compared with existing energy generation projects in the E.U. Plant operates at a thermal efficiency of 80 % and a thermal efficiency of 33% that generates 10 MW of electrical power and 4.3 MW of thermal energy. Each vessel was designed according to EPA constraints, the gasifier When varying it fuel, oxygen and steam feed rates the Highest heat value of 5600 kJ/kg were obtained using 3.5 kg/s stream 8 kg/ s oxygen and 23 kg/s of wood chips.

Introduction

Almost 85 % of energy generation in Europe is based on combustion technology where plant set up and operation is relatively simply and it's been the chosen technology for over 150 years. Electricity is typically generated by superheated steam from combustion chamber of an 'industrial boiler', although energy can be obtained from the high heat content in the flue gas. Large scale energy generation from combustion can be found in Handelovreket Sweden, Grenea Denmark, and Mabjergvareket Denmark. All produce between 12 to 75 MW of thermal energy, and in the case of combined heat and power 10-13 MW_{th} and 4-9 MW_e for thermal and electrical energy respectively Process fouling and corrosion and boiler clinking have been documented by Faaj et al 1995, Hollenbacher 1992 and Simms et al 2002 in which Spliethoff et al, 2002 suggests that gas scrubbing and bed filters are the most effective and cheapest methods of impurity removal. Combustion is the most used wood conversion process. for wood in the context of steam derived energy.

Operational problems of Combustion process and the cleaning requirements that result are described in Jenkins et al, 2004, Jensen et al, 1995, Faaj et al, Dowaki et al 2005. When gasification is considered as a conversion process, cleaning is subject to the durability limits of engines turbines etc. (de Jong et al 2003, Li et al 2004).

Gasifier technology is largely pilot or laboratory scale due to its high energy consumption. Yuan et al, 2007, Hanol et al 2004, Xavier et al, 1999 have introduced gasifier modifications to reduce energy consumption, amongst those reviewed automatic preheating devices are the most promising. In some cases gasification produces the syngas used for further heating requirements. Problems with gas conditioning, concentrated tar formation and intricate process controls required means that there are few applications for energy generation today.

This thesis examines the potential for wood gasification in combined heat and power through a report of energy generation plants and a design of a Model CHP plant incorporating wood gasification.

Materials and Methods

Information Collation and Collection
Four stages were involved in the assessment of a proposed combined heat a power plant. First stage required a collation of plant operating data from a number of plants. Operating data consisted of mass flowrates operating temperature and pressure and thermal and electrical efficiency of the plant. Results data consisted of plant emissions and power generated.

In order to get a visual understanding and visual layout of plant particularly three visits were made to energy generation

plants in Ireland, Grainger Sawmills Enniskean Co Cork, BALCAS wood CHP in Enniskillen Fermanagh and Endinderry Electrical Power in Edinderry Co Offaly.

Process layout
The proposed plant was designed on the basis that ashes, tar, char and metal oxides wood need to be removed from the combustion products to avoid risk of material fouling and clinking. The process was presented in VISION 2000 format, a chemical process engineering design tool. Process instrumentation and process equipment were labelled as shown in (Figure 3). Selection of process equipment was based on the predicted side product path in Figure 3.

Plant Operation
Plant follows conventional combustion controlled by primary and secondary air. As already mentioned the syngas will be combusted at 25 ^{o}C to produce superheated steam at 400 ^{o}C. The syngas gas is cleaned by a cyclone–gas scrubber system. A small fraction of superheated steam is used to 'reheat' the water that enters the boiler and remaining steam enters the turbine for electricity generation

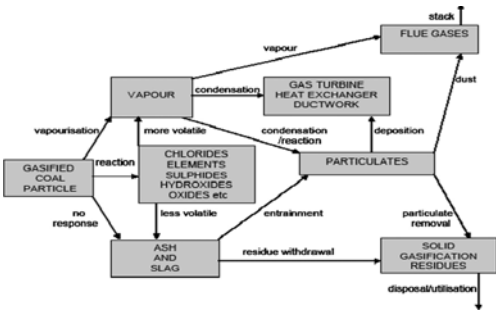

Fig. 1. Flow diagram; fate of elements of an air-blown gasifier with gas clean-up Courtesy of Sims et al

Process Specification and Mass Balances
Due to the complicated mass relationships from gasification reactions a correction factor was used to estimate flue gas composition this formula (*Equation 1*). Notation is as follows, *a* refers to the number of atoms from that j_{th} compound, the correction factor for the j_{th} compound subtracts the final number atoms ($a_{k,f}$) of the k_{th} element from the intial number of atoms ($a_{k,i}$). The difference is divided by the product of the stoichiometric coefficient of the k_{th} element and the initial number of atoms. This figure is multiplied by a scale factor of 100 to speed up convergence. Ash is predicted from data presented in Table 2 whereas the char and tar amounts are based on ball park figures from Perry 2001 and not estimated.

Mass balances of the boiler were obtained from on stoichiometry of the combustion of syngas and oxygen; design equations for input water and design equations for input syngas. Mass balances around the scrubber and cyclone separators were obtained from design equations and unit operation procedures based on Coulson and Richardson 2003 Volumes 3 and 4 respectively.

$$f_j = \left(\frac{a_{k,f} - a_{k,i}}{\upsilon_k a_{k,i}} + \frac{a_{k+1,f} - a_{k+1,i}}{\upsilon_{k+1} a_{k+1,i}} \right)_j \textbf{X } 100$$

Equation 1 correction factor (mol/s)

Mass balances of the turbine and recycle streams (*Streams S19-23*, *Figure 3*) are 'solved' by energy balances and thermodynamic constraints imposed by Rankin Regenerative Cycle.

Process Design
From a design problem perspective, dimensions of all process equipment are considered. The cyclone separators, gas scrubber tower and wood feeding system were chosen. The design methodology for these equipments can be found in [**2**], [**3**] and [**4**] respectively. Process parameters are estimated from energy balances based on enthalpy *H* (kJ/kg) balance of gas for each stream. For the steam enthalpy, data is simply read from steam tables and incorporated into energy balances which are described in a Rankin Regenerative Cycle.

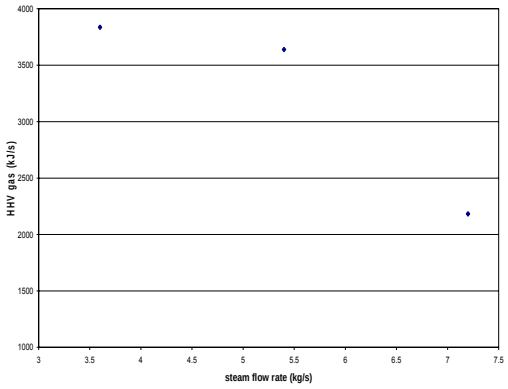

Figure 2.1 steam flowrate vs. HHV (kj/kg)

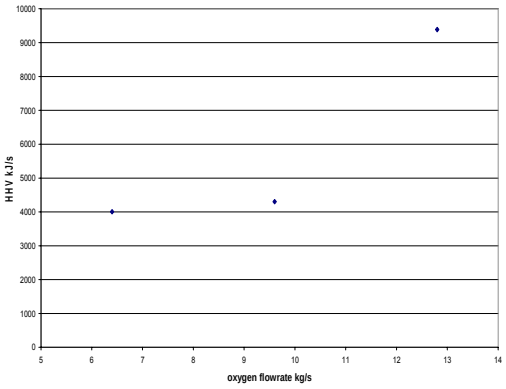

Figure 2.2 oxygen flowrate vs. HHV (kj/kg)

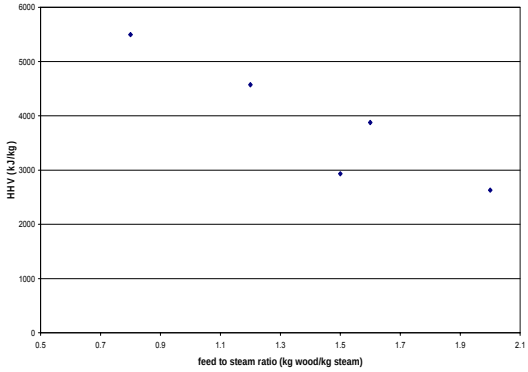

Figure 2.3 steam: oxygen ratio v HHV (kj/kg)

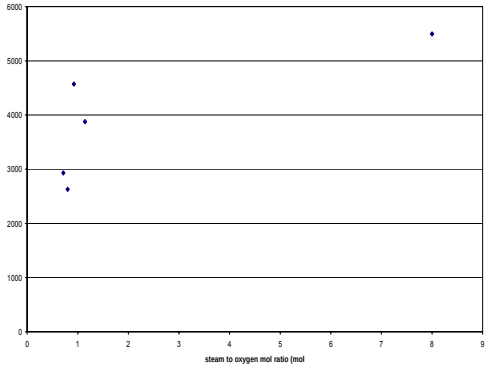

Figure 2.4 feed: steam ratio v HHV (kj/kg)

Results and Discussion

Shown in Table 1 are calculated parameters for each stream *S1 -29*. Compared with existing plants in E.U this CHP plant operates with higher wood feed rate whereas steam and fluegas flowrates are within the operating range (Faaj et al 1996). Formulae used in determining electrical and thermal power are depicted below.

Figures *2.1– 2.4* demonstrate the effects of varying the feed inputs into the gasifier on heating value of the gas. A substantial increase in steam flow (5.5-7.0 kg/s) gives a drop of almost 2900 kJ/kg (*Figure* 2.1). The converse applies to oxygen flow rate where an increase in oxygen flow (5.5-7.0 kg/s) gives rise of 4000 kJ/kg, doubling the heating value (*Figure* 2.2). It follows that when feed to steam ratio was varied the heating value fell by same amount (*Figure* 2.2). Similarly Figure 2.4 shows when the steam to oxygen ratio was increased the heating value rose by 4000 kJ/kg. These trends suggest that an energy efficient gasification process will favour lower values of steam and greater amounts of oxygen and wood feed. Steam dilutes the syngas mixture thus of those gas species of large heating values like H_2 and CO_2.

From a boiler operation (Equation 2) perspective a larger 'syngas heating value' will demand less gas feed into the boiler thus more gas can be transported for storage which can be sold as low grade heating fuel. In this sense money would be generated for the plant along with money generated from power and heating sold from the plant.

Equation 2 presents the fundamental approach in determining the operating temperature of each stream. For conciseness only the most important energy balances are presented. The designs electrical and heating production of 10 MW_{th} and 4.3 MW_e respectively is within the range of that supplied in E.U CHP

plants. Plant operates at a thermal efficiency of 80 % and a thermal efficiency of 33% that generates energy.

$$E_{wood\,conv} + E_{steam} + E_{oxygen} = E_g + E_l \quad (2)$$

$$E_{wood\,conv} = \dot{m}_{wood} LHV_{wood} \quad (3)$$

$$E_u = \dot{m}_g LHV_g \quad (4)$$

Sensible heat energy in gasifier accounted for

$$E_s = \frac{\dot{m}_g \sum (y_i h_i)}{\sum (y_i Mw_i)} \quad (5)$$

Energy balance for combustion boiler

$$E_{gas} - E_{heat,reacts} = E_{heat\ product\ Taf} \quad (6)$$

$$\eta_e = \frac{w_{turbine}}{w_{pump1} + w_{pump2}}$$

$$\dot{m}_5 h_5 = \dot{W}_{turb} + \dot{m}_6 h_6 + \dot{m}_7 h_7 \quad (7)$$

Table 1 Process Parameter estimates

species	stream	flow rate	temp, pressure		stream	flow rate	temp, pressure
	S #	kg/s	K, kPa		S #	kg/s	K, kPa
wood	1	9.96	283, 101	steam extract	14	2.04	534, 180 000
oxygen	2	3.84	305, 167	steam I	15	11.26	340, 50 000
steam	3	1.80	421, 30000	water con	16	0.12	383, 800 000
syngas+imp[1]	4	15.90	673, 830	water con	17	0.12	400, 800 500
ash	5	0.38	200, -	sat water	18	11.26	310, 24 000
water	6	15.98	25, 400	sat water	19	11.26	310, 24 050
syngas+char	7	15.62	638, 729	heated water	20	13.69	363, 600 000
waste water	8	16.02	95, 400	heated water	21	13.69	363, 600 000
syngas	9		487, 606	air	22	42.20	310, 534
char	10	0.48	487,-	water	23	13.69	363, 600 000
fluegas	11	40.37	303, 400	sat steam	24	1.8	421, 30000
fluegas	12	65.22	1098, 978	district steam	25	12.3	-
steam sup	13	13.30	673,400 000	district steam	26	12.3	-

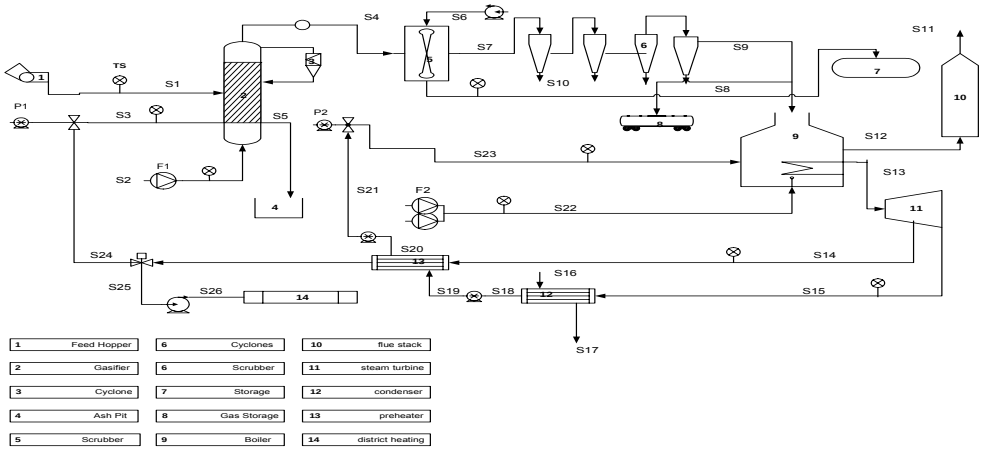

Figure 3. Process flow and instrumentation diagram

Conclusions

Using optimum HHV flowrates of oxygen and wood for provides largest HHV value gas. This lowers the demand in the fuel feed rate to the boiler thus leaving a higher fraction of fuel for storage. This can be sold as a low-medium HHV value fuel. The model plant provides 10 MW and 4.3 MW of electrical and thermal energy respectively. This falls production of all E.U CHP plants.

References

Paulrud S, Nilsson C. The effects of particle characteristics on emissions from burning wood fuel powder. Fuel 2004;83:813–21.

G. Chen, J. Andries and H. Spliethoff. Biomass conversion into fuel gas using circulating fluidized bed technology: the concept improvement and modelling discussion. Renewable Energy 2003; 28(6): 985–994.

Richard van den Broek, André Faaij, Ad van Wijk. Biomass Combustion for Power generation. Biomass *and Bioenergy*, *Volume 11, Issue 4*, *1996*, *Pages 271-281*

THE OPTIMISATION OF ANAEROBIC DIGESTION OF BIO-WASTES (INCLUDING ANIMAL SLURRIES) IN ORDER TO OPTIMISE GAS YIELDS

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Abstract
Three laboratory bench scale anaerobic digestion systems (along with a unit for bubbling the gas through water to remove CO_2) are currently being constructed in the UCD energy laboratory in Biosystems. Cattle wastes collected from a farm in Kilkenny will be used in the digester. A series of co-digestion tests will be conducted using a range of biomass feedstocks (including grass, straw, maize, and waste fats) in order to optimise the gas yields.

Introduction
Anaerobic digestion (AD) is a natural process of decomposition and decay that takes place in the absence of oxygen and by which organic matter is broken down to its simpler chemical components. The digestion process produces biogas, comprising largely of methane (60%) and carbon dioxide (40%) and a digested material.

The anaerobic digestion of animal slurries could potentially deliver several environmental and farming benefits. The digestion of animal slurries transforms organic nitrogen into inorganic nitrogen which makes a better fertiliser because the nitrogen is more available to plants (Palm, 2008). Compared to the raw animal slurries, anaerobically digested animal slurries are significantly less odorous, and have lower organic pollution potential, which ultimately has water quality benefits (Marcato et al., 2008).

Over the past decade, national and EU policy debate has highlighted the need to investigate alternative energy. The biogas produced through AD is a renewable energy source and whether used as a transport fuel or to produce electricity, it displaces fossil fuel energy production (Murphy and Power, 2006). Consequently, there is the potential for an overall reduction in emissions of greenhouse and acidifying gases, both of which Ireland has international commitments to reduce.

Anaerobic digestion is also a technology that can make a significant contribution to the management of organic wastes in Ireland. The EU's Landfill Directive (99/31/EEC) will increasingly prohibit landfill of organic waste. Anaerobic digestion recovers energy from such waste and produces a material that is suitable for land spreading.

A majority of work done on AD used animal slurries as raw materials. Additives to this basic raw material (e.g. grass, straw or maize) can be used to improve conditions for gas production and therefore a larger quantity of gas can be produced.

The aim of this project is to study the effect of the co-digestion of biomass with animal slurries for the optimisation of gas yields.

Materials and Methods

Experiment 1: Mixing test

This experiment is being done in order to determine the best mixing techniques for the waste material in the digester. Two techniques will be used to determine the best mixing techniques. The materials used in both tests will be a 3000ml Pyrex flask with 1000ml of slurry and grass, maize or straw.

The first test will use a magnetic stirrer plate. Two sizes of stirrer bars will be used (45mm and 60mm) in order to determine

which size will stir the waste material the best.
The second test will be using a pump to re-circulate any biogas produced from the waste and pump it through a pipe into the waste near the bottom of the pyrex flask (Figure 1).

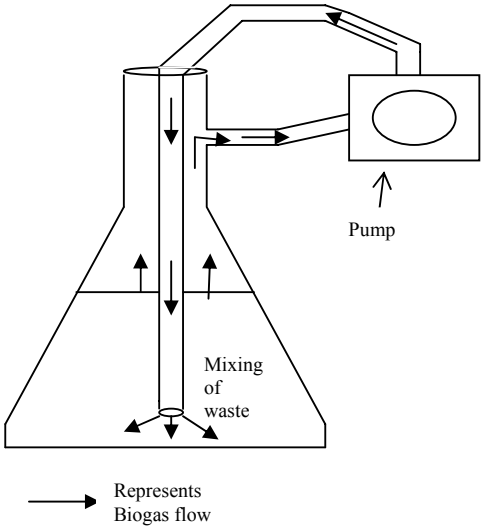

Figure 1: Diagram representing the re-circulating of biogas mixing method.

There will be a nozzle at the end of the pipe to increase the velocity of the gas entering the slurry and therefore help increase the mixing potential of the re-circulated gas.

Experiment 2: A bench scale anaerobic digester

This experiment will be built around a 5000ml conical glass flask with an integral side arm (which is the digester). The flask will be then placed on a hot plate and kept at a temperature between 30°C and 35°C, which has been proven the most efficient for stable and continuous production of methane (Chynoweth and Isaacson, 1988). A magnetic stirrer will be placed inside it. A rubber stopper with two holes will be used to seal the top of the flask (Figure 2). This unit will be made anaerobic by using a water vacuum attached to the integral side arm on the flask, drawing out all the air.

The other major unit in this system will be the gas collection and bubbling of gas through water, in order to remove impurities. Gas collection will be achieved by using homemade cellophane bags, which will also facilitate gas volume calculation

.

The gas bubbling unit consists of a 2000ml conical glass flask, which is sealed at the top with a two holed rubber stopper, one hole for the inlet pipe and the other hole for an outlet pipe. The inlet pipe is coming from the digester and the outlet pipe is connected to the gas collection bags. There will be a peristaltic pump on the outlet line in order to draw the gas through the bubbling unit and fill the gas bags (see Figure 2)

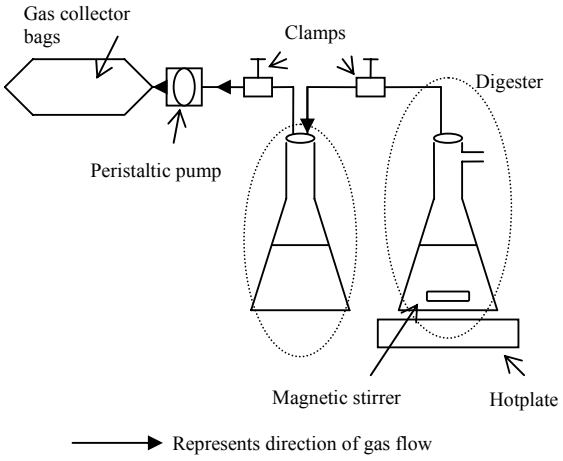

Figure 2: Diagram representing a bench scale anaerobic digester

It is planned that four bench scale models as shown above will be constructed. In each digester there will be different mixtures of substrate as shown in table below.

Digester 1	Cattle slurry (control)
Digester 2	Cattle slurry & chopped grass
Digester 3	Cattle slurry & maize
Digester 4	Cattle slurry & waste fat

From these four digesters the gas yield will be calculated over a given time along with the amount of methane produced in the biogas

Experiment 3: Gas chromatography

In order to analyse the biogas that is produced from above digesters, it is intended to use gas chromatography. This is a chemical analysis instrument for separating chemicals in a sample and enabling the exact components of the biogas produced from the digester to be determined.

Results and Discussion

As experiments have not being concluded yet, no definitive results have being obtained. But expected results are as follows.

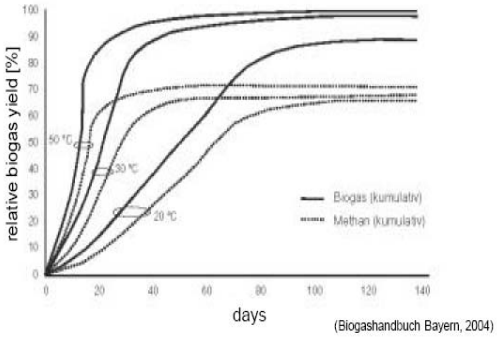

Figure 3: Graph representing relative Biogas and methane production over time for the shown temperatures (Wulf 2005)

Figure 3 represents the typical biogas production of cattle slurry. Biogas production is optimised after about 40 days and methane production which makes up around 65% of the biogas produced is optimised after about 40 days also.

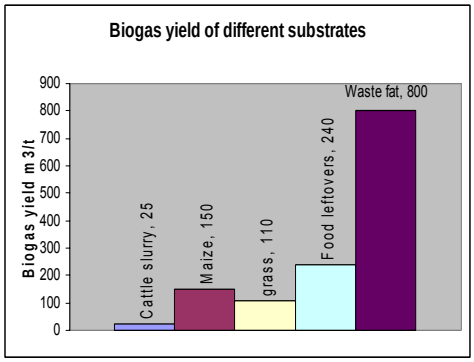

Figure 4: Graph representing Biogas yields of different substrates (Wulf 2005)

Figure 4 represents the biogas yields of different substrates of fresh matter, without any drying. So it can be expected that the digester 4 will produce more biogas over a given time than the other digesters

Conclusions

If all of the above experiments go as plan and the expected results are achieved, it would be safe to assume that the most efficient way of producing biogas from the experiments done would be to use a cattle slurry and waste fat mix in the digester. The main problem with this is the availability of substrates.

Cattle slurry is readily available and this is why it is used as the main substrate in the digesters above, but biogas yield from this is relatively low compared to the other substrates. However mixing it with grass, maize and waste fat should help biogas production efficiency.

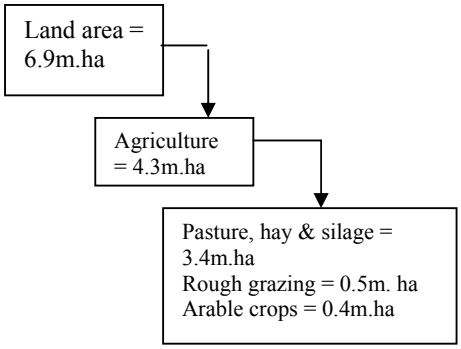

Figure 5: Land usage in Ireland (O'Kiely 2009)

From figure 5 it can be seen that grass covers around 56% of Irelands total land area therefore there is good potential to use in co-digestion with cattle slurry. While arable crops including maize only cover 0.05% (O'Kiely, 2009) of the total land area these might not be as good an option for co-digestion since they only offer a small increase in biogas yield per m^3/t. On the other hand waste fat would be far less available than the aforementioned but produces a vast amount of biogas yield per m^3/t when compared to other substrates; also because restaurants and food producers have difficulty disposing of these wastes financial incentives could

be negotiated to help make it a more attractive option for anaerobic digestion plant owners.

Acknowledgements

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References

Chynoweth D. P. and Isaacson R., 1988 Anaerobic Digestion of Biomass, in: R. Sleat, R. Mah, Hydrolytic Bacteria, p15 – 35

EC, 1999 European Communities (EC), 1999. Council Directive on the landfill of waste (99/31/EEC).

Marcato C. E., Mohtar R., Revel J. C., Pouech P., Hafidi M. and Guiresse M. (2008) Impact of anaerobic digestion on organic matter quality in pig slurry. *International Biodeterioration & Biodegradation* 63, (3), 260-266

Murphy J. D. and Power N. (2006). A technical, economic and environmental analysis of energy production from newspaper in Ireland. *Waste management* 27, (2), 177-192

O'Kiely P. (2009) Grass Crop Research. www.irbea.org/files/grasscropresearchpadraigo'kiely.pdf. Teageasc, Grange beef research centre, Dusany, Co. Meath

Palm O. (2008) The Quality of liquid and solid digestate from biogas plants and its application in agriculture. ECN/ORBIT e.V. Workshop: the future for anaerobic digestion of organic Waste in Europe; Jan 2008, Nurnberg, Germany

Speece R. E. (1995) Anaerobic Biotechnology for Industrial Wastewaters. Tennessee: Archae Press

Wulf S. (2005) Anaerobic Digestion and Biogas Production. Summer school on sustainable agriculture, Aug 2005. http://www.ipe.unibonn.de/vorlesung/abr120/anaerobic_digestion.pdf (accessed 18/4/09)

ON FARM COMBUSTION AND ENERGY RECOVERY FROM POULTRY LITTER

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Abstract

The competitiveness of the poultry industry is highly dependent on the cost of energy (primarily heating) and the management and disposal of poultry litter. Current poultry litter management practices are seen as unsustainable and alternative solutions are required. A potential solution is the use of an on-farm Fluidised Bed Combustion (FBC) unit which has the dual benefit of a cost neutral heat source and reduction of litter. The study will determine the litter fuel quality and optimise combustion through the monitoring of flue gas emissions. This will facilitate establishment of best practices to meet the regulatory requirements of Integrated Pollution Prevention Control (IPPC) licensing. This project will optimise the thermal efficiency and reduce maintenance requirements by matching heat exchanger output with heat load through the use of buffer tanks. The nutrient value of sterile ash will be determined and its economic value established. It will monitor flue gas emission, building a dispersion model based on local topography and meteorology which will be included in an environmental impact study assisting IPPC regulations. It will undertake a risk assessment and decide best practise for the management and storage of the litter. The cost benefit model for the poultry producer will be produced. The correct welfare conditions of the chickens is also paramount to the success of this task.

Introduction

Chicken litter is an unavoidable by product of chicken farms. With growing concerns over environmental pollution, recent regulatory constraints, and manure disposal by landfill becoming expensive, an environmentally sound method of disposing animal waste is needed.

Using a 120kW FBC unit, chicken litter from broilers reared on the research farm is capable of creating a substantial amount of heat. The unit is able to combust up to two tonnes of litter and create 140 kilowatts of energy given correct conditions in litter quality. The heat used is known as in-direct heat as opposed to gas; direct heat. Given the cost neutral benefit of in-direct heat the sheds can be preheated creating a far more comfortable environment for the chicks, on arrival, but also resulting in a decrease in the moisture content of the litter at the end of a cycle. This process will greatly decrease the amount of biomass on the farm and helps solve problems with excess spreading and storage. As a system it has to be monitored closely however and poor litter condition results in the creation of less energy, the fuel can even become unusable if moisture contents are too high. Low quality feed, uncomfortable living conditions, high levels of ammonia in the air i.e. bad ventilation and poor health among other things will all lead to a decrease in the quality of the litter and fuel.

Project objectives

- **To establish the optimum combustion and control conditions for the FBC technology to meet EPA and IPPC licensing requirements including an assessment of propensity for dioxin formation.**
- **To establish a code of best practice for storage and management of the litter prior to combustion to minimise odours, nuisance and to prevent the spread of pathogens or disease.**
- **To determine the nutrient value of the ash as a soil additive.**
- **To assess the market acceptability and benefits of using this technology**

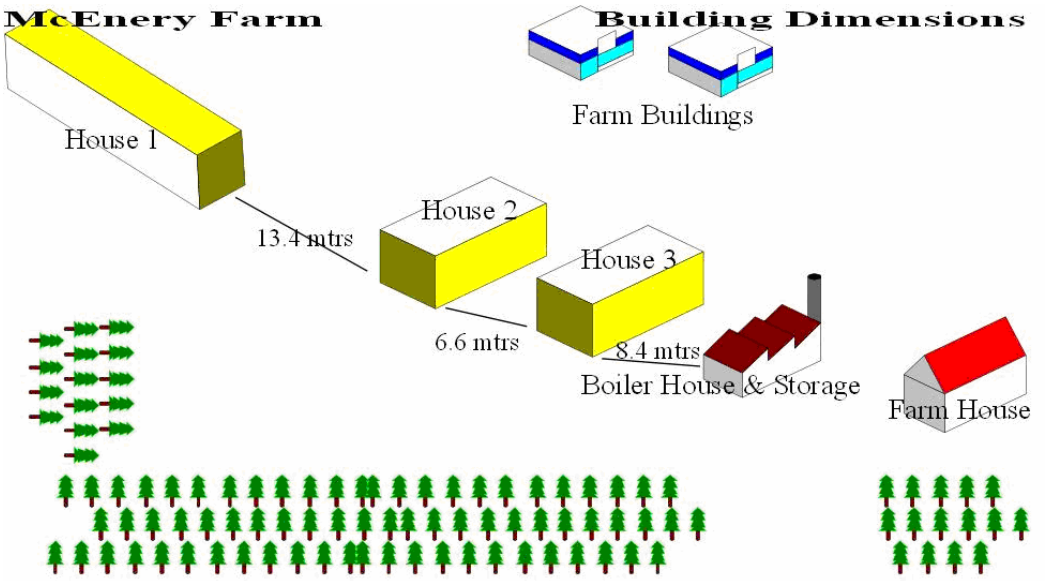

Figure 1 Layout and Building Dimensions of Research farm in Co. Limerick.

Materials and Methods

Determination of moisture content of poultry litter.

Experiment 1

Samples are taken from the three houses and the storage shed where they are tested under a variety of conditions in order to determine the calorific value and moisture content of the litter and also a leachate test to determine the content of the remaining ash by-product.

A moisture comparison is attained by comparing litter taken from house A and house C. House A which is run on direct heat and House C on indirect heat. The aim of the test is to prove the theory that lower moisture content exists in the litter of a shed run on in-direct heat.

- Four aluminium dishes are individually weighed and then re weighed with the litter samples.
- The samples are placed in a pre-heated oven at 105°C and left for twelve hours.
- The samples are then re-weighed to test for moisture loss.
- The samples are placed back in the oven and weighed hourly in order to determine when the moisture is completely removed (This will occur when weight loss is no longer recorded).
- From the difference in weight, the moisture percentage of each sample can be determined. The wetter samples will take longer to dry out.

Experiment 2

Determination through thermal analysis; of optimum temperatures for the release of energy from the litter.

Differential Scanning Calorimetry (DSC)

Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. Any chemical or physical change will manifest itself as a peak in a measurement curve produced as a result of the experiment and from this we can read optimum temperatures to produce such a reaction.

Experiment 3.

Fortifying regulations on best practices for the welfare of chickens

Recent regulations (Department of Agriculture, Fisheries and Food and Farm Animal Welfare Advisory Council) introduced regarding the welfare of broiler chickens fundamentally play a large part in the running of a successful fluidised bed combustor.
It is the motto of this project that "a happy chicken is a sustainable and productive chicken"
The welfare of the chickens affects the quality of the litter directly. This point is being reiterated at every opportunity showing that the welfare of the chickens will directly affect the monetary value of the litter. *Figure 2.*

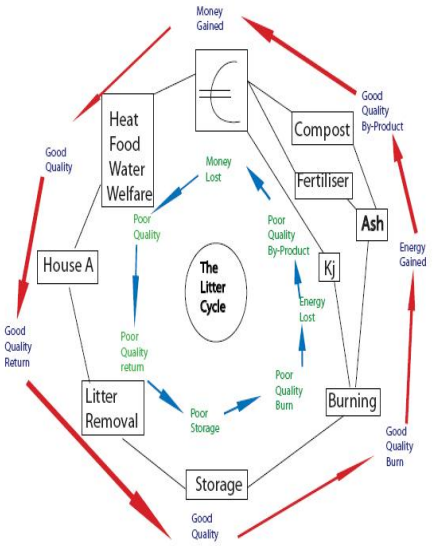

Figure 2. The litter cycle

Experiment 4
Best practice policies for the storage of litter intended to be used in the Fluidised Bed Combustor Unit.

The storage of the litter once removed from the chicken sheds is paramount to its quality. Poor quality storage in areas of high moisture will result in poor quality return from the FBC. Drying at this stage is also important to help remove excess moisture which may still be present. Stacking and spreading of the litter over larger areas among others are being investigated to deduce best practices. Housing quality, ventilation and heating in the storage areas are being examined to determine quality standards. Methods used in other farms are also being pursued at this stage.

Results and Discussion

Experiment 1
Although these tests are still undergoing initial results and observations both from lab experiments and field trips are showing that houses run on indirect heat have lower moisture content than those run on direct heat.

Experiment 2
The DSC machine has yet to be calibrated, therefore methods/training has not yet been received and as a result experiments have been put on hold.

Very shortly work in the laboratory will begin. Results are expected to yield precise temperatures of thermal reactions.

Experiment 3
The importance of the poultries welfare with regard to energy output and as such total income should ensure farmers continuously strive to better their own welfare habits and facilities. The use of diagrams will strengthen and make a clearer point of how the welfare will directly affect the final profit made from this system. The knock on effect from this is that poultry producers will have different reasons for improving the welfare facilities of the birds.

Experiment 4

Regulations as to what defines drying play a crucial role in this aspect of the experiment. Litter may only be dried to a certain point before it is considered altered so as to become a fuel. Guidelines on this are somewhat vague. Research into the regulations stipulated by the

Environmental Protection Agency (EPA) is currently being carried out to determine the best practices the research farm can use to improve current conditions. A definite method of drying, showing quality reduction of moisture while still being within these guidelines will be deduced from these investigations.

Conclusions

As well as its benefits in cost neutrality and the offering of a new and viable means of using the litter, it appears from the first experiment that the combustion of chicken litter will add to the quality of the fuel by making it drier and therefore more efficient. The other experiments are ongoing and results will be published later.

The alternative use of farm waste materials as a substitute for fossil fuels is gaining importance because of the limitations on the nature of waste placed in landfills. The excessive spreading of waste on soil can lead to an enriching of water nutrients through runoff resulting in the eutrophication of water bodies, the spread of pathogens and the production of a number of toxins. This also leads to air pollution and the emissions of greenhouse gases.

On farm FBC is a viable method of using waste material as fuel and has a number of benefits such as a cost, litter waste reduction to 10% of original volume and the use of the ash as an easy to handle fertiliser; as a by-product. It is the authors' expectation that the testing and research carried out will result in standards been set that will regulate the combustion of chicken litter as a form of energy.

Acknowledgements

The authors wish to acknowledge the Department of Agriculture, Fisheries and Food for their financial support.

References

Kelleher BP, Leahy JJ, Henihan AM, O'Dwyer TF, Sutton D, Leahy MJ. (2003). Advances in poultry litter disposal technology – a review. Bioresource Technology 81(1): 27-36

Henihan AM, Leahy MJ , Leahy JJ, Cummins E, Kelleher BP (2002). Emissions modelling of fluidised bed co-combustion of poultry and peat. Bioresources Technology 87(2003): 289-294

Shijun Zhu, S. Lee, S.K. Hargrove, G. Chen (2006). Prediction of combustion efficiency of chicken litter using an artificial neural network approach. Science Direct 86 (2007) 877-886

Department of Agriculture, Fisheries and Food and Farm Animal Welfare Advisory Council. Animal Health and Welfare Division, Agriculture House, Kildare Street, Dublin 2.Code of practice for the welfare of Broiler Chickens.

POTENTIAL OF BIOLOGICAL MEDIA TO SEQUESTER CARBON FROM POINT SOURCES

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Abstract

Electricity generation currently accounts for around 33% of world CO_2 emissions. One potential method of offsetting these emissions is through biological sequestration of the produced CO_2. This is the process of capturing carbon dioxide from the flue gases of a power plant and using it to cultivate photosynthetic autotrophic organisms. These organisms convert the CO_2 into organic compounds producing biomass. The produced biomass can subsequently be converted into biofuels, decreasing the demand for fossil fuels. This paper assesses which organisms are the most suitable biological media for carbon sequestration.

Introduction

Concerns over global warming and carbon emissions have sparked interest in methods of sequestering carbon which has been released through the burning of fossil fuels. Human activity is already directly and indirectly affecting almost half of the terrestrial biological carbon cycle. If this cycle were properly managed, it could be a major contribution to mitigation of this greenhouse gas (Hughes and Benemann, 1997).

A large fraction of the anthropogenic emissions of carbon dioxide results from the combustion of fossil fuels for energy production. With energy needs increasing, especially in the developing world, CO_2 emissions are expected to rise considerably in the coming years. Meeting energy demands without high emissions will require stringent management of CO_2 including the use of post combustion carbon sequestration. Carbon capture and sequestration is a process of removing CO_2 from flue gases and storing it for extended periods, preventing emissions. Biological sequestration is a temporary storage of CO_2 whereby the biomass produced can be used as an energy source by converting it to biofuels. Essentially the CO_2 is being used twice while the biomass-to-energy displaces the use of fossil fuels in energy production. The net use of fossil fuels is decreased while the same net energy is produced. Biological sequestration coupled with biofuel production offers great potential for this purpose. Photosynthesis is the age old method of utilising anthropogenic carbon and was the original process that fixed carbon millions of years ago creating today's fossil fuels. Using this process captured flue gases containing high concentrations of CO_2 can be used to cultivate large amounts of biological media. In a controlled environment, this will produce large yields of valuable biomass for producing biofuels, as well as some value added by-products. Figure 1 shows a schematic of the production of micro algal biomass from power plant flue gases. Selection of the best media for carbon sequestration is crucial in achieving a high level of CO_2 removal while also ensuring maximum economic gain from the process (Olaizola et al., 2002).

The objective of this paper is to review and assess a range of biological media to determine which may be the most effective for sequestering carbon from the flue gases of a laboratory scale boiler.

Materials and Methods

Selection of biological media
Initially biological media were reviewed and selected for further experimental study

based on their suitability for carbon sequestration. There are a number of different autotrophic organisms suitable for carbon sequestration.

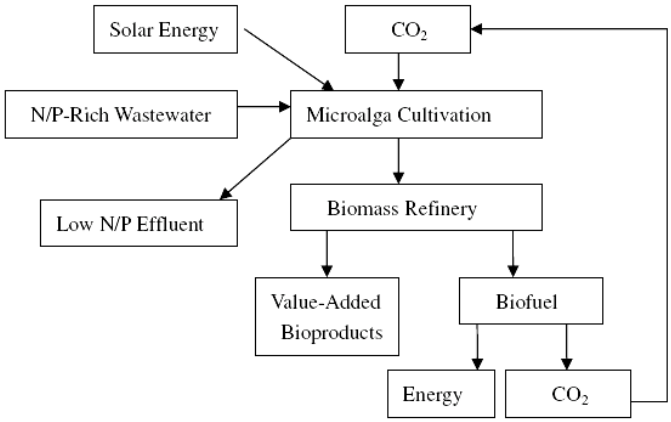

Figure 1. A conceptual biological system for combined biofuels production(Wang et al., 2008)

Micro algae, macro algae, bacteria and grasses may all be useful for this purpose. To differentiate them from one another a set of criteria for comparison was developed to facilitate selection of the most appropriate biological media. Essentially the selected media should have a rapid growth rate, be easily cultivated on a large scale, have a high CO_2 fixing rate, generate a large biomass yield and produce valuable by-products. Using existing literature, micro algae, macro algae, bacteria and grasses can be compared and contrasted to select the most suitable for carbon sequestration.

Experimental analysis

Following the selection procedure, experimental analysis will be conducted on each media to determine its ability to sequester carbon and produce large amounts of biomass. This will require the design and construction of a laboratory scale boiler along with capture and provision systems for the flue gases. As there may be many different strains of each media suitable for carbon sequestration, they may have to be compared to obtain a good balance of high carbon fixation rates, large biomass production while being adaptable for the high temperature flue gases.

Results and Discussion

To date the review and selection of biological media has been completed
Comparing the various biological media from current literature, the following was found to be the main attributes of each kind.

Micro Algae

Aquatic micro algae are among the fastest growing photosynthetic organisms, having carbon fixation rates much greater than those of land plants. For most species of micro algae, biomass will double in volume in less than 24 hours fixing large amounts of carbon (Olaizola, 2002). While micro algal culturing is expensive, due to the high capital costs of photobioreactors, the cultivated biomass produces a fuel either for direct combustion, thermochemical or biochemical processing, thereby generating additional revenue. Those revenues could pay for the cost of carbon sequestration. A cost and energy balance shows that energy production from marine biomass is an attainable target with the currently available technologies (Olaizola, 2002). However, the obtained biofuel was quite expensive when compared to fossil fuel prices. Despite this, power plants will be avoiding carbon taxes and with the ever increasing price of oil, biofuels will become more economically viable in the future (Olaizola et al., 2002; Watanabe and Hall, 1996).

Macro Algae

Like micro algae, macro algae are autotrophic aquatic plants using inorganic CO_2 as their food source. Micro algae have received much more attention than macro algae in the past for CO_2 fixation due to their facile adaptability to grow in ponds or bioreactors and the extended knowledge base available for many strains, such as those used for fish feeding. Macro algae have traditionally been collected from natural basins but in recent times, they have been considered for large scale cultivation and energy production. It has rapid growth rates and like micro algae has many value added by-products. Through gasification energy yields of up to 11,000 MJ t^{-1} of dry macro algae have been achieved compared with 9500 MJ t^{-1} for micro algae (Israelet al., 2005). The *Gracilaria cornea* (Rhodophyta) strain is produced on a large scale for animal feed using commercial CO_2. Using flue gases as a CO_2 source would greatly reduce the cost of production of macro algae while similar growth rates have been calculated through a study carried out by Israel et al. (2005).

Bacteria

Like microalgae, bacteria are fast growing unicellular organisms. Cyanobacteria are photoautotrophic, using carbon dioxide as their food source, and therefore are useful in carbon mitigation. They grow in a temperature range of 50 to 75^{o}C and require anaerobic conditions, light and the absence of N_2 for good growth. The also produce hydrogen as a by-product [Eq 1].

$$CO_2 + H_2O + \text{'light energy'} = [Cn(H_2O)n] + O_2 + H_2 0 \quad \text{Eq 1}$$

The biofixation of CO_2 by cyanobacteria in photobioreactors is considered a sustainable strategy, as carbon dioxide can be incorporated into the molecular structure of bacterial cells in the form of proteins, carbohydrates and lipids. This is caused by photosynthetic reactions in bacteria. Lipases such as triacylglycerol acylhydrolase are produced, which may then be catalytically synthesised into biodiesel.

Despite having excellent growth rates and exceptional productivity, the production of biodiesel from bacteria is quite limited. The lipids produced by bacteria must be refined to ensure efficient transesterification. Glycerol is produced as a by-product and must be removed. Results from extensive studies show that glycerol inactivates the enzymes, which was found to be a particular problem during continuous processing (Jacob-Lopes et al., 2008).

Grasses

In this study, the use of grasses for carbon sequestration is considered for a cutaway bog. The biomass produced could be used for cofiring in peat burning power plants. This would assist plants in achieving targets in relation to cofiring peat. However, many problems have been found with this form of carbon sequestration. Grasses are slow growing and their carbon fixation rate is much less than the aquatic organisms. Crop establishment is poor on cutaway bog and studies carried out by BOGFOR in 1997 showed that just 58% of crops established grew, while only 21% grew satisfactorily (Renou and Farrell, 2004). Further study is required to determine if these challenges may be overcome.

These findings suggest that while micro algae present a clear opportunity in terms of their potential to sequester carbon, macro algae and bacteria may also have potential but will require further study.

Conclusions

Following the identification of the opportunities and challenges associated with using each source to sequester carbon, various experiments will now be carried out to quantify this potential. A laboratory scale boiler system will be designed and constructed. The result of varying light intensity and lighting period on carbon sequestration rate, growth rates and yield will be determined. The same results could be examined while altering

the temperature of the flue gases and concentration of CO_2.
Using the results from these experiments the optimum conditions for growth can be established while sequestering the maximum amount of CO_2.

Acknowledgements

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References

Hughes, E., Benemann, J.R., 1997. Biological fossil CO2 mitigation. *Energy Conversion and Management*, 38, S467-S473.

Jacob-Lopes, E., Cacia Ferreira Lacerda, L.M., Franco, T.T., 2008. Biomass production and carbon dioxide fixation by Aphanothece microscopica Nägeli in a bubble column photobioreactor. *Biochemical Engineering Journal*, 40, 27-34.

Olaizola, M., Bridges, T., Flores, S., Griswold, L., Morency, J., Nakamura, T., 2002. Microalgal removal of CO2 from flue gases: CO2 capture from a coal combustor. Mera Pharmaceuticals, Inc. Kailua-Kona, Andover.

Renou, F., Farrell, E.P., 2004. Reclaiming peatlands for forestry: the Irish experience. University College Dublin, Dublin, pp. 541-555.

Wang, B., Li, Y., Wu, N., Lan, C.Q., 2008. CO2 bio-mitigation using microalgae. Springer-Verlag, Berlin.

Watanabe, Y., Hall, D.O., 1996. Photosynthetic CO2 conversion technologies using a photobioreactor incorporating microalgae - energy and material balances. *Energy Conversion and Management*, 37, 1321-1326.

Evaluation of pyrolysis and co-pyrolysis of biomass and plastics for production of liquid transport fuels

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Abstract

Pyrolysis is a thermochemical conversion process that can be employed to produce liquid transport fuels from feedstocks including biomass and plastics. Pyrolysis cannot, at present, provide a commercially viable transport fuel due to poor economies-of-scale and some technical issues producing a high quality fuel (especially from biomass feedstocks). This research aims to assess whether a multi-feedstock pyrolysis facility capable of processing biomass and waste plastic feedstocks is technically feasible.

Introduction

In 2006, energy use in the Irish transport sector was over 99% dependent on oil products, all of which were imported (Rourke et al., In Press). In light of faltering oil reserves and increasing consumption from emerging economies (Huber et al., 2006), it is essential for Ireland to develop alternative feedstocks to crude oil as well as the technologies required to convert them to transport fuels.

In 2007, 77.5% of the 288,700t of plastic waste generated in Ireland was sent to landfill (Le Bolloch et al., 2009). This represents considerable wastage, and could potentially be used as a feedstock for transport fuel production.

Waste biomass like waste wood and forestry residue as well as the emerging second-generation energy crop sector (e.g. willow and miscanthus) in Ireland are a renewable source of carbon that may also have potential for production of liquid transport fuels.

Pyrolysis is a conversion process capable of converting feedstocks including plastics and biomass to transport fuels (Bridgwater, 2007; Scheirs and Kaminsky, 2006). It is a thermal degradation process occurring in the absence of oxygen (Buekens, 2006) resulting in the production of liquids (oils), gases and char. The yield of each product is highly dependent on the composition of feedstock and the process conditions. The pyrolysis oils need to be upgraded before use in conventional transport systems.

The production of alternative transport fuel needs to be economically competitive with current production methods to be commercially viable. This is currently a major stumbling point for fuel production from plastics and biomass where constrained availability of feedstocks might restrict plant size in Ireland. One way to overcome this might be an integrated pyrolysis facility capable of processing both biomass and plastics (separately or simultaneously (i.e. co-pyrolysis) to transport fuel.

The objective of this research is to investigate whether processing biomass and plastics in an integrated pyrolysis facility is technically viable in Ireland.

Procedure

Current status of project

Characterisation of feedstocks will begin in the coming weeks once the required equipment has been commissioned. Research links are currently being put in place with another Irish University, and an industrial link has also being forged with a pilot pyrolysis facility.

Characterisation of feedstocks

The aim of this work is to collect information about the feedstocks that can be used to explain their behaviour under pyrolytic conditions. This information will be useful, especially when experiments are being scaled up to larger pyrolysis units later on in the project.

Feedstocks that will be investigated include willow, miscanthus, forestry residues, waste wood, waste plastic mixtures, refuse derived fuel (containing paper, cardboard, textiles, wood, and plastics).

Proximate analysis will be conducted in the biosystems laboratory, while ultimate analysis will be performed by a commercial laboratory or the Chemistry Laboratory at UCD.

Thermogravimetry is a widely employed technique used to study the thermal decomposition of feedstocks and the kinetics of the decomposition reaction (Encinar et al., 2008). Thermogravimetry will be applied to biomass and plastic feedstocks to give a better understanding of their pyrolytic decomposition and associated kinetics. The co-pyrolysis behaviour of biomass and plastics will also be investigated.

Analysis of pyrolysis products from a bench-scale furnace

The aim of these experiments will be to simulate industrial pyrolysis and co-pyrolysis on a small-scale and learn more about the influence of feedstock composition and operational parameters on pyrolysis oil yields, and their composition and properties.

Biomass and plastic feedstocks will be pyrolysed and co-pyrolysed under different operating conditions in a small nitrogen swept furnace with a condenser to collect the liquid product. The composition of pyrolysis gas will be analysed for C_1-C_4 gaseous compounds. The composition and behaviour (C, H, and O content, moisture content, pH, density, viscosity, calorific value) of the pyrolysis liquid will also be analysed.

Pyrolysis and co-pyrolysis on a 10kg/h fluidised-bed pyrolysis rig

The authors have developed research links with an industrial scale plant (25 000kg/day), the first of its kind in the EU. The research and knowledge gained in the laboratory will be used to upgrade the throughput of this plant, bringing academic knowledge to a commercial reality.

The aim of this experiment is optimise the operational parameters of the pyrolysis and co-pyrolysis of biomass and plastic feedstocks that can ultimately be applied to this industrial scale plant.

The viability of setting up a small (150-300g/h) fluidised bed pyrolysis unit at UCD has been assessed, and was found to be internally challenging and economically unfeasible. As a result, research links have been put in place with another Irish University, and experiments will be conducted on a 10kg/h fluidised bed pyrolysis rig with catalytic upgrading facilities. See figure 1. for an image of a fluidised bed pyrolysis rig for biomass.

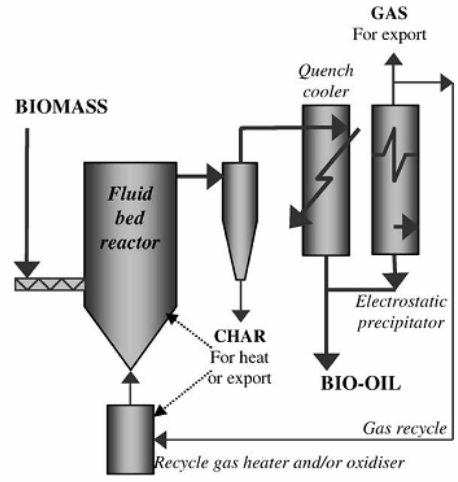

Fig 1. Bubbling fluidised bed pyrolysis rig for biomass (Bridgwater, 2003).

The resultant gases, liquids and char will be analysed. There will be particular emphasis on the pyrolysis oils produced. A

number of simple tests will be conducted on the pyrolysis oils to determine their suitability as a liquid transport fuel. This may include blending pyrolysis oils from biomass and plastics and co-pyrolysis oils with emulsifying agents and diesel, assessing the fuel qualities of the resulting mixtures, storage/stability tests, corrosivity tests etc.

Industrial Case Study

Based on the success of experiments on the 10kg/h fluidised bed pyrolysis unit, there may be potential for a large trial on a pilot scale pyrolysis facility with fuel upgrading capabilities. In addition to optimising the production of transport fuels from the feedstocks and addressing any operational issues, there will be a focus on the environmental impact of the process. A basic life-cycle analysis case study will be conducted on the operation, with emphasis on energy balances and greenhouse gas balances.

Results and Discussion

Proximate and ultimate analysis will show that biomass and waste plastic have very different chemical compositions. Indicative values from literature are given in Table 1.

Table 5 Indicative Proximate and Ultimate Analysis Data for sample biomass and plastic feedstocks (Cornelissen et al., 2008; Encinar and González, 2008)

	Willow	Polystyrene
Proximate (%)		
Moisture	3.24	0.0
Volatiles	74.66	100.0
Fixed Carbon	20.39	0.00
Ash	1.71	0.00
Ultimate(%)		
C	46.91	90.20
H	5.95	8.5
O	41.69	1.30
N	0.63	0
S	-	0
Calorific Value (MJ/kg)	19.088	41.95

Diverse compositions results in the feedstocks having different decomposition kinetics in the thermogravimetric analyser and thus consequently different optimal conditions for maximum liquids production. This may result in difficulties in choosing operational parameters for the co-pyrolysis of feedstocks which do not significantly compromise pyrolysis oil production from either feedstock.

It may instead be more technically feasible to pyrolyse the feedstocks separately under conditions which have been optimised through experimentation and mix the resulting pyrolysis liquids.

Conclusions

It is hoped that this research will ultimately provide valuable information for the commercial development of pyrolysis systems for transport fuel production from renewable carbon sources and waste products in Ireland.

Information gathered from experimentation and data analysis will provide valuable academic knowledge that can be applied commercially. Results at this stage of the research are speculative, and though pyrolysis of biomass and plastic feedstocks for transport fuel may be technically feasible, there is likely to be a compromise between the economics of pyrolysis and the quality of the fuel product. It is probable, however, that increasing crude oil prices in the long term will favour the economic feasibility of the process.

Acknowledgements

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References

Bridgwater, A.V., 2003. Renewable fuels and chemicals by thermal processing of biomass. *Chemical Engineering Journal*, 91, 87-102.

Bridgwater, A.V., 2007. IEA Bioenergy 27th update. Biomass Pyrolysis. *Biomass and Bioenergy*, 31, VII-XVIII.

Buekens, A., 2006. Introduction to Feedstock Recycling of Plastics. in: J. Scheirs, W. Kaminsky (Eds.), Feedstock Recycling and Pyrolysis of Waste Plastics, pp. 1-41.

Encinar, J.M., González, J.F., Martínez, G., González, J.M., 2008. Two stages catalytic pyrolysis of olive oil waste. *Fuel Processing Technology*, 89, 1448-1455.

Huber, G.W., Iborra, S., Corma, A., 2006. Synthesis of Transportation Fuels from Biomass: Chemistry, Catalysts, and Engineering. *Chem. Rev.*, 106, 4044-4098.

Le Bolloch, O., Cope, J., Kurz, I., Meaney, B., Higgins, T., 2009. National Waste Report 2007: A Report of the Year 2007. Environmental Protection Agency, Johnstown Castle, Wexford, Ireland

Rourke, F.O., Boyle, F., Reynolds, A., Renewable energy resources and technologies applicable to Ireland. *Renewable and Sustainable Energy Reviews*, In Press, Uncorrected Proof.

Scheirs, J., Kaminsky, W., 2006. Preface. in: J. Scheirs, W. Kaminsky (Eds.), Feedstock Recycling and Pyrolysis of Waste Plastics, pp. i-xxix.

PRODUCTION, EXTRACTION AND CONVERSION OF MICROALGAL BIOFUELS AND BY-PRODUCTS: A REVIEW OF PROCESS CHAIN TECHNOLOGIES

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Abstract

The development of renewable energy resources to replace fossil fuels (petroleum and coal) as the primary energy source has gained importance due to the multiple environmental benefits of the derivable biofuels and in due recognition of the latter's finite reserves. However, utilisation of biofuels from some energy crops may be in direct competition with their utilisation for food and may also incur penalties in land-use change. The frequently variable and limited energy yield potential of energy crops also sets limits to the proportion of fossil fuels that can be sustainably replaced by biofuels. Available evidence suggests that microalgae may be capable of producing liquid biofuels to meet a significant proportion of global energy demand, without negative impacts on food production. Microalgae are simple organisms that require only light, carbon dioxide and nutrients to grow successfully. They can provide feedstock for the production of a wide range of biofuels including biodiesel, bioethanol, biogas and biohydrogen, together with valuable by-products for feed and pharmaceuticals.

Introduction

It is widely accepted that the use of fossil fuels as a primary energy resource is unsustainable in respect to depleting resources and progressive environmental degradation arising from the accumulation of greenhouse gases in the atmosphere (Schenk et al., 2008). Renewable, carbon neutral fuels are required to meet the world's energy demands while contributing to the amelioration of climate change. At present, biofuels are mainly produced from conventional oil crops such as corn, oilseed rape and sugar cane. However, increased biofuel production with these crops could have severe consequences for global food supplies. Microalgae appear to be the only capable source of renewable fuels to meet the global energy demand, while maintaining current food production (Chisti, 2007).

Microalgae are unicellular or multi-cellular microorganisms that can be found in abundance in a diverse range of eco-systems. The simple organisms use sunlight to convert carbon dioxide and nutrients into biomass, which can provide a wide range of feedstock for the production of biofuels such as biodiesel, bioethanol, biogas and biohydrogen (Schenk et al., 2008),

For biofuel extraction, microalgae offer numerous advantages over conventional energy crops, including: (1) Higher photosynthetic efficiency therefore higher yield; (2) Higher oil contents that are non-toxic and biodegradable; (3) Nearly all year round continuous harvesting potential; (4) Carbon negative fuel production when combined with CO_2 sequestration and biochar incorporation into soil; (5) Can be grown on marginal or waste ground; (6) Can utilise salt and brackish waters, thereby reducing the load on freshwater sources, and; (7) Can be used for treatment of organic effluents and bioremediation.

However, there are limitations to microalgae production, harvesting and extraction of biofuel, including potential utilisation for CO_2 capture.

This paper reviews the state-of-art in process chain technologies for production, extraction and utilisation of algal biofuels.

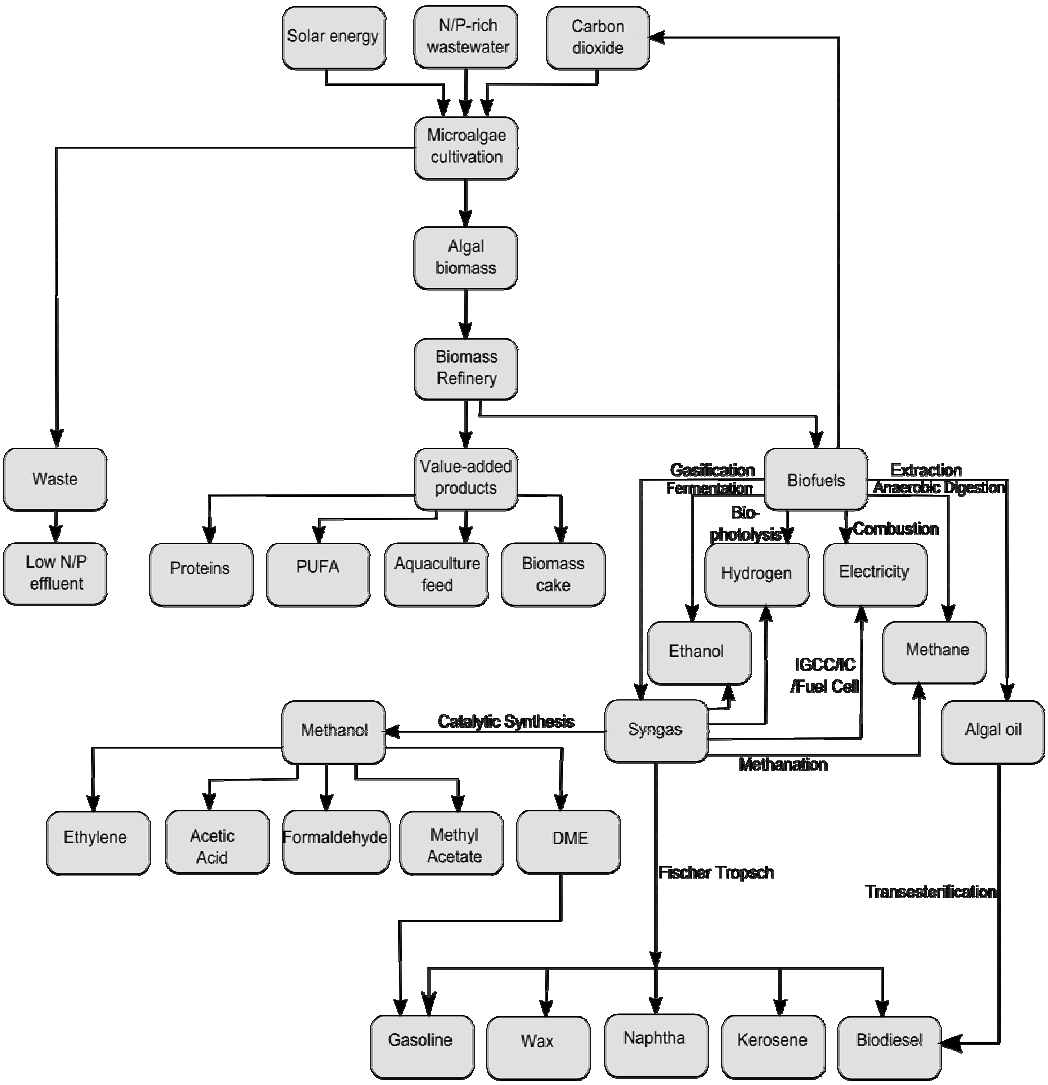

Figure 17. Outline of microalgal process chain model. The model follows the chain from inputs (solar energy, nutrients, CO_2) to the final products. It includes the production and energy conversion technologies used as well as the various energy carriers along the line to produce the final products.

Production of algal biomass

Microalgae are simple organisms that require only light, carbon dioxide and some nutrients to grow successfully. In the natural environment, algae obtain light from sunlight, while carbon dioxide is assimilated from the air and nutrients are taken from the water. A successful algae production facility should create the desirable natural conditions for optimum growth (Chisti, 2007).

Photoautotrophic production is arguably the only practicable large-scale production of algae biomass. Two methods for autotrophic production have been developed including, production in open ponds and closed photobioreactors. The selection of a particular system is influenced by intrinsic properties of the algae as well as climatic conditions and the costs of land and water.

Open pond production is a relatively cheap method of mass producing algal biomass in comparison to closed photobioreactors. In 2008, the unit cost of producing *Dunaliella salina*, one of the most commonly cultivated algae strains, in an open pond system is about €2.55 per kilogram of dry biomass (Tan, 2008). This is still considered to be too high to justify

production for biofuel. Due to the relatively lower energy inputs and simple operating procedures, open pond production has the potential to achieve a positive lift cycle energy balance, but is characterised by poor biomass productivity when compared with closed photobioreactors (Chisti, 2007).

Closed photobioreactors are designed to overcome some of the major problems associated with open ponds. Common photobioreactor design types including tubular, flat-plate, and column reactors. Unlike open ponds, photobioreactors permit single-specie culture of microalgae for prolonged durations for increased biomass production. Due to higher cell mass productivity attained (up to 3-fold compared with open ponds), harvesting costs per unit mass can be significantly reduced. However, the costs of closed systems are substantially higher than open pond systems (Schenk et al., 2008).

Recovery of microalgal biomass

The recovery of microalgae biomass is considered to be the most challenging and expensive step in microalgae biomass production process (Wang et al., 2008). Generally, it requires one or more solid-liquid separation steps.

Harvesting is usually taken in a two step approach. The first step is bulk harvesting. The concentration factors for this operation are generally 100 to 800 times. This step is carried out by flocculation, flotation and gravity sedimentation. The subsequent thickening step aims to increase slurry concentration by up to 30 times more. Most common methods employed are centrifugation, filtration and ultrasonic aggregation. The harvesting technique to be used is dependant on the characteristics of microalgae, such as size and density and the value of the target products (Chisti, 2007).

Commercial potential of microalgae biomass

There are numerous commercial applications of microalgae (**Figure 17**). For example, (1) they can be used to enhance the nutritional value of food and animal feed, (2) can be incorporated into cosmetics, (3) produce valuable biofuels, (4) food colouring, and (5) medical application (Spolaore et al., 2006). Markets are still in developmental stage for most of these applications.

Ongoing research is geared to identification of valuable microalgae strains and improvement of production systems. Consequently, microalgae biotechnology will become more diversified and economically competitive.

CO_2 sequestration using microalgae

With the increase in the emission of anthropogenic greenhouse gases (GHGs), it is vital to develop mitigation technologies capable of neutralising emissions. Microalgae can fix CO_2 from three different sources: (1) CO_2 from the atmosphere (2) CO_2 in discharge gases from heavy industry (3) CO_2 from soluble carbonate (Wang et al., 2008). The potential use of microalgae to sequester CO_2 emissions from flue gases from power plants burning fossil fuels has good prospects. Flue gases have high CO_2 concentration up to 20%. These gases can also be used on both photobioreactors and raceway ponds which allow more control over the production process.

It has also been demonstrated by Kadam (2002) that there is possible significant benefits to recycling CO_2 toward microalgae production for power generation via coal-microalgae co-firing. The LCA results showed both CO_2 emission reduction and reduced use of coal, thus reducing GHG emissions. The study also registered lower net values of SO_x, NO_x, particulates, CO_2, methane and fossil fuel consumption with the direct injection of flue gases to produce algae. However, further analyses are required to determine the net energy balance of the microalgal bioenergy process.

Applications of microalgae in wastewater treatment

Microalgae also have potential role in treatment of domestic and industrial wastewaters. Microalgae provide a pathway for the removal of nutrients, organic contaminants, heavy metals and

pathogens from wastewater and produce biomass which can be further exploited for biofuel production. The production of algal biomass in conjunction with wastewater treatment gives additional economic incentives due to savings from chemicals (nutrients) (Wang et al., 2008) and environmental benefits such as minimising the use of freshwater (Li et al., 2008). For example, *Botryococcus braunii* is able to remove nitrate and phosphate from secondarily treated sewage while producing a hydrocarbon-rich biomass (Li et al., 2008). Overall, possible applications in wastewater treatment could enhance efficiency in microalgae production.

Conclusions

Microalgal biotechnology provides a technically feasible pathway for biomass production for energy feedstock (solid and liquid fuels) with potential utilisation for CO_2 sequestration and wastewater treatment. Research and development aimed at optimisation of different aspects of production and processing chains are in progress. It is envisaged that the next stages in development will be in:

1. Identification of viable species for oil extraction including potential utilisation of by-products based on chemical make-up.
2. Optimisation of production systems to enhance economical competitiveness vis-à-vis fossil fuels, with specific consideration on potential production conditions in Ireland.
3. Pilot production of microalgae and characterisation of biofuels qualities, including co-firing of algal biomass with coal.
4. Assessment of scaling feasibility from pilot experiments and modelling of potential environmental impacts of production chains and conversion pathways by LCA.

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References

Chisti, Y., 2007. Biodiesel from microalgae. *Biotechnology Advances*, 25, 294-306.

Kadam, K.L., 2002. Environmental implications of power generation via coal-microalgae cofiring. *Energy*, 27, 905-922.

Li, Y., Horsman, M., Wu, N., Lan, C., Dubois-Calero, N., 2008. Biofuels from Microalgae. *Biotechnology Progress*, In Press.

Schenk, P., Thomas-Hall, S., Stephens, E., Marx, U., Mussgnug, J., Posten, C., Kruse, O., Hankamer, B., 2008. Second Generation Biofuels: High-Efficiency Microalgae for Biodiesel Production. *BioEnergy Research*, 1, 20-43.

Spolaore, P., Joannis-Cassan, C., Duran, E., Isambert, A., 2006. Commercial applications of microalgae. *Journal of Bioscience and Bioengineering*, 101, 87-96.

Tan, H.H., 2008. Algae-to-biodiesel at least five to 10 years away. Energy Current: News for the Business of Energy., Singapore

Wang, B., Li, Y., Wu, N., Lan, C., 2008. CO2 bio-mitigation using microalgae. Applied Microbiology and Biotechnology, 79, 707-718.

SUSTAINABLE WATER SUPPLY & CONSUMPTION IN COUNTY SLIGO

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Abstract

The Government's National Water Pricing Policy Framework requires the charging of non-domestic users of water so as to recover the full costs of providing these services. In County Sligo for many water users as in other parts of Ireland, the issue has become a major topic for discussion and is subject to much objection from many stakeholders. The available water conservation technology focuses on resources for local businesses, industries, communities and individuals. Population distribution and density are key factors influencing the availability of water resources. Increased urbanisation concentrates water demand and can lead to the over exploitation of local water resources.

Introduction

The Government's National Water Pricing Policy Framework requires the charging of non-domestic water users of water so as to recover the full costs of providing such services to these water users. The roles of government and especially the private sector in water management are being radically reappraised. The EU Water Framework Directive requires Member States to ensure, by 2010, that water-pricing policies provide adequate incentives to use water resources efficiently and to recover the true costs of water services in an equitable manner (Cotruvo, 1988). Most countries are progressing towards water pricing systems. Investing in water supply and sanitation has produced benefits far greater than those directly related to the cost of treating water-related diseases.

A supply of drinking water is only one of the primary functions of a water system. In addition to this, water is needed for bathing, cleaning, cooking, washing clothes, and waste disposal (Sekar & Randhir, 2007). Irish domestic water systems produce enough water each day to supply every person with approximately 600 litres for general use.

The primary source of water, which is usually a lake or river, may be located several miles from the area where it is actually being used. The individual parts of a water system may be situated at remote locations; a building, for example, represents the end result of a water system. A network of pipes serves as the transmission path. System control is accomplished by cut-off valves, flow regulators, and anything that alters the flow of water. Indicators appear at numerous places throughout the system. Water meters are typically placed in the service connection of each building to monitor water consumption.

Most of the water that is available to us today is through surface streams, and is unsafe for human consumption. It must be cleared of chemical and bacterial contamination of significant value. It is then piped under pressure from the primary source to respective building sites, where it is used. All water systems distribute potable water, which must be clear, cool, and free of any special taste or odour. It should contain very little or only a small amount of mineral salts (Cotruvo, 1988). Potable water normally goes through three unique purification operations before it is distributed for consumption. In simplified terms, this is achieved by coagulation and sedimentation, filtration, and disinfection.

The objective of this project was to carry out a baseline study of water supply and consumption in Sligo and draw up proposals to develop sustainable water management systems for a range of water consumers.

Materials and Methods

Sligo County Council delivers 38 million litres of water a day to homes, schools, businesses, farms and others. The water system in County Sligo serves 59,000 people through 7,000 service connections. The charge for the public sector will only relate to the non-domestic element of the water supply i.e. business, farming, institutions, and all connections not strictly for domestic use. Local Authorities are prohibited by law from charging for a domestic supply. It is government policy that all non-domestic water users should be metered and charged for water from 2006.

Water charges are determined on an annual basis by Sligo County Council. The charges are made up of two elements, a standing charge and a volumetric charge (based on usage). The charges for 2008 were as follows: (A) Non-domestic water charges, standing charge per annum per quarter per meter: the vast majority of the meters installed in Sligo are less than 25mm in size and the rate per annum of €80 will apply. The volumetric charge for water is €1.29 per cubic metre and the volumetric charge for wastewater is €0.87 per cubic metre; (B) Domestic allowance, an important concession under the new arrangement is that water users who have supplies with a domestic element will benefit from a domestic allowance for water and wastewater of 227.3 cubic metres (or 50,000 gallons) per annum. This will apply, for example, in the case of a farmer whose house and land are on the same connection, or where a shop and living accommodation are in one premises.

Charges have been applied to the non-domestic sector on a metered basis since the 1st January, 2006 in County Sligo. Approximately 25% of the non-domestic water users are commercial and the remainder is agricultural (EPA, 2001).

In County Sligo for many water users as in other parts of Ireland and Europe, the issue has become a major topic for discussion and is subject to much objection from many stakeholders. Cost modelling is shown in Figure 1 for commercial and agricultural water consumption before and after installation of a meter.

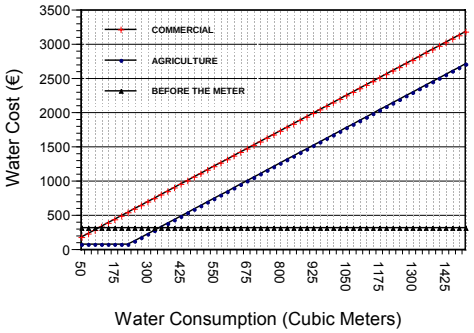

Figure 1. Cost modelling example for one connection in different categories during one quarter in County Sligo.

Population distribution and density are important factors influencing the availability of water resources. Increased urbanisation concentrates water demand and can lead to the over exploitation of local water resources. A tourist in Ireland consumes around 400 litres per day (EPA, 2001); European household consumption is around 150-200 litres and the Irish consumption in urban areas is over 250 litres (EPA, 2001). Approximately 60% of the non-domestic water supplied by Sligo County Council is used by the commercial sector. In addition, recreational activities such as swimming pools, golf, and other sports contribute to put pressure on water resources. All of the non-domestic water users are already paying for water on a meter basis. The amount of water used by the larger users within this sector is usually very well controlled as failure to do so can result in substantial increased costs (EPA, 2001).

Water conservation is the most cost-effective and environmentally friendly way to reduce demand for water; it is a key link between balancing current and future water needs. The available water

conservation technology focuses on resources for local businesses, industries, communities and individuals (Sekar & Randhir, 2007). However the main loss in a water supply system is caused primarily by leakages in the pipe network. Other influences such as loose fittings and joints and water meters can cause permanent loss.

While a dripping tap is likely the most common leak, there are many others that can be considered. Even small leaks have large waste associated with them. It is estimated that a leak that only drips one time per second can waste over 12 m^3 annually. The majority of the leakage was found since the introduction of meters. Figure 2 illustrates the estimated amount of water lost (%) by leakage in some European Countries.

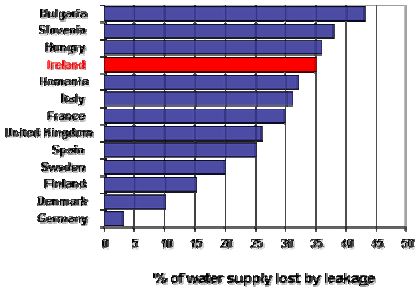

Figure 2. Estimated amount of water lost (%) by leakage in some European Countries.

An important point is that the top five countries on the above graph are those where the meter system has not yet been fully implemented.

Higher standards of living are changing water demand patterns. This is reflected mainly in increased domestic water use, especially for personal hygiene. The result is that most of urban water consumption in Ireland is for domestic use. Most of the water use in households is for toilet flushing (33%), bathing and showering (20-32%), and for washing machines and dishwashers (15%). The proportion of water used for cooking and drinking (3%) is minimal compared to the other uses. One of the biggest problems is that there is not an incentive to control and save water for many users.

Some very effective conservation measures may be implemented immediately at a nominal cost, whereas others may be classified as major cost items. A general survey of the water system usually points to a number of conservation measures that may be improved. It is a good idea to perform the following to conserve water:

- Repair leaks including taps and toilets.
- Use aerators.
- Install hands-free for high volume areas.
- Install low-flow showerheads.
- Use of Rain Water Harvesting systems
- Install a water control logger
- Use greywater for irrigation and landscape watering.

Many end-users including domestic households in the developed world have water flow meters. However, the data is not readily interpreted from basic rotating clock meters, thereby resulting in slow responses from end-users, usually not until they receive a water bill. The cost of existing electronic devices is usually prohibitive even for commercial activities and some public facilities such as schools. Electronic devices are often connected to an intermediate signal interpretation and logging device, which is then connected to a computer.

This project has produced a low-cost alternative to existing electronic measurement devices. The major benefit is that the data can be plugged in to any computer with the driver and software on it. There is potential for existing flow meters to be retrofitted with this and also for end-users with basic computer knowledge to interpret the data. The data can be converted to real-time water costs and therefore, result in the end-user changing behaviour to save water and money. This device will be used during planned case studies to determine baseline values for water consumption in various sectors. This will then provide data to enable decisions to made on the use of water conservation measures and suitable technology to be installed in certain cases (e.g. rainwater harvesting, waterless urinals, dual-flush toilets, etc.).

Results and Discussion

For most people, the amount of drinking water that each water application uses is a mystery. From the toilet to the shower to the washing machine to the car washing, each device or application consumes drinking water and there are little opportunities available to reduce water consumption.

One challenge, from the point of view of water conservation, is that it is hard for water users to understand the impact of each action they made. If water users could easily visualise the amount of water they used by each action, then they would be more likely to change their behaviour to reduce the amount of water consumed in the household.

The problem is that drinking water usage is largely invisible, and few water consumers use appliances with any thought to the impact of their actions. Each flip of the switch, however, results in some amount of drinking water use that is reported to the meter and then billed at the end of each month. In most cases, this is the only engagement the user has with their water consumption.

The future probably will move to more sustainable devices designed to change the way water users use drinking water. Made of a communications module integrated with an ordinary water meter, those devices not only will measure drinking water usage, it also will provide to water users with actionable intelligence on real-time water consumption.

With the development of this green technology, the level of service that utility providers can provide to their water users will be redefined. Intelligent green meters will improve account statement interaction for water users rather than waiting for the bill to arrive. Consumers will track water consumption throughout the billing cycle, which encourages regular engagement with water usage and leads to better consumer awareness.

Conclusions

This study offers an excellent example of how technology will be able to assist people who want to be greener today, use less energy, help the environment, and be more responsible water consumers.

Acknowledgements

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References

Cotruvo, J. A. (1988). Drinking water standards and risk assessment. *Regulatory Toxicology and Pharmacology*, 8(3), 288-299.

EPA, (2001). Soil, herbage, feed and water. Environmental Protection Agency, Wexford, Ireland.

Hooda, P. S., Edwards, A. C., Anderson, H. A., & Miller, A. (2000). A review of water quality concerns in livestock farming areas. *The Science of the Total Environment*, 250(1-3), 143-167.

Sekar, I., & Randhir, T. O. (2007). Spatial assessment of conjunctive water harvesting potential in watershed systems. *Journal of Hydrology*, 334(1-2), 39-52.

UN, (1993). Earth Summit. Agenda 21: *Programme of Action for Sustainable Development*. The United Nations Programme of Action from Rio (UNCED).

HYDROGEN SULPHIDE GAS EMISSIONS FROM SPENT MUSHROOM COMPOST DURING DISTURBANCE AND REMOVAL

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Abstract

Emission of hydrogen sulphide (H_2S) gas was monitored from three different ages (9-11, 4-5 and 1-2 months old) of Spent Mushroom Compost (SMC) during removal over a period of two hours. The SMC heaps were generated from weekly deliveries of approximately 45-50 tonnes between October 2007 and August 2008. It was stored loosely on a concrete platform with retaining side walls on three sides and was left uncovered outdoors for up to 11 months at a site in Co. Cavan, Ireland. During the SMC removal operation, seven H_2S gas monitors were positioned at various locations around the perimeter of the heap which included a gas monitor above the face of the SMC heap, on the outside of the tractor, on the tractor operator and on research personnel. Results suggest that older material produces a greater quantity of H_2S than the younger material. The highest concentration of H_2S detected at the SMC face was >1000 mg kg^{-1}, when 4-5 months old SMC was removed, while the personal monitor of the tractor operator recorded a level of >100 mg kg^{-1}. The personal H_2S gas monitor of the tractor operator recorded a maximum short term exposure value of 86 mg kg^{-1} which exceeded the current short term exposure limit of 10 mg kg^{-1}. Results of this study indicate that there is a significant health and safety risk associated with the release of H_2S gas during disturbance and removal of SMC.

Introduction

Spent Mushroom Compost (SMC) is stored in large heaps until it is required for spreading on land or other usage. During its removal, it releases H_2S gas, which is malodorous and toxic, as a result of anaerobic decomposition of organic matter. The occupational exposure standard (OES) and the short term exposure limit (STEL) for H_2S are currently 5 and 10 mg kg^{-1}, for a period of 8 h, and 15 min, respectively (HAS, 2007). In a preliminary study, H_2S concentrations of 80 mg kg^{-1} (indoor SMC heap) and > 250 mg kg^{-1} (outdoor SMC heap) were detected above the SMC face during its removal for spreading on land (Grogan *et al*., 2008). Recent research suggests that higher concentrations of H_2S are released when older SMC is disturbed and removed (386 mg kg-^{1}) compared to younger material (80 mg kg^{-1}) (Velusami *et al.*, 2009). This confirms the importance of implementing safety procedures in the vicinity of stored SMC, when it is disturbed.

The aim of this work was to characterize the dynamics of H_2S emissions from SMC of different ages during disturbance and removal and ultimately to develop health and safety guidelines for tractor operators working in the vicinity of the SMC heap.

Materials and Methods

SMC storage conditions

Approximately 45-50 tonnes of SMC were removed weekly from a single mushroom grower to a storage site in Co. Cavan, Ireland, over a period of 11 months between October 2007 and August 2008. SMC of different ages (9-11, 4-5 and 1-2 months old) were stored as shown in Figure 1. SMC delivered to this site was not steamed at the end of the mushroom crop. It was stored outdoors, uncovered, on a concrete platform with retaining walls, 2 meters high, on three sides. The dimensions of the concrete platform were 43 m (L) x 36 m (W). The height of the SMC heap was 3.5 metres at the highest point. The average monthly rainfall ranged from 24 to 180 mm and average monthly

air temperature ranged from 6 to 15ºC during the storage period (Met Éireann, Personal communication). Runoff water from the SMC heaps was collected in an underground storage tank.

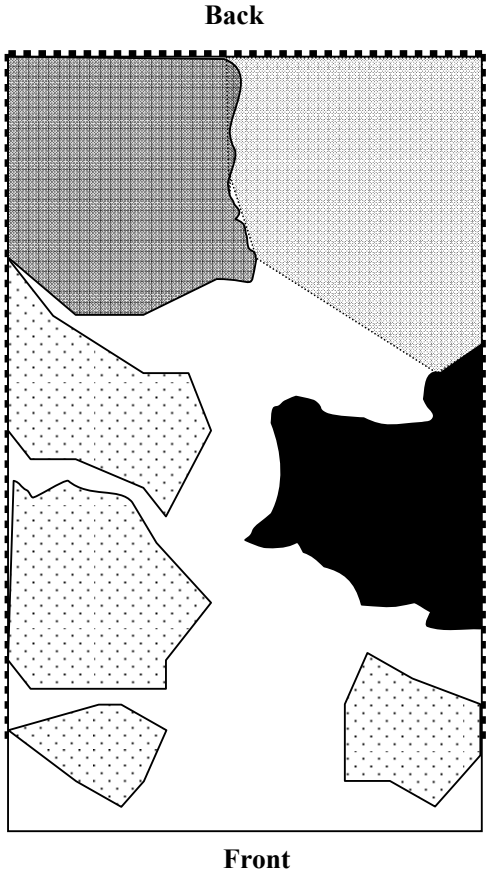

Figure 1. Schematic diagram of SMC storage area.

SMC removal process

The normal operation at this SMC site is to remove and mix the SMC prior to loading into a truck for dispatch. The operation takes up to two hours. SMC was removed from heaps of three different ages (9-11, 4-5 and 1-2 months old) over a period of about two hours using a Volvo 4400 (www.volvo.com) tractor with a standard cab and front end loader. Monitoring of H_2S emissions was conducted on 21st August 2008. The average air temperature, average wind speed and wind direction on the day of the experiment around the SMC storage region in Co. Cavan, Ireland was about 14ºC, 11 km/h and northwest respectively (Met Éireann, Personal communication).

H_2S monitoring during SMC removal

QRAE +, QRAE II (RAE Systems Europe ApS, www.raesystems.eu) and iTX (Industrial Scientific Corporation, www.indsci.com) gas monitors with a data logging facility were used. The maximum H_2S concentration that can be detected by QRAE + and QRAE II monitors is 250 and 100 mg kg^{-1} respectively. The iTX gas monitor can detect H_2S concentration up to 1000 mg kg^{-1} H_2S gas concentration was recorded continually by the data loggers which were set to automatically calculate the average concentration at 10 second intervals for the duration of the experiment. Short term exposure values (STEV) (15 minute average) were automatically calculated and recorded continuously by the monitors. During the SMC removal operation, seven H_2S gas monitors were positioned at various locations around the perimeter of the heaps which included a gas monitor above the face of the SMC heap being worked at, on the outside of the tractor, on the tractor operator and on research personnel.

Results and Discussion

H_2S gas was detected by all monitors. The highest concentrations of H_2S emitted from the SMC face were 1064, 1060 and 576 mg kg^{-1} when the storage period was 9-11, 4-5 and 1-2 months, respectively (Figure 2). The STEV at the SMC face varied between 0 and 341 mg kg^{-1} (Figure 2). The highest concentrations of H_2S recorded outside of the tractor were 375, 423 and 288 mg kg^{-1} when the storage period was 9-11, 4-5 and 1-2 months respectively (Figure 3). The STEV values at the outside of the tractor varied between 0 and 148 mg kg^{-1} (Figure

3). The highest concentrations of H_2S recorded for the tractor operator were 85, 100 and 25 mg kg^{-1} when the storage period of the SMC was 9-11, 4-5 and 1-2 months respectively (Figure 4). The STEV values for the tractor operator varied between 0 and 86 mg kg^{-1} (Figure 4).

Highest H_2S concentrations of > 1000 mg kg^{-1} were detected above the SMC face (Figure 2). Single exposure to H_2S concentrations in the region of 1000 mg kg^{-1} and above causes death within minutes (Costigan, 2003). The peak and trough pattern of H_2S concentration as shown in Figure 2 has been observed previously at SMC storage sites in Kildare, Meath and Offaly (Grogan *et al*., 2008; Velusami *et al.*, 2009). However, the H_2S concentration recorded for SMC material stored at the Cavan site for 4-5 months (Figure 2) was very much higher compared to these earlier studies. It may be due to the high moisture content (68 - 72%) of the SMC heaps at this site compared with the SMC at the Kildare site (64 - 69%) (unpublished data). Further studies are planned in this area.

Comparing the H_2S gas concentration patterns detected at the SMC face (Figure 2) and outside the tractor (Figure 3), both follow a similar pattern but the concentration detected outside the tractor is always lower than the concentration detected at SMC face. H_2S gas emitted from SMC heap dissipates quickly into the atmosphere aided by the prevailing wind. The distance between the SMC face and tractor also makes the H_2S concentration more dilute in the vicinity of the tractor. A maximum H_2S concentration of 423 mg kg^{-1} was detected outside the tractor (Figure 3). Exposure of sections of rabbit trachea to 400 mg kg^{1} H_2S for 10 minutes resulted in cessation of ciliary activity (Beauchamp *et al*, 1984).

The tractor operator was exposed to concentrations of H_2S of > 100 mg kg^{-1} when 4-5 months old SMC was being handled. (Figure 4). This reflects the high concentrations of H_2S detected at the face of the same material (Figure 2), with some of it entering the tractor cab. The tractor driver was continuously working for 2 hours without a break. The maximum STEV recorded for the tractor operator was 86 mg kg^{-1}, which exceeded the current maximum permissible concentration limit of 10 mg kg^{-1}.

In a previous study in Kildare, SMC was removed and loaded into a spreader. The loading operation took about 10 minutes and the spreading operation took about 15 minutes. As a result, the tractor operator was not exposed continuously to H_2S gas emission. Hence, the maximum H_2S concentration that the tractor operator at the Kildare site was exposed to was 56 mg kg^{-1}. The maximum STEV recorded for the tractor operator was 7 mg kg^{-1}, which did not exceeded the current maximum permissible concentration limit of 10 mg kg^{-1} (Velusami *et al*, 2008 and 2009).

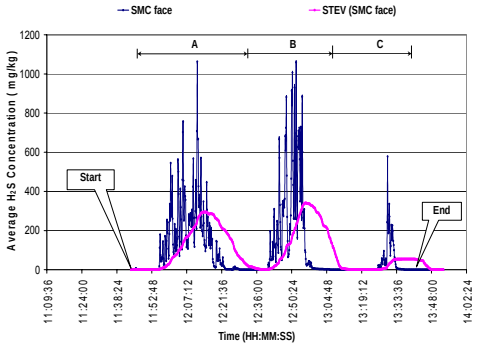

Figure 2. Average H_2S concentration (10 seconds average) and STEV (15 minute average) at SMC face when SMC up to (A) 9 to 11, (B) 4 to 5 and (C) 1 to 2 months old were removed respectively.

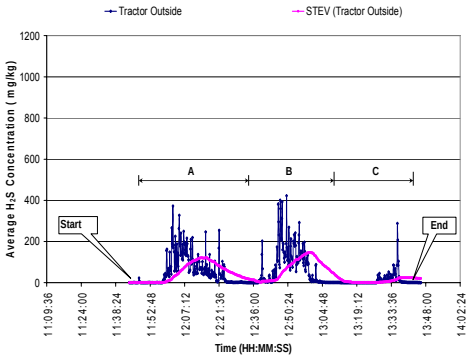

Figure 3. Average H_2S concentration (10 seconds average) and STEV (15 minute average) at tractor outside when SMC up to (A) 9 to 11, (B) 4 to 5 and (C) 1 to 2 months old were removed respectively.

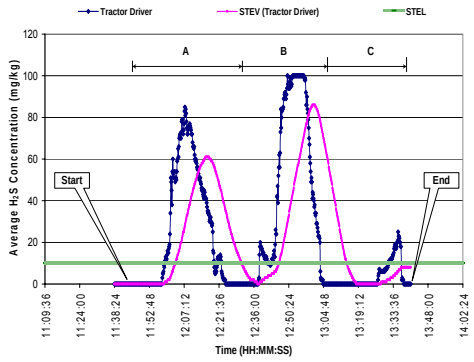

Figure 4. Average H_2S concentration (10 seconds average) and STEV (15 minute average) at tractor operator when SMC up to (A) 9 to 11, (B) 4 to 5 and (C) 1 to 2 months old were removed respectively.

Conclusions

Results confirm that higher concentrations of H_2S are released when 4-11 months old SMC is disturbed and removed compared to younger material of 1-2 months. It is strongly recommended that no personnel should be in the vicinity of the SMC face and around the immediate tractor region during removal and loading operations. If the STEL alarm is activated on the tractor operator's H_2S personal gas monitor, it is strongly recommended that the operator should take a suitable break until the STEL reading returns to zero.

Acknowledgements

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References

Beauchamp R. O. JR , Bus J. S. , Popp J. A. , Boreiko C. J. and Andjelkovich D. A., (1984), A critical review of the literature on hydrogen sulfide toxicity, Critical Reviews in Toxicology, 13(1):25-97.

Costigan, M.G., (2003), Hydrogen sulphide: UK occupational exposure limit. Occupational and Environmental Medicine, 60: 308-312.

Grogan, H., Walsh, G., and Kellegher, T., (2008), Preliminary studies on hydrogen sulphide gas (H_2S) emissions from stored spent mushroom compost. 17th International Society of Mushroom Science (ISMS), 20-24 May 2008, Cape Town, South Africa.

HAS, (2007), Code of Practice for the Safety, Health and Welfare at Work (Chemical Agents) Regulations 2001 as of S.I. No. 619 of 2001, Health and Safety Authority, James Joyce Street, Dublin 1, Ireland.

Velusami, B., Grogan, H., Curran, T.P., and McGuinness, B., (2008), Dynamics of hydrogen sulphide gas production in spent mushroom compost during storage and handling and its impact on Health and Safety issues, Biosystems Engineering Research Review 13, University College Dublin, Ireland.

Velusami, B., Grogan, H., Curran, T.P., and McGuinness, B., (2009), Hydrogen sulphide gas emissions from spent mushroom compost during land spreading. Agricultural Research Forum (ARF), 12-13 March 2009, Tullamore, Ireland.

ODOUR EMISSIONS FROM SPENT MUSHROOOM COMPOST

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Abstract
Spent mushroom compost (SMC) has proven to be an attractive material for improving soil structure and texture in tilled soils and increasing dry matter production in grassland soils. There are some concerns about the environmental implications about the sulphurous odour that accompanies SMC production, processing, storage and spreading.

Some windrow processing of SMC has created strong odours that have led to complaints by neighbours of the processing operations. The increase of residential development near mushroom operations has created some conflicts between these operations and the residents of the neighbouring communities. The main concern has been over odour production. Thus, there is the need for proper management of SMC. Mushroom compost formulation is one of the factors responsible for odours from spent mushroom compost.

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Introduction
Mushroom substrate is the material on which mushroom spawn is grown; it is usually composed of hay and/or straw, horse or poultry manure, gypsum, and other minor ingredients. After the mushrooms have grown on this material, the substrate is disposed of in a variety of ways, including spreading on fields, processing in windrows, or sold directly to nurseries or landscapers. The used material or the left over is usually referred to as spent mushroom compost (SMC). Compost production, however, can become a source of malodours.

Recently, characteristics of composting odours and ecological factors associated with their formation have been reviewed by Miller and Macauley (1988). Composting odours are dependent on nutrients available in the compost formulation and on processing conditions, such as temperature, moisture content, pH, but especially oxygen availability. High nutrient availability linked with anaerobic conditions is likely to cause odour problems; also, increasing substrate density promotes anaerobic conditions as the unit volume demand for oxygen can exceed the potential for re-supply.

Odour problems occur in Phase I. Phase II conditioning can compensate for large variations in Phase I composting practice. Composting and the post–production composting of SMC have the potential for generating odours, particularly if the piles of substrate are not handled carefully (Miller and Macauley, 1988). Anaerobic zones can form in the piles, generating malodorous compounds (Derikx et al., 1990).

The overall objective of this project is to determine the influence of moisture content and age on the emissions of odour and hydrogen sulphide from spent mushroom compost.

Materials and methods

Before outlining the proposed materials and methods for this project, a review of a relevant study comparing an aerated floor process and windrows is outlined here.

SMC and aerated floor vessel

This process took place under controlled SMC moisture content. The strongest odours produced by SMC processing are from anaerobic microbial activity. Borrowing an idea that is commonly used in mushroom compost preparation and in other types of composting, an aerated floor vessel was built for reducing the anaerobic activity, the optimal temperature range was maintained between 50 C and 55 C (at an ideal moisture content). Thermocouples were on the vessel that monitored the SMC temperature. The blower was located in the instrument room to maintain forced aeration on the vessel.

SMC and windrow layout

The SMC used was without any further composting or weathering. The SMC is generally composed of hay, gypsum, poultry manure, and various other minor ingredients such as cocoa shells and corncobs. It includes peat moss, mushroom stems, and mushroom mycellia left from production. The SMC sample was divided into two, one portion into the windrow vessel, while the second portion served as a control in another windrow. Odour assessments took place, beginning eight days after the windrow was built. The SMC in the control windrow vessel was not turned.

Water was added to the two experiments at the start of the processing period. No additional water was added to the control treatment, but the windrow received only natural precipitation after the initial watering.

Odour complaints regarding the processing of SMC appears to have involved the release of hydrogen sulphide and other malodorous compounds. Air samples were also analyzed by gas chromatography/ flame photometric detection (GC/FPD) on a weekly or bi–weekly basis.

This technique separates and quantifies the volatile sulphur compounds (VSC) found in any air sample. The VSC compounds include (carbonyl sulphide), (hydrogen sulphide), MT (methanethiol), DMS (dimethyl sulphide), and (carbon disulphide). It has been previously applied to SMC air samples (Bazemoreet al., 2000). The Tables below show the outcome of the windrow experiments.

Three experimental trials were also run during 2001 and 2002 to assess the effects of aeration on the processing of SMC. It was obtained fresh from mushroom houses and divided, the first ran between January and February 2001, the second ran from 13 June through 1 August 2001, and the third trial ran from 3 June through 28 August 2002. Due to low temperatures in the control windrow during the January to February 2001 trial, it may be difficult to directly compare the results of the two treatments. However, differences in odours were still noticeable. The panellists sampled the treatment in two ways, The pumped sample was the sample taken before aeration while the plume sample was taken after aeration.

Results and Discussion

Table 1. Results of GC/FPD analysis of SMC forced into anaerobic condition on 3 November 2000 . (P.H. Heinnemann et al., 2002).

Concentration of Sulphur compounds(ng /ml)					
Sample	**Carbonyl-Sulphide**	**Hydrogen sulphide**	**MT**	**DMS**	**Carbon disulphide**
SMC1	0.44	481.14	16.51	17.84	0.48
SMC2	1.14	254.45	9.32	30.78	5.98

Table 2. Average assessments from panellist evaluations of odours from January to February 2001 trial.(P.H .Heinnemann et al., 2002)

	Intensity	**Pleasantness**	**Difference intensity**	**Difference pleasantness**
(In January)				
Windrow pump	38.8	-5.4	-	-
Vessel pump	32.8	-3.8	6.0	1.6
Windrow plum	22.1	-2.2	-	-
Vessel plume	19.8	-1.8	2.3	-0.4
(In February)				
Windrow pump	33.1	-4.9	-	-
Vessel pump	19.6	-2.3	13.5	-2.7
Windrow plume	22.7	-2.2	-	-
Vessel plume	18.2	-1.2	4.5	-1.1

Table 3. Hydrogen Sulphide (H_2S) and other Sulphur Compounds levels from June, July, August 2001 & 2002 trials. (P.H. Heinemann et al., 2002).

Dates	**Windrow pump**		**Vessel pump**		**Windrow plume**		**Vessel plume**	
	H_2S level (ng/ml)	Total other Sulphur (ng/ml)	H_2S level (ng/ml)	Total other Sulphur (ng/ml)	H_2S level (ng/ml)	Total other Sulphur (ng/ml)	H_2S level (ng/ml)	Total other Sulphur (ng/ml)
13/06/2001	89.14	29.13	3.97	0.64	0.05	0.06	0.18	0.19
03/07/2002	67.29	1.26	10.0	0.93	0.08	0.17	0.00	0.00
05/07/2001	13.93	0.58	5.67	0.71	1.74	1.13	0.00	0.00
17/07/2002	59.55	0.67	0.14	0.26	2.56	0.05	0.00	0.00
01/08/2001	74.30	3.52	'a'	'a'	0.32	0.49	'a'	'a'
14/08/2002	20.77	0.4	0.00	0.41	0.00	0.27	0.00	0.15

'a' means vessel trial was terminated before these sampling dates.

Proposed tests and expected results

Various assays such as moisture content, odour intensity and pleasantness are going to be carried out on each sample collected. Odour perception may likely be intensified in the uncovered and/or aged sample of SMC when compared with covered SMC and/or fresh sample because of the increase in anaerobic composting which is known to be highly favoured by an increase in moisture content.

General conclusions

Aeration (which reduces moisture content and anaerobic conditions) holds great promise for reducing odours from mushroom compost processing. Samples pumped (before aeration) from the windrows generally had higher odour intensity and were less pleasant than samples taken from the plumes (after aeration), but the vessel showed less odour intensity and was less unpleasant than the windrow in almost all samples.

Quantitative assessment of sulphur compounds helped to confirm that odorous compounds were lower in concentration in the aerated SMC than in the windrows

References

Bazemore, R.A., C.J Wysocki, S. Murray, H.J. Lawley, and G.Preti, 2000. Ameloration of odorous Component in spent mushroom compost. J. Agriculture, food chemistry 48(8): 3694-3697.

Derikx, P. J. L., H. J. M. Op Den Camp, C. Van-der Drift, L. J. L. Van Griensven, and G. D. Vogels. 1990. Odorous sulphur compounds emitted during production of compost used as a substrate in mushroom cultivation. Applied and Environmental Microbiology 56(1):176-80.

Fermor, T. R., Randle, P. E., and Smith, J. F. (1985). Compost as substrate and its preparation. In 'The Biology and Technology of the Cultivated Mushroom'. (Eds P.B. Flegg, D.M. Spencer and D.A. Wood). pp 81-109. John Wiley & Sons Ltd: Chichester, G.B.

Labance, S. E., P. H. Heinemann, and D. M. Beyer. 1999. A simple olfactometric evaluation of microporous covers for the reduction of mushroom substrate preparation odours. Applied Engineering in Agriculture 15(5): 559–566.

Miller, F. C., and B. J. Macauley. 1988. Odours arising from mushroom composting: A review. Australian J. of Experimental Agriculture 28(4): 553–560.

P.H. Heinnemann, G.Pretti, C.J Wysocki, R.E. Graves. S.P. Walker, D.M.eyer, E.J. Holcomb, C.W. Heuser, F.C Miller. 2002. In -vessel processing of spent mushroom substrate for odour control. Applied Engineering in Agriculture 19(4):461-471.

THE EFFECT OF APPLICATION TECHNIQUE ON AMMONIA EMISSIONS FROM CATTLE SLURRY

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Abstract

Under legislation, national ammonia (NH_3) emissions are limited to 116,000 tonnes by 2010. As agriculture is responsible for 98% of Ireland's total NH_3 emissions, the industry will need some mitigation strategies in order to allow the nation to comply with these future targets. Low-emission slurry spreading technologies can reduce emissions. In this paper splashplate (SP) and trailing shoe (TS) application methods will be compared. On various dates during 2006, 2007 and 2008 cattle slurry was applied at 30 m^3 ha^{-1} to grassland plots using the TS or SP methods at Johnstown Castle, Co. Wexford. The NH_3 emissions were measured using a micrometeorological mass balance technique. There was an effect of application type on NH_3 emissions from cattle slurry. The average emission from the 6 application dates for splashplate and trailing shoe applications were 66.18 and 49.08% of TAN applied. This was a significant emission reduction of 25.8% (p= 0.03) for emissions from trailing shoe as compared to the splashplate application. Also there was an overall reduction in NH_3 emissions between the two treatments of 8.81kg ha^{-1} (P= 0.028). During the 6 application events, there was a greater proportion of NH_3 volatilised within the first 24 hours post application from splashplate (76.7%) compared to trailing shoe (61.37%) applications.

Introduction

The National Emissions Ceilings Directive (1999) aims to reduce emissions of pollutants that cause acidification, eutrophication and ground-level ozone in order to protect the environment and human health. Under this legislation national ammonia (NH_3) emissions are limited to 116,000 tonnes by 2010, with further, more stringent targets currently under discussion. As agriculture is responsible for 98% of Ireland's total NH_3 emissions, the industry will need some mitigation strategies in order to allow the nation to comply with these future targets. Inventory calculations show that the land spreading of cattle manure accounts for 47% of the total agricultural emissions (Hyde *et al.*, 2003). Therefore, there is an interest in slurry spreading methods that will reduce NH_3 emissions. Low-emission spreading technologies can reduce emissions by up to 95% compared with the conventionally used splash plate method (SP) (Misselbrook et al., 2002). Of these, the trailing shoe (TS) is of particular interest in Ireland not only because of its potential to reduce NH_3 emissions but also its potential to extend the spreading window, by allowing placement of slurry below a high grass canopy rather than on top of it. The rate of NH_3 emission from slurry can depend on various factors such as slurry type, dry matter (DM) and total ammonical nitrogen content (TAN) of the slurry. Also various weather conditions such as wind speed, precipitation and solar radiation at spreading time can also affect emission levels. **The objective of this work was to assess the effect of the two application techniques as well as prevailing weather conditions on NH_3 emissions from cattle slurry.**

Materials and Methods

On various dates during 2006 (12/7), 2007 (24/4, 14/5, & 30/7) and 2008 (23/4 & 9/6) cattle slurry (DM- 66.5-99.8 g kg^{-1}; TAN- 1.28- 2.42 kg t^{-1}) was applied at 30 m^3 ha^{-1} to grassland plots (30 m diameter and 23 m apart) using the TS or SP methods. All plots were cut to 10 cm 1-2 days prior to

spreading. There were two plots per treatment located on grassland at Johnstown Castle, Co. Wexford. The NH_3-N emissions were measured using a micrometeorological mass balance technique. Masts (4) were located in the centre of each area to which the slurry had been applied and two masts were positioned upwind from the four plots. Passive flux samplers (internally coated with 3% oxalic acid in acetone) were placed on four masts in the centre of the plots at 0.2, 0.4, 0.8, 1.2, 2.2 and 3.3 m above ground level. The upwind masts had samplers at 0.2, 0.8, 2.2 and 3.3 m above ground level. The passive flux samplers were changed during the seven day measurement period at approx 1, 3, 6, 24, 48 96 and 168 hours following the slurry application. The NH_3-N that is captured by the shuttle under acidic conditions is converted into ammonium (NH_4). The samplers were washed out with 30 ml of deionised water and the NH_4 -N concentration of this solution was then determined photometrically. On each occasion an emission of NH_3 was calculated from each plot. The students T test was used to determine the significance of treatment effects.

Results and Discussion

The overall temporal trends of the NH_3 emissions as a percentage of the TAN applied from the splashplate and trailing shoe treatments are outlined (Figure 1). The average total NH_3 emission over the 7 day measurement period for the splashplate application was 66.2% with values ranging from 47% to 92.9% of the TAN applied, whereas the average total NH_3 emission over the seven day measurement period for the trailing shoe application was 49.1% with values ranging from 43.3% to 71.4% of the TAN applied. With regards to splashplate application, 76.7% of all NH_3 volatilised over the 7 days occurred within the first 24 hours post application, whereas significantly lower values were observed for trailing shoe (61.4%) for the same period.

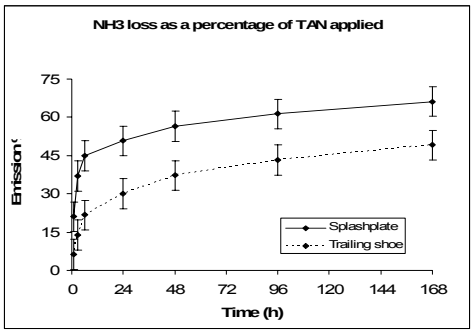

Figure 1. The overall temporal trend of NH_3 loss as a percentage of TAN applied for splashplate and trailing shoe applications during six application events

The cumulative loss of NH_3 in kg ha^{-1} for splashplate and trailing shoe applications during six application events are outlined (Figure 2). On average the splashplate application lost 36.7 kg ha^{-1}, whereas the trailing shoe application lost 27.9 kg ha^{-1} over the 7 day period. On average there was an 8.8 kg ha^{-1} difference ($p = 0.028$) between the application types or a 24.03% reduction in the trailing shoe NH_3 emission compared to the splashplate application. Previous studies have shown 23-57% reduction in emissions (Smith et al., 2000).

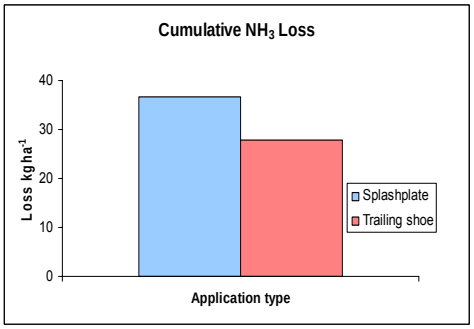

Figure 2. The cumulative loss of NH_3 in kg ha^{-1} for splashplate and trailing shoe applications during six application events ($p = 0.028$)

The lower emissions from the trailing shoe application can be explained by the area taken up with the applied slurry. There is a difference of 79% between the two treatments with splashplate having 100% surface area. This surface area allows the splashplate applied slurry to dry out faster

than the trailing shoe applied slurry.

During drying, crust formation begins to occur on the slurry surface and this causes NH_3 emissions drop dramatically. The rate of NH_3 volatilisation is lower for the splashplate spread slurry from days 2 to 7 post application than trailing shoe applied slurry. This is due to the trailing shoe applied slurry being somewhat sheltered by the surrounding canopy, which allows the slurry to remain emitting at very low rates over a longer period than the splashplate applied slurry.

Conclusions

There was a significant effect of application type on NH_3 emissions from cattle slurry ($p = 0.03$). The reduction in emissions was consistent across a range of dates and climatic conditions. The higher losses under splashplate application were due to (a) greater surface area exposure and (b) placement of slurry on the crop canopy surface.

Acknowledgements

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References

Hyde, B.P., Carton, O.T., O'Toole, P. & Misselbrook, T.H. (2003). A new inventory of ammonia emissions from Irish agriculture. Atmospheric Environment **37** (1):55–62

Misselbrook, T.H., Smith, K. A., Johnson, R. A. & Pain, B. F. (2002). Slurry Application Techniques to reduce Ammonia Emissions: Results of some UK Field-scale Experiments. Biosystems Engineering. **81** (3): 313–321.

Smith, K.A. Jackson, D.R Misselbrook, T.H. Pain, B.F. & Johnson, R.A. (2000). PA-Precision Agriculture: Reduction of Ammonia Emission by Slurry Application Techniques. Journal of Agricultural Engineering Research **77** (3): 277-287

United Nations Economic Commissions for Europe (UNECE), Geneva. (1999). Protocol to the 1979 convention on long range transboundary air pollution to abate acidification, eutrophication and ground-level ozone.

Raw material impact on condensate production within an animal rendering facility as predicted using neural network forecasting

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Abstract

The raw material intake of an animal rendering plant was investigated over an 18 month period in order to determine what impact if any the mix within the cookers had on the level of condensate requiring treatment by the Waste Water Treatment Plant (WWTP). A model was then developed to indicate the volume of vapour generated from the processing of varying types of raw material and its subsequent treatment by the Waste Water Treatment Plant. This was achieved using two analytical methods, one was to build a multiple regression model to validate the core assumptions on the cause and effect between different types of inputs; and the second was to use the greater forecasting power of neural networks to develop a forecasting tool to get an indication of what the condensate flow to the WWTP would be when certain key metrics are input. To date, a coefficient of determination of 0.54 has been achieved in the relationship between inputs and outputs.

Introduction

Animal rendering can potentially have a significant environmental impact if adequate abatement systems are not *in situ.* Although processing is multi staged, one important aspect of the rendering industry is the mix and moisture content of the raw material being processed. After the death of an animal, purification is the most important destruction process of organic material. Environment can speed up or slow down the natural progression of putrefaction with temperature, ventilation and humidity being the main influencing factors. Higher fat levels cause more rapid decomposition due to greater amount of liquid in the tissues. Taking the decomposition into account, raw material is said to generally consist of 60% moisture, all of which has to be removed and treated during processing. When examined closely however, individual material varies on its moisture content. Upon cooking, the vapours generated due to the moisture in the raw material mix are normally drawn to the Thermal Oxidation air purification units TEAP. TEAP units treat vapours from the cooking process and room air. The thermal exhaust purification process is a process in which VOC compounds contained in the process exhaust air are destroyed. When the amount of vapours coming from the cookers exceeds the design parameters or the in-house settings of the TEAP, the extra vapours are recondensed (condensate) and treated in the WWTP. Condenser fans are used as a backup system to the TEAP units and will draw vapours automatically via draft fans if for some reason the TEAP units are unable to treat the vapours.

The aim of this project was to develop a condensate forecasting tool at a meat by-products plant.

Procedure

Data Collection
Daily records were collected on the tonnages of raw material processed and the quantity of condensate generated from the cooking process. Raw material was broken down into 17 different categories. These categories included ruminant, non ruminant, category 1 material, waste water, sludge, fat, blood, fish offal, turkey offal, chicken offal, food waste, pork offal, mixed offal, sheep offal, bone, beef offal and feathers. For each category of material the quantity of moisture generated through processing was calculated. Taking the decomposition into account, raw material is said to generally consist of 60%

moisture, all of which has to be removed and treated during processing. When examined closely however, individual material varies on its moisture content as demonstrated in table 1.

Table 6. Raw material moisture level (EPA, 1995)

Moisture content of raw material			
Offal	**%**	**Whole fallen animals**	**%**
meat plant offal and bone	55	**calves**	68
cow offal	60	**sheep**	53
calf offal	70	**pig**	42
Sheep	50	**butcher fat and bone mix**	37
Pigs	60	**blood**	90
Poultry	65	**grease**	25
Feathers	67	**sludge**	85
		Food waste	60

Bovine, pig offal, poultry, blood, sludge and feathers all contain greater than 60% moisture which has to be evaporated off during processing.

Statistical Analysis

Initially a gamma test was applied to the data. A gamma test is a statistical technique which examines how much of the changes in the output (the condensate flow) can be explained by changes in the inputs (raw material tonnages and categories) using all known smooth functions. The gamma test allows the identification of 'noise' or error within the data because of real world interferences from other potential impacts due to the rendering process.

Following this, the data was approached from two fronts. Multiple regression models were used to identify the key drivers of the condensate flow. Secondly the use of the greater forecasting power of neural networks was used to develop a forecasting tool which would give a general indication of what the flow should be when certain key metrics are inputted.

Results and discussion

When the gamma test was run, it was found that if the perfect model were constructed, the input variables would explain 48% of the variation in the flow. For the regression model, data was grouped in accordance to the inputs based on the moisture content of the raw material per tonne. That is material which contained less than 55% moisture (Dry), material which contains 60% moisture (Medium), material that contained between 65-85% (Wet) moisture and then the material which contained more than 85% moisture (More Wet). Table 2 details the key output from the regression model.

Table 2. Key output of regression model

Variable	Coefficient	t-stat
(Constant)	12.643	3.204
APR06_Dummy	27.383	5.996
DRY	-0.038	-2.134
MED	-0.010	-0.593
WET	0.072	1.42
More WET	0.114	2.517

The APR06_Dummy is a simple variable to allow for the structural change in the system that took place in April 2006. The key thing to see is that the coefficients for the variables in the model validate the idea that the moisture affects the flow.

What is crucial to note is that when the different categories are examined, that is, as a progression from dry to med to wet to more wet, they all have a greater effect on the flow.

The t-stat, demonstrates the confidence of the model for each variable. The t-stat for Med is the weakest, this is as to be expected as this group would have the lowest effect on condensate flow during normal operational parameters.

The neural network forecasting tool was then used to input the various tonnages. This forecasting tool can demonstrate the

flow of condensate in m^3 generated during normal operating conditions.

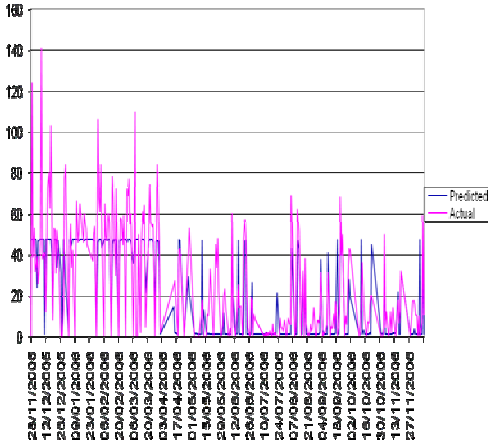

Figure 1. Graphical representation of actual versus predicted quantities of condensate production

A change in process in April 2006 where draft fans pulling the vapours to the condensers were reset to only come on when needed rather that drawing a small amount on a continuous basis demonstrated how condensate volume requiring treatment could be reduced. Prior to this operational change, there were less controls in operation on the condensers fans and they would have been running to some degree all the time. Although the negative pressure that is created from both the condenser fans and draft fans being on would be considerably less than that exerted by the TEAP units, the cold surface of the condensers acts as a 'draw' for the hot vapours much as in the same way a chimney works. These fan speeds are now being kept at minimum once both TEAP units are operating correctly thereby reducing their pull. The result of this change in process was that there was less condensate generated per tonne of raw material processed.

There are multiple advantages to this. Neural network forecasting can then be used to for day to day operational procedures within the rendering process and can benefit energy consumption within the plant and also allow for greater control on loadings onto water and air abatement systems. To date the r^2 i.e. how much variation in output variable is being explained by the input variable is 54%. This is in real terms is to be expected. There are a large number of operational parameters which would also impact the quantity of condensate generated from the rendering process. These include parameters such as cooking speed, condenser fan settings and break downs, i.e. TEAP units cutting out due to surges of vapour. When the model was run, there was an obvious correlation between the actual quantity of condensate produced and that predicted by the forecasting tool as can be seen in figure 1.

Conclusion

This benefits of neural networking as a forecasting tool include being able to quantify loadings onto the waste water treatment plant. The advantages of using neural forecasting to demonstrate the correlation between raw material intake and condensate are numerous. The algorithm uses computer simulation to predict the behaviour of a facility and later, with this information, modifies the inputs of the process to optimise the operational results and/or costs.

Neural networking has the ability to deal with difficulties arising from uncertainty, imprecision, and noise in a natural environment. The advantages of using neural networking is the learning capabilities of the forecasting tool which allows for it being an ideal approximating tool in a processing facility from which the environmental discharges can vary so dramatically.

Future aims are to further refine the neural network forecasting tool so as to develop a procedure that can be implemented within the rendering facility so that further controls on energy and optimisation of the waste water treatment plant can be developed.

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References

Environmental Protection Agency, (2008). Integrated Prevention and Control (IPPC) BAT Guidance Note for the Disposal or Recycling of Animal Carcasses and Animal Waste. EPA, Wexford

Campobasso. C.P., Di Vella, G., Introna, F., (2001). Factors affecting decomposition and Diptera colonization Forensic Science International 120 (2001) 18-27,

Auvermann, B., Ahmad, K., Anindita, A., (2004). Rendering: Carcass Disposal: A comprehensive review, National Agriculture Biosecurity Centre, Kansas State University

Goldshmid, Y., (2005), Destroying Organic Wastes: Thermal Oxidiser Basics, www.cepmagazine.org

Saleh M. Al-Alawi, Sabah A. Abdul-Wahabb, Charles S. Bakheit, (2008). Combining principal component regression and artificial neural networks for more accurate predictions of ground-level ozone, Environmental Modelling & Software 23 (2008)

USEPA, (1995). Emission Factor Documentation for AP-42 Section 9.5.3 Meat rendering plant, September 1995

Heravi, S., Osborn, D., and Birchenhall, C. R., (2004). Linear versus neural network forecasts for European industrial production series, International Volume 20, Issue 3, July-September 2004, Pages 435-446

Ruiz-Suárez, J.C., Mayora-Ibarra, O.A., Torres-Jiménez, J., and Ruiz-Suárez, L.J., (1995), Short-term ozone forecasting by artificial neural networks, Advances in Engineering Software, Volume 23, Issue 3, Pages 143-149

Zhang, G., Patuwo, B.E., Hu, M., (1998) Forecasting with artificial neural networks: The state of the art, International Journal of Forecasting, Volume 14, Issue 1, Pages 35-62

SPREADING ORGANIC WASTE ONTO MISCANTHUS: IMPACTS ON GROUND WATER QUALITY

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Abstract

The impact of landspreading biosolid sludge and brewers waste on groundwater (GW) quality was studied. The wastes were spread on plots of *Miscanthus Giganteus*. Spreading was dictated by spreading regulations. Groundwater was sampled at monthly intervals from wells sunk at various locations in plots. Samples were filtered and analyzed for concentrations of three major nutrients, N, P, and K and six heavy metals Cu, Cd, Cr, Pb, Ni, and Zn. Results indicate that there is a correlation between the level of P, K, Cu, Zn, and Ni applied and their subsequent occurrence in the groundwater sampled. Such a correlation was not observed for N, Pb, Cd and Cr. There is potential for groundwater pollution to occur due to such spreading practices.

Introduction

The need to access alternative sources of sustainable, commercially-viable energy is recognized in tandem with concerns regarding the disposal of domestic and industrial effluents. Previous disposal routes are no longer acceptable and this fact, coupled with increasing volumes of waste being produced, makes sustainable disposal a priority. Land-spreading is a possible option for the disposal of waste by-products with a nutrient value for non-food crops such as *Miscanthus*. However, concern related to possible water-pollution risks from such practices make determining the potential impact of such land-spreading practices a priority.

The objective of this work was to monitor the loss to GW of heavy metals and nutrients from wastes spread on land (used to grow biomass energy crops) and their subsequent transport through soil to groundwater.

Materials and Methods

Well and Plot layout.
Three plots of size 0.1174 ha (with external dimensions of 28 x 42 m) were laid out. Three of these plots were located in the Barley Field (BF) area of Oak Park, Carlow, and three in the Near Avenue Meadow (NAM) area of the same facility. Bore holes for GW wells were sunk in the six plots of *Miscanthus*, and wells placed in them.

Landspreading Procedure
Two wastes were selected for landspreading: biosolid waste obtained from wastewater facilities, and brewer's waste obtained from distilleries and breweries. Plots were treated over a period of three years with biosolid waste applied to NAM plots, and brewer's waste applied to BF plots. The treatment levels used were heavy (100%, BF 7 and NAM 3), light (50%, BF 8 and NAM 2) and control (0%, BF 9 and NAM 1), with 100% being the heaviest permissible load per regulation. Application of biosolid on the NAM was by conventional spreading equipment. Brewer's waste was spread on the BF using an irrigation system. All spreading procedures were in line with relevant Irish regulations (DOE 1998).

Wells were constructed from preassembled Teflon tubes (outside diameter 30mm). The bottom-section of each well was perforated by cut-like openings that allowed GW to penetrate the well. A nylon sock was fitted over the bottom sections to filter fines. Gravel was poured into the space between the well and the soil-wall to serve as an outer-filtrate. Bentonite was used to seal the top of the well hole and the perforated section at the well-bottom. A plastic cap was used to prevent rainwater and particulate matter from entering the tubes once in situ.

There were fourteen wells sited in the six plots in total, three wells on each of the heavy- and light-application rate plots and one well on the control plots. The placement of multiple wells per plot ensured a representative sample of GW was obtained.

Sampling Methods.
Monthly samples were collected from all GW wells. Samples were bulked, from plots where multiple wells were in place. Sampling commenced in October 2007 and will be ongoing until October 2009. Sampling was carried out according to methods developed by Teagasc, and US EPA Region 1 regulations (EPA, 1996). Ground water levels were determined using an electronic depth gauge (Art No. 11.03.40 Eijkelkamp). This information was recorded to create a hydrograph, and to calculate the depth to which the sampling tube needed to be positioned in each well. The position of the sampling tube, the rate of evacuation, and the pumping rate were calculated before sampling to ensure samples were representative of the wells. The wells were evacuated prior to sampling (EPA, 1996). To determine an appropriate sampling rate, the hydraulic conductivity at the well sites was established using the pumped borehole method (ILRI, 1980). However, this rate was low and could not be matched by sampling rates. The first set of samples was collected using a brass hand-powered pump, with later samples collected using a peristaltic pump (Model No. 12.26 Eijkelkamp) which induced less stress in the water system during sampling.

Filtration and Analysis
Samples were collected in PET containers, brought back to the laboratory, and filtered to remove sediment materials and particulates. Two filtration phases were used. In the first, a simple gravity filter using Whatman® 185 mm paper filters removed heavy sediments. This filtrate was then filtered again using a Sarstedt 0.45µm micropore filter to remove finer materials. The samples were sealed and kept at a temperature below 4ºC. Samples were sent to the Teagasc Water Laboratory in Johnstown Castle, Co. Wexford and analysed for N, P, K, Cu, Cd, Cr, Pb, Ni, and Zn. Samples were normally sent for analysis within seven days of sampling, though this was not always possible.

Results and Discussion

The results presented represent data collected for the period from October 2007 to June 2008. Due to the small dataset, further analysis is required in order to confirm the results of this preliminary dataset.

Tables 1 and 2 show the nutrient and heavy metal content of sampled groundwater from each experimental plot. The results for ground water concentrations are summed results for all available samples taken between October 2007 and June 2008. The spreading quantities for both sites are the summed quantities of waste spread from January 2006 to December 2008, and represent three separate spreading seasons. The 2006 spreading figures were taken from a previous work (Fitzgerald, 2007).

The four nutrient graphs provided (Figure 1) show trend-lines for the amounts of waste spread on each plot, compared with the summed concentrations of each nutrient in the groundwater. Four comparative graphs for heavy metals are provided (Figure 2). Figure 2a and 2c relate to Cu, while Figure 2b and 2d relate to the heavy metals Cd, Cr, and Pb. The groundwater concentrations are plotted against the total amount of each metal spread onto the plot during the period 2006-09. For the last graph, a composite figure was obtained by adding the quantities of Cd, Cr, and Pb spread during the period from 2006 and 2008. From the results obtained, several trends were observed. In terms of nutrients, no overall trend was apparent between treatment levels and the occurrence of nitrate in GW, and this was true of both the NAM and the BF sites (Figures 1a, 1c).

Table 1. Nutrient content of groundwater in experimental plots following land spreading of waste

Plot Name, Waste Type, and Treatment level	NAM Biosolid (control)	NAM Biosolid (light)	NAM Biosolid (heavy)	BF Brewers Waste (control)	BF Brewer's Waste (light)	BF Brewer's Waste (heavy)
Total Waste Spread (t)	0	4.0	5.9	0	29	58
Summed Nitrate in GW (mg/l)	119.1	78.0	125.0	160.7	73.8	122.3
Summed K in GW (mg/l)	8.97	7.40	30.77	13.8	15.9	908.3
Summed P in GW (mg/l)	0.8	0.8	2.0	0.7	1.1	5.3

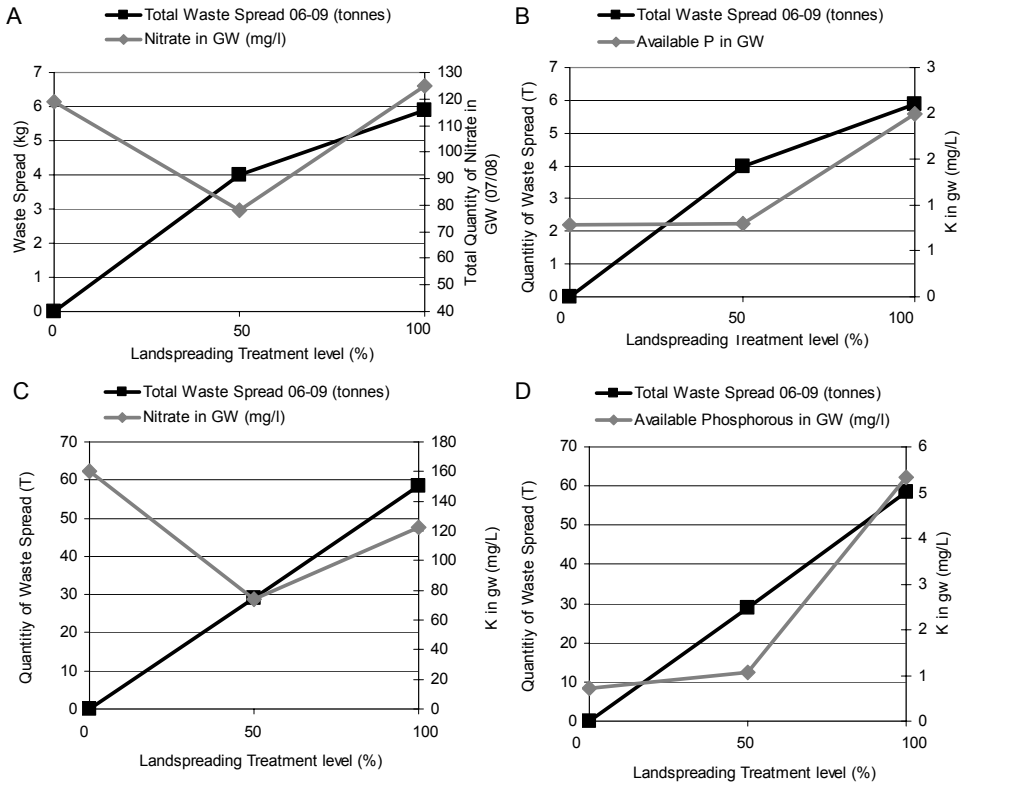

Figure 1. Effect of landspreading on the level of nitrates (a, c), and phosphorus (b, d) in groundwater samples for the Near Avenue Meadow (a, b) and Barley Field (c,d) plots.

Table 2. Heavy metal content of groundwater in experimental plots following land spreading of waste.

Plot Name, Waste Type, and Treatment level	NAM 1 Biosolid (control)	NAM 2 Biosolid (light)	NAM 3 Biosolid (heavy)	BF 9 Brewers Waste (control)	BF 8 Brewer's Waste (light)	BF 7 Brewer's Waste (heavy)
Sum of all heavy metals in GW (mg/L)	276.0	256.8	258.7	*217.2*	*275.6*	*372.3*
Sum of all heavy metals spread (kg)	0.0	81.3	156.0	0.0	29.0	58.4
Copper (mg/ L)	*83.8*	*80.1*	*95.2*	*63.1*	*106.4*	*157.1*
Total Copper spread (kg)	0.0	19.1	38.4	0.0	19.1	38.4
Zinc (mg/L)	*50.8*	*51.4*	*43.1*	*19.0*	*47.3*	*49.1*
Total Zinc Spread on BF (kg)	0	37.3	72.7	0.0	27.2	55.3
Nickel (mg/L)	*31.9*	*27.7*	*32.6*	*33.6*	*37.3*	*43.0*
Total Nickel spread on NAM (kg)	0	2.9	5.8	0.0	2.8	5.7
Lead in NAM GW (mg/L)	*55.7*	*65.0*	*26.3*	*64.8*	*53.1*	*69.8*
Cadmium in NAM GW (mg/L)	*14.4*	*9.7*	*14.5*	*11.5*	*11.9*	*17.9*
Chromium in NAM GW (mg/L)	*39.4*	*22.9*	*47.1*	*25.2*	*19.5*	*35.3*
Total Pb, Cr, and Cd spread (kg)	0.0	11.2	21.9	0.0	7.5	15.1

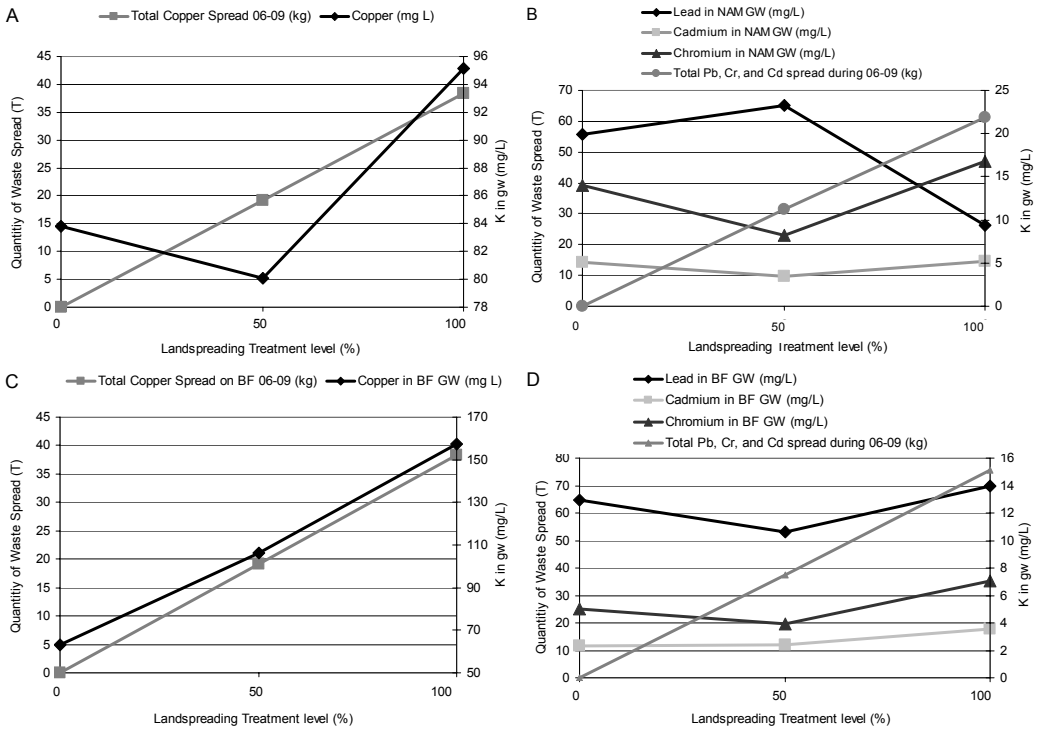

Figure 2. Effect of landspreading on the level of copper (a, c), and lead, cadmium, chromium (b, d) in groundwater samples for the Near Avenue Meadow (a, b) and Barley Field (c,d) plots.

However, for P and K it appeared that the application of waste materials onto both sites resulted in higher concentrations of these nutrients in GW (Figure 1b, 1d). For heavy metals, the picture was complicated by the number of heavy metals being analyzed. A clear trend was observed for the BF that indicated the application of waste containing Cu resulted in larger quantities of Cu subsequently occurring in GW (Figure 2c). For the NAM, the correlation was not as pronounced (Figure 2a). For Zn and Ni, a similar trend was observable on the BF site, but not on the NAM site (Table 2). For the remaining three heavy metals Pb, Cr, and Cd; no observable trend was apparent from either site (Figure 2b, 2d).

Conclusions

Despite the incomplete data set available, it can be concluded that trends exist implying a link between the application of wastes, and the increased occurrence of components of these wastes in ground waters. This suggests that it is not unreasonable to assume that GW pollution might arise due to spreading organic waste on energy crops.

References

DoE (1998). In: Statutory Instrument No. 148. European Communities (Use of Sewage Sludge in Agriculture) Regulations, The Stationery Office, Dublin.

EPA (1996). Low Stress Purging and Sampling Procedure for the Collection of Ground Water Samplers from Monitoring Well. Washington, DC, US.

ILRI (1980). Drainage Principles and Applications (iii Surveys and Investigations), Ritzema, H.P. (Ed), Wageningen, Netherlands.

Fitzgerald M. (2007) The use of energy crop sites for effluent disposal. MSc. Thesis, University College Dublin, Ireland.

DRINKING WATER QUALITY IN IRELAND - THE IMPACT OF IRISH AGRICULTURE

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Abstract
The loss of nutrients, particularly nitrogen, into aquifers and surface waters is an inevitable consequence of intensive agriculture. In many parts of Europe, for instance, the inputs to agricultural systems and the subsequent losses are so large that they constitute a threat to the quality of both surface and groundwater. Several groundwater monitoring studies around the world have indicated that nitrate concentrations in shallow groundwater beneath agricultural fields routinely exceed 10 mg/L. This study proposes to relate this surface and ground water quality to agricultural management practices in Ireland and to discuss possible alternatives for minimising nitrogen and phosphorus loss from agricultural fields, firstly, through the accumulation of data in relation to possible contaminants of drinking water and secondly, through the implementation of land based trials.

Introduction
Approximately 97% of the earth's water is salty and unsuitable for drinking; leaving just 3% remaining as freshwater. Of that 3%, two-thirds is frozen in ice caps and glaciers, which means only 1% of the earth's water is available for drinking and other uses (Brady and Weil, 2002). Factor in that the human body consists of up to 70% water and can survive for only a few days without it, and the rationale behind calling freshwater the most precious resource on the planet becomes clear. Faced with a myriad of domestic and industrial activities that consume and pollute water, nature and the hydrological cycle can do only so much to maintain the purity of this vital resource (Tarver, 2008).

The enrichment of surface water is a particularly worrying problem in many parts of Ireland. In recent years, accidental spillage of slurry and silage effluent has been reduced but the flow of nutrients into surface water is increasing (Ryan, 2000). A recent study deemed 28% of Irish rivers to be polluted (EPA, 2007).

Now that concerns about eutrophication of surface waters and contamination of ground waters have come to the fore, of singular interest is the potential for nutrient loss from farming. The nutrients of greatest unease are Nitrogen and Phosphorus. Pollution of water by nitrate contributes to eutrophication and is therefore an environmental threat (Leifert and Golden, 2000), while it is recognised internationally that the best way to prevent algal blooms and excessive weed growth is to limit the amount of phosphorus in the water (Ryan, 2000). Much of the nitrate in ground and surface waters are attributable to agricultural practices (Johnson *et al*., 2002) with EU Governments taking steps to control losses: via the designation of Nitrate Vulnerable Zones and the full implementation of the Directive, while farmers await the roll-out of the phosphorus directive.

The focus of this research is to assess the quality of drinking water in Ireland. Specifically, the likely contaminants, their route of entry to the drinking water system and the vulnerability of the drinking water chain to contamination from agriculture.

Materials and Methods
This research study consists of three individual components, stage 1 and 2 are complete and stage 3 will continue until August 2009.

Stage 1. A review of drinking water production in Ireland through the development of a traceability chain from source to consumer to identify stages and possible "weak links" in the drinking water production and supply system.
This component of work manifested itself as a "Drinking Water Chain Map" constructed in Microsoft VISIO and follows the production of potable water from its source as either ground or surface water to its destination at the consumers tap (Figure 1).

Stage 2. The development of a contaminant database highlighting the possible pollutants of a drinking water supply including information on their consequences and control.

Data was collected on the likely impurities of drinking water globally and number 187 in total. The categories of contaminants included: microbial, chemical, physical and radiological. The database contains information on entry to the water network, detection and identification, consequences, control and corrective action and ultimate risk of each listed pollutant. Figure 2 is a screen view of the contaminant database for drinking water.

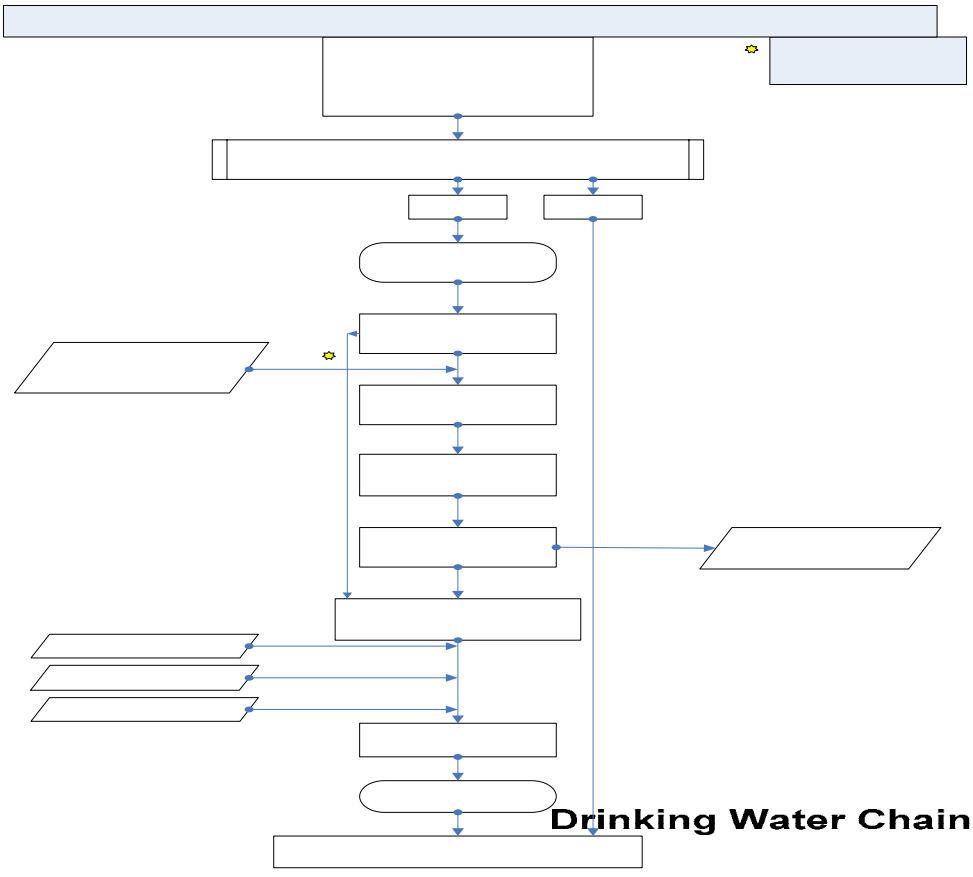

Fig 1. Drinking water supply/production chain.

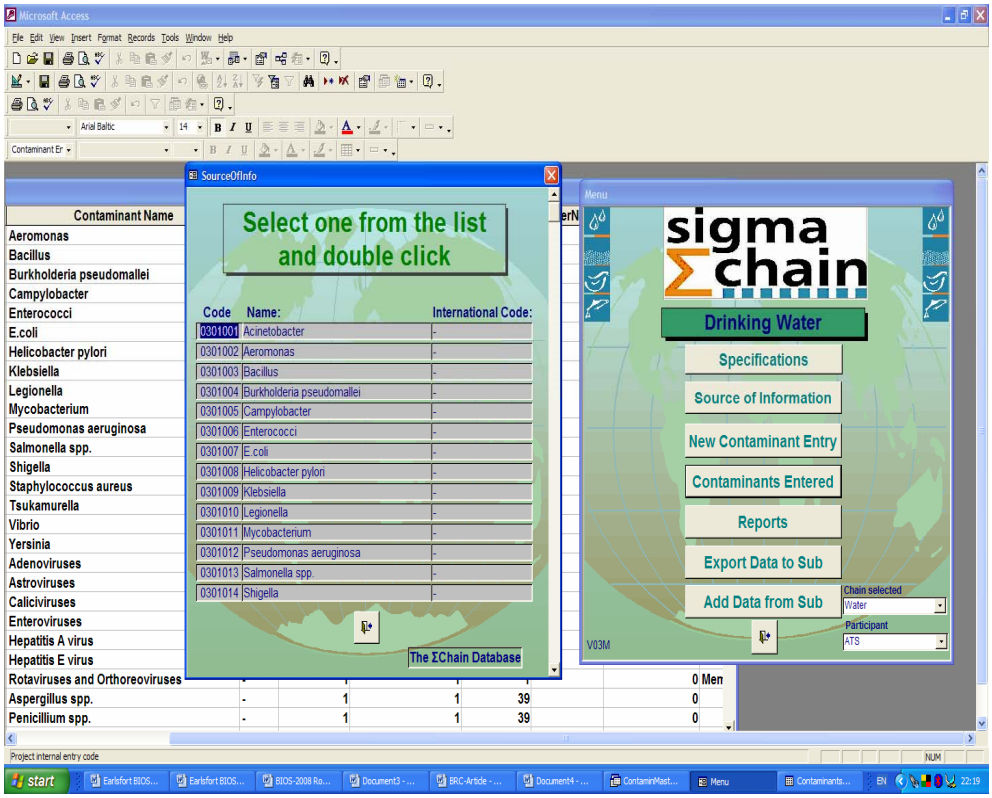

Fig 2. Drinking water contaminant database

Stage 3. Field based trials to understand the loss of nutrients from slow release fertilisers, such as animal manures, after application, to determine and design practices to reduce and/or control nutrient losses to aquatic environments.

In May 2007, 2 ha of Short Rotation Coppice (SRC) Willow (*Salix*) and 2 ha of Miscanthus (*Miscanthus x gigantueus)* were planted at UCD Lyons Research Farm, Newcastle, Co. Dublin. The intention in this research study is to apply a number of agricultural wastes (slurries and dirty waters) to these crops at a number of application rates and to monitor the movement for nutrients through the soil and water systems. Ground water samples will be collected at regular intervals and analysed for nitrate content while surface water assessment will take place for phosphorus detection. These two alternate methods have been chosen based on the movement of these nutrients and recommendations based on the literature i.e. nitrate leaches down through the soil; phosphorus movement is across the soil surface as run-off. The collection of sub-surface ground water samples is facilitated through the use of suction-cup lysimeters.

Suction cups are constructed of hydrophilic materials with fine pores. When suction is generated within the sampling system, water is sucked inwards out of the pores of the cup until a corresponding capillary pressure occurs in the pores. If the capillary pressure in the suction cup is lower than that in the soil, water flows from the soil into the suction cup until the capillary pressure in the suction cup and in the soil are equal (Grossmann and Udluft, 1991).

For assessment of surface run-off to represent the movement of phosphorus a "weir" system has been established. This will allow for surface flow collection, recording and accommodate sampling for phosphorus estimation in the lab. Once nitrate and phosphorus estimations have been made it will then be possible to model the flow of these nutrient through the soil and relate their use to polluting potential.

Results and Discussion

The component of this study based on "The Quality of Drinking Water in Ireland" has been presented as the water chain traceability map, identifying the individual steps in the production/supply chain of potable water to the consumer. For example, once the water leaves its source and is delivered to the water treatment plant it is subject to screening through wire mesh sieves to remove large particles. Chemical treatment commences to remove any micro particles and final stage filtration begins. Post filtration and removal of impurities; disinfection, pH correction and addition of fluoride are carried out, as the final stages in the production of potable water.

It becomes apparent from the construction of this map that the water supply network is vulnerable to contamination from a number of sources, whether as a result of direct discharge of pollutants into the water source or a discrepancy in the water treatment process.

The water chain map is complemented by the database of contaminants which identifies the likely entry of contaminants, their movement along this chain and consequence in a drinking water supply. With e-coli, for example, it is present in human and animal gut flora and is detected in the aquatic environment in the presence of faecal contamination and thus, becomes an indicator of faecal pollution. Its most likely entry to the water chain is from a contaminated water source. However, adequate treatment upon detection and source protection can greatly reduce the incidence of e.coli in drinking water, the consequence of which can be harmful to human health. These two components are further balanced with the established land based trials assessing the impact of fertiliser usage in Irish agriculture on drinking water quality and reviewing the risk that poor farming practices in relation to this fertiliser use may pose to drink water quality and thus, human health.

Conclusions

Drinking water by its very nature and properties is subject to contamination from a wide range of sources and by numerous methods. It is widely recognised that an unclean water supply is detrimental to human health on a global scale. Among these sources of water pollution stands agriculture, particularly where slight/moderate damage is concerned. Therefore, this source needs to be tackled if agriculture is to play its part in reducing pollution of surface and ground waters, through further development of codes of good practice in relation to water quality.

References

Brady, N.C. and Weil, R.R., 2002. The Nature and Properties of Soils, 13th Ed,. Prentice Hall, New Jersey, USA.

EPA 2007. Water Quality in Ireland, 2006- Key indicators of the Aquatic Environment.
Environmental Protection Agency. Johnstown Castle Estate, Co. Wexford, Ireland.

Grossmann, J., and Udluft., 1991. The extraction of soil water by suction-cup method: a review. *Journal of Soil Science*, 1991, 42, 83-93.

Johnson, P.A., Shepherd, M.A., Hatley, D.J and Smith, P.N., 2002. Nitrate leaching from shallow limestone soil growing a five course combinable crop rotation: the effects of crop husbandry and nitrogen fertiliser rate on losses from the second complete rotation. *Soil Use and Management*, 18, 68-76.

Leifer, C and Golden, M.H., 2000. A re-evaluation of the beneficial and other effects of dietary nitrate. The international Fertiliser Society Proceedings 456, pp 22.

Ryan, T.D. 2000. The identification of sites and farming systems prone to pollution by surface run-off. Crops Research Centre, Oakpark, Carlow.

Tarver, T. 2008. "Just Add Water": Regulating and Protecting the Most Common Ingredient. Journal of Food Science Vol. 73, Nr. 1, 2008, pp 1-13.

A laboratory study of pesticide adsorption/desorption processes in five Irish soils

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Abstract

Adsorption and desorption (hence called sorption) processes are the crucial phenomena determining the behaviour of organic chemicals in the soil environment. Sorption mechanisms are described by solid – liquid distribution coefficients empirically measured in the batch equilibrium method.

Introduction

Pesticide behaviour in soils greatly depends on adsorption/desorption phenomena (de Jonge and de Jonge, 1999) and knowledge of these processes is important to predict their mobility in soil. Adsorption process may vary from complete reversibility to total irreversibility (Gevao *et al*., 2000) and the reversibility of the adsorption reaction plays a significant role in determining the mobility of any pesticide in the soil profile (Singh *et al.*, 1989, Celis and Koskinen, 1999). Some workers also reported the presence of hysteresis in the adsorption/desorption reactions of pesticides in soil (van Genuchten *et al*., 1974; Gao *et al*., 1998a). Hysteresis suggests that sorption of pesticides occurs with a limited degree of reversibility depending upon the physico-chemical properties of the molecules and the soils involved (Gao *et al*., 1998a, b) Generally, sorption of unpolar pesticides is mainly due to hydrophobic interactions with organic soil substances whereas sorption of polar chemicals is influenced by the pH value of soil, because the pH value determines the degree of dissociation (Richter, 1996).

Since the amount of adsorbed solute is difficult to measure directly, the extent of adsorption is usually determined indirectly by measuring the change in solution concentration after an adequate equilibration period (Green and Yamane, 1970). In equilibrium, the empirical relationship between the amount adsorbed at constant temperature and the concentration of the solute in solution is usually called the adsorption isotherm (Hance, 1988) indicating a near-linear relationship between amounts adsorbed and concentrations in residual solution (Hartley, 1976) but for many pesticides, the isotherm is nonlinear (Richter, 1996). The earliest empirical equation used to describe equilibria data is the Freundlich isotherm (1932). **The objective of this study is to quantify adsorption and desorption isotherms of pesticide active substances commonly used in Ireland to provide data on pesticides mobility in soils and predict their possible risk of leaching to groundwater.**

Materials and Methods

Soils

The experiment is being carrying out with five major Irish soils types: Oakpark, Castlecomer (Co. Carlow); Rathangan, Clonroche (Co. Wexford) and Elton (Co. Limerick). Tillage and grassland sites were sampled with a soil auger. 5 subsamples per site were removed from 0-15 cm and 15-30 cm depth to plastic bags and transported to laboratory. Each subsample was air dried, sieved to <2mm and then composited for each site and depth. Three stainless steel cores were also removed from each site and depth to determine the soil bulk density. Soil bulk density analyses were undertaken immediately. Samples were oven dried at 105 ºC for 24 hours, while composite samples were being subjected to analysis for parameters thought to be largely responsible for adsorptive capacity: pH (in H_2O and $CaCl_2$), soil texture, soil organic carbon and CEC.

Pesticides

Four of the most common pesticide active ingredients were selected for this study: MCPP-p, MCPA, glyphosate and chlorothalonil (Department of Agriculture and Food, 2006 and 2007). Chemical structures, names and properties are presented in Table 1.

Adsorption/desorption batch equilibrium method principles

The study is being undertaken according to the adsorption/desorption batch equilibrium method (OECD, 2000). In this method, a known volume of solution of the tested pesticide (at least 95% purity grade) at known concentrations in 0.01 M $CaCl_2$ is added to the soil samples of known dry weight (2 g) which have been equilibrated in 0.01 M $CaCl_2$. $CaCl_2$ solution is used to give better phase separation and to keep ionic strength similar to that of a natural soil solution before the addition of the pesticide (Thorstensen *et al*., 2001). The mixture is agitated for an appropriate time established in preliminary experiments. The soil suspensions are then separated by centrifugation. The distribution of the chemical between the water phase and the solid phase is quantitatively measured by a suitable analytical method. The amount of tested pesticide adsorbed on the soil is calculated as the difference between the amount of tested pesticide initially present in the solution and the amount remaining at the end of the experiment (indirect method). Sorption constants are calculated using the Freundlich isotherm. Desorption is measured immediately after adsorption to prevent further degradation (Boivin et al., 2005). The supernatant removed in the adsorption experiment is replaced by an equivalent volume of herbicide free 0.01 M $CaCl_2$ solution.

The adsorption/desorption batch equilibrium method comprises 3 tiers:

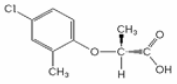
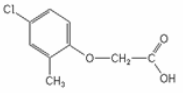
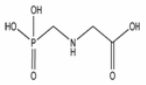
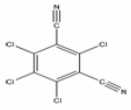
Tier 1: Preliminary study to determine:

- the soil/solution ratio;
- the equilibration time for adsorption and the amount of the test substance adsorbed at equilibrium;
- the adsorption of the test substance on the surface of the test vessels and the stability of the test substance during the test period

Tier 2: Screening test:

- adsorption is studied in different soils by means of adsorption kinetics at a single concentration;
- determination of distribution coefficients

Table 1 Pesticides selected for the study

Pesticide name: IUPAC and CAS [No]	Formula	pKa	Koc (ml/g)	Solubility in water (g/l)
(R)-2-(4-chloro-o-tolyloxy) - propionic acid (R)-2-(4-chloro-2-methylphenoxy)-propanoic acid [16484-77-8] **Mecoprop – p (MCPP-p)**		3.78 (20°C)	12-25	860 (pH 7, 20°C)
4-chloro-o-tolyoxyacetic acid 4-chloro-2-methylphenoxy) acetic acid [94-74-6] **MCPA**		3.07	10	734 (25°C)
N-(phosphonomethyl)-glycin Glycin, N-(phosphonomethyl)- [1071-83-6] **Glyphosate (Glyph)**		pK_1 2.27 pK_2 5.57 pK_3 10.86	300- 20, 100	1.57 wt% in water at 25°C
Tetrachloroisophthalonitrile 2, 4, 5, 6-Tetrachloro-1, 3-benzenedicarbonitrile [1897-45-6] **Chlorothalonil**		-----	1600 (sand) to 14000 (silt)	810 (25°C)

Tier 3: Final test

- determination of Freundlich adsorption isotherms at different concentrations;
- study of desorption by means of desorption kinetics/ Freundlich desorption isotherm

Freundlich isotherm
Pesticide sorption isotherms are calculated using the Freundlich equation:

$x/m = K_{fa} Ce^{1/n}$ Equation 1

where x/m is the amount of pesticide sorbed on the soil (mg/kg of soil), calculated from the concentration difference between the initial pesticide solution and the corresponding centrifuged supernatant after equilibrium; Ce is the pesticide concentration in the supernatant solution (mg/L); K_{fa} and n are empirical adsorption coefficients. Desorption isotherms are calculated using Equation 1 where K_{fd} and n are desorption coefficients.

Distribution coefficients Kd (L/kg) are calculated from linearization of the sorption isotherms:

$Kd = (x/m) / Ce$ Equation 2

If the Freundlich adsorption or desorption exponent 1/n is equal to 1, the Freundlich adsorption or desorption binding constant will be equal to the adsorption or desorption equilibrium constant (Kd) respectively, and plots x/m versus Ce will be linear. If the exponents are not equal to 1, plots x/m versus Ce will be nonlinear and the adsorption and desorption constants will vary along isotherms.

An organic carbon normalized coefficient (Koc) is calculated as:

$Koc = Kd * (100 / \%OC)$ Equation 3

Koc values are used in different models to predict pesticide behaviour in the environment.

Instruments and analytical methods
Analytical separation method of supernatants should be highly sensitive to measure small changes in the solution concentration during the test and thus Gas Chromatography equipped with Electron Capture Detector has been selected for this study. Analytes are being separated by a Zebron Multi-Residue capillary column: 30m x 0.32mm x 0.25µm (Phenomenex), helium is the carrier gas and nitrogen is the make up gas. The MCPP-p and MCPA instrument programme is: oven at 50ºC for 0.5 min to 100 ºC at 25 ºC/min to 200 ºC at 22 ºC/min for 2 min to 320 ºC at 17 ºC/min with the flow rate 3 ml/min. Injection mode is splitless (1µl) at 250 ºC and ECD oven is at 335 ºC. Samples for MCPP-p and MCPA need to be derivatized prior to injection to GC either with pentafluorobenzyl – bromide or diazomethane. The instrument programme for chlorothalonil is: oven profile: 120 ºC for 0.5 min to 210 ºC at 30 ºC/min to 300 ºC at 6 ºC/min for 2 min with the flow rate 1.2 ml/min; injection is splitless (1 µl) at 123 ºC and ECD oven is at 340 ºC. A method for glyphosate is being developed at present.

Results and Discussion

As distribution coefficients (Kd) are depended on physico - chemical properties of the test substance and the soil involved, it is hard to predict the values. In general, high values of Kd (of the order of 100 or more) indicate that a pesticide is strongly adsorbed by soil (Wauchope *et al*., 2002) and is likely to be more persistent, because it is protected from chemical or biological degradation and volatilization by the binding (Hornsby *et al*., 1996).

Conclusions

This study will quantify adsorption and desorption isotherms of four commonly used pesticides in Ireland. The data will be used to predict pesticide mobility in major Irish soils and hence their possible leaching into groundwaters

Acknowledgements

This project is funded by Department of Agriculture, Fisheries and Food, Research Stimulus Fund 2008, *Assessment of the vulnerability of groundwater to pesticides inputs from Irish agriculture.* RSF 07-554.

References

Celis R. and Koskinen W.C. 1999. An Isotopic Exchange Method for the Characterization of the Irreversibility of Pesticide Sorption-Desorption in Soil. Journal of Agriculture and Food Chemistry, **47**:782 – 790.

de Jonge H. and de Jonge L.W. 1999. Influence of pH and solution composition on the sorption of glyphosate and prochloraz to a sandy loam soil. Chemosphere **39** (5): 753 – 163.

Gao J.P., Mguhn J., Spitzauer J. and Kettrup A. 1998 a. Sorption of pesticides in the sediments of the Teufelsweiher pond (Southern Germany). I. Equilibrium assessment, effect of organic carbon content and pH. Water Research, **32** (5): 1662 – 1672.

Gao J.P., Mguhn J., Spitzauer J. and Kettrup A. 1998 b. Sorption of pesticides in the sediments of the Teufelsweiher pond (Southern Germany). II. Competitive adsorption, desorption of aged residues and effect of dissolved organic carbon. Water Research, **32** (7): 2089 – 2094.

van Genuchten M.Th., Davidson J.M. and Wierenga P.J. 1974. An evaluation of Kinetic and Equilibrium Equations for the Prediction of Pesticide Movement Through Porous Media. Soil Science Society of America J., **38**: 29 – 35.

Gevao B., Semple K.T. and Jones K.C. 2000. Bound pesticides in soil: a review. Environmental Pollution, **108**: 3 – 14.

Green R.E and Yamane V.K. 1970. Precision in Pesticide Adsorption measurements. Soil Science Society of America Proceedings, **34** (2): 353 – 355.

Hance R.J. 1988. Adsorption and Bioavailability. In: Environmental Chemistry of Herbicides. Vol. 1. Grover R. (Ed.) CRC Press, Florida.

Hartley G.S. 1976. Physical behaviour in the soil. In: Herbicides Physiology, Biochemistry, Ecology. Vol. 2. Audus L.J. (Ed.) 2nd Edition, Academic Press, London, UK.

Hornsby A.G., R.D. Wauchope. 1996. Pesticide Properties in the Environment. Springer Publishers, New York, 1996.

OECD, 2000. OECD Guidelines for the Testing of Chemicals. Adsorption/desorption using a batch equilibrium method. OECD Test Guideline, vol. 106. OECD Publications, Paris.

Pesticide Usage Survey, Report Number 1, Grassland and Fodder Crops. 2006. Department of Agriculture and Food, Ireland.

Pesticide Usage Survey, Report Number 2, Arable Crops. 2007. Department of Agriculture and Food, Ireland.

Richter O., Diekkrüger B. and Nörtersheuser P. 1996. Environmental Fate Modelling of Pesticides. From the Laboratory to the Field Scale. VCH, Weinheim, 1996.

Singh R., Gerritse R.G. and Aylmore L.A.G. 1989. Adsorption – Desorption Behaviour of Selected Pesticides in some Western Australian Soils. Australian Journal of Soil Research, **28**: 227 – 243.

Wauchope R.D., Yeh S., Linders J.B.H.J., Kloskowski R., Tanaka K., Rubin B., Katayama A., Kördel W., Gerstl Z., Lane M. and Unsworth J.B. 2002. Review. Pesticide soil sorption parameters: theory, measurements, uses, limitations and reliability. Pest management Science, **58**: 419 - 445.

Appendix 1

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

Lancaster J and N M Holden. Development of a climatic driven water balance model to predict slurry run-off (**PhD**) Johnstown Castle Research Centre, (Teagasc), Wexford/Met Eireann, Dublin

McDonald S, N M Holden and T Murphy. Detection methods for Cryptosporidium Spp. in environmental samples (**PhD**) Irish Environmental Protection Agency

O'Flynn M and K McDonnell. The influence of front axle load on compacion of a recently cultivated soil (**PhD**) Teasasc.

Kennedy R and E Cummins Development of a quantitative risk assessment with particular reference to Cryptosporidium and water treatment for public drinking water supplies in Ireland (MEngSc1) Irish Environmental Protection Agency

O'Connell J and N Holden. Assessment and monitoring of vegetation disturbance on peatlands (**PhD**) Irish Environmental Protection Agency.

Herbin T and N Holden. Effects of dairy technology management on soil structure and nitrogen content (**PhD**) Irish Environmental Protection Agency

Glynn E and McDonnell Kevin. Impacts of Alternative land uses for energy crops (**MSc**) Sustainable energy Ireland

Norton T, J Grant, R Fallon and D W Sun. Towards the ultimate calf house: Designing with computational fluid dynamics (**PhD**) Teagasc Horticulture and Forestry Research Centre, Kinsealy, Dublin/Teagasc Research Centre, Grange Co. Meath

Bergin D, U G Barron and F Butler. A meta analysis of the effect of chilling on prevalenvce of salmonella spp on pig carcasses (PhD) SafeFood, The food Safety Promotion Board/Food Institutional Research Measure (FIRM)

Schvartzman M S, F Butlker and K Jordan Microbial Modelling of food systems (PhD) Walsh Fellowship, Teagasc/Moorepark Research Centre, Fermoy

Drummond L and D W Sun Simplified mathematical model for the vacuum cooling of water (PhD) Food Institutional Research Maesure/Irish Department of Agriculture, Fisheries and Food

Appendix 2

(Profiles of Postdoctoral Research Scholars only includes Dr Ayalew, Mr. Bowen, Drs Connolly, Delgado, Devlin, Fagan, Gowan, Mendoza, Pacquit, Tansey, Zhang).

Gashaw Ayalew, B.Sc., M.Eng.Sc., PhD, MIEI

Project Title: Sigma Chain
Project Leader: Professor Shane M. Ward

Abstract

Printed graphic identifier (PGI) and RFID systems are the two most important tracking technologies. Current trends in PGI are concentrated in the increase of data capacity and density by way of miniaturization. In that regard, GS1 DataBar and Composite Symbol families are the most important, the former being applied in the traceability of fresh food. With regards to RFID, developments include reduction of production cost, embedded RFID, RFID sensors, peer-to-peer RFID, and mobile RFID networks. These developments have the potential to enhance the traceability of fresh and processed food significantly.

Background, Skills and Qualifications

I obtained my B.Sc. in Agricultural Engineering from Alemaya University of Agriculture, Ethiopia, in 1987, my M.Eng. Sc. From the Department of Agricultural and Food Engineering, UCD in 1992, and my PhD in 2005. Between 1992 and 1999, I lectured at the Department of Agricultural Engineering, Alemaya University and the Department of Agricultural Engineering and Mechanisation, then Awassa College of Agriculture (for the last 3 years leading up to 1999). During my stay, at Alemaya,I was involved in additional curricular and administrative tasks. Since completing my PhD studies, I have been working as a Postdoctoral Researcher, at which position, I participate, with varying levels of involvement, in the BioTrack, Avian BioTrack, and Sigma-Chain Projects; and postgraduate supervision. My specific experiences include near infrared, X-ray and microwave biomaterial characterization; physical and biological sensors; instrumentation circuits; shape characterisation & measurement; Monte Carlo simulation; electronic tracking (using ID data carriers such as barcodes and RFID) & tracing; and computation.

Recent publications

Ayalew, G., N. M. Holden, Ward, S.M., 2009. Ranking of risk of injury from glass contaminants using Fourier shape measures of fragment outlines. *Biosystems Engineering.* 102(3):265–273.

McCarthy, U., G. Ayalew, F. Butler, K. McDonnell, Ward, S., 2009. The effects of item composition, tag inlay design, reader antenna polarisation, power and transponder orientation on the dynamic coupling efficiency of backscatter UHF RFID. *Packaging Technology and Science*. In press. doi:10.1002/pts.849.

Shanahan, C., B. Kernan, G. Ayalew, K. McDonnell, F. Butler, Ward, S., 2009. A framework for beef traceability from farm to slaughter using global standards: An Irish perspective. *Computers and Electronics in Agriculture*, 66:62–69.

Ayalew, G., N. Holden, Ward, S., 2008. Identification of high-injury-risk glass contaminants using simple shape measures of fragment outlines. *Biosystems Engineering*, 101:145–151.

Ayalew, G., Holden, N., Grace, P., Ward, S., 2008. Evaluation of the detection of glass contamination in horticultural peat and compost using microwave reflection by Monte Carlo simulation. *Biosystems Engineering,* 99: 9–21.

Barry Bowen, M.Agr.Sc (Researcher)

Project Title: On farm combustion and energy recovery from poultry litter

Project Leader: Dr. Kevin McDonnell

Abstract:
Current poultry litter management practices are seen as unsustainable and alternative solutions are required. This project is addressing some outstanding regulatory and technical issues required to overcome problems encountered by waste management problems through the combustion of poultry litter. The project will determine the litter fuel quality and optimise combustion through the monitoring of flue gas emissions including potential for dioxin formation. This will facilitate establishment of best practices to meet the regulatory requirements of Integrated Pollution Control (IPC) licensing. The project will optimize the thermal efficiency and reduce maintenance requirements by matching heat exchanger output with heat load and through the use of buffer tanks. The monitoring of flue gas emissions including dioxin, building a dispersion model based on local topography and meteorology which will be included in an environmental impact study to assist compliance national IPC regulations. Funded by the Department of Agriculture, Fisheries and Food, this project is been carried out in conjunction with University of Limerick (UL). UCD's responsibilities for this project are focused on the development of a dispersion model to predict pollutants, risk assessment of storage and management practices and the assessment of health and welfare for the birds and local environment.

Background, skills and Qualifications:
My thesis examined the crucial areas that were involved in the installation of a 1MW biomass boiler in UCD. Through monitoring the plans revolving around the installation of the boiler a computer program was designed and produced to aid decision making for similar projects. The computer program also doubled up as a decision support system for domestic users examining the possibility of converting to indirect heating applications.

Through my involvement in the Bioresources Research Centre (BRC), I am also editor of the BRC Energy and Commodities Bulletin and also update the BRC website regularly.

Recent Research:
Bowen, B., McDonnell, K.P, (2008) *Design and Development of an Energy Supply Chain as a Support System for the Installation of a Biomass heating System* – Thesis

Bowen, B., McDonnell, K.P, (2009*) Decision support aid designed to inform homeowners how to benefit from the installation of a domestic biomass boiler*- Awaiting publication

Lynch, D., Bowen, B., McDonnell, K.P (2009) *Code of practice for the welfare of broiler chickens heated by biomass* – Awaiting publication

John Connolly, BA, M.Sc., Ph.D.

Project Title: Identification, mapping assessment and quantification of the effects disturbance on the peat soil C stock in Ireland

Project Leaders: Dr. John Connolly and Prof. Nicholas Holden

Abstract

Peatlands in Ireland contain between 53 % and 62 % of the national soil carbon (C) stock. Many peatlands throughout the country have been and are currently disturbed. Peatland disturbance impacts on the resource's ability to sequester C. It is essential that disturbance of peatlands be examined and quantified in order to manage this critical C resource. This project will use high resolution satellite imagery along with ground based indicators to develop a method to quantify the effect of disturbance and climate change on peatland C stock. This research will enable policymakers to identify critical peatland areas requiring management intervention.

Background, Skills & Qualifications

In 2000, I completed my B.A. (International) in Geography at University College Dublin. From 2000 to 2001, I received a part scholarship from the Department of Geography at the University of Sheffield to do a M.Sc. in Environmental Monitoring and Assessment in Drylands. In 2002, I started a PhD. with Prof. Shane Ward and Prof. Nicholas Holden in Biosystems Engineering. In 2007, I completed this PhD. titled: A Biogeographical Study of Peatlands using Geographical Information Systems and Remote Sensing. I worked, for two years, as a postdoctoral researcher on the Bogland project. I am currently working on the above project.

Recent publications and Manuscripts

Holden, N. M. and **Connolly, J**. (Under Review). A model to estimate depth of blanket peat (Accepted to: Soil Science Society of America Journal

Connolly, J., Roulet, N. T., Seaquist, J. W., Holden, N. M., Lafleur, P. M., Humphreys, E. R., Heumann, B. W., and Ward, S. M. (2009) Using MODIS derived fPAR with ground based flux tower measurements to derive the light use efficiency for two Canadian peatlands, Biogeosciences

Connolly, J., Holden, N. M. and Ward, S. M. (2007). Mapping peatlands in Ireland using a rule-based methodology and digital data. Soil Science Society of America Journal, 71:492-499.

Connolly, J. and Holden, N. M. Mapping peatland in Ireland; updating the Derived Irish Peat Map. (Manuscript to be submitted to: Soil Science Society of America Journal as a technical note)

Connolly, J., Holden, N. M., Seaquist, J. W., Roulet, N., and Ward, S. Detecting disturbance on montane blanket bogs in the Wicklow Mountains using the MODIS Enhanced Vegetation Index. (Manuscript to be submitted International journal of Remote Sensing)

Adriana Delgado, Eng., M.Sc., PhD

Project Title: Minicrystal – Method for improving the quality of frozen foods by assisting the freezing process and reducing the size of the ice crystals.

Project Leader: Professor Da-Wen Sun

Abstract

The use of power ultrasound within the food industry is an innovative subject. Application of sound to monitor a process or product is common (e.g. quality assurance). However, the use of ultrasound to directly improve processes and products is less popular in food manufacturing. This project will design and develop a prototype high power ultrasound system for industrial validation in food freezing facilities. It will be cost-effective, easy to operate and easily integrated with commercially available freezing equipment.

Background, Skills & Qualifications

After obtaining a degree in Food Engineer I was working in the Institute of Technological Development for the Chemical Industry (INTEC, Santa Fe, Argentina), from 1986 to 1998 under the supervision of Dr. Amelia Rubiolo. From 1988 to 1989 I took a 9 month duration course in Viterbo (Italy) entitled Economy of Agricultural and Food Systems, and joined INTEC later, after completion of this course. When working in INTEC I was involved in projects related to the preservation of fruits and vegetables by freezing, I took part as lecturer in undergraduate and postgraduate courses (e.g. Transport phenomena in food engineering, Food processing equipments, Food preservation, etc.) and obtained a Master in Food Technology in 1997. In 1999 I came to Ireland to pursue doctoral studies. From 2002 to 2004 I was working as a research officer in a joint project between the Ashtown Food Research Centre and UCD related to the use of chilling in HACCP systems for beef. In 2005 I completed the PhD degree in Biosystems Engineering Department, UCD, with the thesis "Mathematical Modelling and Experimental Studies of Freezing and Thawing Processes and Sorption Isotherms of Cooked Cured Pork and Beef. From 2005 to present I was working as a postdoctoral researcher in UCD.

Recent Publications

Delgado, A.E. and Sun, D.-W. (2008) Ultrasound-Assisted Freezing. In Feng, H.F.; Weiss, J. and Barbosa-Cánovas, G. (eds.), *Ultrasound Technologies for Food and Bioprocessing*. New York, USA: Springer (in press).

Zheng, L.; **Delgado**, A.E. and Sun, D.-W. (2008) Surface Heat Transfer Coefficients with and without Phase Change. In Rahman, S., (ed), *Food Properties Handbook, 2nd Edition.* Boca Raton, FL, USA: CRC Press, Inc. (in press).

Norton, T.; **Delgado**, A.; Hogan, E.; Grace, P. and Sun, D.-W. (2009). Simulation of high pressure freezing processes by enthalpy method. *Journal of Food Engineering,* 91 (2), 260–268.

Delgado, A.E.; Zheng, L. and Sun, D.-W. (2008) Influence of Ultrasound on Freezing Rate of Immersion-frozen Apples. *Food and Bioprocess Technology: an International Journal, DOI 10.1007/s11947-008-0111-9*.

Dr. Ger J Devlin, BSc., PhD.

Project Title: GPS Tracking and Loadsensor development for increased telemetry and communications in transport and logistics.

Project Leader: Dr. Kevin McDonnell

Abstract

Vehicle tracking technology and associated software reporting and monitoring facilities are readily available for use in the timber haulage sector. Such systems have the potential to improve efficiencies and control of truck movement. As in other sectors, the provision of timely information provides timber hauliers with vital information, which allows them to remain competitive in an increasingly changing work environment.

Background, Qualifications and Skills

Obtained primary BSc. in Applied Physics from Dublin City University in 2001. In 2007 was awarded my PhD degree from the Department of Biosystems Engineering, UCD. The project to date addresses the issues of incorporating technology advancements into the haulage sector for increased efficiency in terms of revenue per km VS cost per km. From his recent appointment as Charles Parsons research fellow, Dr Devlin's other research interests also include the monitoring and modelling of exhaust emissions from articulated trucks together with engine, driver and fuel performance within the area of increased GHG emissions in the transport sector in Ireland. The core area of research involves using GIS and Remote Sensing for Feedstock Energy Mapping and the logistical economic assessments in the supply chain of biomass feedstocks and the carbon footprint of such an optimised logistical haulage sector. Dr. Devlin also teaches the module "Alternative Biofuels and Renewable Energies" in conjunction with Dr. Kevin McDonnell.

Peer-reviewed Publications

Devlin, G. J., K. McDonnell. 2009. TO DEVELOP A ROUTE COSTING MODEL USING GIS, GPS AND SDSS TECHNOLOGY. Book Publication. ISBN 978-3-639-13636-4.

Devlin, G. J., K. McDonnell. 2009. Performance accuracy of real-time GPS asset tracking systems for articulated trucks travelling on both internal forest road network and public road network. International Journal of Forest Engineering. (In Press).

Devlin, G. J., K. McDonnell. 2009. Real time GPS asset tracking – Fuel for thought. Journal of Transport Geography. (In review).

Devlin, G. J., K. McDonnell. 2008. To assess GPS tracking devices and associated software suitable for real time monitoring of timber haulage trucks. Proceedings of Coford Technical Workshop *"Developing cost effective systems for wood procurement, harvesting and transport"* 22nd February 2008.

Devlin, G. J., K. P. McDonnell and S. M. Ward. 2008. Development of a Spatial Decision Support System (SDSS) for route costing calculations within the Irish timber haulage sector. Transactions of the ASABE. 51 (2) 763 – 773

Devlin, G. J., K. P. McDonnell and S. M. Ward. 2007. Timber Haulage in Ireland: An Analysis using GIS and GPS. *Journal of Transport Geography* **16 (1) 63–72.**

Devlin, G. J., K. P. McDonnell and S. M. Ward. 2007. Positional accuracy of Dynamic Non – Differential GPS on an articulated truck travelling across Irish roads. *Journal of Applied Engineering in Agriculture, published by the ASAE* **23 (3): 273-279.**

Devlin, G. J., K. P. McDonnell and S. M. Ward. 2007. Dynamic Non DGPS positional accuracy performance between recreational and professional GPS receivers. *Journal of Location Based Services* **1 (1) 77-85**

Colette Fagan, BSc, MSc(Agr), PhD.

Project Title: Environmental impact assessment of biomass-to-energy systems

Project Leaders: Prof. Shane Ward and Dr. Kevin McDonnell

Abstract
Holistic assessments of energy balances associated with biomass utilisation systems are required which take account of issues such as agricultural production systems and land-use change impacts. Rapid sensing techniques could assist in the reduction and assessment of the environmental impact of biomass-to-energy systems. Conversion of biomass to energy is influenced by the type of feedstock, its physical characteristics and chemical composition. Chemical composition of biomass can influence, for example, the combustion technology used in a given energy conversion pathway. Energy crops and agricultural residues are inherently heterogeneous. Robust analytical methods are therefore required to support/enable and optimize biomass-to-energy conversion processes. The development of rapid sensing technologies for in-field feedstock characterisation, feedstock monitoring during storage and environmental impact assessment of biomass-to-energy systems should increase overall conversion efficiency, reduce environmental impacts and enhance process reliability.

Background, Skills & Qualifications
I graduated in 2002 from the Faculty of Science, UCD with a BSc(Hons) in Industrial Microbiology and in 2003 from the Faculty of Agriculture, UCD with a MSc(Agr) in Engineering Technology. My PhD in Biosystems Engineering, concerning the development of process analytical technology (PAT) tools to improve control of key processing steps in cheese manufacture, was awarded in May 2007 by UCD. It involved the development of PAT tools (infrared, and dielectric spectroscopy, computer vision and image analysis) in conjunction with multivariate data analysis for quality characterization and process control of cheese manufacture. Following my PhD I took up a postdoctoral position in Biosystems Engineering (2006-2008) working on the development of a NIR sensor for control of syneresis during cheese processing. I joined the UCD Bioresources Research Centre in 2008 as a Parsons Research Fellow working in the area of sustainable utilisation of bioresourses, with a particular focus on environmental impact assessment of biomass-to-energy systems.

Peer-reviewed Publications
Spicer, M., **Fagan**, C.C., Ward, S., McDonnell, K. (2009) *Economic assessment of commercial biofuel production in Ireland*. Energy Sources, Part B, In press.

Fagan, C.C., Castillo, M., O'Callaghan, D.J., Payne, F.A. and O'Donnell (2009) *Visible-near infrared spectroscopy sensor for predicting curd and whey composition during cheese processing*. Sens. Instrum. Food Qual. Saf.,, 3, 62-69.

De Marchi, M. **Fagan**, C.C., O'Donnell, C.P., Cecchinato, A., Dal Zotto, R., Cassandro, M. Penasa, M., Bittante, G (2009) *Prediction of coagulation properties, titratable acidity and ph of bovine milk using mid-infrared spectroscopy*, J Dairy Sci, 92,423-432.

Fagan, C.C., Castillo, M., O'Donnell, C.P., O'Callaghan, D.J., Payne, F.A. (2008) *On-line prediction of cheese making indices using backscatter of near infrared light.* Int Dairy J, 18,120-128.

Fagan, C.C., Du, C-J., O'Donnell, C.P., Castillo, M., Everard, C.D., O'Callaghan, D.J., Payne F.A. (2008) *Image texture analysis for predicting curd moisture and whey solids in a laboratory scale stirred cheese vat*. J Food Sci, 73:E250-E258.

Woodcock, T., **Fagan**, C.C., O'Donnell, C.P., Downey, G. (2008) *Application of near and mid-infrared spectroscopy to determine cheese quality and authenticity.* Fd Bioproc Tech,1(2) 117-127.

Fagan, C.C., Castillo, M., Payne, F.A., O'Donnell, C.P., Leedy, M., O'Callaghan, D.J. (2007) *Novel on-line sensor technology for continuous monitoring of milk coagulation and whey separation in cheese making.* J Agr Fd Chem, 55, 8836-844.

Aoife Gowen, BA M.Sc., PhD

Project Title: Hyperspectral imaging system for the non-destructive assessment of mushroom quality and shelf-life prediction

Project Leader: Dr. Colm O'Donnell

Abstract

Hyperspectral imaging (HSI) combines conventional imaging and spectroscopy to simultaneously acquire both spatial and spectral information from an object. This technology has recently emerged as a powerful process analytical tool for rapid, non-contact and non-destructive food analysis. In this study, the potential application of HSI, combined with novel multivariate analysis and image processing techniques, is investigated for damage detection and shelf life prediction of white mushrooms (*Agaricus bisporus*). The aim of this work is the development of a non-destructive shelf life monitoring system to identify sub-standard mushroom batches in the logistic chain.

Background, Qualifications and Skills

I joined UCD in 2007 as a postdoctoral fellow, working on hyperspectral imaging for nondestructive assessment of food quality. My main research interest is the application and development of multivariate analysis and image processing techniques for hyperspectral image data mining. I obtained a PhD from the Dublin Institute of Technology in 2006 for my work concerning the development of quick-cook legumes using innovative processing techniques, such as combined microwave-hot air dehydration. This work included development of nonlinear models to predict the effects of hydration and dehydration processes on legume quality characteristics. Prior to this I worked as a Clinical Imaging Scientist with the Epilepsy department of Beaumont Hospital, Dublin. I was awarded an MSc in Financial Mathematics from Dublin City University (2001) and a BA in Theoretical Physics from Trinity College Dublin (2000).

Recent Publications

- **Gowen, A., Taghizadeh, M., O'Donnell, C.** (2009). Identification of mushrooms subjected to freeze damage using hyperspectral imaging. Journal of Food Engineering, 93, (1), 7-12.
- **Gowen, A., O'Donnell, C., Esquerre, C., Downey, G., Tsenkova, R.** (2009). Water matrix coefficients and absorbance patterns in mushrooms (Agaricus bisporus) subjected to mechanical damage using Hyperspectral Imaging. Journal of Near-Infrared Spectroscopy. *In Press.*
- **Esquerre, C., Gowen, A., O'Donnell, C., Downey, G.** (2009). Initial Studies on the Quantitation of Bruise Damage and Freshness in Mushrooms Using Visible-Near-Infrared Spectroscopy. Journal of Agricultural and Food Chemistry, 57 (5), 1903-1907.
- **Gowen, A., O'Donnell, C., Taghizadeh, M., Gaston, E., O' Gorman, A., Cullen, P.J., Frias, J., Esquerre, C., Downey, G.** (2008). Hyperspectral imaging for the investigation of quality deterioration in sliced mushrooms (Agaricus bisporus) during storage. Sensing and Instrumentation for Food Quality and Evaluation, 2(3), 133-143.
- **Gowen, A., O'Donnell, C., Taghizadeh, M., Cullen, P.J., Downey, G**. (2008). Hyperspectral imaging combined with principal component analysis for surface damage detection on white mushrooms (Agaricus bisporus). Journal of Chemometrics, 22 (3-4), 259 – 267.
- **Gowen, A., Abu-Ghannam, N., Frias, J., Oliveira, J.** (2008) Modeling dehydration and rehydration of cooked soybeans subjected to combined microwave-hot-air drying. Innovative Food Science and Emerging Technologies, 9 (1):129-137.
- **Taghizadeh, M., Gowen, A., O'Donnell, C., Cullen, P.J.** (2008). NIR Chemical Imaging for the Food Industry. Encyclopedia of Agricultural, Food, and Biological Engineering, Taylor and Francis.

Fernando Mendoza Vilcarromero, BSc, Eng, MSc, PhD

Project title: Development of a Novel Non-contact and Rapid Computer Vision System for Quality Evaluation and Control of Pre-sliced Cooked Hams

Project Leader: Professor Da-Wen Sun

Abstract

The production of high quality ham products with an attractive appearance and premium eating quality is an important goal for the meat industry. The digital image of a ham slice contains a large number of image features that can be easily extracted to be read *quantitatively* by a computer; this is analogous to a real ham slice that has quality attributes (such as colour and texture) which can be *qualitatively* perceived by human vision. The main goal of this project is to search and identify the most suitable image features that are linked to the quality attributes of ham, and can be also useful for objective quality control in real time. It considers the implementation of a colour calibrated computer vision system based on the CIE colour standard.

Background, skills & Qualifications

I have graduated from the National Agricultural University (Perú) in the Faculty of Food Engineering (1993). My MSc (1999) and PhD (2005) were carried out in Catholic University in Chile. During my PhD, I developed computer vision systems and image analysis techniques for quality characterization of food surfaces based on pattern recognition methods. The first part of this project was completed in Chile and the second one at Lund University (Sweden). In 2005, I worked as a Postdoctoral researcher in the Postharvest Technology Lab at KU Leuven (Belgium) for two years. In this project I investigated the 3D microstructure of apple tissues using X-ray CT. Currently, I work in Biosystems Engineering, UCD, as a postdoctoral researcher under the guidance of Prof. Da-Wen Sun.

Recent publications

Mendoza, F., Valous, N. A., Sun, D-W, & Allen, P. (2009). *Characterization of fat-connective tissue size distribution in pre-sliced hams using multifractal* analysis. Meat Science, In Press.

Iqbal, A., Valous, N.A., **Mendoza, F.**, Sun, D-W, & Allen, P. (2009). *Image classification of pre-sliced pork and turkey ham qualities based on colour and textural features and their relationships with consumer preferences.* In Press.

Valous, N. A., **Mendoza, F.**, Sun, D-W, & Allen, P. (2009). *Texture appearance characterization of pre-sliced pork ham images using fractal metrics: Fourier analysis dimension and lacunarity*. Food Research International, 42(3):353-362.

Mendoza, F., Valous, N. A., Allen, P., Kenny, T.A, Ward, P., & Sun, D-W. (2009). *Analysis and classification of commercial ham slice images using directional fractal dimension features*. Meat Science, 81(2): 313-320.

Valous, N. A., **Mendoza, F.**, Sun, D-W, & Allen, P. (2009). *Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams*. Meat Science, 81(1): 132-141.

Alexis Pacquit BSc, PhD

Project title: Enhanced traceability of the poultry meat chain using biometrics and e-tracking technology (Avian Biotrack)

Project Leader: Professor Shane Ward

Abstract

Avian influenza, feed contamination and the international trade in poultry poses threats to the Irish poultry industry. The aim of Avian BioTrack is to develop a protocol for assuring the origin and food chain history of poultry. Researchers in UCD have recently shown that the shape of the chicken's comb is a suitable biomarker and can be used to effectively identify batch and individual poultry. In Addition, the team will investigate the use of miniature barcode directly on chicken beak as an additional Track & Trace parameter. Lastly, the project will establish a tamper-proof feed sampling system to tackle feeding poultry contaminated feeds thus closing the loop and ensuring product traceability and integrity of the data and the chain of custody from farm to fork.

Background and skills

I am principally a food chemist with my Ph.D. work focusing specifically on the effect of herbicide dosage and farming practice on crops quality and nutritional status. I established components profiles (protein content and electrophoresis paterns, amino-acids, carbohydrate, minerals, enzymes, etc..) and linked them to the pesticides mode of action. Lastly, their effect on crops detoxification ability was investigated with molecular biology techniques (genomic DNA extraction and amplification by PCR, primer design, sequencing, etc..) in an attempt to link enzymatic detoxification activity to genetic profile.

Peer reviewed journal articles

Pacquit A., K. Crowley and D. Diamond (2008). Use of smart packaging systems for use with fish In *Smart Packaging Technologies for Fast Moving Consumer Goods* (eds Joe P. Kerry & Paul Butler) pp 75-98. Wiley and Sons Ltd. (ISBN 9780470028025)

Pacquit A., Lau K. T., McLaughlin H., Frisby J., Quilty B. and Diamond D. *Development of a volatile amine sensor for the monitoring of fish spoilage*. **Talanta**, 69 (2006), 515.

Pacquit A., Lau K. T., Farrell A., Frisby J., Quilty B. and Diamond D. *Development of a smart packaging for the monitoring of fish freshness*. **Food Chemistry** 102 (2007) 466-470.

A. Pacquit, J. White, R. Pearce, P. Murphy and I. C. Mitchell. *The effects of novel herbicide combination, herbicide dosage, adjuvants and time of herbicide application on the yield and quality of barley*. **Food Chemistry** (to be resubmitted, 2009).

A. Pacquit, M. Febrer, J. White, R. Ryan, J. Murphy, P. Murphy and I. C. Mitchell. Effects of herbicide dosage and farming practice on barley Glutathione S-Transferases: Isolation and characterisation of novel GST gene. **Journal of Plant Physiology** (to be resubmitted, 2009).

Fergal Tansey B.Sc., Ph.D.

Project Title: SigmaChain - developing a stakeholders guide on the vulnerability of food and feed chains to dangerous agents and substances.

Project Leader: Prof. Francis Butler

Abstract

The main objective of the SigmaChain (Σ*Chain*) project (contract no. FP6-518451) is to develop systems that will optimize food chain traceability with respect to minimizing vulnerability to contamination. The SigmaChain website can be accessed at http://www.sigmachain.eu/. The project is based around four case studies: drinking water (rapid contamination chain), milk powder (batch mixing chain), and both poultry meat and farmed salmon (long geographic chains).

Workpackage 1: Development of a conceptual framework to identify and prioritise critical links in the total chain (leader SINTEF Fiskeriog, Havbruk AS, Norway). The contaminant database for the four products, covering microbial/chemical/other (physical/toxins/viruses), was completed.

Workpackage 2: Case studies of four products which are highly vulnerable to contamination (leader Max Rubner-Institut (MRI), Kulmbach, Germany). Chain maps for the four products were completed using Microsoft Visio, each consisting of start/end/main process/process/input/output steps. A review of electronic tracking and tracing systems was completed, covering PGIs, RFID (EPC Class 1, Generation 2) and electronic data interchange.

Workpackage 3: Risk modelling and ranking (leader UCD, Dublin, Ireland). A review of risk assessment models from literature and a report on risk ranking criteria for microbial (Risk Ranger) chemical (ADIs) contaminants were completed. The contaminant database for the four products is complete and risk ranking of selected high risk microbial and chemical contaminants for poultry and milk powder was carried out.

Workpackage 4: Validation of the framework developed in WP1 and development of stakeholders' guide (leader TNO, Netherlands). Virtual (on-line) workshops using the Delphi method were performed and progress is continuing on consumer focus groups to the end of the project. A preliminary draft of the contents of the Stakeholder's Guide was prepared and will be finalized by April 2009.

Workpackage 5: Demonstration (leader Biosystems Engineering Ltd., NovaUCD, Dublin, Ireland). A workshop with legislators was held in Dublin in June 2008 and a risk manager's forum was also held in Dublin in September 2008, with the objective of refining the Stakeholders' Guide for industry use.

Background, Qualifications and Skills

After obtaining a B.Sc. Degree (1989) in industrial microbiology from University College Dublin, I joined Unilever Research, Bedford, England (1989-1997) as assistant research scientist and was involved in one to three-year multi-disciplinary research projects in both the meals and meal components and ice cream groups. These activities produced one peer-reviewed paper and 13 company research and business reports. I then joined Glanbia Meats, Ruskey (1997-2000) as cannery quality assurance manager and was responsible for ensuring the safety, quality and legality of all canned meat and pasteurised meat products. I then joined Ashtown Food Research Centre, Dublin (2001-2004) as research officer and was involved in a three-year FIRM funded project in which I was awarded a Ph.D. Degree (2007) from University College Dublin on 'Effect of freezing on the texture, quality and ultra-structure of *sous vide* ready-meal components.' I am now working with Biosystems Engineering Ltd., NovaUCD, University College Dublin since 2006 and I am currently involved in project management of the above project and I also carry out thermal process validation studies for Irish food companies to BRC and USDA requirements.

Recent Publications

Tansey, F.S., Gormley, T.R. and Butler, F. (2009). The effect of freezing and chilling on selected physico-chemical properties and sensory properties of *sous vide* cooked carrots. *Innovative Food Science and Emerging Technologies.* (submitted)

Tansey, F.S., Gormley, T.R. and Butler, F. (2009). The effect of freezing and chilling on selected physico-chemical properties and sensory properties of *sous vide* cooked cod and salmon. *Innovative Food Science and Emerging Technologies.* (submitted)

Tansey, F.S. and Gormley, T.R. (2005). *Sous vide*/freezing technology for ready-meals. In: *Novel Food Processing Technologies.* Eds. Barbosa-Cánovas, G.V., Tapia, M.S. and Cano, M.P. CRC Press, Boca Raton, Florida, USA, ISBN: 0-82475333-X, pp. 277-290.

Holyoak, C.D., Tansey, F.S. and Cole, M.B. (1993). An alginate bead technique for determining the safety of microwave cooking. *Letters in Applied Microbiology* **16**, 62-65.

Zhihang Zhang, BEng. PhD

Project Title: Use of Power-Ultrasound in the Acceleration of Ice Nucleation and Control of Ice Crystal Distribution during Freezing of Foods.
Project Leader: Professor Da-Wen Sun

Abstract
The use of power ultrasound within the food industry is an innovative subject. Power ultrasound has been proved to be beneficial to crystallization of sugar and antibiotic. Many recent researches also illustrated that power ultrasound can improve food processing, like drying. However, the use of ultrasound to directly improve processes and products is still less popular in food manufacturing. Therefore, the aims of the research project are to understand the acoustic mechanisms in assisting/accelerating food freezing, in particular, the influence of power ultrasound on the ice crystallization process and on the heat and mass transfer process; to identify the efficiency and effectiveness of the application of this technique to various foods products; to determine the effect of various acoustic factors (acoustic power, duration and frequency) on the efficiency of power ultrasound to aid processing; and to develop a mathematical model to describe the freezing process assisted by ultrasound.

Background, Qualifications and Skills
I got my Bachelor degree in Food Engineering in Shanghai fisheries University. My thesis was about ice cream manufacture. After graduation, I did research in School of Light Chemistry and Food Science in South China University of Technology, as a PhD student, for about 4 years. During the period, I was involved in many projects, like date exploitation, sugar manufacture, crystallization of an antibiotic, beer brewing, vinegar soft drink exploitation, and solution of sedimentation in soy sauce. Thereafter, I pursue a doctoral study in UCD. During the study, I carried out an EU project, about vacuum cooling of cooked ready-meal components, like meat (beef, pork and lamb), carbohydrate (rice, pasta and potato), vegetables (broccoli, carrot) and sauces. Between 2005 and 2008, I presented food safety training to food companies in Ireland, on behalf of FSAI. In 2008, I completed the PhD degree in Biosystems Engineering Department, UCD, with the thesis "Experimental and numerical study of vacuum cooling of cooked diced beef and rice". I am currently working as a postdoctoral researcher on the above mentioned project.

Peer-reviewed Publications
Z. Zhang and D.-W. Sun. (2005). Investigation of effects of operation parameters on cooling time *and* weight loss during vacuum cooling of cooked rice and cooked diced beef in tray. *Acta Horticulturae*, 674, 505-509.

Z. Zhang and D.-W. Sun. (2005). Modelling of three-dimensional heat and mass transfer during vacuum cooling of cooked diced beefs. *Acta Horticulturae*, 674, 199-204.

Z. Zhang and D.-W. Sun. (2005). Modelling of two-dimensional heat and mass transfer during vacuum cooling of cooked rice in tray. *Acta Horticulturae*, 674, 495-503.

Z. Zhang and D.-W. Sun. (2006). Effects of cooling methods on the cooling efficiency and quality of cooked rice. *Journal of Food Engineering*, 77 (2), 269-274.

Z. Zhang and D.-W. Sun. (2006). Effect of cooling methods on the cooling efficiencies and qualities of cooked broccoli and carrot slices. *Journal of Food Engineering*, 77 (2), 320-326.