An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

13F508 - Novel spectral and spatial process analytical tools for meat quality and safety assessment

Final Report

This project was funded under the Department of Agriculture, Food and the Marine Competitive Funding Programme.

SUMMARY

The main of objective of the project was to assess the ability of two branches of spectroscopy to monitor beef quality attributes including major beef constituents (ash, moisture, protein and fat) as well as aroma, flavour and texture. The project involved testing novel near infrared (NIR) and guided microwave devices (GMS) as potential at/in-line for the beef industry. The project results show that these devices can predict ash, moisture, protein and fat well. The prediction of beef characteristics such as aroma and flavour were poor however NIR shown some ability to predict tenderness. NIR scanning procedures could be implemented for on-line use after the mixing procedure of ground beef production. The NIR systems can also supply sample images to assist and speed up on-line monitoring. GMS system can be mounted on to a grinder in a processing line, therefore it can monitor the line consistently and penetrate through a bulky material without requiring homogenisation of the material and other maintenances. Overall, the project shows the viability of both methods as potential at/in-line tools for the meat industry.

KEYWORDS

Meat; Quality; Spectroscopy.

ACRONYM	MeatSense
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Section 1 - Research Approach & Result

Start Date

01 December 2013

End Date

31 October 2018

Research Programme

Food Institutional Research Measure

TRL Scale

TRL 4: Technology validated in lab

NRPE Priority area

Sustainable Food Production and Processing

Total DAFM Award

€451,495.00

Total Project Expenditure

€432,530.44

Rationale for undertaking the Research

Global demand for food is expected to increase by 50% by 2030 and to double by 2050, due to population growth, urbanisation and increasing affluence in parts of the developing world (FAO, 2008). The world's population is projected to increase from 6 billion to 9 billion by 2050. A key objective the Joint Programming Initiative on Agriculture, Food Security and Climate Change is the need for methodologies for secure safe, nutritious and affordable food for the future. Increasing productivity and resource efficiency, and understanding and promoting sustainable consumption, will help to reduce environmental footprints of food and improve competitiveness. With regard to beef, Food Harvest 2020 specifically highlights the challenges in the beef sector and asks for "New smart approaches throughout the supply chain to deliver enhanced efficiencies and improved product quality, leading directly to growth in output value". In 2012, Ireland exported an estimated 454,000 tonnes of beef worth approximately €1.9 billion. Having previously been sold primarily in third country commodity markets, Irish exporters are now in a position where 99% of beef is exported within the EU (Food Harvest 2020). Given the importance of this sector to the Irish economy it is critical that effective quality assurance methodologies are in place to ensure consumer confidence in Ireland's meat supply both locally and internationally. The project directly addresses process efficiency and improved product quality by exploring the use of novel devices based on near infrared and guided microwave technology.

Methodology

The proposal brings together expertise in spectral imaging technology, real-time image processing, chemometrics, meat science, sensory analysis and culinary arts to develop and validate novel quality mapping solutions for the meat industry. This expertise will facilitate prediction of meat quality (as assessed by instrumental and sensory means) from on-line real-time measurements. By bringing in culinary arts expertise the project aims to extend the research beyond any previous spectral correlations by providing cooked sensory analysis. Before the use of near

infrared and guided microwave devices to predict various beef quality attributes standard reference methods were used to obtain these quality attributes then these figures were used to measure the perform of these new novel devices. Standard methods of the AOAC (200) were used for determining beef attributes such as moisture content(method 950.46), fat (method 960.39) , ash (method 923.03) and protein via subtraction as beef contains zero carbohydrates. Experiments were repeated (triplicates) to ensure reproducibility of results (batch-to-batch variability). The Warner Bratzler shear force was used as reference method with regard to texture(tenderness). With regard to consumer testing once ethical and safety approval was obtained a hundred consumers participated. The consumers judged parameters such as aroma, flavour and texture of the beef products. The three different temperatures for cooking were 49, 65 and 72 ºC to recreate the rare, medium and well done cook levels.

Project Results

The novel near infrared and guided microwave devices demonstrated their ability to accurate predict various beef attributes (moisture, protein, fat, ash) under static or motion conditions hence these devices could be used at/in-line. Due to the non-contact nature of the NIR devices they are suitable for on-line inspection of various beef productions such as minced beef or whole cuts (e.g. steaks). On the other hand, the GMS system could be mounted on to a grinder in a processing line, monitoring the product (moisture, protein, fat, and ash) via penetration of the bulk material pass by the dielectric barriers. Prediction of consumer attributes such as aroma, flavour and texture is a more challenging issue. However, near infra spectroscopy provided some indication of meat tenderness.

Section 2 - Research Outputs

Summary of Project Findings

Food companies have traditionally focused innovation on products and less on processing. The adoption of Process Analytical Technology (PAT) tools is a major opportunity for the meat industry to boost the competitiveness of its processing industries and gain added value in the global market. PAT is a framework for innovative process manufacturing and quality assurance through timely measurements (i.e., in-line monitoring) of critical quality attributes. Smart sensing solutions can not only provide real-time quality assurance but also provide “big data” which facilitates increased product traceability as product batches can be referenced to their processing history. The novel near infrared and guided microwave systems presented in this work provide the ability to monitor in-real quality attributes of beef. These systems as part of a PAT framework work will provide greater customer assurance and less recalls due to a real time monitoring system and greater process understand. Since in theory every beef product produce could have quality data stored associated with it these devices have the potential to alter the current batch testing approaches in the meat industry.

Summary of Staff Outputs

Research Output	Male	Female	Total Number
PhD Students	1	3	4

Summary of Academic Outputs Research

Outputs	Total Number	Details
Publications in Peer Reviewed Scientific Journals	11	The publications occurred in relevant journals such as Meat Science, Journal of Food Engineering and the Journal of near-infra red spectroscopy. These journals would be read by meat sciences and process engineers.
PhD Theses	4	1. "Novel Spectral and Spatial Process Analytical Tools for Meat Quality and Safety Assessment" by Yash Dixit. 2. "Development and validation of hyperspectral imaging process analytical technology tools for food processing application "by Eva Maria Achata Gonzales. 3. "Rapid methods to facilitate sensory quality determination" by Rachel Kelly. 4. "Development of PAT tools using a range of spectral and chemometric approaches for advanced process control and adulteration detection in selected beef and dairy products" by Ming Zhao.

Intellectual Property

None

Potential Impact related to Policy, Practice and Other Impacts

Impact	Details
Industry	These devices show the potential of in-line real-time sensors based on NIR and GMS to become process monitor tools for the meat industry. This continuous monitoring will call it question the current batch test approaches. In theory every simple meat product could be examine and various quality parameters obtained and stored not just proximate estimates of moisture, fat etc but also consumer attributes such as texture. This new approach will alter what data need to be store and lend to better process understand. These vast data sets will provide deep insight into supplier variability as well as seasonality. The process analytical technology (PAT) paradigm present in the pharmaceutical industry with enter the beef industry via these smart sensors.

Dissemination Activities

Activity	Details
Seminars at which results were presented	• Y. Dixit, M. Casado, R. Cama, T. El-Arnaout, F. Jacoby, P. J. Cullen, C. Sullivan. Novel Multipoint Near Infrared Spectroscopy: Overcoming the Limitation of Sample Heterogeneity by Prediction of Minced Beef in Static and Motion Conditions International Congress on Engineering and Food, Quebec City, Canada, June 14-18, 2015. • M. Casado, Y. Dixit, R. Cama, P. J. Cullen, C. Sullivan. Feasibility of Multipoint NIR Spectroscopy to characterise minced beef samples at rapidly changing sample presentation. "30th International Forum and Exhibition Process Analytical Technology, Washington, USA, 24-27 January 2016". • C. O'Donnell Development of process analytical technology(PAT) tools for enhanced quality and safety in food processing (Invited presentation) 18th World Congress of Food Science and Technology - IUFoST2016 , 21-AUG-16 - 25-AUG-16. • B. Panikuttira, M. Zhao, C. O'Donnell Development of PAT tools using guided microwave spectroscopy and chemometrics for meat and dairy processing applications 18th World Congress of Food Science and Technology - IUFoST2016, Dublin, Ireland , 21-AUG-16 - 25-AUG-16. • Y. Dixit, M. P. Casado-Gavalda, R. Cama-Moncunill, X. Cama-Moncunill, Maria Markiewicz Keszycka , T. El Arnaout , P. J. Cullen, & C. Sullivan Detecting Offal adulteration in meat using LIBS I Food Factor Conference, 2-4 November 2016, Barcelona, Spain. • Achata E.M; Kelly R; Esquerre C; Scannell A.G.M; O'Donnell, C.P. The feasibility of hyperspectral imaging to investigate the effect of cold shortening and aging time of beef longissimus dorsi m. samples 46th Annual Food Science and Technology Conference -Teagasc, Dublin. (Dec 06 - 07, 2017). • Achata E.M; Kelly R; Esquerre C; Scannell A.G.M; O'Donnell, C.P. Application of hyperspectral imaging to measure tenderness of beef Longissimus dorsi m. samples American Society of Agricultural and Biological Engineering (ASABE) Annual International Meeting, Detroit, Michigan USA (Jul 29-Aug 01, 2018).

Knowledge Transfer Activities

Identify knowledge outputs generated during this project.	The accuracy of the novel devices based on near infrared and guided microwave technology at predicting beef constituents such as moisture, fat, protein and ash was established. Their ability to predict consumer attributes such as aroma, flavour and texture was also achieved.
Identify any knowledge transfer activities executed within the project.	Over the course of the projects the work was presented both national and international at a range of food and engineering conferences at which both academic and industries attended for example: • Y. Dixit, M. Casado, R. Cama, T. El-Arnaout, F. Jacoby, P. J. Cullen and C. Sullivan. Novel Multipoint Near Infrared Spectroscopy: Overcoming the Limitation of Sample Heterogeneity by Prediction of Minced Beef in Static and Motion Conditions. International Congress on Engineering and Food, Quebec City, Canada, June 14-18, 2015. • M. Casado, Y. Dixit, R. Cama, P. J. Cullen and C. Sullivan. Feasibility of Multipoint NIR Spectroscopy to characterise minced beef samples at rapidly changing sample presentation.30th International Forum and Exhibition Process Analytical Technology, Washington, USA, 24-27 January 2016. • C. O'Donnell. Development of process analytical technology(PAT) tools for enhanced quality and safety in food processing (Invited presentation). 18th World Congress of Food Science and Technology - IUFoST2016 , 21-25 August 2016. • B. Panikuttira, M. Zhao and C. O'Donnell Development of PAT tools using guided microwave spectroscopy and chemometrics for meat and dairy processing applications 18th World Congress of Food Science and Technology - IUFoST2016, Dublin, Ireland , 21-25 August 2016.
List any impacts resulting from the knowledge transferred during the project.	Although this work has shown the potential of these technologies as a quality monitoring tool for the meat industry these technologies have yet to be adopted. This project has not currently leveraged further funding from the meat industry.

Section 3 - Leveraging, Future Strategies & Reference

Leveraging Metrics

None

Future Strategies

The research in this project continues to influence our current and future work with sensors. The skills and knowledge acquired on this project have aid in the exploration of other novel sensors based on laser induced breakdown and Raman spectroscopy. Future papers and seminars involving these new systems will refer to the earlier work involved NIR and GMS systems. It is hope that new projects via the meat Technology Centre set-up around industrial applications will create continued interest in the novel NIR and GMS systems explored in the Meatsense project.

Project Publications

List publications numerically.

1. Y. Dixit, R. Cama, C. Sullivan, L. Alvarez Jubete and A. Ktenioudaki Near infrared hyperspectral image analysis using R. Part 5: Animated visualisation of hyperspectral data using R and ImageJ NIR news, Vol. 25, No 7. November 2014. DOI:10.1255/nirn.1483.
2. Y. Dixit, M. Casado, R. Cama, P.J. Cullen and C Sullivan Near infrared data analysis using R: Live streaming graph generation and processed data visualisation NIR news, Vol. 26, No 5. July 2015. DOI: 10.1255/nirn.1544.
3. Y. Dixit, Maria P. Casado-Gavalda, R. Cama-Moncunill, Maria Markiewicz-Keszycka, P. Cruise, Franklyn Jacoby, P. J. Cullen and Carl Sullivan NIR spectrophotometry with integrated beam splitter as a process analytical technology for meat composition analysis Anal. Methods, 2016, 8, 4134. DOI: 10.1039/c6ay00816j.
4. Y. Dixit, Maria P. Casado-Gavalda, R. Cama-Moncunill, X. Cama-Moncunill, P. Cruise, Franklyn Jacoby, P. J. Cullen and Carl Sullivan Multipoint NIR spectrometry and collimated light for predicting the composition of meat samples with high standoff distances Journal of Food Engineering, Volume 175, April 2016, Pages 58–64. DOI: 10.1016/j.jfoodeng.2015.12.004.
5. Y. Dixit, Maria P. Casado-Gavalda, R. Cama-Moncunill, X. Cama-Moncunill, P. J. Cullen and Carl Sullivan Prediction of beef fat content simultaneously under static and motion conditions using near infrared spectroscopy "Journal of Near Infrared SpectroscopyVolume 24 Issue 4, Pages 353–361 (2016). DOI: 10.1016/j.jfoodeng.2015.12.004.
6. Y. Dixit, Maria P. Casado-Gavalda, R. Cama-Moncunill, X. Cama-Moncunill, Maria Markiewicz-Keszycka, P. J. Cullen and Carl Sullivan Evaluating the performance of collimated light for near infrared analysis of minced beef samples NIR news, Vol. 27 No. 4 May-June 2016. DOI: 10.1255/nirn.1611.
7. M Zhao, C Esquerre, G Downey, CP O'Donnell Process analytical technologies for fat and moisture determination in ground beef-a comparison of guided microwave spectroscopy and near infrared hyperspectral imaging Food Control, 73 :1082-1094. DOI: 10.1016/j.foodcont.2016.10.023.
8. Ming Zhao, Gerard Downey, Colm P. O'Donnell Exploration of microwave dielectric and near infrared spectroscopy with multivariate data analysis for fat content determination in ground beef Food Control, 68 :260-270. DOI: 10.1016/j.foodcont.2016.03.031 .
9. Y. Dixit, Maria P. Casado-Gavalda, R. Cama-Moncunill, X. Cama-Moncunill, Maria Markiewicz-Keszycka, P. J. Cullen and Carl Sullivan Developments and Challenges in Online NIR Spectroscopy for Meat Processing Comprehensive Reviews in Food Science and Food Safety, 16: 1172-1187. doi:10.1111/1541-4337.12295.
10. Y. Dixit, M. Casado, R. Cama, P.J. Cullen and C Sullivan Challenges in Model Development for Meat Composition Using Multipoint NIR Spectroscopy from At-Line to In-Line Monitoring Journal of Food Science, 82: 1557-1562. doi:10.1111/1750-3841.13770.

11. Eva M. Achata, Elena S. Inguglia, Carlos A. Esquerre, Brijesh K. Tiwari, Colm P. O'Donnell Evaluation of Vis-NIR hyperspectral imaging as a process analytical tool to classify brined pork samples and predict brining salt concentration Journal of Food Engineering, 246, 134-140. 2019. https://doi.org/10.1016/j.jfoodeng.2018.10.022.