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

Food Institutional Research Measure

Final Report

A novel packaging system for food safety and shelf-life extension (FreshPack)

DAFM Project Reference No: 10 RD DIT 712

Start date: 01/12/2011

End Date: 31/10/2013

Principal Coordinator and Institution:
Dr P J Cullen, Dublin Institute of Technology
Email: pjcullen@dit.ie

Collaborating Research Institutions and Researchers:
Prof. Colm O'Donnell, University College Dublin

Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental → Applied → Pre Commercial

1	2	3	4	5 X	6	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	**Priority Area I - Sustainable Food Production and Processing**

Key words: *(max 4) Plasma, packaging, fresh produce,*

1. Rationale for Undertaking the Research

While fresh fruit and vegetable consumption is linked to a plethora of health benefits, it can also be a source of foodborne illness. Globally, there has been an increase in the number of outbreaks of foodborne illness associated with fresh foodstuffs, and in particular with ready-to-eat fruit and vegetables. Unsafe food causes many acute and life-long diseases, ranging from diarrhoeal diseases to various forms of cancer. In 2008 a WHO report on microbial safety in fresh produce prioritised leafy green vegetables as the highest priority in terms of fresh produce safety from a global perspective[1]. High impact outbreaks, such as those associated with spinach contaminated with *E. coli* O157:H7, resulted in almost 200 cases of foodborne illness across North America in 2006 and over $300 million in market losses[2]. In Ireland the FSAI recalled ready-to-eat fresh produce from the market due to contamination with Salmonella[3]. The production of fresh foods such as fresh fruits and vegetables has a requirement for comprehensive hazard analysis and critical control point (HACCP) strategies which should prevent or mitigate against produce contaminated with enteropathogens reaching the consumer. However, outbreaks linked to fruit and vegetable produce do occur, indicating that outbreaks can result from occasional contamination events. These outbreaks are most likely associated with contamination in the field, washing ready-to-eat fresh produce with contaminated water or poor hygiene control during preparation. A desirable increase in fresh produce consumption must be supported by consumer confidence, which requires an exemplary safety record. It is therefore critical that effective decontamination steps are in place to ensure consumer protection and confidence in fresh produce. To this end, there is a requirement to ensure microbiological safety during production of minimally processed fresh foods in order to reduce contaminants, as well as control cross contamination events to maintain microbiological quality and safety.

The fresh-cut industry is heavily dependent on chlorine as an effective sanitiser to assure the safety of their produce[4]. However, in light of concerns about its efficacy, as well as about the environmental and health risks associated with the formation of carcinogenic halogenated disinfection by-products, there is increasing pressure on the industry to eliminate chlorine from the disinfection process. Moreover, the use of chlorine for the disinfection of fresh produce is banned in some countries including Germany and Switzerland. Recontamination of the washed produce by pathogens such as *Listeria monocytogenes* poses a risk even after washing with chlorine, as they multiply faster on cleaned produce. Moreover the technology offers a potential increase in produce shelf-life, thereby facilitating market expansion and a reduction in waste produce.

1. Microbiological hazards in fresh fruits and vegetables. World Health Organization. 2008 http://www.fao.org/ag/agn/agns/files/FFV_2007_Final.pdf
2. Warriner, K., Huber, A., Namvar, A., Fan, W., Dunfield, K. (2009).Chapter 4: Recent Advances in the Microbial Safety of Fresh Fruits and Vegetables. Advances in Food and Nutrition Research. 57, 155-208
3. Food safety authority of Ireland newsletter. 2007. volume 9 issue 1 ISSN 1393-6972. http://www.fsai.ie/news/newsletter/nl_07/newsletter_524.pdf
4. Maria I. Gil, Maria V. Selma, Francisco López-Gálvez, Ana Allende, 2009. Fresh-cut product sanitation and wash water disinfection: Problems and solutions. International Journal of Food Microbiology 134 (2009) 37–45

2. Research Approach

The project aimed to design and build a test rig for in-package plasma treatment of different packaged fruits and vegetables. The system facilitated control over varying parameters including voltage, gap, packaging properties, package gas. The system also included parameter monitoring & diagnostic techniques including electrical and optical.

The efficacy of the system for microbial and enzymatic inactivation was investigated with respect to increasing safety profiles and product extending shelf-life. The technology was evaluated for anti-microbial efficacy against a range of pathogenic and spoilage microorganisms associated with fresh produce, incorporating Gram positive and negative bacteria. Shelf life extension studies were carried out for a range of fresh produce. The effects of treatment on the nutritional and quality parameters of selected products were also studied.

Different food packaging materials were tested from a wide variety of polymers and composites currently used for packaging of fruits and vegetables. Structural, thermal, surface and barrier properties have been evaluated with a focus on mass transfer, i.e., migration, oxygen and water vapour transmission rates. The aim was to identify a suitable packaging material for the process.

3. Research Achievements/Results

The inactivation of enzymes endogenous to fruits and vegetables is one of the most important aims of food preservation operations. The loss of quality parameters such as colour, flavour, texture and nutritional characteristics in raw, minimally or fully processed fruits and vegetables during storage as a consequence of the activity of residual endogenous enzymes is well recognised. The technology was found to be effective in reducing peroxidase enzyme activity. The proposed mechanisms of inactivation have been attributed to the decrease in the enzyme activity due to a change in the secondary protein structure and modification of some amino acids side chains of the enzymes.

Colour is the most obvious parameter for consumers and plays a key role in food choice, food preference and acceptability, and may even influence taste thresholds, sweetness perception and pleasantness. Changes in individual colour parameters were statistically insignificant when compared to the fresh and the untreated control stored under same conditions.

The reductions in total mesophiles and yeasts/moulds found, which are primary contributors to spoilage, suggests the suitability of the technology to extend produce shelf-life. The fact that temperatures that could cause microbial inactivation were never reached, suggests that the microbial reductions were solely due to unique chemical species obtained in plasma state.

The structural, thermal, surface and barrier properties of common food packaging materials were evaluated with a focus on mass transfer, i.e., migration, oxygen and water vapour transmission rates. Increase in surface roughness and slight changes in the crystallinity pattern were detected for all the studied films, without affecting colour or transparency which are the most important properties in terms of consumer acceptability. Water Vapour transmission rate was slightly affected by applying different voltages but maintained very good levels of barrier. Oxygen Transmission Rate did not show significant differences after plasma treatment at different voltages and treatment times. The migration study on food simulants showed an increase in migration rate with increasing voltages and also higher levels of migration when treated samples were subjected to contact with fat simulants, as expected. In all cases, levels of migration where far below the European legal migration limits.

4. Impact of the Research

This research work led to the development of a new approach to plasma treatment of foods, namely In-package plasma. The work shows that cold plasma at atmospheric conditions is a feasible alternative to traditional chlorine washes for fresh produce processing. In particular it was shown that plasma is a rapid, cheap and scalable technology for the process. The optimisation of critical control parameters were progressively assessed in reference and food products. The project showed the potential to scale the process and identified the operational conditions required for processing. Using the obtained information on extrinsic critical control parameters and relating it to the optimum efficacy of In-Package plasma processing could be used as a basis for scale-up to industrial scale.

It is paramount that the effects of treatments are acceptable to consumers and regulatory agencies in terms of quality and nutritional profiles. This research is the first reported study on the effects of In-Package cold plasma parameters for fresh produce treatment in terms of quality and nutritional parameters. Similarly, understanding the mechanism of action of applied treatment could facilitate the enhanced effectiveness of treatment by guiding its application onto the specific susceptible cell targets.

From the present work it is evident that plasma as a non-thermal technology is suitable for extending the shelf life of selected food products. The results shows that the process can eliminate pathogens but also extend the shelf-life of selected products.

The work demonstrated the effects of the treatment on the functional properties of typical food packaging materials. These findings will allow operators to select suitable polymeric packaging materials for the process and product.

The results presented at scientific conferences, journals and workshops would provide sufficient information for companies to adopt the technologies. Overall the project has demonstrated the potential benefits and challenges of employing cold plasma in food industry applications. It is concluded that while cold plasma can be employed as preservation techniques for processing of fresh produce, its impact on nutritional and quality parameters is application specific and should be investigated prior to industry consideration. This research provided a comprehensive assessment of the impact of In-Package cold plasma for

food processing by considering microbial safety challenges, quality aspects and food packaging materials.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

A number of collaborations have been developed or extended during this research including research groups from Purdue University and the DCU plasma centre. Collaborations with companies including Nature's Best, Holfield Plastics, Irish country meats

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

A new in-package cold plasma approach to ensure food safety and extend shelf life of fresh produce has been developed offering an alternative to chlorine washes. The in-package plasma for ensuring microbial safety concerns is very promising. It would also be beneficial in terms of reduced water usage.

(iii) Outcomes with economic potential

The application of cold plasma in this research confirmed that the technology has the potential for practical application as natural and safe tools to preserve the safety of minimally processed foods. The research demonstrated the potential for the control of microbiological concerns associated with solid foods.

The research also showed the potential for the extension of shelf-life for selected fresh produce.

The process was found not to induce significant negative effects interms of changes in the overall mass transfer of compounds from the treated packges to the foods contained.

(iv) Outcomes with national/ policy/social/environmental potential

The technology developed is environmentally friendly with low energy input (~150 W) and as a dry process would significantly reduce the levels of water required by the fresh produce industry.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.

1. Applications of cold plasma technology in food packaging. S.K. Pankaj, C. Bueno-Ferrer, N.N. Misra, V. Milosavljević, C.P. O'Donnell, P. Bourke, K.M.

Keener, P.J. Cullen. Trends in Food Science and Technology. Volume 35, Issue 1, 2014, Pages 5–17

2. Phase-resolved optical emission spectroscopy for an electron cyclotron resonance etcher. Vladimir Milosavljević, Niall MacGearailt, P. J. Cullen, Stephen Daniels, and Miles M. Turner, J. Appl. Phys. 113, 163302 (2013).

3. Diagnostics of an O2-He rf Atmospheric Plasma Discharge by Spectral Emission. Vladimir Milosavljevic, Michael Donegan, Patrick J. Cullen and Denis P. Dowling. Published: 2013/12/10. J. Phys. Soc. Jpn., Vol.83, No.1, Article ID: 014501

(ii) Popular non-scientific publications and abstracts including those presented at conferences

1. Correlation of Spectral Emissions of a He-O2 RF Atmospheric Plasma Discharge with Polymer Surface Activation , Vladimir Milosavljević, Mick Donegan, Patrick J. Cullen and Denis P. Dowling, Invited talk, The AVS 60th International Symposium and Exhibition, Long Beach, California, USA, (2013).

2. DIT Open Day. Fresh-Pack (Poster communication). BioPlasma Research Group, School of food Science and Environmental Health. 12th June 2013. Dublin Institute of Technology, Aungier Street (Dublin, Ireland).

3. Effects of In-Package Dielectric Barrier Discharge (DBD) atmospheric plasma on Polylactic Acid. S.K.Pankaj, C.Bueno-Ferrer, N.N.Misra, L.O'Neill, Paula Bourke, P.J.Cullen. Oral communication. 4th International Conference on Biodegradable Polymers and Sustainable Composites (BIOPOL-2013). Rome, Italy.

4. Effects Of Dielectric Barrier Discharge Atmospheric Plasma On Antimicrobial Zein Film. S.K.Pankaj, C.Bueno-Ferrer, N.N.Misra, L.O'Neill, A. Jiménez, P. Bourke, P.J.Cullen.Poster communication. 4th International Conference on Biodegradable Polymers and Sustainable Composites (BIOPOL-2013). Rome, Italy.

(iii) National Report

None

(iv) Workshops/seminars at which results were presented

(v) Intellectual Property applications/licences/patents

A Method for Reducing the Oil Content of Snacks by Increasing Spreadability. Pending Pending (1322387)

(vi) Other

5. Scientists trained by Project

Total Number of PhD theses: _0___

Total Number of Masters theses: __0__

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
Dublin Institute of Technology	2	0.2
University College Dublin	1	0.1
Total	**3**	**0.3**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	2	1.75
PhD students		
Masters students		
Temporary researchers		
Other		
Total	**2**	**1.75**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
N/A	

9. Project Expenditure

Total expenditure of the project: € 90,626.42

Total Award by DAFM: € 99,651

Other sources of funding including benefit in kind and/or cash contribution(specify): € 0

Breakdown of Total Expenditure

Category	DIT	UCD	Total
Contract staff			
Temporary staff			
Post doctorates	37,627.32	24,224.57	61,851.89
Post graduates			
Consumables	5,594.04	0	29654.32
Travel and subsistence	2266.70	0	7860.74
Sub total	45,488.06	24,224.57	69,712.63
Durable equipment			
Other			
Overheads	13,646.42	7,267.37	20,913.79
Total	**59,134.48**	**31,491.94**	**90,626.42**

10. Leveraging

This project led to the successful awarding of 2 FP7 projects in the area of in-package plasma at DIT. These projects aim to develop new approaches to ensure food safety and extend shelf life. The €3M SAFE-BAG project (http://www.safebag-fp7.eu/) employs in package plasma for the treatment of fresh cut produce with a view offering an alternative to chlorine washes. The project is an SME association project and includes Nature's Best from Ireland.

The second €1.5M MEAT-PACK project will commence in August and aims to use the technology to ensure the safety and extend the shelf life of meats. The project has strong Irish SME involvement including McCarren & Co Ltd, Holfeld plastics and Irish Country Meats.

Both projects will develop a pre-competitive prototype for SME use to provide a competitive advantage for the participating companies.

A modified approach based upon this work using a plasma tunnel and plasma water bath project for the treatment of fresh produce is currently funded under the Food Institutional

Research Measure (FIRM): 'Innovative process technologies for the fresh produce industry' (Ref: 13/F/444).

Research collaboration in the area of plasma was established directly from the work of this project with Purdue University. This collaboration continues to date.

UCD School of Biosystems Engineering staff (T. Curran, P. Solan and C. O'Donnell) were awarded grants worth €15k from Enterprise Ireland under their Innovation Voucher programme to carry out the following industry focused projects using the equipment acquired and expertise developed in this FIRM project:
November 2011 (ref. 1V 20113316) - Assist Irish SME (Donnelly fresh foods /Wonder Foods Ltd) with research to investigate use of ozone as an alternative to chlorine in fresh produce processing.
November 2011 (ref. IV 2011 3240) - Assist Irish SME (Biosystems Engineering Ltd) with research on application of ozone for enhanced cleaning in Algae production.
April 2011 (ref: IV 2011 1232) assist Irish SME (Straw Chip Ltd) with research on application of ozone for microbial inactivation on straw bedding for equine applications.

11. Future Strategies

Work is continuing on this research. The system has been scaled up and modified for various food applications under the FP7 MeatPack and SafeBag projects. Testing is currently ongoing for various food products. Similarly work on plasma treated polymer films is actively researched at DIT.

It is planned to have working scaled up technologies and proof of concept for a wider range of food products. Options to licence the technology or develop prototype systems are currently being looked at by the PI.