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

Food Institutional Research Measure

Final Report

'Development of risk assessment tools of package/product systems for a safe and sustainable food chain (RISKTOOLS)

DAFM Project Reference No: 13/F/505

Start date: 1/1/2014

End Date: 31/12/2016

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Collaborating Research Institutions and Researchers: Dublin Institute of Technology (now TU Dublin), Dr Jesus Frias

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	X5	6	7

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

Priority Area (s)	I Sustainable Food Production and Processing; L Manufacturing Competitiveness; M Processing Technologies and Novel Materials

Key words:

Modified atmosphere packaging (MAP); integrated software; sustainable foods, quality and safety

1. Rationale for Undertaking the Research

Every year one third of all fresh produce is lost along the supply chain. This "desktop" project developed strategies for packaging systems during the cold chain through the implementation of statistical process control at key points to ensure food safety and integrity within the overall food supply chain.

It is possible to develop robust product / package / supply chain systems, which are packages that serve as redundancy safety systems by ensuring that failures in the chain do not result in loss of safety, quality and therefore minimise produce loss.

2. Research Approach

Modified atmosphere packaging (MAP) is a technique that relies on the interplay between the respiratory metabolism of the product and the gas exchange kinetics through the package in order to achieve an optimum gas composition (lower in oxygen and higher in carbon dioxide than atmospheric air). MAP can help extend shelf life of fresh and minimally processed produce and therefore reduce product loss.

MAP as a technology has been studied for many years, but only recently efforts were made to integrate respiratory and film permeability data into predictive models for package gas compositions over time, as well as the effects of temperature.

Nonetheless, most models today still do not include calculations to account for the effect of these compositions and temperature changes in the shelf life and quality decay of fresh produce.

The atmosphere inside a package equilibrates to the point where mass transfer through the package equals respiration rate. The former is largely controlled by the permeability of the film, as the molecular movement through it is so much slower than the natural mixing outside in the bulk air. However, there are situations where this is not so: (i) very tightly packed packages, trays wrapped in secondary films in palletting, trays inside very confined spaces (e.g. the inside of a truck); (ii) micro-perforated films.

The goal of this project was to develop more accurate models which represent these food systems throughout the supply chain, and then design and build up an integrated software platform for MAP design which considers the Quality by Design (QbD) approach, with the final goal to include shelf life and quality loss considerations in the MAP design of fresh produce.

Microsoft Excel was chosen as a platform for the tools to be developed by the project, because this is a ubiquitous software with which most people are already familiar. It will not be necessary for a user to learn anything else, nor to avail of any specialist software which can cost a significant sum. Any packer, retailer, anyone, will be able to use the simulator, requiring only that macros and Visual Basic are enabled in Excel to run the software.

3. Research Achievements/Results

Task 1 Map of conditions in supply chains (temperature, relative humidity, air circulation)

Data and information on storage temperature conditions, relative humidity and air circulation in transport and storage conditions in Irish supply chains were collected from previous projects and from EU projects (ECOBIOCAP and FRISBEE).

Task 2 Numerical simulation to assess the influence of surrounding air conditions in effective permeabilities

The atmosphere inside a package equilibrates to the point where mass transfer through the package equals respiration rate. The former is largely controlled by the permeability of the film, as the molecular movement through it is so much slower than the natural mixing outside in the bulk air. However, there are situations where this is not so: (i) very tightly packed packages, trays wrapped in secondary films in palletting, trays inside very confined spaces (e.g. the inside of a truck); (ii) micro-perforated films.

The effective permeability of a package is the result of the actual conditions where that package operates, and it may vary as a result of temperature, relative humidity, but also of the air circulation conditions outside the package. A mathematical simulation of the mass transfer process through a package requires the numerical solution of a complex set of partial differential equations. These can be solved with finite element software packages and provide simulated data of the effective permeabilities of packages under various conditions. The discretization of the space required by the software describes this variety of conditions, allowing simulation of different scenarios (e.g., trays inside a truck). The modelling approach for the effect of surrounding air conditions in refrigerated storage on the quality and technological parameters of three commodities has been built. The model has been primarily prototyped under the JSIM software and then further developed in R, with the view to offer a possible web-oriented platform for future licensing.

Task 3 Development of models and platform building for predicting internal atmosphere compositions in packed produce

The development of dynamic models, design, build and integrating them in a central platform structure predicting the internal atmosphere composition as a function of effective permeability, temperature, surrounding gas atmospheres and circulation conditions was the core of this integrated software. The software is composed by 5 modules (or subroutines) as shown on the research outcomes section below.

This integrated software platform for MAP design, considers the Quality by Design (QbD) approach, and includes shelf life and quality loss considerations in the MAP design of fresh produce. This work include includes

- A Modified atmosphere packaging model taking into account gas (O2, CO2 and water vapour) together with quality indexes for mushrooms, strawberries and tomatoes has been developed.
- The models above have been applied to ascertain the effect of product variability and retail conditions variability on the final quality parameters of the three commodities.
- A finite element model to describe the gas dynamics in MAP refrigeration installations was also developed.

Task 4 Predictive quality loss and microbial growth models and integration into a Quality by Design umbrella

A collection of quality and spoilage models for strawberries, tomato, and mushrooms was collected and was integrated with the ODE models. Further integration with the finite element models would be needed.

Task 5 Case studies and examples of challenge testing

The modified atmosphere packaging (MAP) for the three selected products, i.e., strawberries and mushrooms was performed under challenging conditions. Kinetic data generated was used for modelling respiration rate, assessing package gas composition and product quality, and developing new methods for assessing package effective permeability, and therefore also improving packaging design simulations.

Task 6 Interaction and dissemination

The strategy used for interaction and dissemination involved four main target groups: i) Fresh Produce (F&V) Industry, ii) Regulatory agencies, iii) Teagasc and providers of advice and consultancy services, iv) scientific community and consumers.

Contacts and visits with F&V industry took place and detailed description of two case studies was presented, showing how packages could be engineering designed for MAP optimization and assessed for their robustness.

A considerable number of scientific peer review journal papers and book chapters (9) were published/ or are being published in high impact journals, and several oral/poster presentations (8) were presented at international and national conferences.

4. Impact of the Research

Development of dynamic models in a central platform structure, predicting the internal atmosphere composition as a function of effective permeability, temperature, surrounding gas atmospheres and circulation conditions is a very **novel processing technological tool** which supports manufacturing competitiveness, potential advancement of the F&V for international markets.

The **integrated software platform for MAP design** considered Quality by Design (QbD) approach, included **models for shelf life and quality loss** considerations in the MAP design of fresh produce. This tool allows food manufacturers, retailers and regulators to go beyond the factory and ensure quality and safety for the consumer. These outcomes can have major benefits for sustainable food production and processing of F&V, by maintaining product quality, safety, longer shelf-life, minimizing product loss and ensuring waste minimization.

A **considerable number of scientific publications** (17), i.e., peer review paper publications, book chapters, and oral/poster presentations were published or prepared for publication at conferences which strategically helped the dissemination of the major results and outputs, and maximizing the interaction with those target groups.

As a result of the research results achieved in this project in the area of waste estimation through the cold chain of mushrooms, strawberry and tomatoes the DIT partner (now TU Dublin previously) has been able to lead and collaborate in a multidisciplinary team (involving horticultural, sustainability and consumer researchers) that was successful in competing at the Science Foundation Ireland Food Challenge 2021. The mathematical models developed here are being further extended and applied to demonstrate an agricultural intervention to facilitate the transition of Irish horticultural products towards more sustainable packaging (Please note, award is presently in communication embargo pending the SFI announcement expected in the second week of September 2022). The expected impact of this project is the development of a business to offer innovation facilitating this transition for the benefit of the horticultural sector in Ireland and contributing the prevention of waste of these products by consumers.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

The strategy used on this project was to maximise the interaction with four main target groups:

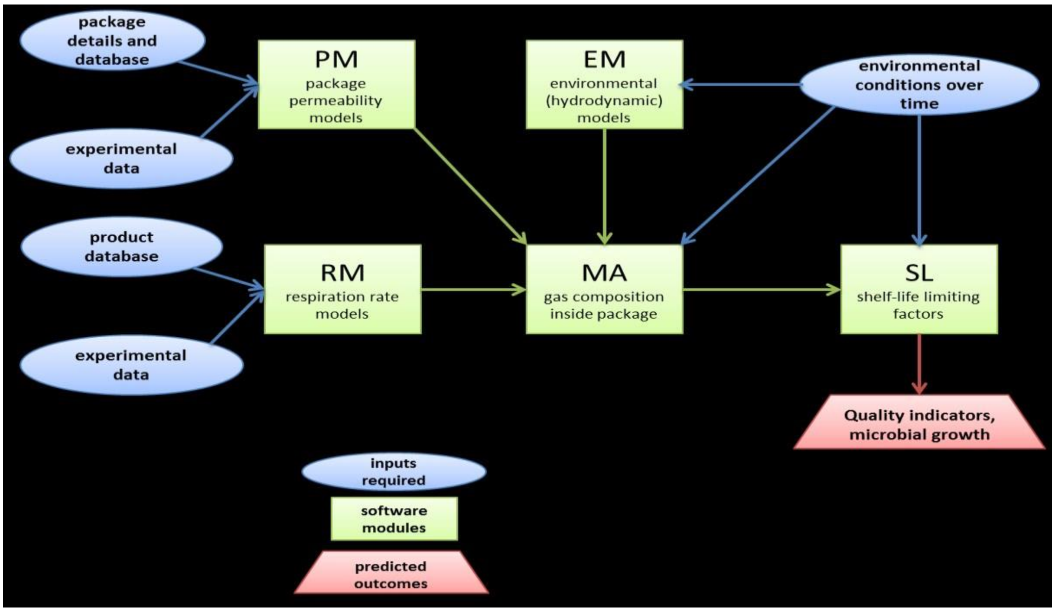
i) Fresh Produce (F&V) Industry: producers, packers, packaging suppliers and retailers;
ii)Regulatory agencies: Food Safety Authority of Ireland and also the European Food Safety Authority, ii) Teagasc and providers of advice and consultancy services, and
iv) Scientific community and general public (consumers) to raise awareness about Quality by Design for packaging and its importance for quality, safety and shelf-life.

The project was developed in collaboration with Irish F&V Industry, and the following companies were engaged in activities with the two research groups involved in this project.

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

Develop dynamic models in a central platform structure predicting the internal atmosphere composition as a function of effective permeability, temperature, surrounding gas atmospheres and circulation conditions

This platform software is composed by 5 modules (or subroutines)**,** which is summarized in the Figure below to provide an overall view of the whole project. The overall view of the software is given in the screen shoots below.



The Table below summarises the capabilities and status of all modules. Modules PM and RM are ready for providing parameters from the database compiled from many previous projects and continuing work.
New methods for handling experimental data have been developed in order to determine effective parameters, should a user prefer to provide this precise data rather than relying on typical database

values. Effective parameters will be specific of the product and package, and they integrate various effects, such as the influence of relative humidity on permeability and the influence of possible seal leakages. The methods developed do not require the user to be familiar with data handling; the software produces the parameters and analysis required. These are completed for working with the spreadsheets independently, and now need to be converted to VBA.

Modules EM and SL were developed in a similar fashion. Module EM is a small subroutine working for module PM, and typical correlations have already been loaded, these however will need updating with the precise outcome of Task 2. Models have been collected from literature for module SL.

Module	Purpose	Mathematical development	Independent functioning in Excel	Conversion to VBA subroutine
MA	core module, predicts internal atmosphere composition from mass balances, given the parameters of package permeability and product respiration	Completed	Completed	Completed
PM	predicts the gas exchange flows through the package from either a typical value in the database and the package details, or by handling actual experimental data of packages	Database completed. Methods for handling experimental data completed	Completed	**Completed for database input**
RM	predicts the rate of consumption of oxygen and production of carbon dioxide and water vapour from either typical values in the database, or by handling actual experimental data of product	Database completed. Methods for handling experimental data completed	Completed	**Completed for database input**
EM	predicts the effective permeability increase due to perforations as a function of external hydrodynamic conditions	Models being developed (from Task 2.1 and 2.2)	Completed	**Completed**
SL	predicts the evolution of selected quality factors and microbial loads, given the shelf-life models, temperature history and atmosphere composition	Models were compiled (from Task 4.1)	ongoing	**Completed for database input**

Some typical screenshots are shown below. These are not final, and have been used to verify the various parts of the software.

Module **RM** (working from actual experimental data)

Summary of respiration model fits, model choice and optimum atmosphere target for package

Write only in yellow cells. Cells requiring values that are critically required have a darker shade of yellow

The choice suggested is shown in bold and red

In any case, check the graphs, and change if appropriate

Model reference	Assumes that O2 respiration is	CO2 respiration is
Constant	constant	constant
unInh	dependent on O2 uninhibited by CO2	constant RQ no added CO2 production
inH	dependent on O2 inhibited by CO2	constant RQ no added CO2 production
inH unc	**dependent on O2**	**variable RQ, O2 dependent uncompetitively inhibited by CO2**
inH comp	dependent on O2	variable RQ, O2 dependent fully inhibited by CO2

To proceed to package design, input also the optimum range of gas compositions for maximum shelf life of this product *(in molar percentages)*

Then move to spreadsheet "Package"

	Oxygen	Carbon dioxide	Relative humidity
minimum	2	3	
maximum	3	4	

To change the model choice, write 1 in model choice box

CHANGE CHOICE TO:	
Constant	
unInh	
inH	
inH unc	
inH comp	

Scroll down to check graphs

Scroll right to check model statistics

Model statistics

Parameters of O2 respiration rate models

MODEL	a	b	c	u	Goodness of fits R2
Constant	8.59904E-06 ±	n.a.	n.a.	n.a.	0.970995
unInh	5.7145E-05 ±	0 ±	n.a.	n.a.	0.996239
inH	6.63008E-05 ±	0.170096 ±	2.945838 ±	0 ±	0.992248
inH unc	6.67661E-05 ±	1.130024 ±	0 ±	n.a.	0.996915
inH comp	6.594E-05 ±	1.036518 ±	0 ±	1.226634 ±	0.996915

Parameters of CO2 respiration rate models

MODEL	Q	ac	bc	cc	uc	
Constant	0.831010472 ±	n.a.	n.a.	n.a.	n.a.	0.856653
unInh	0.832827326 ±	n.a.	n.a.	n.a.	n.a.	0.967045
inH	0.837192325 ±	n.a.	n.a.	n.a.	n.a.	0.981275
inH unc	n.a.	7.72E-05 ±	0.085686 ±	14.22766 ±	n.a.	0.996097
inH comp	n.a.	7.61E-05 ±	0.04781 ±	13.83973 ±	0.914635 ±	0.996099

Module **RM** (working from a database)

SYSTEM LANGUAGE:

STEP 1: define product(s)

yellow cells must be filled (light yellow cells may be left blank)

to change content of pull down menus or values in blue cells, click double arrow button to go to supervisor access mode

BATCH REFERENCE *batch reference number and/or code*

Recommended storage conditions (based on US FDA guidelines)

PRODUCT(S) *(single, or mix of up to 5)*	Temperature	minimum O2	maximum O2	minimum CO2	maximum CO2
1	0.5	5	10	15	20
2					
3					
4					
5					

(when done, click blue arrow to proceed)

Headspace volume ratio suggested for respiration test: 3168 mL / kg of sample

Module **PM** (when working from a database - module EM is replaced by a checkbox choice until it is ready from Task 2)

STEP 3: define package

Hydrodynamic conditions of storage: ◉ 1 stagnant air ○ 2 normal circulation ○ 3 forced convection

yellow cells must be filled (light yellow cells may be left blank)

Total weight of product to be packed, in g: 250

Total volume of the package, in mL: 320

Section 1 (use this section to characterise the polymeric film, or tray lid, which will be perforated)

area exposed, in cm2: 1000

Permeabilities of the materials, in mL.cm/(m2.atm.day)

layers of film (up to 3)	thickness, in micron	material	O_2	CO_2
1	10		5.08	20.29968
2	10		15.66672	60.96
3				

to change content of pull down menus or values in blue cells, click double arrow button to go to supervisor access mode

Section 2 (use this section to characterise a tray that will not be perforated, if applicable, otherwise leave blank)

area exposed, in cm2: 15

Permeabilities of the materials, in mL.cm/(m2.atm.day)

layers of film (up to 3)	thickness, in micron	material	O2	CO2
1	100		6.58368	19.32432
2	100		6.28142	21.27758
3	120		∞	∞

Section 3 (use this section to add a label that will be glued on the package top - section 1 - without covering any perforations, if applicable, otherwise leave blank)

area exposed, in cm2: 15

Permeabilities of the materials, in mL.cm/(m2.atm.day)

	thickness, in micron	material	O2	CO2
1	5		∞	∞

(click green arrow for design result)

4 (b) Summary of Research Outputs

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

1. Ramos, A.V., Sousa-Gallagher, M.J., Oliveira, J.C. (2022). Dimensionless Correlations for Estimating the Permeability of Perforated Packaging Films to Oxygen. Journal of Food Engineering, in press (https://doi.org/10.1016/j.jfoodeng.2022.111252)
2. Oliveira, J.C., Ramos, A.V. and Sousa-Gallagher, M.J. (2022). A Meta-study of the Permeance of Perforated Packaging Films to Oxygen and Carbon Dioxide. Food Engineering Reviews, 14 (2), 328 – 352. (https://doi.org/10.1007/s12393-019-09202-2)
3. Bremenkamp, I., Ramos, A.V., Lu, P., Patange, A., Bourke, P., Sousa-Gallagher, M.J. (2021). Combined effect of plasma treatment and equilibrium modified atmosphere packaging on safety and quality of cherry tomatoes. Future Foods, 3, 100011 (DOI: 10.1016/j.fufo.2021.100011)
4. Ramos, A.V., Sousa-Gallagher, M.J., & Oliveira, J.C. (2019). Effect of Hydrodynamic Conditions and Geometric Aspects on the Permeance of Perforated Packaging Films. Food and Bioprocess Technology, 12(9), 1527–1536. (https://doi.org/10.1007/s11947-019-02309-8)
5. Joshi, K., Tiwari, B., Cullen, P.J., Frias, J.M. (2019). Predicting quality attributes of strawberry packed under modified atmosphere throughout the cold chain. Food Packaging and Shelf Life, 21, p.100354.
6. Joshi, K., Warby, J., Valverde, J., Tiwari, B., Cullen, P.J., Frias, J.M. (2018). Impact of cold chain and product variability on quality attributes of modified atmosphere packed mushrooms (Agaricus bisporus) throughout distribution. Journal of Food Engineering, 232, pp.44-55.
7. Sousa, A.R., Oliveira, J.C., Sousa-Gallagher, M.J., (2017). Determination of the respiration rate parameters of cherry tomatoes and their joint confidence regions using closed systems. Journal of Food Engineering.
8. Sousa-Gallagher M.J., Tank A., Sousa A. R. (2016). Emerging technologies to extend the shelf-life and stability of fruits and vegetables In: Persis Subramaniam and Peter Wareing (Eds.), Food and Beverage Stability and Shelf-Life, 2nd edition, Chapter 20, Woodhead Publishing, Cambridge, UK.

(ii) Scientific publications and abstracts presented at conferences

1. Joshi, K.J., Tiwari, B., Cullen, P.J., Frias, J. M. (2017). A toolbox for minimising waste in the supply chain management of modified atmosphere packed strawberry. 46th Annual Food Science and Technology Conference, December 6 and 7, Teagasc Food Research Centre, Ashtown, Dublin. Oral Presentation.
2. Joshi, K.J., Tiwari, B., Cullen, P.J., & Frias, J. M. (2017). A toolbox for minimising waste in the supply chain management of modified atmosphere packed strawberry. 32nd EFFOST International Conference, November 6-8, 2018. Poster Presentation.
3. Capelo A., Oliveira J.C., Sousa Gallagher M.J. (2016) Software platform for engineering packaging design and shelf life analysis of perishable products, Process & Chemical Engineering, March Poster presentation, UCC.
4. McCarthy V., Montanez J.C., Tank A., Oliveira J.C., Sousa Gallagher M. J. (2016). Quality by Design for engineering MAHP of strawberries using biobased packaging materials, Process & Chemical Engineering, March Poster presentation, UCC.
5. Moloney J., Montanez J.C. Tank A., Oliveira J.C., Sousa Gallagher M.J. (2016). Effect of Relative Humidity on the Effective Permeability of Bio and Non-Bio based packaging, Process & Chemical Engineering, March Poster presentation, UCC.

6. Joshi, K., Frias, J.M. (2016). Predicting storage and quality attributes of Strawberry packed under modified atmosphere packaging throughout the cold chain. 18th World Congress of Food Science and Technology, IUFoST 2016, August 21-25, 2016. Dublin, Ireland. 161.
7. Joshi, K and Frias, J.M. (2015). Predicting storage and quality properties in modified atmosphere packaging for mushrooms. Oral Presentation at the 29th EFFoST Conference. November 10-12th, Athens, Greece.
8. Tank A., Oliveira J.C., Sousa-Gallagher M.J. (2015). "Evaluation of Effective permeability of biobased and non-bio-based films used for equilibrium modified atmosphere packaging (EMAP)", 44th Annual Food Research Conference, December 14th, Teagasc Food Research Centre, Moorepark, Ireland.
9. Tank A., Oliveira J.C., Sousa-Gallagher M.J. (2015). "Performance of modified atmosphere packaging (MAP) systems using bio-based and non-bio-based packaging films", Innovations in Food Packaging, Shelf Life & Food Safety Conference. September 14-17th, Munich, Germany.
10. Tank A., Oliveira J.C., Sousa-Gallagher M.J. (2015). "Effect of relative humidity (RH) on the effective permeability of bio-based and non-bio-based films used for modified atmosphere packaging", Innovations in Food Packaging, Shelf Life & Food Safety Conference. September 1517th, Munich, Germany.
11. Ramos A.V., Sousa-Gallagher M. J., Oliveira. J. C. (2015) Effect of air velocity, perforation diameter and position on the permeability of perforated packaging films. In: 1st Brazil Ireland Science Week, February 23-26th Dublin, Ireland.

5. Scientists trained by Project

Total Number of PhD theses: __2__

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

YEAR	Author	Qualification	Thesis Title
2017	*Andresa Viana Ramos*	**PhD** in Process & Chemical Engineering, School of Engineering, UCC	"Mass Transfer Analysis of Gas Exchange through Microperforated Packaging Films"
2020	*Kompal Joshi*	**PhD**	"Development Of Assessment Tools Of Package/Product Systems For A Sustainable Food Chain"

Total Number of Masters theses: __2__

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

YEAR	Author	Qualification	Thesis Title
2017	*Ashutosh Tank*	**MEngSc** in Process & Chemical Engineering, School of Engineering, UCC	"ENGINEERING DESIGN OF MODIFIED ATMOSPHERE PACKAGING (MAP) FOR STRAWBERRIES" (Supervisor)
2016	*Ana Rita Sousa*	**MEngSc** in Process & Chemical Engineering, School of Engineering, UCC	"ENGINEERING DESIGN OF MODIFIED ATMOSPHERE PACKAGING (MAP) FOR CHERRY TOMATOES" (Supervisor)

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
UCC	2	20% (0.45 person years)
DIT	1	10% (0.2 person years)
Total		

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract	0	
Researchers	0	
PhD students: *(Kompal, Joshi and Ramos Andresa)*	2	1 partially funded (2 Years) (100%= 4 Years) and 1 independently funded
Masters students *(Sousa, Ana Rita and Tank Ashutosh)*	2	1 100% funded and 1 independently funded
Temporary researchers	0	
Other	8	independently funded
Total	**11**	

At the start of the project, there was some difficulty in finding postgraduate students with the required interdisciplinary qualifications (engineering, mathematics related disciplines). However, these issues have been mitigated by the contribution of extra staff listed below (visiting students and final year Process & Chemical Engineering students) who contributed to the advancement of the project at no cost, rather than the extra supervision time by the permanent staff.

- Ms. Kompal Joshi, a graduate from B. Tech (Food Processing Engineering): Indian Institute of Crop Processing Technology, Tamil Nadu, India, joined the project only on the 1st of July 2014; she worked on the assigned tasks to DIT (Task 2).
- Rita Sousa was an Erasmus exchange BEng student from University of Minho (Biological Engineering), Braga, Portugal. Initially, she contributed in part-time to Risktools and Innofresh projects from February-June 2015 as part of her Integrated Master's thesis work.

  Rita was then recruited for the Master position at UCC on the 1st of July 2015, and she worked on Task 5 and Task 6. She assessed the quality loss of strawberries and cherry tomatoes under challenging conditions throughout the supply chain.
- Ms. Andresa Viana Ramos, PhD student independently funded (PG Brazilian Science Without Borders Programme), contributed to the work of task 2, and worked on Task 2.3.

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
NA	

9. Project Expenditure

Total expenditure of the project:	€	**94,270.61**
Total Award by DAFM:	€	**129,000.00**
Other sources of funding including benefit in kind and/or cash contribution(specify):	€	

Breakdown of Total Expenditure

Consolidated Total Expenditure, UCC & DIT

Category	Yr 1 Actual	Yr 2 Actual	Yr 3 Actual	Yr 4 Actual	Yr 5 Actual	Total Actual
Category						
Contract Staff	0.00	0.00	0.00	0.00	0.00	0.00
Temporary Staff	0.00	0.00	0.00	0.00	0.00	0.00
Post graduates	17,400.64	30,384.97	21,505.50	0.00	0.00	69,291.11
Post doctorates	0.00	0.00	0.00	0.00	0.00	0.00
Consumables	0.00	160.00	883.80	0.00	0.00	1,043.80
T&S	97.00	1,218.30	3,118.00	0.00	0.00	4,433.30
Subtotal	17,497.64	31,763.27	25,507.30	0.00	0.00	74,768.21
Durable Equipment	467.54	342.31	0.00	0.00	0.00	809.85
Other	0.00	0.00	0.00	0.00	0.00	0.00
Subcontracting	0.00	0.00	0.00	0.00	0.00	0.00
Overheads 25%	4,374.66	7,941.07	6,376.82	0.00	0.00	18,692.55
Total Grant Requested	**22,339.84**	**40,046.65**	**31,884.12**	**0.00**	**0.00**	**94,270.61**

Institute 1: UCC

Category	Yr 1 Actual	Yr 2 Actual	Yr 3 Actual	Yr 4 Actual	Yr 5 Actual	Total Actual
Contract Staff						0.00
Temporary Staff						0.00
Post graduates	2,234.00	13,885.00	12,172.50			28,291.50
Post doctorates			0.00			0.00
Consumables		160.00	878.15			1,038.15
T&S	97.00	182.00	2,711.00			2,990.00
Subtotal	2,331.00	14,227.00	15,761.65	0.00	0.00	32,319.65
Durable Equipment	467.54					467.54
Other						0.00
Subcontracting						0.00
Overheads 25%	583.00	3,557.00	3,940.41			8,080.41
Total Grant Requested	**3,381.54**	**17,784.00**	**19,702.06**	**0.00**	**0.00**	**40,867.60**

Institute 2: DIT						
Category	**Yr 1 Actual**	**Yr 2 Actual**	**Yr 3 Actual**	**Yr 4 Actual**	**Yr 5 Actual**	**Total Actual**
Contract Staff						0.00
Temporary Staff						0.00
Post graduates	15,166.64	16,499.97	9,333.00			40,999.61
Post doctorates			0.00			0.00
Consumables			5.65			5.65
T&S		1,036.30	407.00			1,443.30
Subtotal	15,166.64	17,536.27	9,745.65	0.00	0.00	42,448.56
Durable Equipment		342.31	0.00			342.31
Other			0.00			0.00
Subcontracting			0.00			0.00
Overheads 25%	3,791.66	4,384.07	2,436.41			10,612.14
Total Grant Requested	**18,958.30**	**22,262.65**	**12,182.06**	**0.00**	**0.00**	**53,403.01**

10. *Leveraging*

- Mr. Calvin O'Callaghan, Undergraduate student in Process & Chemical engineering at UCC, worked full time in the project from January- March 2014, as he was registered only for one module during 2013-14. Calvin was recruited to start Task 1, avoiding delays due to lack of postgraduate students.
- Ashutosh Tank (Master student) working on Innofresh project contributed to Task 5.1 by developing and assessing the performance of packaged strawberries. He also generated data for modelling respiration rate, package gas composition/quality analysis, and developing new methodologies for assessing package effective permeability for improving packaging design simulation.
- Céline Lavaud, exchange student independently funded (École de Biologie Industrielle, France), contributed to Task 2.3
- Ravena Casemiro undergraduate student on an internship independently funded (UG Brazilian Science Without Borders Programme) contributed to Task 2.3
- Álvaro Capelo, undergraduate student on an internship independently funded (Brazilian Science Without Borders Programme), has begun working part-time (October-February 2015) in the project assisting Task 3 and later during his summer internship (May-August 2015). The work developed by Alvaro Capelo has been compiled in the form of a scientific poster.
- Valerie McCarthy and Jeremy Moloney (Final Year Undergraduate Process & Chemical Engineering students) began working on Task 5.1 as part of their final year research project by performing packaging for two selected products strawberries and mushrooms under challenging conditions. The work developed by Valerie McCarthy and Jeremy Moloney has been compiled in the form of scientific posters submitted to International conferences.

11. Future Strategies

The development of a website with a dynamic integrated platform would have allowed the dissemination of the software and interaction with the major four potential users.

The excel files were developed, but to maximise dissemination of these outputs, the initial plan was then to have the integrated Excel files available for free download using only user-provided inputs. If a user wants to work with the database, models and parameters collected, or to work out of the raw experimental data with the software itself doing all required calculations, the user would then need a registration and interaction. This would allow potential users to try the software and assist dissemination and use.

This novel approach would facilitated the interaction with industry. We had used previous versions of similar software interfaces with 3 international companies (Ultimate Packaging and Innovia, UK; and Roffin, Germany), - examples of screenshots were included in the previous reports. The feedback received, was that a simpler and easier to use interface was required for untrained users.

The modifications introduced in this integrated platform software and changes to the screens and interface to the user go precisely in line with the recommendations we collected with these companies. We thus have a much more robust product to show (and provide to) industry for the project outcome.