THE 4TH INTERNATIONAL FOOD OPERATIONS & PROCESSING SIMULATION WORKSHOP

SEPTEMBER 17-19, 2018
BUDAPEST, HUNGARY

EDITED BY

AGOSTINO G. BRUZZONE
FRANCESCO LONGO
MIQUEL ANGEL PIERA
GIUSEPPE VIGNALI

PRINTED IN RENDE (CS), ITALY, SEPTEMBER 2018

ISBN 978-88-85741-19-5 (Paperback)
ISBN 978-88-85741-18-8 (PDF)

ISBN 978-88-85741-19-5 (Paperback)
ISBN 978-88-85741-18-8 (PDF)

THE 4TH INTERNATIONAL FOOD OPERATIONS & PROCESSING SIMULATION WORKSHOP, FOODOPS 2018

SEPTEMBER 17 – 19, 2018
BUDAPEST, HUNGARY

ORGANIZED BY

DIME – UNIVERSITY OF GENOA

LIOPHANT SIMULATION

SIMULATION TEAM

IMCS – INTERNATIONAL MEDITERRANEAN & LATIN AMERICAN COUNCIL OF SIMULATION

DIMEG, UNIVERSITY OF CALABRIA

MSC-LES, MODELING & SIMULATION CENTER, LABORATORY OF ENTERPRISE SOLUTIONS

HUNGARIAN ACADEMY OF SCIENCES CENTRE FOR ENERGY RESEARCH

AUTONOMOUS UNIVERSITY OF BARCELONA

UNIVERSITY OF PARMA

MODELING AND SIMULATION CENTER OF EXCELLENCE (MSCOE)

LATVIAN SIMULATION CENTER – RIGA TECHNICAL UNIVERSITY

LOGISIM

LSIS – LABORATOIRE DES SCIENCES DE L'INFORMATION ET DES SYSTEMES

MIMOS – MOVIMENTO ITALIANO MODELLAZIONE E SIMULAZIONE

MITIM Perugia Center – University of Perugia

Brasilian Simulation Center, LAMCE-COPPE-UFRJ

MITIM - McLeod Institute of Technology and Interoperable Modeling and Simulation – Genoa Center

M&SNet - McLeod Modeling and Simulation Network

Latvian Simulation Society

Ecole Superieure d'Ingenierie en Sciences Appliquees

Facultad de Ciencias Exactas. Ingegneria y Agrimensura

University of La Laguna

CIFASIS: CONICET-UNR-UPCAM

INSTICC - Institute for Systems and Technologies of Information, Control and Communication

National Russian Simulation Society

CEA – IFAC

University of Bordeaux

University of Cyprus

Dutch Benelux Simulation Society

I3M 2018 Industrial Sponsors

CAL-TEK SRL

LIOTECH LTD

MAST SRL

SIM-4-FUTURE

I3M 2018 Media Partners

Inderscience Publishers – International Journal of Simulation and Process Modeling

Inderscience Publishers – International Journal of Service and Computing Oriented Manufacturing

IGI Global – International Journal of Privacy and Health Information Management (IJPHIM)

Halldale Media Group: The Military Simulation and Training Magazine

Halldale Media Group: The Journal for Healthcare Education, Simulation and Training

SAGE
Simulation Transaction of SCS

De Gruyter
International Journal of Food Engineering

MDPI - Sustainability

Euromerci: The Italian Monthly Logistics Journal

EDITORS

AGOSTINO BRUZZONE
MITIM-DIME, UNIVERSITY OF GENOA, ITALY
agostino@itim.unige.it

FRANCESCO LONGO
DIMEG, UNIVERSITY OF CALABRIA, ITALY
f.longo@unical.it

MIQUEL ANGEL PIERA
AUTONOMOUS UNIVERSITY OF BARCELONA, SPAIN
MIQUELANGEL.PIERA@UAB.CAT

GIUSEPPE VIGNALI
UNIVERSITY OF PARMA, ITALY
giusppe.vignali@unipr.it

THE INTERNATIONAL MULTIDISCIPLINARY MODELING AND SIMULATION MULTICONFERENCE, I3M 2018

GENERAL CO-CHAIRS

AGOSTINO BRUZZONE, *MITIM DIME, UNIVERSITY OF GENOA, ITALY*
MIQUEL ANGEL PIERA, *AUTONOMOUS UNIVERSITY OF BARCELONA, SPAIN*

PROGRAM CO-CHAIRS

FRANCESCO LONGO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
YURY MERKURYEV, *RIGA TECHNICAL UNIVERSITY, LATVIA*

THE 4TH INTERNATIONAL FOOD OPERATIONS & PROCESSING SIMULATION WORKSHOP, FOODOPS 2018

GENERAL CHAIR

GIUSEPPE VIGNALI, *UNIVERSITY OF PARMA ITALY*

PROGRAM CHAIR

FRANCESCO LONGO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*

FoodOPS 2018 International Program Committee

MAtteo Agresta, *University of Genoa, Italy*
Eleonora Bottani, *University of Parma, Italy*
Agostino Bruzzone, DIME, *University of Genoa, Italy*
Gerson Gomes Cunha, *COPPE UFRJ, Brazil*
Riccardo di Matteo, *University of Genoa, Italy*
Michel Havet, *GEPEA research unit, France*
Francesco Longo, *MSC-LES, University of Calabria, Italy*
Francesco Marra, *University of Salerno, Italy*
Marina Massei, *Liophant Simulation, Italy*
Ruben Mercade Prieto, *Soochow University, China*
Yuri Merkuryev, *Riga Technical University, Latvia*
Roberto Montanari, University of Parma, Italy
Letizia Nicoletti, *Cal-Tek Srl, Italy*
Antonio Padovano, *University of Calabria, Italy*
Miquel Angel Piera, *University of Barcelona, Spain*
Olivier Rouaud, *GEPEA research unit, France*
Stefano Saetta, *University of Perugia, Italy*
Federico Solari, University of Parma, Italy
Tomas Skoglund, *Tetrapak, Sweden*
Jack Vander Vorst, *ORL Group - Wageningen Universiteit, NL*
Giuseppe Vignali, *University of Parma, Italy*
Mustafa Tahsin Yilmaz, *Yildiz Teknik Üniversitesi, Turkey*

Tracks and Workshop Chairs

Liquid Food Processing
Chair: Marco Better, OptTek Systems (US)

Modelling and Simulation of food processing
Chair: Michel Havet, GEPEA research unit, France

Modelling and Simulation of food properties
Chair: Mustafa Tahsin Yilmaz, Yildiz Teknik Üniversitesi, Turkey

Sustainability of Food processes
Chair: Giuseppe Vignali, University of Parma, Italy

Modelling and simulation of food fouling and cleaning techniques
Chair: Ruben Mercade Prieto, Soochow University, China

Modeling of transport phenomena in food processes assisted by microwaves and radio-frequencies
Chair: Francesco Marra, University of Salerno, Italy

WELCOME MESSAGE 2018

On behalf of the Organization Committee, we would like to welcome and thank all the people who have contributed to this Fourth edition of "The international Food Operations & Processing Simulation Workshop" (FoodOPS 2018). In this edition FoodOPS workshop is intended to continue the experience of the last three years. Starting from the previous editions, this year FoodOPS workshop aims at extending the field of application of simulation not only to the sustainability of food processing but also to the assessment of the logistic performances of food supply chains. The aim of this initiative is to show the particular nature of the food sector where several multidisciplinary approaches are needed to model real-world systems and to come up with solutions able to improve their performances.

The FoodOPS Workshop offers the possibility to show how Modeling & Simulation can be profitably used to achieve significant results and solve critical issues in the food industry sector. Nevertheless, different topics concerning processes, microbiology and supply chain management in food industry have been well-accepted. We thank the authors for their high-quality, original scientific contributions; all the FoodOPS articles will be considered, as it has been done since 2012, for publication in a Special Issue on the ISI indexed Journal "International Journal of Food Engineering". To this end, a special thanks goes to the Editor in Chief of this prestigious Journal, Prof. Dong Chen, who agreed to support our workshop.

Based on the peculiarities of the food sector and on the application fields of the accepted articles, the International Program Committee decided to split the workshop in 2 sessions:

1. Modelling and Simulation of Food Processing;
2. Simulation for Food Production, Supply Chain and Sustainability.

Therefore, FoodOPS 2018 is an opportunity to meet, discuss and create new opportunities for cooperation and also joint research projects. We would like also to thank the General Chairs of the I3M Multi-Conference for their kindness and effort in organizing all the I3M conferences.

Finally, we wish to all the FoodOPS and I3M attendees a fruitful conference and a wonderful stay in Budapest!

Giuseppe Vignali
University of Parma
Italy

Francesco Longo
University of Calabria
Italy

ACKNOWLEDGEMENTS

The FoodOPS 2018 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The FoodOPS 2018 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

I3M 2018 INTERNAL STAFF

MATTEO AGRESTA, *SIMULATION TEAM, ITALY*
AGOSTINO G. BRUZZONE, *DIME, UNIVERSITY OF GENOA, ITALY*
ALESSANDRO CHIURCO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
RICCARDO DI MATTEO, *SIMULATION TEAM, ITALY*
JESSICA FRANGELLA, *CAL-TEK SRL, ITALY*
CATERINA FUSTO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
LUCIA GAZZANEO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
FRANCESCO LONGO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
MARINA MASSEI, *DIME, UNIVERSITY OF GENOA, ITALY*
LETIZIA NICOLETTI, *CAL-TEK SRL, ITALY*
ANTONIO PADOVANO, *DIMEG, UNIVERSITY OF CALABRIA, ITALY*
ANTONIO REDA, *CAL-TEK SRL, ITALY*
CATALDO RUSSO, *CAL-TEK SRL, ITALY*
KIRILL SINELSHCHIKOV, *SIMULATION TEAM, ITALY*
CARMINE TOTERA, *CAL-TEK SRL, ITALY*
MARCO VETRANO, *CAL-TEK SRL, ITALY*
BEATRICE ZACCARO, *SIMULATION TEAM, ITALY*

This International Workshop is part of the I3M Multiconference: the Congress leading **Simulation around the World and Along the Years**

Index

COMPARATIVE LIFE CYCLE ASSESSMENT OF DIFFERENT PACKAGING SYSTEMS FOR COFFEE CAPSULES

Annachiara Tonelli[(a)], David Mosna[(b)], Giuseppe Vignali[(c)]

[(a) (b) (c)] Department of Industrial Engineering, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma (Italy)

[(a)]tonelli.annachiara@gmail.com; [(b)] davidmosna@hotmail.it; [(c)] giuseppe.vignali@unipr.it

ABSTRACT
The aim of this work is to compare the environmental impact of three different packaging systems for coffee capsules, which can be used in the same coffee machine. A comparative Life Cycle Assessment has been performed considering the following three types of coffee capsules:
1. Compostable coffee capsules packaged into a multi-chamber PET tray.
2. Capsules made of aluminium and packaged into cardboard boxes.
3. Capsules made of polypropylene with an aluminium top lid, singularly packaged in modified atmosphere into a bag made of multilayer film of aluminium and polypropylene.
The functional unit considered is a coffee capsule.
To evaluate the environmental impact, the EPD (Environmental Product Declaration) method is used. This work shows that it is possible to reduce the environmental impact of compostable capsules packaged in PET tray by two ways: by using a less polluting starch polymer and by producing biogas instead of compost from the organic waste. With these improvements, the compostable coffee capsule in PET tray results the less damaging packaging system for all categories except than for the ozone layer depletion and the fossil fuels depletion.

Keywords: *Coffee, Capsules; Environmental impacts, LCA, Packaging.*

1. INTRODUCTION

This paper aims to compare the environmental impact of different packaging systems for coffee capsules. This type of capsules is nowadays very common and recently studied also from a scientific point of view (Spanu et al, 2016). The environmental impact of food and food packaging waste has become an important issue (Manfredi et al., 2015). Vitale et al., 2018 says that, with respect to the whole mass of municipal waste, the waste fraction from packaging is constantly increasing: in Italy packaging waste represents 50% in volume of total municipal waste. Moreover, food packaging causes the largest demand for plastic packaging and contributes to aggravate the global challenge with plastics waste management (Bertolini et al., 2016; Plastics Europe, 2017). The consumption of coffee capsules generates a big amount of landfill waste because, even if the capsule is made of recyclable material, if the coffee powder is not separated from the capsule, neither the coffee nor the capsule can be correctly discarded (which means that the coffee is taken to the compost or biogas production plants and the capsule to the recycling center) (Humbert et al., 2009).

Several studies have been done on this issue (Salomone, 2003; De Monte et al. 2005; Salinas, 2008; Hassard et al., 2014) but every year new solutions appear on the market, and they are sold as environmental friendlier that the previous ones.

Based on these premises, an alternative packaging system for coffee capsules has been designed: it consists in biodegradable capsules (made of PLA) packaged in modified atmosphere into a coated PET tray. This packaging system is completely made of biodegradable or recyclable materials and, by this way, the municipal landfill waste can be reduced (Liu, 2006). In 2013 in Italy, in fact, 12000 tons/year of used coffee capsules are discarded to landfill[1]. In order to understand if a completely biodegradable primary packaging plus a recyclable secondary packaging produce a lower environmental impact respect than other conventional packaging for coffee capsules, a comparative Life cycle Assessment has been implemented, considering the following three types of coffee capsules:

1. Compostable coffee capsules packaged into a multi-chamber PET tray. This packaging is completely made of biodegradable and recyclable materials, which permits to reduce the amount of landfill waste. The capsules, containing the coffee powder, can be discarded within the organic waste. They are packed in nitrogen modified atmosphere into a multi-chamber tray made of recyclable coated PET. Each capsule is individually packed into a chamber and can be singularly extracted without compromising the modified atmosphere of capsules that are still packed in other chambers.

2. Capsules made of aluminium and packaged into cardboard boxes.

3. Polymeric capsules, made of polypropylene with an aluminium top lid, singularly packaged in modified

[1] Data available at: https://resource.co/article/italian-job-6989

atmosphere into a bag made of a multilayer film of aluminium and polypropylene.

2. NEW PACKAGING SYSTEM DESIGNED

The packaging system designed consists in biodegradable capsules (made of a bio-based polymer) packaged in modified atmosphere of nitrogen into a PET tray. The PET film used to produce the tray is covered by a coating, named Oxyflav®, which improves the oxygen barrier properties of the polymer. Before the thermoforming this coating is then covered by another thin film of PET. The coating is necessary because the PET film has not good enough oxygen barrier to protect coffee powder from oxidation. The Oxyflav® was developed by the HMI (High Materials Innovation), a spin off of the Chemical Department of University of Parma. It is a water based coating, which provides good oxygen barrier properties to the polymer on which it is spread, without preventing its recyclability. A thin layer of this coating is spread over a PET film that will be coupled to another after the coating solidification. The result is a double-layer PET film with the Oxyflav coating between the two PET films. The PET double-layer film is than thermo-formed to create a tray. The tray is closed by a top film, made of a double-layer PET film, thinner than the bottom one. After the thermoforming the tray is composed of 15 chambers, each capsule is singularly packaged in nitrogen atmosphere into a chamber and can be individually extracted without compromising the modified atmosphere of other capsules that are still packaged.

3. LIFE CYCLE ASSESSMENT METHODOLOGY AND DATA

The LCA methodology was applied according to the requirements provided by ISO standards. LCA consists of four main phases of analysis: definition of goal and scope; inventory analysis; impact assessment; interpretation (ISO 14040,2006; ISO 14044, 2006). The SimaPro 8.3 LCA software was used for this assessment.

3.1. Goal and scope definition

The purpose of this work is to evaluate and compare the environmental impacts of 3 different packaging systems for coffee capsules.

3.1.1. Functional unit

The reference unit for which the inventory data are normalized is the functional unit (ISO 14040, 2006). In order to compare alternative products and services, the concept of functional unit is a key point in LCA (ISO 14044, 2006). The functional unit of this study is one coffee capsule. Firstly we have compared the environmental impact produced by three different coffee capsules with different packaging systems: a PLA capsule packaged into a recyclable PET tray, an aluminium capsule packaged in a cardboard box and a polypropylene capsule sealed with an aluminium top lid, packaged into a multi-layer bag made of aluminium and polypropylene. All these three capsules are usable in the same coffee machine. Secondary, we compared the life cycle environmental impact of the two latest capsules listed before with the impact of a possible starch polymer capsule packaged into a recyclable PET tray, with production of biogas instead of compost from the organic waste collected after consumption (the organic waste consists in the coffee powder and the starch polymer capsule).

3.2. System boundaries and assumptions

In order to quantify the life cycle impact of the analysed product, system boundaries must be determined: an approach *from cradle to grave* was adopted, which consists in considering all phases of the product life cycle, from raw materials extraction/coffee plantation to waste disposal. The phase of domestic preparation of coffee was excluded from the analyses because it is equal for all the three types of coffee capsules, so it is not significant for the comparison.

3.3. Inventory analysis and data collection

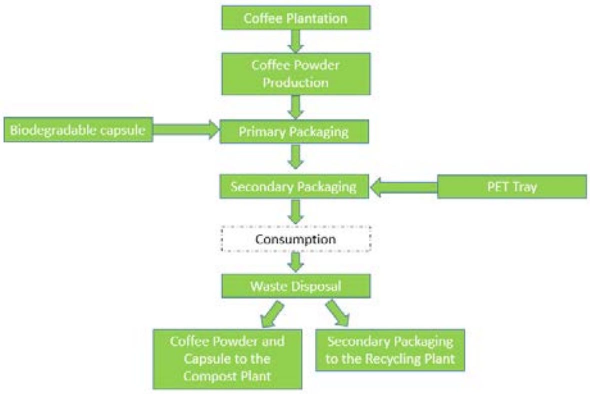
The life cycle inventory analysis quantifies the resources used, the energy consumption and the environmental releases associated with the system being evaluated (ISO 14040, 2006). Some data are experimentally taken; the secondary data are assumed using the Ecoinvent Database 3.3 (Ecoinvent, 2017).
The aim of the inventory analysis is to collect the data used as the basis for the impact assessment phase, where the potential environmental impact of the system is evaluated (ISO 14040, 2006), considering effluent emissions, releases into the environment and resources consumption. The three analysed capsules present the same life cycle main phases:

1. Coffee Plantation, which includes the cultivation of coffee and all the processes made at the plantation site necessary to obtain coffee beans ready to be transformed in coffee powder.
2. Coffee Powder Production, which includes the energy and resources consumption of all the processes done to obtain the coffee powder starting from the green bean. It also includes the energy consumption for the filling of coffee powder.
3. Packaging, it includes all the packaging materials used and the energy for their production, starting from row materials extraction. For what concerns the transports of packaging materials from the producer plant to the coffee capsules factory, an average distance is considered, calculated through Ecoinvent Database.
4. Waste disposal, which varies according to the packaging materials used.

The main differences between the life cycles of the three kinds of analysed capsules concern the packaging materials and their disposal after consumption:
The biodegradable capsule is made of PLA, so PLA granule production and capsule injection processes

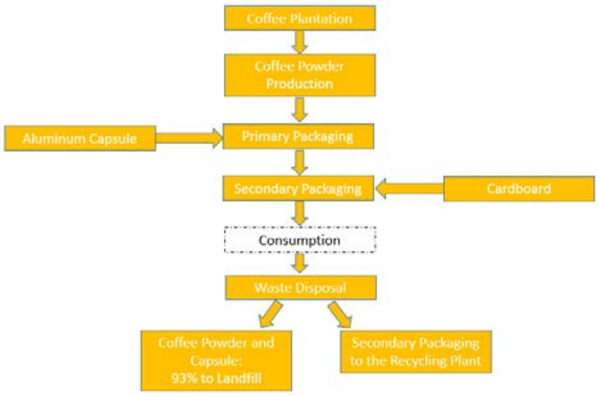
contribute to the environmental impact. Secondary packaging consists in a recyclable coated PET tray, so the granule PET production, the film and coating production processes and the coated-films coupling are included in the analyses of the impact. Nitrogen consumption during the modified atmosphere packaging process is considered too. Each tray contains 15 capsules. For what concerns the waste disposal after coffee capsules consumption, biodegradable capsules are discarded within the organic waste, while the PET tray is discarded within plastic waste and is sent to the recycling plant. In the first analysis made, the biodegradable waste derived from a capsule is destined to compost production. Secondary, another analyses has been implemented considering the production of biogas instead of compost (Figure 1).

Figure 1: Flow chart of biodegradable capsule life cycle



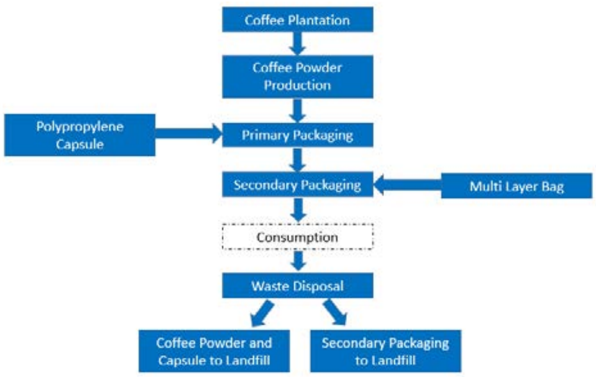
The aluminium capsule presents the advantage that aluminium is the best food packaging material in terms of oxygen barrier properties compared to the thickness of packaging. Coffee is packaged using a nitrogen modified atmosphere inside the capsule. This primary packaging system offers two main advantages: the consumption of nitrogen gas is much lower than that of the biodegradable capsule and the excellent oxygen barrier properties of aluminium permits to use a simple cardboard box as a secondary packaging, since an oxygen barrier effect is not required. The negative aspect of aluminium is that the production of this material is much expensive in terms of energy consumption. For what concerns the waste disposal after usage, the aluminium capsule cannot be recycled if it is not separated from the coffee powder inside of it. So, aware of the huge amount of aluminium wasted due to this issue, the capsules producers considered in this analysis have organized a collection of capsules after usage, so that they can personally manage the appropriate disposal of both coffee powder, which is sent to compost plants, and capsules, which are taken to aluminium recycling plants. This allows however to recycle only the 7% of the total of aluminium capsules sold in Italy[2] (Figure 2).

Figure 2: Flow chart of the aluminium capsule life cycle.



According to Quantis (2011), the polypropylene coffee capsule using an aluminium top lid, as already told before, is packaged in modified atmosphere of nitrogen (40%) and carbon dioxide (60%) into a multi-layer bag, made of aluminium and polypropylene film. The primary packaging has not good oxygen barrier, so a secondary packaging with barrier effect is required. If not separated from the coffee powder, the polypropylene capsule cannot be recycled, neither can the aluminium top lid film. The multi-layer bag is not recyclable because polypropylene and aluminium film cannot be separated. Therefore, as far as the waste discarding is concerned, both the capsule containing the coffee powder and the bag are sent to landfill (Figure 3).

Figure 3: Flow chart of the polypropylene capsule life cycle.



For the collection of inventory data used for the analysis, the following assumptions and limitations are applied:

- The impact of coffee plantation to produce 1 kg of coffee beans is assumed to be the same for all the three types of coffee capsules analysed.

[2] Available at: http://www.cial.it/english_post/collection-recycling-coffee-capsules/

- The data of the transport of coffee beans from the producer country to Europe was obtained based on the average distance of the main coffee producer countries in the world from Rotterdam harbour. It is assumed to be the same for all the three capsules.
- The distance travelled for the distribution of coffee capsules from the production factory to the clients is assumed to be the same for the three coffee capsules.
- Since most of the coffee capsules are produced in Switzerland, the average Switzerland electricity mix is used in this study.
- In this study, data from Switzerland were used when available. In case of unavailable data, relevant background data from Europe were used.
- For what concerns the cut-off criteria applied, less than 1% of the energy and mass flows of the inputs and outputs was excluded from this analysis.

3.4. Methods of impact assessment

The impact analysis was carried out using the Environmental Product Declaration method (EPD). The EPD method consists in a self-declaration schema, realized by the companies themselves in order to divulgate the environmental impact of their products and services. It must be realized according to the UNI EN ISO 14025:2010 standard. The certification shows the data about the potential environmental impact generated by the product or service, calculated through the LCA analysis. The declaration must be verified and approved by a certified authority, which is Accredia in Italy. After completing the controls, the authority releases a declaration and a certification brand that match the Environmental Product Declaration.

The environmental impact is calculated in terms of seven impact categories: (i) acidification, (ii) eutrophication, (iii) global warming, (iv) photochemical oxidation, (v) ozone layer depletion, (vi) abiotic depletion, (vii) fossil fuels depletion.

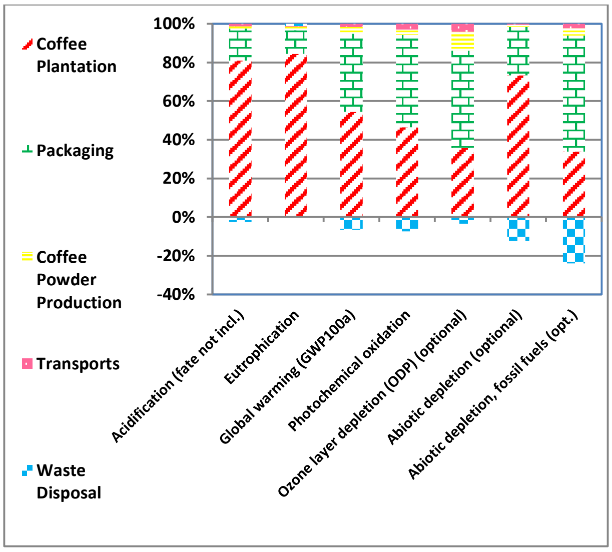
3.5. Environmental impact produced by the biodegradable capsule in PET tray

As shown in Table 1 and Figure 4, for all categories except than ozone layer depletion, photochemical oxidation and fossil fuels depletion, the most impactful phase in biodegradable coffee capsule life cycle is coffee plantation. Packaging is the second most polluting phase for all categories except than ozone layer depletion, photochemical oxidation and fossil fuels depletion, for which it is the first one; it includes energy and materials necessary to produce the packaging system. The environmental impact generated by packaging is due especially to the capsule, because of the granule production process of PLA and the injection process, and to the PET tray, because of the granule production process of PET and film production process.

Table 1: Environmental impact produced by a biodegradable capsule packaged in PET tray

Impact Category	Unit	Total	Coffee Plantation	Packaging	Coffee Powder Production	Transports	Waste Disposal
Acidification (fate not incl.)	kg SO2 eq	6,22E-04	5,17E-04	1,06E-04	7,87E-06	8,24E-06	-1,69E-05
Eutrophication	kg PO4--- eq	4,34E-04	3,67E-04	5,34E-05	7,80E-06	1,24E-06	5,33E-06
Global warming (GWP100a)	kg CO2 eq	4,61E-02	2,68E-02	1,99E-02	1,74E-03	8,27E-04	-3,26E-03
Photochemical oxidation	kg C2H4 eq	1,15E-05	5,77E-06	5,93E-06	3,60E-07	3,65E-07	-9,21E-07
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	3,66E-09	1,35E-09	1,91E-09	3,71E-10	1,56E-10	-1,30E-10
Abiotic depletion (optional)	kg Sb eq	2,13E-07	1,78E-07	6,08E-08	2,84E-09	1,30E-09	-3,00E-08
Abiotic depletion, fossil fuels (opt.)	MJ	4,17E-01	1,86E-01	3,29E-01	2,11E-02	1,28E-02	-1,32E-01

Figure 4: Relative environmental impact of the biodegradable capsule life cycle.



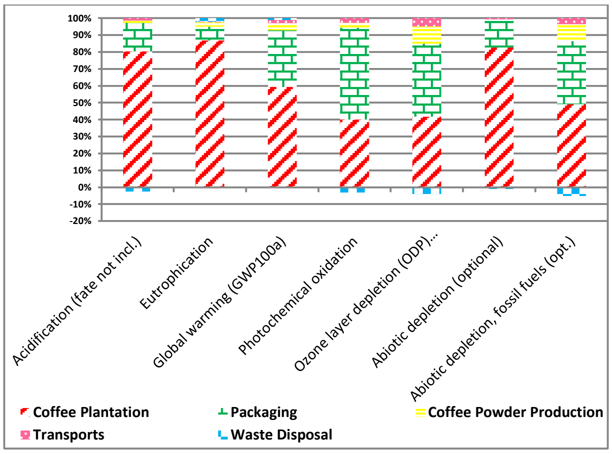
3.6. Environmental impact produced by an aluminium capsule in cardboard box.

Table 2 and Figure 6 show the impact generated by the aluminum capsule life cycle. The most damaging phase is coffee plantation for all impact categories except than photochemical oxidation and ozone layer depletion, for which the most impactful phase is packaging. Packaging produces high impacts because of the aluminum extraction and capsule production processes.

Table 2: Environmental impacts produced by an aluminium capsule packaged in cardboard box.

Impact Category	Unit	Total	Coffee Plantation	Packaging	Coffee powder Production	Transports	Waste disposal
Acidification (fate not incl.)	kg SO2 eq	6,3E-04	5,2E-04	1,1E-04	8,5E-06	9,4E-06	-1,7E-05
Eutrophication	kg PO4--- eq	4,2E-04	3,7E-04	3,4E-05	1,1E-05	1,5E-06	8,5E-06
Global warming (GWP100a)	kg CO2 eq	4,5E-02	2,7E-02	1,5E-02	1,9E-03	9,2E-04	4,6E-04
Photochemical oxidation	kg C2H4 eq	1,4E-05	5,8E-06	7,9E-06	4,1E-07	4,0E-07	-4,6E-07
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	3,1E-09	1,4E-09	1,4E-09	3,3E-10	1,6E-10	-1,3E-10
Abiotic depletion (optional)	kg Sb eq	2,1E-07	1,8E-07	3,4E-08	2,3E-09	1,4E-09	-2,4E-09
Abiotic depletion, fossil fuels (opt.)	MJ	3,6E-01	1,9E-01	1,4E-01	3,8E-02	1,3E-02	-2,0E-02

Figure 5: Relative environmental impacts of the aluminium capsule life cycle.



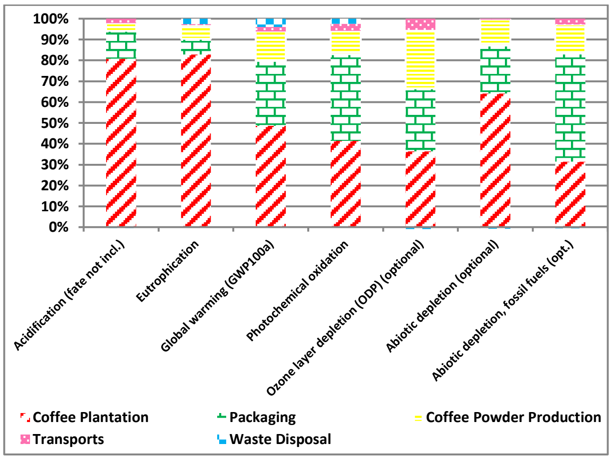
3.7. Environmental impact produced by the polypropylene capsule in multi-layer bag.

As depicted in table 3 and figure 5, also for the polypropylene capsule the most impactful life cycle phase for most of the analysed categories is coffee plantation. Packaging represents the most impactful phase for what concerns photochemical oxidation and fossil fuels depletion. The big amount of packaging material used (greater than those used for the two other capsules analysed) and the fact that both the primary and the secondary packaging can not be recycled produce a huge environmental impact.

Table 3: Environmental impacts produced by the polypropylene capsule packaged in multi-layer bag

Impact category	Unit	Total	Coffee Plantation	Packaging	Coffee Powder Production	Transports	Waste disposal
Acidification (fate not incl.)	kg SO2 eq	7,1E-04	5,8E-04	9,5E-05	2,6E-05	1,5E-05	-3,0E-06
Eutrophication	kg PO4--- eq	4,9E-04	4,1E-04	3,7E-05	3,2E-05	1,9E-06	1,3E-05
Global warming (GWP100a)	kg CO2 eq	6,1E-02	3,0E-02	1,9E-02	8,7E-03	1,2E-03	2,5E-03
Photochemical oxidation	kg C2H4 eq	1,6E-05	6,4E-06	6,5E-06	1,7E-06	5,4E-07	3,8E-07
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	4,1E-09	1,5E-09	1,2E-09	1,2E-09	2,3E-10	-7,0E-11
Abiotic depletion (optional)	kg Sb eq	3,1E-07	2,0E-07	7,1E-08	3,8E-08	1,5E-09	-2,2E-09
Abiotic depletion, fossil fuels (opt.)	MJ	6,6E-01	2,1E-01	3,4E-01	9,1E-02	1,9E-02	-3,4E-03

Figure 6: Relative environmental impacts of the polypropylene capsule life cycle.



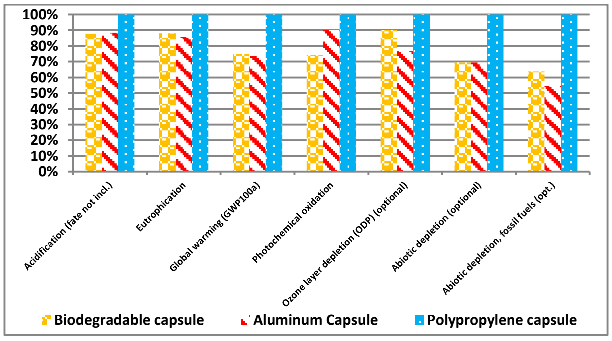
3.8. Comparison of environmental impact produced by the three coffee capsules.

The results of comparative LCA analysis of the impact generated by the three coffee capsules presented before are reported in Table 4 and showed in Figure 7.

Table 4: Comparison of environmental impacts produced by the three coffee capsules

Impact category	Unit	Biodegradable capsule	Aluminum Capsule	Polypropylene capsule
Acidification (fate not incl.)	kg SO2 eq	0,000622388	0,000627555	0,00070927
Eutrophication	kg PO4--- eq	0,000434485	0,000422585	0,000493211
Global warming (GWP100a)	kg CO2 eq	0,046070457	0,045201014	0,061431819
Photochemical oxidation	kg C2H4 eq	1,15105E-05	1,3988E-05	1,55265E-05
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	3,66194E-09	3,1111E-09	4,06362E-09
Abiotic depletion (optional)	kg Sb eq	2,13174E-07	2,13517E-07	3,07082E-07
Abiotic depletion, fossil fuels (opt.)	MJ	0,417440645	0,357732909	0,655038844

Figure 7: Relative environmental impact produced by the three coffee capsules analysed.



The polypropylene capsule in multi-layer bag is the most impactful one for all the categories considered. This is primarily due to the packaging system, made of a huge amount of non–recyclable neither biodegradable materials. For what concerns the two other capsules, the aluminum one is more polluting than the biodegradable one as regards acidification, photochemical oxidation and abiotic depletion. This is due to aluminum production from bauxite and to mechanical processes to obtain the aluminum film and capsule. For all the other categories, the most impactful capsule between the two is the biodegradable one, especially due to the production of PLA and PET granules and to the processes of capsule injection and tray production.

4. SENSITIVITY ANALYSIS

Sensitivity analysis is a procedure aimed to estimate the influence of different choices about methods and data on the results of the study (ISO 14040, 2006). A sensitivity assessment was performed to evaluate how to reduce the environmental impact of the biodegradable capsule life cycle. After some attempts, a less polluting bio-based polymer with which realize the capsule was found: a starch based polymer, suitable for injection moulding process. A study about the environmental impact of organic waste disposal revealed that biogas production releases in the atmosphere a lower amount of Global Warming gases than compost production. So a Life Cycle Assessment of a starch polymer capsule, packaged in PET tray, with biogas production from the organic waste disposal was implemented. The environmental impact of this improved biodegradable capsule is shown in Table 5 and Figure 8.

Table 5: environmental impacts of an optimized biodegradable capsule

Impact Category	Unit	Total	Coffee Plantation	Packaging	Coffee Powder Production	Trasports	Waste Disposal
Acidification (fate not incl.)	kg SO2 eq	6,0E-04	5,2E-04	9,9E-05	7,9E-06	8,2E-06	-2,8E-05
Eutrophication	kg PO4--- eq	4,1E-04	3,7E-04	4,7E-05	7,8E-06	1,2E-06	-9,8E-06
Global warming (GWP100a)	kg CO2 eq	4,1E-02	2,7E-02	1,8E-02	1,7E-03	8,3E-04	-6,3E-03
Photochemical oxidation	kg C2H4 eq	1,1E-05	5,8E-06	5,9E-06	3,6E-07	3,6E-07	-1,7E-06
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	3,9E-09	1,4E-09	2,3E-09	3,7E-10	1,6E-10	-2,8E-10
Abiotic depletion (optional)	kg Sb eq	2,1E-07	1,8E-07	6,1E-08	2,8E-09	1,3E-09	-3,3E-08
Abiotic depletion, fossil fuels (opt.)	MJ	4,3E-01	1,9E-01	3,5E-01	2,1E-02	1,3E-02	-1,4E-01

Figure 8: Environmental impact of starch biodegradable capsule with production of biogas from the organic waste disposal.

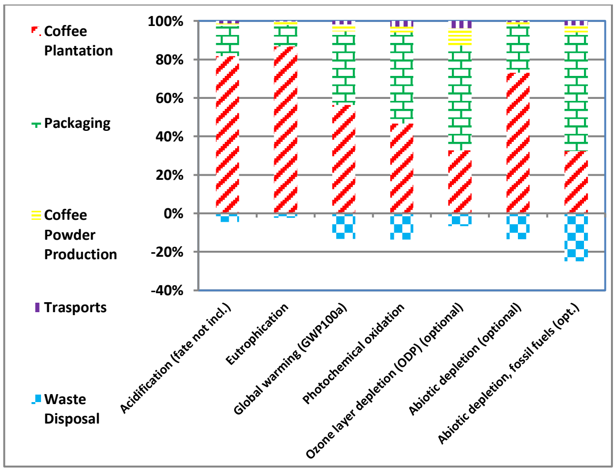


Table 6 and Figure 9 depict how it is possible to reduce the environmental impact of waste disposal of the biodegradable capsule by producing biogas instead of compost from the organic waste.

Table 6: Compost vs biogas production (capsule end-of-life)

Impact category	Unit	Compost production	Biogas production
Acidification (fate not incl.)	kg SO2 eq	-7,46286E-06	-1,910E-05
Eutrophication	kg PO4--- eq	8,51296E-06	-6,654E-06
Global warming (GWP100a)	kg CO2 eq	-0,00106924	-4,157E-03
Photochemical oxidation	kg C2H4 eq	-3,62479E-07	-1,147E-06
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	-3,60869E-11	-1,855E-10
Abiotic depletion (optional)	kg Sb eq	-1,78024E-08	-2,080E-08
Abiotic depletion, fossil fuels (opt.)	MJ	-0,077250371	-8,905E-02

Figure 9: Relative environmental impact of compost vs biogas production (capsule end-of-life)

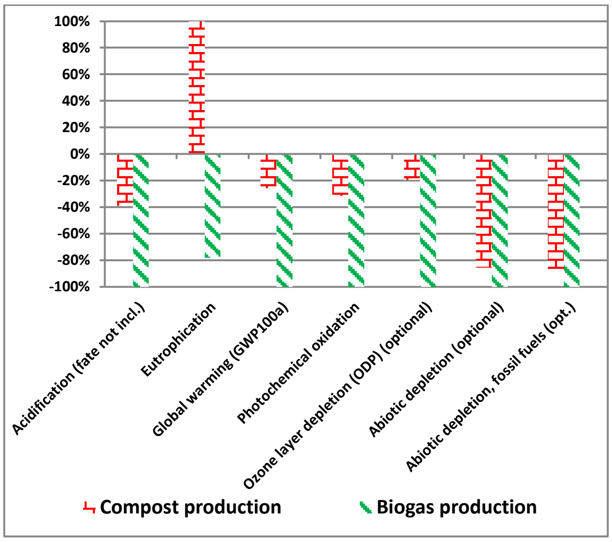
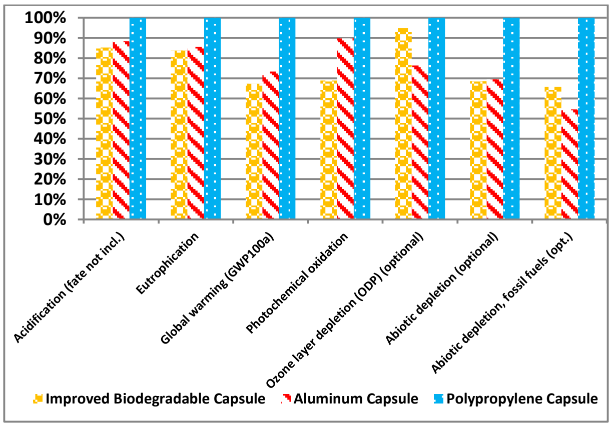


Table 7 and Figure 10 show the comparison of the environmental impact produced by the improved biodegradable capsule with the aluminium one and the polypropylene one. It was assumed the production of biogas instead of compost also with the organic waste collected from the 7% of aluminium capsules disposal. Compared to the comparison made before between the standard biodegradable capsule and the two other capsules, the polypropylene one is still the most impactful capsule for all the categories considered. For what concerns the improved biodegradable capsule and the aluminium one, the first one results less polluting than the second one in all categories analysed except than ozone layer depletion and fossil fuels depletion, where the PET tray is the main responsible of emissions and resources consumption.

Table 7: environmental impacts of the optimised biodegradable capsule vs the aluminium one and the polypropylene one

Impact Category	Unit	Improved Biodegradable Capsule	Aluminum Capsule	Polypropylene Capsule
Acidification (fate not incl.)	kg SO2 eq	6,04E-04	6,27E-04	7,09E-04
Eutrophication	kg PO4--- eq	4,13E-04	4,22E-04	4,93E-04
Global warming (GWP100a)	kg CO2 eq	4,13E-02	4,51E-02	6,14E-02
Photochemical oxidation	kg C2H4 eq	1,07E-05	1,40E-05	1,55E-05
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	3,85E-09	3,10E-09	4,06E-09
Abiotic depletion (optional)	kg Sb eq	2,11E-07	2,13E-07	3,07E-07
Abiotic depletion, fossil fuels (opt.)	MJ	4,30E-01	3,57E-01	6,55E-01

Figure 10: Comparison of the relative environmental impacts produced by the optimised biodegradable capsule, aluminium capsule and polypropylene capsule.



5. CONCLUSIONS

The purpose of this work is to evaluate the environmental impact produced by a completely biodegradable capsules and a recyclable packaging system for coffee capsules and to compare it with the impacts generated by two other types of packaging for coffee capsules and the coffee capsule itself. LCA analyses show that the polypropylene capsule in multi-layer non-recyclable bag is the most impactful one, because of the big amount of packaging material used with landfill end of life. The aluminum capsule is more polluting than the biodegradable one as regards acidification, photochemical oxidation and abiotic depletion, due to the aluminum production and manufactoring. For the other categories the biodegradable capsule results more damaging than the aluminum one because of PLA and PET granule production and manufacturing. The sensitivity analyses shows that it is possible to reduce the environmental impacts produced by the biodegradable capsule by substituting PLA with a starch bio-polymer and by producing biogas instead of compost from the organic waste collected. With these improvements, the biodegradable capsule results the less impactful one in all categories except than ozone layer depletion and fossil fuels depletion, where the PET tray is the main responsible of the impact produced.

REFERENCES

1. Bertolini, M., Bottani, E., Vignali, G., Volpi, A. 2016. Comparative Life Cycle Assessment of Packaging Systems for Extended Shelf Life Milk. Packaging Technology and Science 29(10), pp. 525-546;

2. De Monte M, Padoano E., Pozzetto D., 2005. Alternative coffee packaging: an analysis from a life cycle point of view, Journal of Food Engineering, 66, 4, pp. 405-411;

3. Hassard, H.A., Couch, M.H., Techa-Erawan, T., Mclellan, B.C. 2014. Product carbon footprint and energy analysis of alternative coffee products in Japan. Journal of Cleaner Production, 73, pp. 310-321.

4. Humbert, S., Loerincik, Y., Rossi, V., Margni, M., Jolliet, O. 2009. Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso) Journal of Cleaner Production, 17 (15), pp. 1351-1358.

5. ISO 14040: 2006. Environmental Management –Life Cycle Assessment. Principles and Framework. International Organisation for Standardisation, Geneva, Switzerland.

6. ISO 14044: 2006. Environmental Management –Life Cycle Assessment. Requirements and Guidelines. International Organisation for Standardisation, Geneva, Switzerland;

7. ISO 14025: 2006. Environmental labels and declarations - Type III environmental declarations - Principles and procedures International Organisation for Standardisation, Geneva, Switzerland;

8. Liu Lillian, *Bioplastics in Food Packaging: Innovative Technologies for Biodegradable Packaging*, San Jose State University, Packaging Engineering.

9. Manfredi, M., Fantin, V., Vignali, G., Gavara, R. 2015. Environmental assessment of antimicrobial coatings for packaged fresh milk, Journal of Cleaner Production 95, pp. 291-300;

10. Plastics Europe, 2017. The Facts. Available at: https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

11. Quantis, 2011, Comparative full life cycle assessment of B2C cup of espresso made using a packaging and distribution system from Nespresso Espresso and three generic products. available at https://www.nestle-nespresso.com/asset-library/Documents/Quantis%20-%20Comparative%20LCA%20Study%20on%20Four%20Capsules%20Systems%20-%20Executive%20Summary%202011.pdf ;

12. Salinas B., 2008, Life Cycle Assessment of Coffee Production. Available at http://bsalinas.com/wp-content/uploads/2009/10/paper.pdf ;

13. Salomone R. 2003. Life Cycle Assessment applied to coffee production: investigating environmental impacts to aid decision making for improvements at company level. Journal of Food Agriculture and Environment 1(2):295-300

14. Spanu, S., Mosna, D., Vignali, G. 2016. CFD Analysis of Coffee Packaging in Capsules using Gas Flushing Modified Atmosphere Packaging. International Journal of Food Engineering 12(9), pp. 875-887;

15. Vitale, G., Mosna, D., Bottani, E., Montanari, R., Vignali, G., 2018. Environmental impact of a new industrial process for the recovery and valorisation of packaging materials derived from packaged food waste. Sustainable Production and Consumption 14, pp. 105-121.

AUTHORS BIOGRAPHY

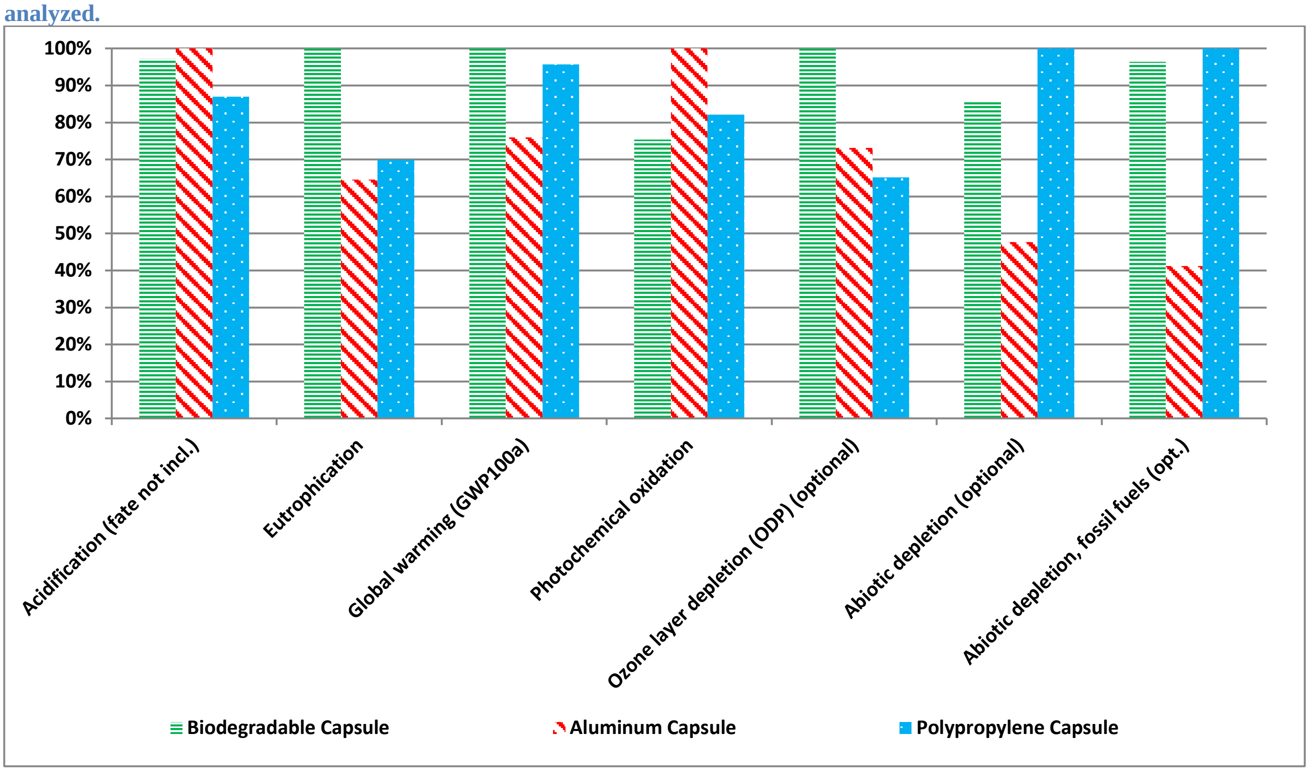
Annachiara TONELLI has been a scholarship holder at the Department of Engineering and Architecture of the University of Parma for 4 months. In December 2017 he has achieved a Master Degree in Mechanical Engineering for the Food Industry at the same university.

David MOSNA is Ph.D. Student in Industrial Engineering at the University of Parma. In October 2014 he has achieved a master degree in Mechanical Engineering for the Food Industry at the same university. His main fields of research concern LCA on food products, packaging systems and industrial applications in general.

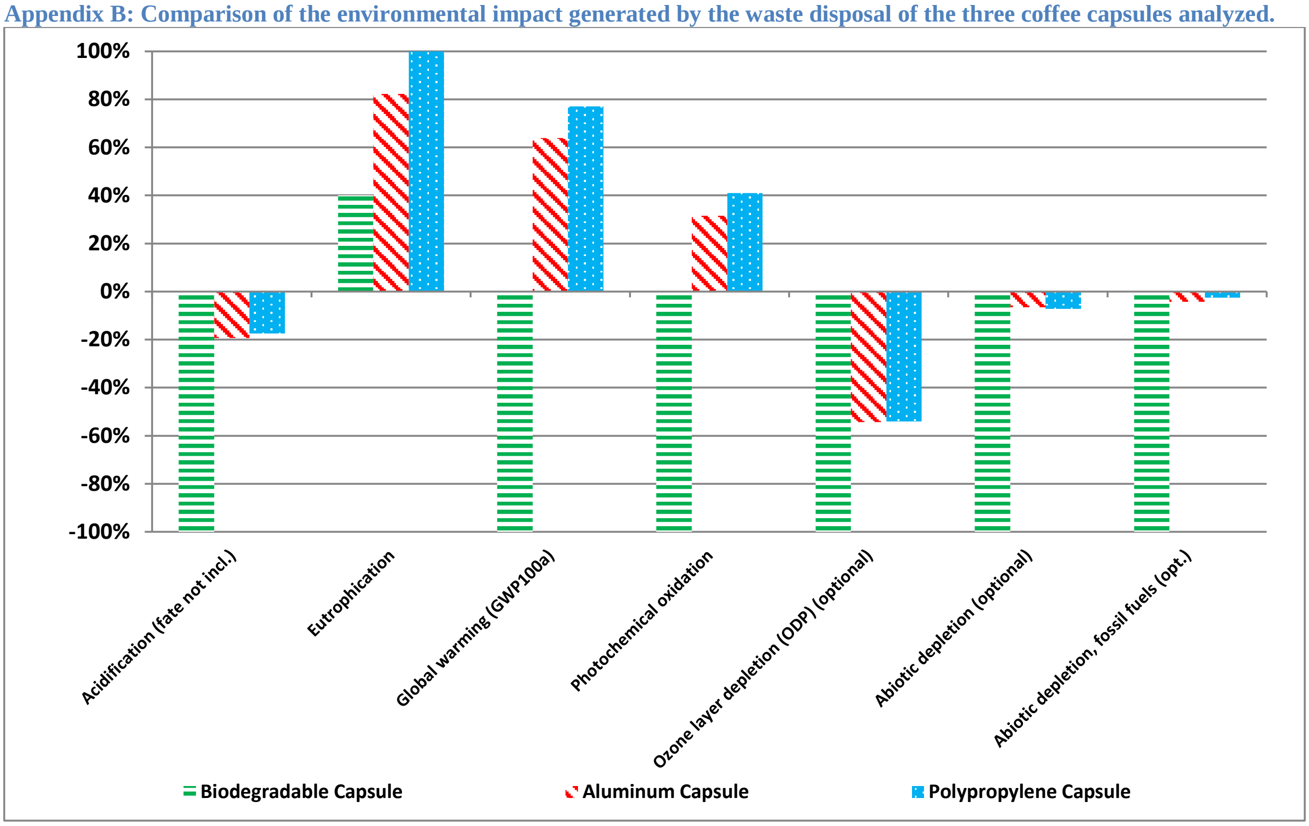
Giuseppe VIGNALI is Associate Professor at University of Parma. He graduated in 2004 in Mechanical Engineering at the University of Parma. In 2009, he received his PhD in Industrial Engineering at the same university, related to the analysis and optimization of food processes. His research activities concern food processing and packaging issues and safety/security of industrial plant. Results of his studies related to the above topics have been published in more than 100 scientific papers.

APPENDIX

Appendix A: Comparison of the environmental impact generated by the packaging materials of the three coffee capsules analyzed.



Appendix B: Comparison of the environmental impact generated by the waste disposal of the three coffee capsules analyzed.



A QUANTITATIVE MICROBIOLOGICAL EXPOSURE ASSESSMENT MODEL FOR *BACILLUS CEREUS* IN PACKAGED RICE CAKES WITH THERMAL PROCESSING

Hyeon Woo Park[(a)], Kyung Mi Kim[(b)]
Gwi Jung Han[(c)], Won Byong Yoon[(d)]

[(a),(d)]Department of Food Science and Biotechnology, College of Agricultural and Life Science, Kangwon National University, Chuncheon 24341, S. Korea
[(b), (c)]Department of Agrofood Resources, National Institute of Agricultural Science, Rural Development Administration, Jeonju, 54875, S. Korea

[(a)]hwpark0978@gmail.com, [(b)]kimkm@korea.kr
[(c)]hgjaz@korea.kr, [(d)]wbyoon@kangwon.ac.kr

ABSTRACT
The objective of this study was to develop quantitative microbial exposure assessment models for *Bacillus cereus* in packaged rice cakes (PRC). Probability distribution for growth of *B. cereus* in PRC was estimated and effects of thermal processing and acidification on extending the shelf-life of PRC were quantitatively assessed. Heat penetration curves at cold point for retort process and pasteurization were successfully predicted using heat transfer simulation model (RMSE < 0.77 ºC). The retort process showed a better sterilization effect than the pasteurization process, but degraded the quality of rice cakes such as color, shape, and texture. The final contamination level in PRC of slab shape package (> 6.63 log CFU/g at 95% level) was lower than that in randomly packed sample (> 7.77 log CFU/g at 95% level) because the cold point in the slab shape package was closer to the surface. Acidification significantly inhibited the growth of *B. cereus* and also affected the inactivation of *B. cereus*. A combination of acidification and low temperature pasteurization extended the shelf-life of PRC, while minimizing quality degradation of products (< 0.43 log CFU/g at 95% level).

Keywords: Rice cake, sterilization, pasteurization, quantitative microbiological exposure assessment

1. INTRODUCTION
Rice cake is a traditional food in many Asian countries. Packaged rice cake is one of the fastest growing products in rice-based processed food categories in South Korea because of its popularity in oversea markets (Kang et al. 2012; Na et al. 2014; Shin et al. 2014; Wang et al. 2016). Due to their high moisture and nutrient-rich contents, packaged rice cakes (PRC) have relatively short shelf life. Such the products are unsuitable for distribution into oversea markets from S. Korea (Wang et al. 2016). For rice-based products, *Bacillus cereus* is a major spore-forming pathogen that can cause food poisoning in humans. Food illness due to *B. cereus* in rice-based processed food has been reported many times (Kramer and Gilbert 1989; Scallan et al. 2011; WHO 1992). Controlling the growth of *B. cereus* in rice-based products is necessary to protect public health.
Thermal treatment is a major method to inactivate both spoilage and pathogenic microorganisms in foods. However, thermal process often causes quality degradation of food products. To improve their quality, low temperature pasteurization combined with cold storage is usually used to assure microbial safety of processed rice cakes. While pasteurization may inactivate vegetative cells, spores and surviving vegetative cells of *B. Cereus* may be present in products and present potential food safety risk for consumers. Thus, thermal processing temperature for packaged rice cakes needs to be carefully designed and optimized to assure their safety while minimizing quality degradation. Acidification of food is another approach to extend the shelf life of a raw material or pasteurized food. While low pH may be efficient in extending the shelf life, the resulting acid taste may negatively affect the taste of food. Both pH control and thermal processing may be used to inactivate *B. cereus* in rice cakes while maintaining product quality.
For thermally conductive food such as packaged rice cake, it is necessary to determine the cold point of product package for evaluating the effectiveness of a thermal process. Computer simulation is an effective way to determine the cold point of solid food during thermal processing (Hong et al. 2014; Lee and Yoon 2014).
Quantitative microbiological exposure assessments (QMEA) for *B. Cereus* in many food products have been reported (Afchain et al. 2008; Bahk et al. 2007; Daelman et al. 2013; Nauta 2001). To obtain more comprehensive risk assessment, both QMEA and quantitative microbiological risk assessment (QMRA) are needed. However, no reliable dose-response relation is currently available. QMEA is the best practice to estimate the possible risk associated with PRC. Thus, the objectives of this study were: 1) to determine accurate cold points of pasteurized PRC with different packing methods, 2) to evaluate quality changes of rice cake prepared from sterilization and pasteurization with acidification, and 3) to develop a QMEA model to assure the safety of

pasteurized PRC considering product processes and product pathways.

2. MATERIALS AND METHODS

2.1. Scope of exposure assessment

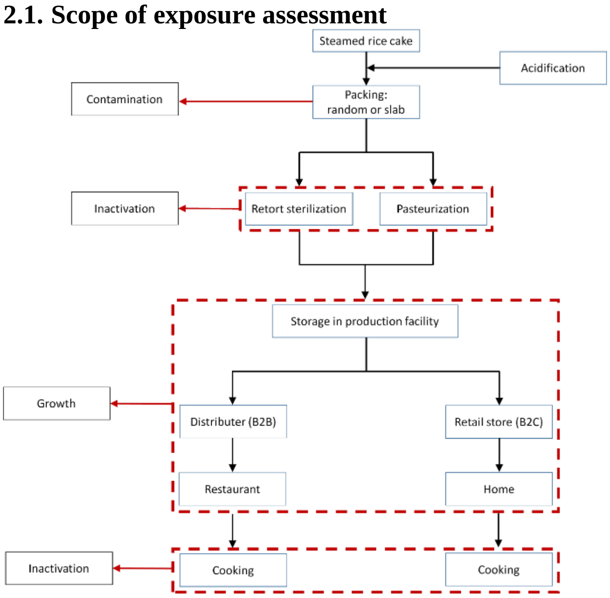


Figure 1: Diagram of the quantitative exposure assessment model for *B. cereus* on rice cake.

The diagram of the exposure assessment model for *B. cereus* in rice cake during B2B and B2C processes is shown in Fig. 1. The production facility-to-table pathway comprises a sequence of unit operations such as packaging and thermal processing in the production facility, transport and storage for sale and consumption. To control exposure to *B. cereus* due to consumption of contaminated rice cakes, it is important to predict contamination levels of *B. cereus* after thermal treatment, contamination level during packaging, and growth of *B. cereus* during storage and transportation.

2.2. The product pathway

Commercial rice cakes were steamed, packaged, and thermally treated in a mass production scale. They were manufactured by a rice cake factory in Yeoju, South Korea. Variability distributions or the constant values of processing parameters for the pathway of rice cake products were estimated based on literature data, expert's opinion of the company, or the data collected by the company. They are summarized in Tables 1 and 2.

Table 1: Distributions or values of processing parameters used to simulate the level of *B. cereus* in the production facility.

Parameters	Distribution/values	Sources/note
Retort sterilization		
Heating temperature (°C)	*Normal(121, 0.4)	Measured
Heating time (min)	Normal(60, 0.5)	Assumed
Cooling temperature (°C)	Normal(22, 0.6)	Measured
Cooling time (min)	**Uniform(15, 25)	Assumed
Pasteurization		
Heating temperature (°C)	Normal(95, 0.5)	Measured
Heating time (min)	Normal(60, 0.5)	Assumed
Cooling temperature (°C)	Normal(25, 2.3)	Measured
Cooling time (min)	Uniform(15, 25)	Assumed
Storage in production facility		
Storage temperature (°C)	***Pert(5, 12, 18)	Company info
Storage time (h)	Pert(5, 72, 120)	Company info

*Normal (mean, standard deviation)
**Uniform (minimum, maximum)
***Pert (minimum, most likely, maximum)

During processing, steamed rice cakes were packaged and thermally treated at 121 °C (sterilization) or 95 °C (pasteurization) for 60 min. After thermal treatment, rice cake products were cooled at 22 °C and 25 °C for 20 min (for sterilized and pasteurized products, respectively). Before leaving the production facility, packages were stored in the company warehouse under storage conditions modelled by Pert distributions as shown in Table 1. These stored products were then sent to retail establishments and distributers in B2B and B2C processes, respectively. Before consuming B2B and B2C products at home and restaurant, varied circumstances for transportation and storage were applied to describe pathways of B2B and B2C products.

Table 2a: Distributions of processing parameters used to simulate the level of *B. cereus* in B2C process.

Parameters	Distribution/values	Sources/note
Transportation from production facility to retail		
Temperature during transportation (ºC)	Pert(6, 14, 23)	Company info
Time of transportation (h)	Pert(2, 4, 12)	Company info
Retail storage		
Storage temperature (ºC)	*Extvalue(4.94, 2.82)	De Vriese et al., 2005
Storage time (h)	70% ***Uniform (0, 360)	Assumed
	30% Uniform (360, 720)	
Transportation from retail to home		
Temperature during transportation (ºC)	Pert(8.7, 13.4, 18.8)	De Vriese et al., 2005
Time of transportation (min)	Pert(10,35,90)	De Vriese et al., 2005
Home storage		Measured
Storage temperature (ºC)		
	Normal(6.68, 2.8, **Truncate(-1, 17))	Nauta et al., 2003.
Storage time (days)	***Expon((SD-PD)/3)-PD	Nauta et al., 2003.
Consumption		
Cooking temperature (ºC)	Normal(90,2)	Assumed
Cooking time (min)	Normal(20,3)	Assumed

Table 2b: Distributions of processing parameters used to simulate the level of *B. cereus* in B2B process.

Parameters	Distribution/values	Sources/note
Transportation from production facility to distributer		
Temperature during transportation (ºC)	Pert(6, 14, 23)	Company info
Time of transportation (h)	Pert(2, 3, 6)	Company info
Distributer storage		
Storage temperature (ºC)	Extvalue(4.94, 2.82)	De Vriese et al., 2005
Storage time (h)	Pert(72, 240, 720)	Company info
Transportation from distributer to restaurant		
Temperature during transportation (ºC)	Pert(6, 14, 23)	Company info
Time of transportation (h)	Pert(1,4,12)	Company info
Restaurant		
Storage temperature (ºC)	Extvalue(4.94, 2.82)	De Vriese et al., 2005
Storage time (h)	70% Uniform (0,180)	Assumed
	30% Uniform (180, 360)	Assumed
Consumption		
Cooking temperature (ºC)	Normal(90,2)	Assumed
Cooking time (min)	Normal(20,3)	Assumed

*Extvalue (alpha, beta)
**Truncate (minimum, maximum)
***Expon (beta)
SD: Sell by date (180 days)
PD: Date of purchase (time from storage in production facility to retail storage)

2.3. Thermal process lethality

In order to calculate cumulative lethality (or Log reduction, LRD), measured and modelled temperature histories were used. LRD was calculated with the General method (Biglow et al. 1920) as follows:

$$LRD = \frac{1}{D^*}\int_0^t 10^{\frac{T-T^*}{z}} dt \quad (1)$$

where D_{ref} is the D-value of *B. cereus* at reference temperature (T_{ref}) and z is the Z-value defined as temperature required to cause a one-log cycle reduction in D-value.

2.4. Microbial basic processes

Table 3: Distributions or values of growth or inactivation parameters used to simulate the level of *B. cereus*.

Parameters	Distribution/values	Sources/note
Initial condition		
Initial level of B. cereus (Log CFU/g)	Normal(1.1, 0.29)	Jeong et al., 2012
Initial level of B. cereus (contaminated) (Log CFU/g)	Normal(1.3, 0.23)	Jeong et al., 2012
Initial temperature of products (°C)	Uniform(23, 28)	Assumed
Growth of B. cereus		
pH_{min}	Normal(4.68, 0.02)	Carlin et al., 2013
pH_{opt}	Normal(6.79, 0.81)	Carlin et al., 2013
T_{min} (°C)	Normal(6.96, 0.82)	Carlin et al., 2013
T_{opt} (°C)	Normal(40.05, 0.47)	Carlin et al., 2013
T_{max} (°C)	48	Carlin et al., 2013
ln(Lag time)	5.422-0.156T	Kang et al., 2010
N_{max} (Log CFU/g)	8.5	Wang et al., 2014
Thermal resistance of B. cereus spores		
pH_{opt}	7	Luu-Thi et al., 2014
Z_{pH}	3.7	Luu-Thi et al., 2014
D_{90} (min)	101.9	Luu-Thi et al., 2014
Z_T (°C)	6.2	Luu-Thi et al., 2014

As shown in Fig. 1, each stage of the food pathway has one microbial basic biological process (Fig. 1), assuming that retort sterilization, pasteurization, and cooking will lead to *B. cereus* inactivation while the pathway from storage in production facility to storage at home or restaurant allows *B. cereus* growth. Table 3 lists values and distributions of microbial growth or inactivation parameters for *B. cereus* in Monte Carlo simulation. *B. cereus* is known to have substantial strain diversity (ICMSF 1996; Mazas et al. 1999). Since the strain type of *B. cereus* in a product pathway is commonly unknown, QMEA simulation must be conducted in worst-case scenarios. Therefore, among 39 strains of *B. cereus* belonging to six phylogenetic groups, the most heat resistant strain (F4810/72) was considered for QMEA simulation in this study (Carlin et al. 2013; Luu-Thi et al. 2014).

2.4.1. Thermal inactivation model

Thermal inactivation model was applied to each inactivation stage to predict combined effects of pH and temperature on thermal resistance of *B. cereus* was applied to each inactivation stage (Mafart and Legueriner 1998):

$$\log D_{(T,pH)} = \log D_{(T^*,pH^*)} - \frac{T-T^*}{z_T} - \frac{(pH-pH^*)^2}{{z_{pH}}^2} \qquad (2)$$

where T*, pH*, zT, z_{pH}, and $D_{(T^*,\ pH^*)}$ are reference temperature, pH at the maximum heat resistance of *B. cereus*, conventional z-value, a one-log cycle reduction associated with pH increase or decrease from pH*, and D-value at pH* and T*, respectively.

2.4.2. Growth model

Most QMEA or QMRA models are developed with primary models that comprise an exponential growth model without stationary or lag phase, for example, those developed by Meija et al. (2011). However, when thermal treatment is applied to bacterial spores, the effect of lag phase is relevant (Stringer et al., 2009). The two-phase logistic model (eq. (3)) by Rosso et al. (1995) is the simplest model that includes the lag phase as applied in the study of Afchain et al. (2008) for *B. cereus*:

$$N_t = \begin{cases} \frac{N_{max}}{1+\left(\frac{N_{max}}{N_0}-1\right)e^{-\mu max(t-\lambda)}} & \text{if } t \geq \lambda \\ N_0 & \text{if } t < \lambda \end{cases} \qquad (3)$$

where N_t is the contamination level at time t, N_0 is the initial contamination level, N_{max} is the maximum contamination level at the stationary phase, μ_{max} is the maximum growth rate (h^{-1}), and λ is the lag time (h).
Developing a primary model that can reflect the effect of lag time during temperature fluctuations is difficult. Several researchers have tried to normalize the effect of environmental changes on the lag time. However, these relationships have not been sufficiently explored and it cannot cover a wide range of environmental conditions

either (Delignette-Muller 1998; Mellefont and Ross 2003; Robinson et al. 1998; Swinnen et al. 2004). Therefore, a proportional lag time model was proposed and used in this study. A modified logistic model was developed and used in this study as follows:

$$N_{t,i} = \begin{cases} \frac{N_{max}}{1+\left(\frac{N_{max}}{N_{0,i}}-1\right)e^{-\mu_{max}(t_i-\lambda_i)}} & \text{if } t_i \geq \lambda_i \\ N_{0,i} \text{ and } \lambda_{i+1} = (\lambda_i - t_i)\frac{\lambda_{T,i+1}}{\lambda_{T,i}} & \text{if } t_i \geq \lambda_i \end{cases} \quad (4)$$

where t_i is the duration at stage i in the food pathway (h), $N_{t,i}$ is the contamination level after a growth period for time t at stage i (CFU/g), $N_{0,i}$ is the initial contamination level at the beginning of stage i (CFU/g), $\mu_{max,i}$ is the maximum growth rate at stage i (h^{-1}), λ_i is the lag time at stage i (h), and λ_{T+i} is unnormalized total lag time at stage i condition (h).

In order to use a secondary model for describing a specific growth rate of *B. cereus* appropriately, both pH and temperature of the product need to be considered. Several secondary models have been used, among them the cardinal model (Rosso et al. 1995), which clearly reflect the trend in pH and temperature for the growth of *B. cereus* (Carlin et al. 2013), was used.

$$\mu_{max} = \mu_{opt}\tau(T)\rho(pH) \quad (5)$$

$$\tau(T) = \frac{(T-T_{max})(T-T_{min})^2}{(T_{opt}-T_{min})[(T_{opt}-T_{min})(T-T_{opt})-(T_{opt}-T_{max})(T_{opt}+T_{min}-2T)]} \quad (6)$$

$$\rho(pH) = \frac{(pH-pH_{min})(pH-pH_{max})}{(pH-pH_{min})(pH-pH_{max})-(pH-pH_{opt})^2} \quad (7)$$

where

$$\mu_{max} = \begin{cases} T < T_{min}, & 0 \\ T_{min} < T < T_{max}, & \mu_{opt}\tau(T) \\ T > T_{max}, & 0 \end{cases} \quad \text{and} \quad \mu_{max} = \begin{cases} pH < pH_{min}, & 0 \\ pH_{min} < pH < pH_{max}, & \mu_{opt}\rho(pH) \\ pH > pH_{max}, & 0 \end{cases}$$

This model encloses physiological parameter, named cardinal values: subscripts min, opt and max means minimum, optimum and maximum values of pH and temperature, respectively. μ_{opt} is the maximum specific growth rate when T and pH are set to their optimal values.

2.5. Quality changes during thermal processing

2.5.1. Texture

Texture property was measured using a CT3 texture analyzer (Brookfield, Middleboro, MA, USA). Samples were equilibrated at 36 °C before tests. For compression tests, 50% deformation and 1 mm/s of cross head speed were applied. Hardness was used to indicate texture changes during thermal treatment. An average value from 10 times of measurement for each treatment was used for analysis.

2.5.2. Color

Color of rice cake was measured using a colorimeter (CR-300, Minolta, Japan). A standard value of white (L=93.6; a=0.314; b=0.320) was used for calibration. Total color difference (ΔE*) was calculated using the following equation:

$$\Delta E^* = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad (8)$$

where L*, a* and b* are initial values and L_0, a_0 and b_0 are the color values at various thermal processing conditions.

2.5.3. Image analysis

To estimate non-uniformity of samples, image processing was conducted using MATLAB (Mathworks® Inc., Natick, MA, USA). Image processing procedures in this study included the following: (1) image acquisition, (2) edge detection, (3) thresholding, and (4) image analysis. A digital camera (DSLR-500D, Canon Inc., Tokyo, Japan) was vertically located over the rice cake sample at a distance of 20 cm. For edge detection, a Canny edge operator was used after image acquisition. With a black background, the shape of the sample was extracted with white color. Segmentation technique based on threshold was efficient to detect white rice cake samples placed on a contrasting black background (Fig. 2).

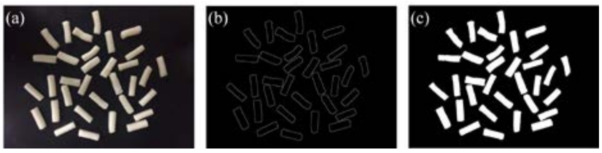


Figure 2: The overall procedure for image analysis. (a) Original image, (b) edge detected image, and (c) extracted area of the object.

The non-uniformity of samples was estimated using Eq. (9):

$$N = \sqrt{\frac{\sum_{i=1}^{n}(A_i - \bar{A})^2}{n}} \quad (9)$$

where N is the non-uniformity, n is the number of sample, A_i is each of the detected area of the sample, and $\bar{A}$ is the mean of A_i.

2.6. Acidification of product

The initial pH of the rice cake was 5.92 ± 0.06. To achieve proper acidification of rice cakes, 0.1 M of lactic acid was used as an acidulant. Target pH of product was set at 5.0 to inhibit microbial growth and maintain the quality of rice cake. Rice cake samples were acidified in lactic acid at 25 ºC. The soaking time to achieve target pH was estimated to be 80 s based on experiments (data not shown). The estimated soaking time was used for the acidification process of rice cake product.

2.7. Heat transfer simulation model

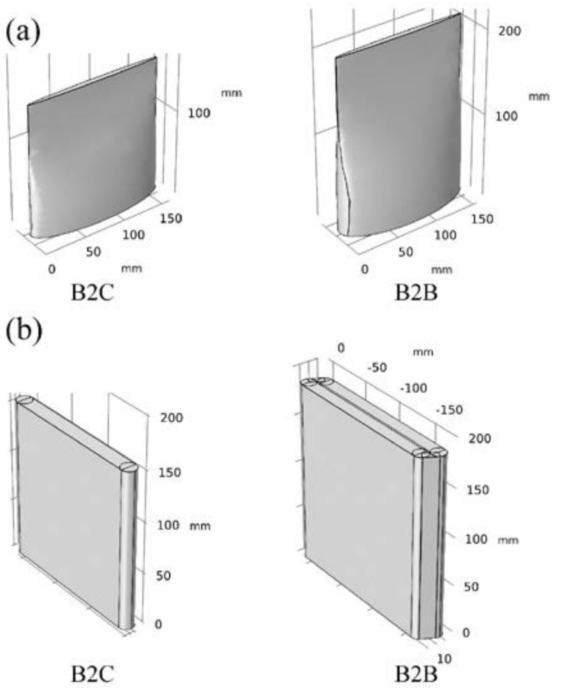


Figure 3: The geometric models of B2C and B2B products for heat transfer simulation during thermal processing. (a) Random packing, and (b) slab arrangement.

To simulate heat transfer of two different packaging methods (random packing and manual arranging), geometric models for these two packaging methods. Results are shown in Fig. 3. A heat transfer model was developed to determine the cold point in the packages during thermal processing. The governing heat transfer equation can be written as follows (Mohan and Talukdar 2010):

$$\rho C_p \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial z^2} + \frac{\partial^2 T}{\partial r^2}\right) \quad (10)$$

The initial condition is:

$$T(z, r, 0) = T_i \quad (11)$$

Boundary conditions are:

$$z = 0, \frac{\partial T}{\partial z} = 0 \text{ and } r = 0, \frac{\partial T}{\partial r} = 0 \quad (12)$$

On the surface:

$$k\frac{\partial T}{\partial z} = h(T_\infty - T_s) \text{ and } k\frac{\partial T}{\partial r} = h(T_\infty - T_s) \quad (13)$$

In these equations, C_p is the specific heat, ρ is density, k is thermal conductivity, h is heat transfer coefficient, T_∞ is the temperature of the heating medium, T_s is the temperature on the surface of the sample.
A KD2 Pro Thermal Properties Analyzer (Decagon Devices Inc., Pullman, WA, USA) was used to measure thermal properties such as specific heat and thermal conductivity of rice cake. The water displacement method described by Eccles (1956) was used to measure the volume and density of the rice cake sample. Ten replicate measurements were performed for each sample.

2.8. Monte Carlo simulation

Monte Carlo simulation uses probability distributions for an input to estimate the risk. The accuracy of simulated results depends on the iteration number. A commercial software tool, @RISK (version 7.5, Palisade, Newfield, NY), was used to conduct Monte Carlo simulation. The simulation model in this study was conducted with 10,000 iterations, Latin Hypercube sampling, and a random number generator seed of one (Palisade Corporation 2002).
For both diarrheal and emetic toxins produced by *B. cereus*, dose-response relationship has been unavailable. Evidence from epidemiology indicates that most outbreaks worldwide caused by *B. cereus* are associated with concentration higher than 10^5 CFU/g while consumption of 10^4 CFU/g of *B. cereus* does not appear to be harmful (Notermans and Batt 1998). Therefore, the probability of exposure to > 10^4 CFU/g product is considered.

3. RESULTS & DISCUSSION

3.1. Determination of cold point using CFD

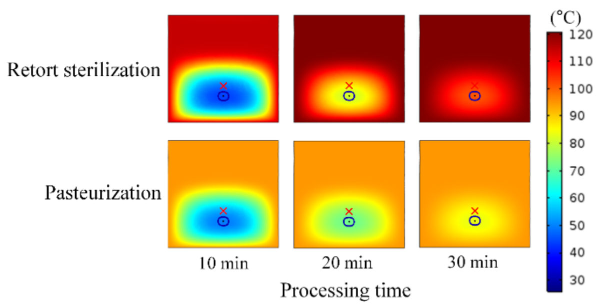


Figure 4: The distribution of product randomly packed during thermal processing. O is the cold point and X is the geometric center.

Cold points of PRC under retort sterilization and pasteurization were estimated by CFD simulation (Fig. 4). The heating rate of retort sterilization was faster than that of pasteurization since the temperature used in the retort sterilization process was higher. Cold points of both thermal treatments were not located at the geometrical center. Since the degree of sterilization must be measured at the cold point, accurate determination of cold points in PRC is an essential step for thermal processing. Simulation results accurately predicted the transient temperature at cold points (RMSE < 0.77 ºC). The temperature profiles at cold points of both pasteurization and sterilization process clearly showed lower temperature than those measured at the geometrical center.

3.2. Quality changes during thermal processing

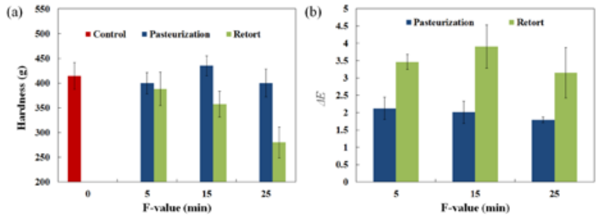


Figure 5: Changes in (a) the hardness and (b) color depending on F-value for each thermal processing condition (F_{95} and F_{121} for pasteurization and retort, respectively).

Hardness and color values of PRC after retorting and pasteurization were measured to determine quality changes due to thermal degradation. The hardness of PRC after the retorting process was decreased as F-value was increased. However, the hardness of PRC after the pasteurization process was not significantly different from that of the control (Fig. 5a). Color differences were observed after both treatments, although the difference after pasteurization was much lower than that after the retort process (Fig. 5b).

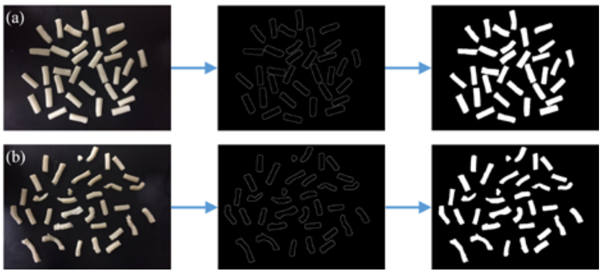


Figure 6: Image processing procedure of rice cake after (a) pasteurization and (b) retort sterilization.

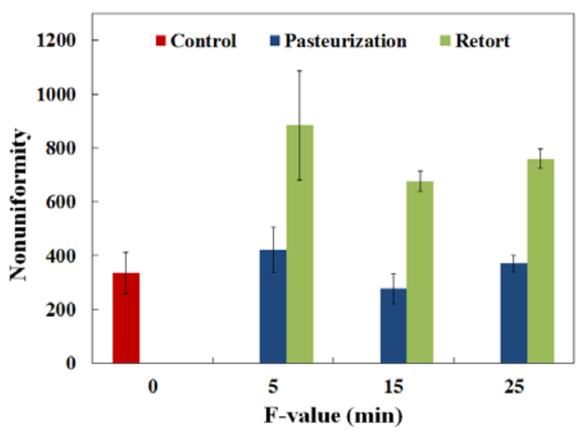


Figure 7: Results of image analysis on nonuniformity depending on F-value for each thermal processing condition (F_{95} and F_{121} for pasteurization and retort, respectively).

The shape of PRC after thermal treatment was evaluated by image analysis (Fig. 6). After retort sterilization, the shape of PRC was dramatically changed. Rice cakes were stuck together after this process. Dissolved starches in rice cakes at high temperature can leach out and act as glue between rice cakes (Iturriaga et al. 2006; Li et al. 2016; Palav and Seetharaman 2006). These changes in the shape of rice cake after thermal treatments were quantitatively analyzed by measuring non-uniformity based on image analysis data (Fig. 7). The non-uniformity was significantly increased after the retort process. However, the non-uniformity of PRC after pasteurization was close to that of the control. Thus, the quality of retorted PRC was significantly changed due to thermal degradation. Therefore, thermal treatment of PRC was limited to pasteurization and microbial safety of pasteurized PRC was comprehensively evaluated.

3.3. Exposure assessment

Microbial exposure assessment of pasteurized PRC was conducted to determine the risk of *B. cereus* in PRC. Contamination levels from the initial stage of processing to storage in consumers' place were simulated based on probability distribution models. Final contamination levels of *B. cereus* in B2C and B2B products were simulated by Monte Carlo simulation (Fig. 8). Minimum values (at 5% level) of B2B and B2C were 0.12 log CFU/g and 0.11 log CFU/g, respectively while maximum values (at 95% level) of B2B and B2C products were 7.80 log CFU/g and 7.77 log CFU/g, respectively. According to Notermans and Batt (1998), to assure safety during storage or distribution, *B. cereus* level should be lower than 4 log CFU/g. Probabilities of *B. cereus* levels in B2C and B2B products to be higher than this criterion (> 4log CFU/g) analyzed by Monte Carlo simulation were estimated to be 12.3% and 18.3%, respectively. These results suggest a high potential risk. Thus, it is highly necessary to improve inactivation and inhibition of the growth of *B. cereus* to ensure the safety of rice cake product.

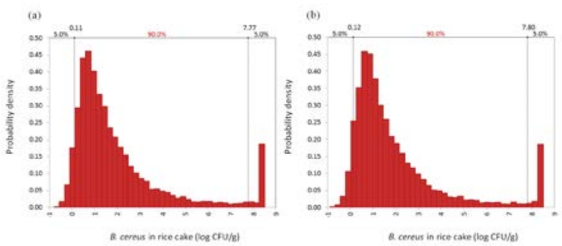


Figure 8: Monte Carlo simulation of final contamination levels of *B. cereus* in pasteurized rice cake with random packaging. (a) B2C and (b) B2B processes.

3.4. Case study

3.4.1. Effect of contamination level through operators during packaging and dimensions of packages on thermal processing

Two different packaging methods were applied in this study. Rice cakes were randomly packed with an automatic rotary packing machine or manually arranged to make a slab shape of package by operators. Randomly packed sample had an oval shap due to the thickness of the package. Temperature increase with this method was slower, especially in the early stage of thermal processing. However, heat transfer rate with slab shape package was faster than that with randomly packed method because the cold point in the slab shape of package was closer to the surface (Fig. 9a). F-values of these two packaging methods were analyzed (Fig. 9b). As shown in Fig. 9, the heating rate of sample with the slab shape of packaging was significantly higher than that with the randomly packaging method, resulting in different lethality under the same thermal processing condition. Hence, the effect of shape (or dimension) of the package on probability distribution of the final contamination level of *B. cereus* was simulated.

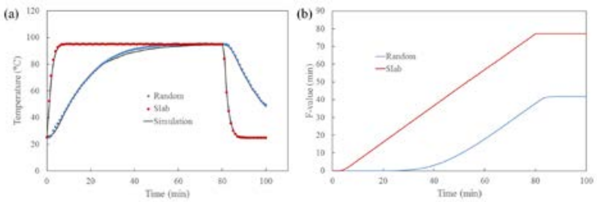


Figure 9: Results of (a) temperature history and (b) changes in the F-value during pasteurization with random and slab arrangement.

Although the initial contamination level of *B. cereus* in products was increased from 1.1 to 1.3 log CFU/g during packing manually by operators, median values of *B. cereus* were decreased from 1.28 to -2.26 log CFU/g and from 1.63 to -1.93 log CFU/g for B2C and B2B, respectively (Fig. 10). These results suggest that the slab shape packaging for thermal processing of rice cake could improve the safety of pasteurized rice cake products due to its effective heat transfer rate. However, probabilities for B2C and B2B processes to contain *B. cereus* at more than 4 log CFU/g were 5.20% and 7.30%, respectively. This means that the process still poses some potential risk.

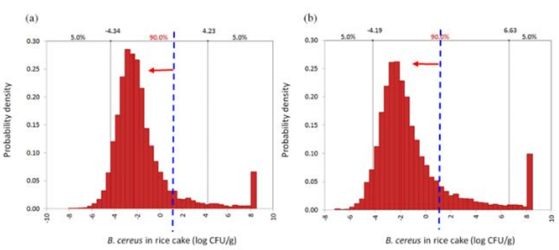


Figure 10: Monte Carlo simulation of final contamination levels of *B. cereus* in pasteurized rice cake with slab arrangement. (a) B2C and (b) B2B processes.

3.4.2. Effect of acidification after pasteurization on shelf-life of B2C and B2B products

Generally, acidification can inhibit the growth of *B. cereus* or inactivate it (Carlin et al. 2013; Luu-Thi et al. 2014). Effect of acidification and the shape of packages on median values of contamination levels of *B. cereus* after pasteurization were analyzed. The slap shape packaging method in which rice cakes were manually rearranged showed a median contamination level of *B. cereus* ranging from 0.356 log CFU/g to -3.31 log CFU/g after thermal treatment. Such a high reduction rate might be due to high inactivation rate of *B. cereus* associated with a high heating rate observed in the slab package. When acidification was added to thermal treatment, the median value of *B. cereus* after thermal treatment was reduced to -5.08 log CFU/g. This might be because thermal resistance of *B. cereus* was reduced after acidification (pH 5.0) (Luu-Thi et al. 2014). Monte Carlo simulation was conducted to estimate final contamination levels of *B. cereus* with slab arrangement and acidification in B2C and B2B products (Fig. 11). Maximum levels of *B. cereus* in B2C and B2B products at 95% level were -0.67 log CFU/g and 0.43 log CFU/g, respectively. These results imply that the safety of PRC is more stable after a combination of acidification and thermal treatment (i.e., pasteurization). Thus, lower temperature pasteurization with acidification is a useful thermal technique to assure the safety of PCR for both B2C and B2B products.

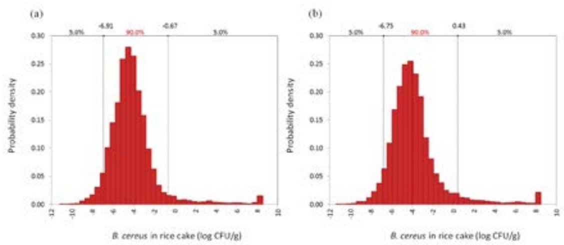


Figure 11: Monte Carlo simulation of final contamination levels of *B. cereus* in pasteurized rice cake with slab arrangement and acidification. (a) B2C and (b) B2B processes.

4. CONCLUSION

QMEA models of PRC for both B2C and B2B products were developed using CFD and Monte Carlo simulation. Probability distributions for the growth of *B. cereus* in PRC were estimated. Effects of thermal processing and acidification on extending the shelf-life of PRC were also quantitatively assessed. High temperature sterilization (i.e., the retort process) showed better sterilization effect than the pasteurization process. However, it degraded the quality of rice cakes more. The initial contamination level of *B. cereus* in randomly packed PRC sample was lower than that in slab shape packed PRC sample in which the rice cakes were manually rearranged by operators. However, due to faster heating rate in the slab shape packed sample, PRC showed better microbial stability. Acidification significantly inhibited the growth of *B. cereus*. It also the inactivated *B. cereus*. A combination of acidification and low temperature pasteurization extended the shelf-life of PRC while causing minimum quality changes of products.

ACKNOWLEDGMENTS
This work was carried out with the support of "Cooperative Research Program for Agricculture Science & Technology Development (Project No. PJ012844022017)" Rural Development Administration, Republic of Korea.

REFERENCES
Afchain, A.L., Carlin, F., Nguyen-the, C., Albert, L., 2008. Improving quantitative exposure assessment by considering genetic diversity of *B. cereus* in cooked, pasteurised and chilled foods. International Journal of Food Microbiology, 128, 165-173.

Bahk, G., Todd, E.C.D., Hong, C., Oh, D., Ha, S., 2007. Exposure assessment for *Bacillus cereus* in ready-to-eat Kimbab selling at stores. Food Control, 18, 682-688.

Biglow, W.D., Bohart, G.S., Richardson, A.C., Ball, C.O., 1920. Heat Penetration in Processing Canned Foods. Bulletin No. 16-L, Res. Lab. National Canners Association, Washington, DC.

Carlin, F., Albagnac, C., Rida, A., Guinebretiere, M., Couvert, O., Nguyen-the, C., 2013. Variation of cardinal growth parameters and growth limits according to phylogenetic affiiliation in the *Bacillus cereus* Group. Consequences for risk assessment. Food Microbiology, 33, 69-76.

Daelman, J., Membre, J., Jacxsens, L., Vermeulen, A., Devlieghere, F., Uyttendaele, M., 2013. A quantitative microbiological exposure assessment model for *Bacillus cereus* in REPFEDs. International Journal of Food Microbiology, 166, 433-449.

Deboosere, N., Pinon, A., Delobel, A., Temmam, S., Morin, T., Ghislaine, M., Blaise-Boisseau, S., Perelle, S., Vialette, M., 2010. A predictive microbiology approach for thermal inactivation of Hepatitis A virus in acidified berries. Food Microbiology, 27(7), 962-967.

Delignette-Muller, M.L., 1998. Relation between the generation time and the lag time of bacterial growth kinetics. International Journal of Food Microbiology, 43, 97-104.

De Vriese, S., De Backer, G., De Henauw, S., Huybrechts, I., Kornitzer, M., Leveque, A. Moreau, M., Van Oyen, H., 2005. The Belgian food consumption survey: aims, design and methods." Archives of Public Health, 63, 1-17.

Eccles, M.V., 1956. Hand volumetics. The British Journal of Physical Medicine: including its application to industry, 19(1), 5.

Granum, P.E., Lund, T., 1997. *Bacillus cereus* and its food poisoning toxins. FEMS Microbiology, 157, 223-228.

Hong, Y.K., Huang, L., Yoon, W.B., Liu, F., Tang, J., 2016. Mathematical modeling and Monte Carlo simulation of thermal inactivation of non-proteolytic Clostridium botulinum spores during continuous microwave-assisted pasteurization. Journal of Food Engineering, 190, 61-71.

Hong, Y.K., Uhm, J., Yoon, W.B., 2014. Using numerical analysis to develop and evaluate the method of high temperature Sous-Vide to soften carrot texture in different-sized packages. Journal of Food Science, 79(4), E546-E561.

ICMSF., 1996. Microorganisms in Foods. Blackie Academic and Professional, London, pp 513.

Iturriaga, L.B., de Mishima, B.L., Anon, M.C., 2006. Effect of amylose on starch pastes viscoelasticity and cooked grains stickiness in rice from seven argentine genotypes. Food Research International, 39, 660-666.

Jeong, S. Choi, S., Cho, J., Lee, S., Hwang, I., Na, H., Oh, D., Bahk, G., Ha, S., 2012. Microbiological contamination levels in the processing of Korea rice cakes. Journal of Food Hygiene and Safety, 27(2), 161-168.

Kang, H.J., Lee, J.K., Lim, J.K., 2012. Quality characteristics of *Topokki Garaedduk* with different moisture ratios. Journal of Korean Society of Food Science and Nutrition, 41(4), 561-565.

Kang, K., Kim, Y., Yoon, K., 2010. Development of predictive growth models for *Staphylococcus aureus* and *Bacillus cereus* on various food matrices consisting of ready-to-eat (RTE) foods. Korean Journal for Food Science of Animal Resources, 30(5), 730-738.

Kim, J., Chung, H., Choi, S., Eun, J., 2016. Effect of retort sterilization on microbial safety and quality characteristics of a rice cake, *songpyeon*. Food Science and Biotechnology, 25(4), 1047-1052.

Kramer, J.M., Gillbert, R.J., 1989. *Bacillus cereus* and other *Bacillus* species. In *Foodborne Bacterial Pathogens*, (Doyle, M.P., ed.) pp. 21-70. Marcel Dekker, New York.

Lee, M.G., Yoon, W.B., 2014. Developing an effective method to determine the deviation of *F* value upon the location of a still can during convection heating using CFD and subzones. Journal of Food Process Engineering, 37(5), 493-505.

Lee, M.G., Yoon, W.B., 2016. Developing an effective method to determine the heat trnasfer model in fish myofibrillar protein paste with computer simulation considering the phase transition on various dimensions. International Journal of Food Engineering, 12(9), 493-505.

Li, H., Prakash, S., Nicholson, T.M., Fitzgerald, N.A., Gilbert, R.G., 2016. The importance of amylose and amylopectin fine structure for textural properties of cooked rice grains. Food Chemistry, 196, 702-711.

Lund, D.B., 1975. Heat processing. In: Karel, M., Fennema, O.R., Lund, D.B. (Eds.), Principles of Food Science Part II: Physical Principles of Food Preservation. Marcel Dekker, New York, pp. 31-92.

Luu-Thi, H., Khadka, D.B., Michiels, C.W., 2014. Thermal inactivation parameters of spores from different phylogenetic groups of *Bacillus cereus*. International Journal of Food Microbiology, 189, 183-188.

Mafart, P., Leguerinel, I., 1998. Modeling combined effects of temperature and pH on heat resistance of

spores by a linear bigelow equation. Journal of Food Science, 63(1), 6-8.
Mazas, M., Martinez, S., Lopez, M., Alvares, A.B., Martin, R., 1999. Thermal inactivation of *Bacillus cereus* spores affected by the solutes used to control water activity of the heating medium. International Journal of Food Microbiology, 53, 61-67.
Meija, S.Z., Beumer, R.R., Zwietering, M.H., 2011. Risk evaluation and management to reaching a suggested FSO in a steam meal. Food Microbilogy, 28, 631-638.
Mellefont, L.A., Ross, T., 2003. The effect of abrupt shifts in temperature on the lag phase duration of *Escherichia coli* and *Klebsiella oxytoca*. International Journal of Food Microbiology, 83, 295-305.
Na, Y., Jung, J., Lee, J., Oh, H., Park, Y., Cho, D., Lee, T., Cho, S., 2014. Menu development and market testing for localization of fermented meat tteokbokki in foregn markets. The Korean Journal of Culinary Research, 20(2), 183-198.
Nauta, M.J., 2001. A modular process risk model structure for quantitative microbiological risk assessment and its application in an exposure assessment of *Bacillus cereus* in a REPFED. RIVM Report 149106007.
Nauta, M.J., Litman, S., Barker, G.C., Carlin, F., 2003. A retail and consumer phase model for exposure assessment of *Bacillus cereus*. International Journal of Food Microbiology, 83(2), 205-218.
Notermans, S., Batt, C.A., 1998. A risk assessment approach for food-borne *Baccillus cereus* and its toxins. Journal of Applied Microbiology, 84, 51S-61S.
Palav, T., Seetharaman, K., 2006. Mechanism of starch gelatinization and polymer leaching during microwave heating. Carbohydrate Polymers, 65, 364-370.
Palisade Corporation., 2002. *Guide to Using @Risk*. Palisade Corporation, Newfield, NY, USA.
Robinson, T.P., Ocio, M.J., Kaloti, A., Mackey, B.M., 1998. The effect of the growth environment on the lag phase of *Listeria monocytogenes*. International Journal of Food Microbiology, 44, 83-92.
Rosso, L., Lobry, J.R., Bajard, S., Flandrois, J.P., 1995. Convenient model to describe the combined effects of temperature and pH on microbial growth. Applied and Environmental Microbiology, 61, 610-616.
Scallan, E., Robert, M.H., Frederick, J.A., Robert, V.T., Marc-Alain, W., Sharon, L.R., Jeffery, L.J., Patricia, M.G., 2011. Foodborne illness acquired in the United States-major pathogens. Emerging Infectious Diseases, 17(1), 7-15.
Shin, D., Kim, H., Hong, H., Oh, S., Yoo, S. 2014. The effects on the quality of *Tteokbokki* tteok by different types cultivars of rice. Korean Journal of Food and Cookery Science, 30(3), 271-277.
Stringer, S.C., Webb, M.D., Peck, M.W., 2009. Contrasting effects of heat treatment and incubation temperature on germination and outgrowth of individual spores of nonproteolytic *Clostridium botulinum* bacteria. Applied and Environmental Microbiology, 75, 2712-2719.
Swinnen, I.A.M., Bernaerts, K., Dens, E.J.J., Geeraerd, A.H., Van Impe, J.F., 2004. Predictive modelling of the microbial lag phase: a review. International Journal of Food Microbiology, 94, 137-159.
Wang, J., Ding, T., Oh, D., 2014. Effect of temperatures on the growth, toxin production, and heat resistance of *Bacillus cereus* in cooked rice. Foodborne Pathogens and Disease, 11(2), 133-137.
Wang, J., Park, J., Choi, N., Ha, S., Oh, D., 2016. Microbiological analysis of rice cake processing in Korea. Journal of Food Protection, 79(1), 157-162.
WHO Surveillance Programme., 1992. *Fifth Report of WHO Surveillance Programme for Control of Foodborne Infections and Intoxications in Europe*, 1989-1989. Berlin, Institute of Veterinary Medicine.

AUTHORS BIOGRAPHY

Hyeon Woo Park is a second-year graduate student in Food Science and Biotechnology at Kangwon National University (KNU) in South Korea. He received his Bachelor’s Degree in Food Science and Biotechnology from the Kangwon National University in 2015. His research interests include process optimization and new process design, surimi and surimi seafood processing and numerical and CFD simulation.

Dr. Yoon is a professor at Kangwon National University (KNU) since 2008. He has a unique academic background. He has a B.S. and M.S. in Food Science and Technology, and M.E. in Mechanical Engineering, and a Ph.D. major in Biological Systems Engineering and minor in Chemical Engineering. Before joining KNU, he worked in a processed food industry (associate director in Food R&D Center, CJ CheilJedang, Seoul, S. Korea) and a flavor company (Asia-Pacific regional marketing manager and Seafood specialist, Firmenich-Asia, Singapore). He has been working on food process engineering, food rheology and seafood processing for more than 17 years. His research interest includes gelation characterization of proteins and hydrocolloids, drying and powdering, high viscous fluid mechanics, heat and mass transfer during food processing, least cost formulation development, and computational fluid dynamics. He has so far published more than 100 articles in highly regarded journals in the field of food process engineering. In addition, he has coauthored a chapter of Surimi Paste Preparation, Gel Analysis, and Rheology in the 3rd Edition of Surimi and Surimi Seafood.

SIMULATION IN FOOD CATERING INDUSTRY. A DASHBOARD OF PERFORMANCE INDICATORS

Alessandro Tufano[(a)], Riccardo Accorsi[(b)], Andrea Gallo[(c)], Riccardo Manzini[(d)]

[(a) (b) (c) (d)]Department of Industrial Engineering (DIN), Alma Mater Studiorum - University of Bologna, Viale del Risorgimento, 2, 40122 – Bologna – Italy
[(a)]alessandro.tufano2@unibo.it, [(b)]riccardo.accorsi2@unibo.it, [(c)]andrea.gallo7@unibo.it
[(d)]riccardo.manzini@unibo.it

ABSTRACT
Contract catering industry is concerned with the production of ready-to-eat meals for schools, hospitals and private companies. The structure of this market is highly competitive, and customers are rarely willing to pay a high price for this catering service. A single production sites may be demanded up to 10.000 meals per day and these operations can hardly be managed via rule of thumbs without any quantitative decision support tool. This situation is common at several stages of a food supply chain and the methodologies presented in this paper are addressed to any food batch production system with similar complexity and trade-offs.

This paper proposes an original KPI dashboard, designed to control costs, time and quality efficiency and helping managers to identify criticalities. Special emphasis is given on food safety control which is the management's main concern and must be carefully monitored in each stage of the production. To calculate the value of KPIs a Montecarlo simulation approach is used to deal with production complexity and uncertainty.

A case study showcases the potential of simulation in this complex industrial field. The case study illustrates an application of the methodology on an Italian company suffering local recipe contamination. The company aims at defining the best standard for production, identifying cycles being sustainable from an economic and environmental point of view.

Keywords: food service industry, Montecarlo simulation, production process evaluation

1. INTRODUCTION

Contract catering industry is concerned with the production of ready-to-eat meals for schools, hospitals and private companies (Fusi, Guidetti, and Azapagic 2015). The structure of this market is highly competitive, and customers are rarely willing to pay a high price for this catering service (Europe Food Service 2017). This is the reason why meals should be cheap to maintain competitive advantage on the market. On the other side, regulatory authority imposes tight food safety norms to respect in order to preserve food from bacteria contamination (Jacxsens et al. 2011). Once cooked, ready-to-eat meals must have a temperature within the range 10-65°C until consumption (European Parliament 2004). The application of these rules leads to higher production costs which may become out-of-control if production activities are not carefully designed and monitored. Within this cost-quality trade-off, companies' managers contrive ploys to reduce lead times, increase quality and decrease production costs (Taylor 2008).

Despite their efforts, when complexity rises, a single production sites is demanded up to 10.000 meals per day to gain economies of scale. These operations can hardly be managed via rule of thumbs without aid of quantitative decision support tools. This situation is common at several levels of a food supply chain, for this reason this paper presents a quantitative methodology addressed to any food batch production system with high complexity and cost quality trade-offs aiming at the benchmarking and measurement of its production processes.

In facilities with these characteristics, the plant layout is often job-shop organized and an intense manual material handling flow complicates the daily organization of the production activities (Penazzi et al. 2017). The operations in a contract catering production site is similar to an assembly line where sequential tasks assemble raw materials and semi-finished. Nevertheless, the layout is organized, for regulatory reasons, into sequential departments processing raw materials (i.e. ingredients) and transforming them into finished products.

The production of a finished product is defined by its production cycle (i.e. the recipe) composed by a sequence of tasks (e.g. boil water, add pasta, retrieve pasta, add sauce). Production machines are designed to perform more than a single type of task and, in practice, the assignment of tasks to machine is randomly managed by operators during the daily production. A consistent degree of uncertainty is connected with the choice of the machine. Nevertheless, this choice directly affects production cost, production time, and energy consumption and indirectly reflects on the product quality and safety (i.e. temperature). For this reason, a technology should consider the assignment issue during process design and the decision should not be taken by an operator. To pinpoint production complexity and variability, Figure 1 introduces the six production steps located into six different department of a generic contract

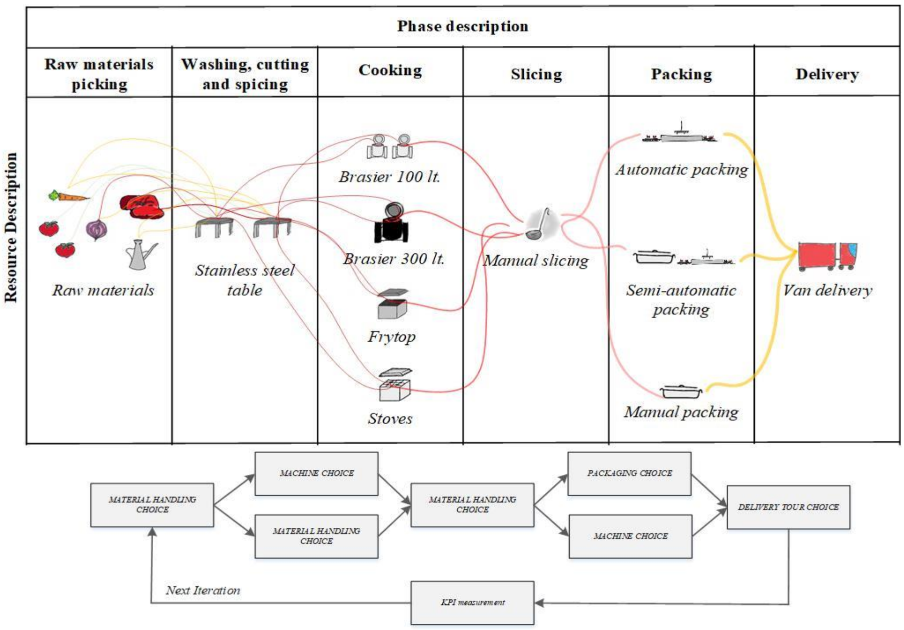


Figure 1: Production stages and variability in the use of resources

catering production plant. For each of these steps, there are alternative resources and connected decisions presented in the flow chart. Raw materials are picked from warehouse or refrigerated cells and thawed if needed. The following step is in the pre-cooking department where ingredients are washed, cut and spiced. These activities are usually manual and labour-intensive, and few variabilities occur in the use of resources. Processed ingredients are cooked in the cooking area where several resources are often able to perform the same task. Once cooked, the production batch is sliced into single or multi portion and packed manually or using automated packing lines. Before and after packing, hot meals wait into hot-holding machine to avoid temperature loss which increases the probability of bacterial contamination. When a whole order is completed, it is loaded into a van for the delivery to final consumer. Each of these steps contribute to time, quality and cost efficiency of a finished product.

To benchmark performance of such complex production systems, Montecarlo simulation is chosen as methodology since simulation approaches have already been demonstrated to be powerful tools when applied to food industry. Discrete event simulation is used to approach supply chain design problem (Mittal and Krejci 2017; Jansen et al. 2001), plant design (Elmasry and Tarek 2016) and resources scheduling (Pérez-Rodríguez et al. 2014). All these problems are logistics oriented and cover all the aspect from production to storage and distribution.

On the other side, typical processing simulation approach in the food industry aims at the definition of the transformation of the product during a single production task (Mullineux and Simmons 2007). Simulation modeling and virtualization are used to set the best production parameters (e.g. speed, temperature) on a single processing machine (Huda and Chung 2002; Erdogdu, Sarghini, and Marra 2017; Lemus-Mondaca, Vega-Galvez, and Moraga 2011). These problems are technology oriented and aims at the description and prediction of the behavior of a product before and after a transformation.

Montecarlo simulation is usually linked with the estimation of risk or costs and, for the sake of our knowledge, its application is novel in the food industry. A search in the Ei Compendex for articles mentioning "*montecarlo simulation*" and *"food industry"* return no results. The only utilization of Montecarlo simulation in a food context is found in (Medina-Marin et al. 2011) where Montecarlo simulation is used to define the capacity of a production plant. The authors consider this methodology suitable for an intermediate approach between logistics and technological aspects, aiming at the measurement of both technological parameters (i.e. the pre- and post-processing temperature) and logistics indicators (i.e. cost, time, energy environmental impact). Montecarlo simulation is, then, used as a methodology to deal with job-shop complexity aiming at populating an original KPI dashboard. This dashboard is designed to control costs, time and quality helping managers to identify critical production task and processes. Special emphasis is given on food safety control which is the management's main concern and must be carefully monitored in each stage of the production.

The proposed methodology addresses the following unsolved research questions.
RQ1: Which are the relevant parameters to control in catering production?

RQ2: How much these parameters affect the performance of a catering production system?

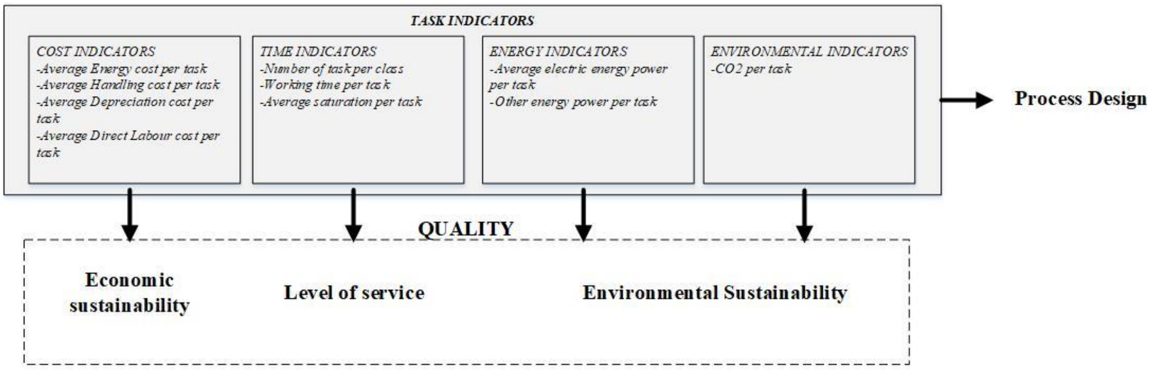


Figure 2: KPIs dashboard

RQ3: How can be the variability of cooking process be measured and controlled to preserve food safety?

A case study showcases the potential of simulation in this complex industrial field. The case study illustrates an application of the methodology on an Italian company suffering local recipe contamination. This is a typical phenomenon for which the same preparation has different recipes depending on the regional or provincial influences. This is unaffordable and not recommendable for an industrial context since it leads to a multitude of heterogeneous processes distributed on a large production network. To research the best standard recipe for each preparation, the company needs to identify which process has the best cost, time and quality performances.

The remainder of this paper is organized as follows: Section 2 presents the KPI dashboard to identify the relevant parameters to measure. Section 3 introduces the Montecarlo simulation algorithm. Section 4 sets major attention on the case study covering from data collection to simulation and interpretation of the results. Finally, the implications of this works are discussed in Section 5 and Section 6 concludes the paper.

2. KPI DASHBOARD

This section introduces a dashboard of indicators to benchmark performances of a food service industry. The main focus is the production task i.e. a single and individual activity performed by an operator (e.g. boil, grill, bake). It is important to define and classify tasks which compose a production cycle (i.e. a recipe) to assess its performance and identify areas of improvement.
Figure 2 introduces the dashboard which is organized into four main assessment groups:

1. cost indicators,
2. time indicators,
3. energy indicators,
4. environmental indicators.

Cost indicators count four cost items (i.e. energy, handling, depreciation and direct labor) aiming at the measurement of the economic sustainability of the production. Time indicators are linked with the level of service delivered to the customers and measures the number of cycles (i.e. the number of times machines are used for a given task), the machine saturation and the overall working time for each task. Energy and environmental indicators describe the energy absorption and the consequent environmental impact for each task. Table 1 introduces the notation used to calculate KPIs and summarizes all the KPIs of the dashboard with formulae and units of measure.
The evaluation of this dashboard allows comparing different production cycles from four points of view. The dashboard is designed for this purpose and aids technologists to design production cycles with respect of economic and environmental sustainability and a given level of service to deliver to the final consumer.

3. METHODOLOGY

The aforementioned dashboard embeds deterministic indicators. In practice, many operational decisions (e.g. each operator independently chooses which quantity and which machine to use) affect these indicators and it is difficult to determine an exact value of a KPI. For this

Table 1: KPI notation and definition

Notation	KPI	Formulae
$T = set\ of\ tasks.\ i \in T, i = 1, \dots, n$		
$M = set\ of\ machines.\ j \in M, j = 1, \dots, k$		
$H = time\ horizon\ considered.\ t \in H, t = 1, \dots, m$		
$c_{en}^{el} = cost\ of\ 1\ kWh\ of\ electric\ power$ [€]	Energy cost per task:	$\frac{t_i}{60} \cdot (c_{en}^{el} \times k_i^{el} + c_{en}^{gas} \times k_i^{gas})$
$c_{en}^{gas} = cost\ of\ 1\ kWh\ of\ thermal\ power$ [€]		
$c_{dl} = direct\ labour\ cost\ per\ hour$ [€]	Handling cost per task:	$\frac{t_i^h}{60} \cdot c_{dl}$
$c_{dp} = cost\ (depreciation)\ per\ hour\ of\ machine$ [€]	Depreciation cost per task:	$\frac{t_i}{60} \cdot c_{dp}$
$t_i = working\ time\ of\ a\ task\ [min]$	Direct labour cost per task:	$\frac{t_i}{60} \cdot c_{dl}$
$d_i = traveled\ distance\ to\ perform\ task\ i$	Number of task per class:	$\sum_{t=1}^{m} n_{i,t}$
$t_i^h = handling\ time\ of\ a\ task\ [min]$	Working time per task:	$\sum_{i=1}^{n} n_{i,t} \cdot t_i$
$c_{en} = cost\ of\ 1\ kWh\ of\ energy$	Saturation per task:	$\frac{1}{k}\sum_{j=1}^{k} p_{i,j}$
$n_{i,t} = number\ of\ task\ type\ i\ processed\ in\ the\ time\ horizon\ t$	Electric energy power per task:	$\sum_{i=1}^{n} n_{i,t} \cdot k_i^{el}$
$k_i^{el} = eletric\ power\ to\ perform\ task\ i\ [kWh]$	Gas energy power per task:	$\sum_{i=1}^{n} n_{i,t} \cdot k_i^{gas}$
$k_i^{gas} = thermal\ power\ to\ perform\ task\ i\ [kWh]$	CO2 per task:	$\sum_{i=1}^{n} n_{i,t} \cdot (q^{el} \times k_i^{el} + q^{gas} \times k_i^{gas})$
$q^{el} = CO2\ per\ kWh\ of\ electricity\ [Kg]$		
$q^{gas} = CO2\ per\ kWh\ of\ gas\ [Kg]$		
$p_{i,j} = percentual\ saturation\ to\ perform\ task\ i\ on\ machine\ j$		

reason, a Montecarlo simulation approach is introduced to model processes variability and calculate KPI values dealing with their degree of uncertainty. A simulator developed in C# .NET randomly virtualizes operator's decisions and iteratively assess the value of each KPI of the dashboard. At the end of the simulation, statistics are collected, and the dashboard is populated. The simulator is designed for a job-shop production where a machine is able to perform more than a single type of task. These machines may have a different investment cost, a different capacity and a different position on the plant layout. These parameters affect both logistics and technological performance. The simulator needs the following inputs:

- a list of recipes to realize within a given time horizon;
- a list of sequential tasks for each recipe;
- a set of resources and their position on the plant layout,
- a set of rules defining all the tasks a resource may perform.

Each iteration of the simulator generates the following output:

- distance d_i travelled between pairs of control points,
- working time t_i spent on a single machine to perform a task
- handling time t_i^h spent in travelling and picking activities
- machine saturation p_{ij} for each task

Cost, time, energy and environmental KPIs are defined based on these values considering the parameters introduced in Table 1. Figure 3 defines the pseudocode of the Montecarlo simulation algorithm.

```
Initialize;
Set z = number of iterations;
r_l, l = 1, ..., p recipe ∈ R;
ct_il, i = 1, ..., n task ∈ T if i ∈ recipe l ; 0 otherwise;
m_j, j = 1, ..., m machine ∈ M;
k_ij = 1 if machine j is able to perform task i ; 0 otherwise;
while R not empty do
    pick _l ∈ R;
    for q ← 1 to z do
        for i ← 1 to |T_l > 0| do
            find list of m_j ∈ M|k_ij = 1;
            randomly select a value of j in the list;
            identify the previous control point of cp_f;
            identify the control point cp_t where m_j is placed;
            Set d_i = distance from the previous control point;
            Set t_i = working time of task i ;
            Set t_i^h = handling time of task i ;
            Set p_ij = percentual saturation of machine j ;
            Update statistics ;
        end
        Print statistics for recipe i;
    end
end
for i ← 1 to n do
    Aggregate statistics for task i;
    Print statistics for task i;
end
```

Figure 3: Simulation pseudo-code algorithm

After a number of iteration defined by the user, mean value μ_i and standard deviation σ_i is defined for each production task i as statistics of all the tasks of the same class performed in all the simulated recipes. The dashboard and the Montecarlo simulation have been validated on a real case study with encouraging results.

4. CASE STUDY

The aforementioned KPI dashboard has been implemented to assess the performance of production processes in a facility of a food service network with about 50 production plants located in Italy. The company was interested in the identification of critical tasks, where criticality is based on:

- cost reasons, i.e. to perform the task it is economically inconvenient;
- time reasons, i.e. the time required by production for a task is so high that it becomes a bottleneck of the production system.
- quality reasons, i.e. the task may significantly affect the degree of safety of the finished product and must be carefully monitored.

The output of the study aids the research and development department of the company in the re-design of production processes aiming at enhancing the economic sustainability of the operations, the quality and the level of service offered to the final consumer.

The case study focuses on a production facility delivering about 10.000 meals per day located in northern Italy whose main customers are schools located in the nearby area (up to 20 km from the production site). School are very demanding since children should have lunch within a precise time window and delays must be avoided or they lead to a great social resonance with negative implication for the reputation of the company. The analyzed facility is about 25 years old and a frequent rotation of the customers portfolio in the years causes technical obsolescence of the production machines and unsuitableness of the production processes unable to satisfy a complex and heterogeneous customer demand. For these reasons, the company decides to completely redesign the facility providing a new production site with new assets and processes to gain competitive advantage on their business.

As a first phase of the study, a classification of the existing production processes is needed. For this reason, an on-field *time and motion* monitoring campaign aim at the definition of production tasks and at measuring processing times and quantities. As a result of the campaign, a list of 90 tasks is deduced by the explanation of cooking operators describing their version of each recipe and a list of tasks is associated to each finished product. Each task is characterized by a processing time and a type of machine used by the operator. The monitoring campaign unveils a discrete degree of uncertainty in the choice of the machine for the completion of a task. This fact happens randomly, and no rule of thumbs exist to suggest which machine is suitable the most to perform a given task. The outcome is an irregular utilization of resources with production cost and processing time out of control.

The data from the monitoring campaign feeds the Montecarlo simulation algorithm and allows to investigate time and cost bounds of the extant process. The Montecarlo simulation run for about 2 minutes generating 100 iterations of the considered instance: for each task a mean processing time is deduced, and a confidence interval is defined. The same rationale is used to evaluate the aforementioned cost items (i.e. energy, handling, depreciation and direct labor) linked to each task.

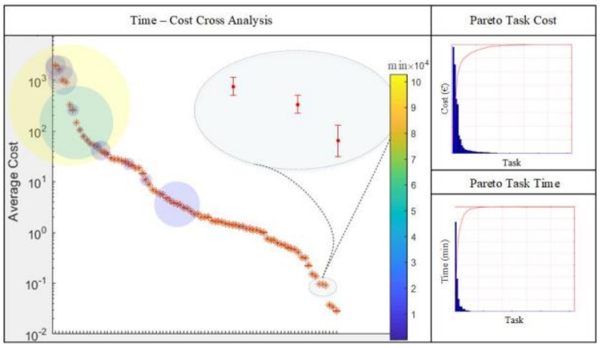


Figure 4: Cost and time cross analysis

Figure 4 presents a cross-representation of cost and time performance for each of the 90 tasks. X-axis represents tasks while y-value of the red markers describes the average cost (i.e. €) to produce one unit of finished product. For each marker a bubble contour defines the total time to complete a production plan of a week, expressed in minutes. Finally, a boxplot describes the cost variability bounds. The analysis indicates that, except for one case, tasks requiring a large amount of time are critical in cost too. These tasks are connected to cooking operations (braise and boil) or handling of ingredients and cooking or packaging tools. The pareto analysis shows how 3 out of 90 type of tasks account for 90% of the total production costs and processing time.

Time data match with the technical data sheets of production assets to evaluate energy consumption (expressed in kWh). Energy consumption depends on the type of energy power supply of the machine which may be electricity or gas depending on the cooking technology. Considering the energy production mix, the average environmental impact is expressed in kg of CO_2 and assessed for each task. Tasks requiring more power are identified and the environmental impact of each task is defined consequently (see Figure 5). This information is used to plan the energy consumption of the production facility and to make final consumers aware of the environmental impact of what they decide to eat every day.

Cost, time, energy and environmental indicators implicitly defines the degree of quality of the finished product. Some task out of the 90 defined with the first monitoring campaign, are critical for the HACCP protocol. They are: slicing, packing, consolidation and delivery. The time spent in these tasks defines a temperature loss and a consequent amount of energy is necessary in hot-holding to maintain meals at a safe temperature. To identify recommendable duration times for each of these tasks a second monitoring campaign has been set to profile the temperature decay of four product families (i.e. pasta, meat, steamed vegetables and cold dishes) at each of these tasks. The operating temperature conditions have been replicated to measure the

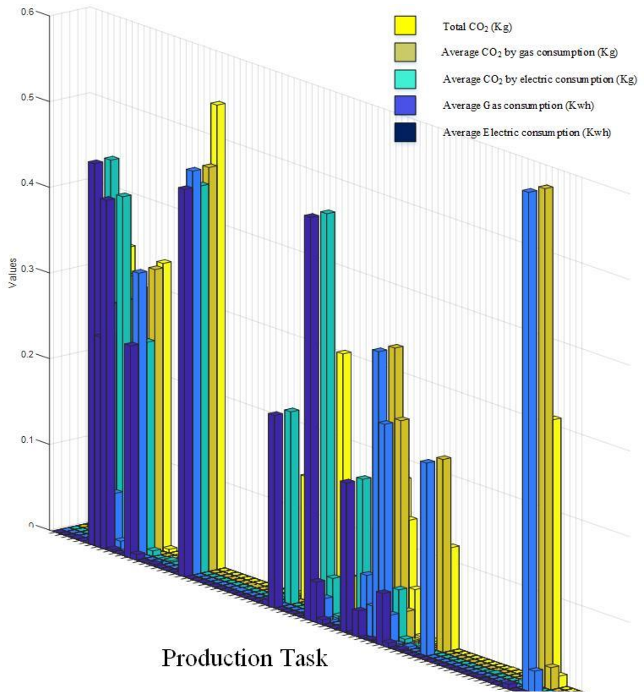


Figure 5: Energy and environmental impact indicators

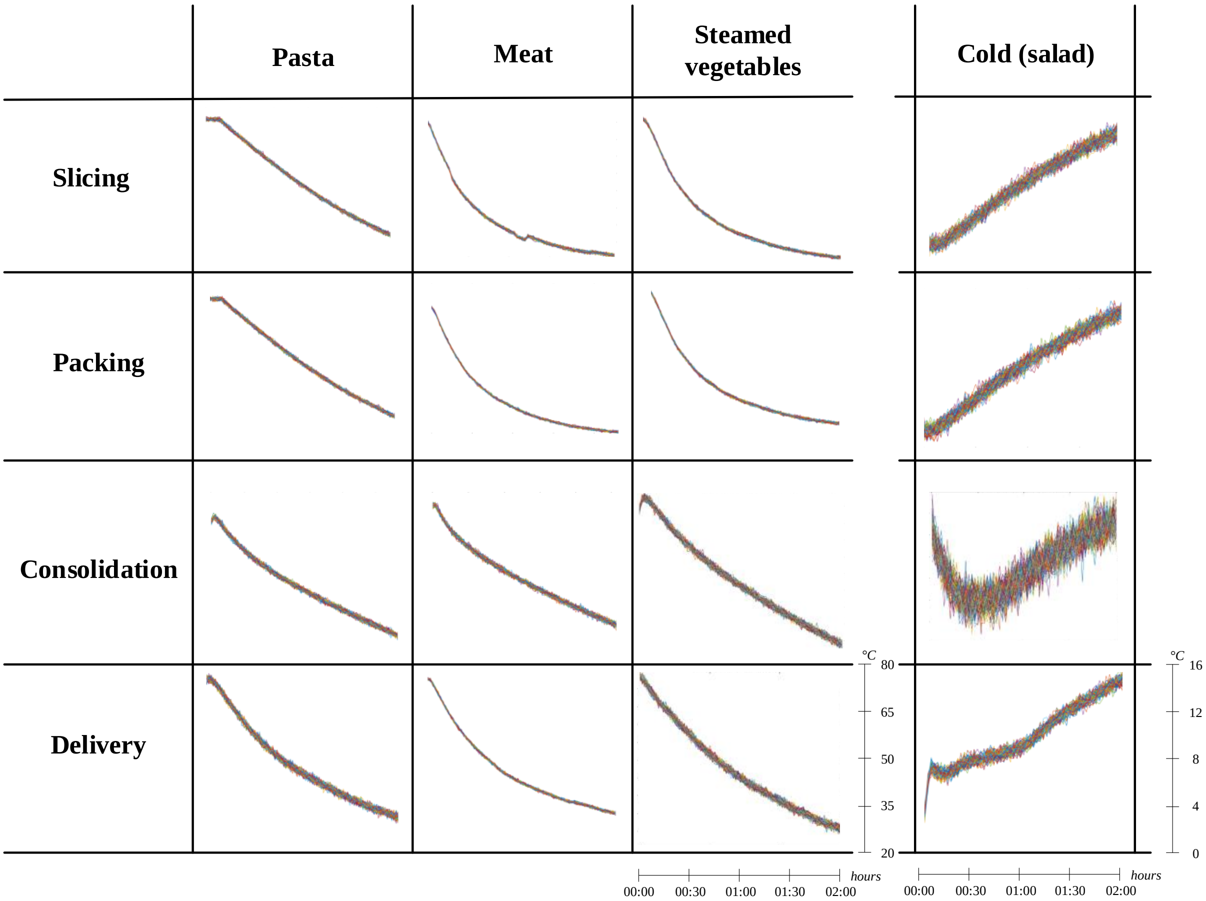


Figure 6: Monitored temperature profile per task and product family

temperature decay of a product performing a task for a very long time (e.g. 2 hours) compared to processing times measured during the first campaign. The result is, then, used to identify a maximum duration for each task corresponding to the maximum affordable temperature loss for that product during that task. Tasks are processed in department with a different room temperature and with different decay profiles. As a consequence, some tasks result critical only for a subset of product families. Figure 6 presents the result of the second monitoring campaign on the product families and the four critical tasks revealing the temperature decay profile for each pair task-product family. Montecarlo approach is used to model a temperature decay with sample from several observation for each decay profile. This information is a starting point to identify the maximum recommendable duration time for each task. For example, the slicing task of pasta may last up to 20 minutes before the product reaches the critical temperature around 65°C. On the other side, slicing of meat should only last 10 minutes not to incur in critical temperatures. After each of these tasks, a hot-holding phase is needed to recover the product at a safe temperature waiting for the following task. The same rational is used for the cold products which may stay behind 10°C to avoid the danger temperature zone. A profile of a cold product (i.e. salad) is presented in the last column of Figure 4. The Montecarlo simulation is here used to analyze different monitored profiles and identify a risk region in which the product should fall after a given task duration. The technologist is, then, in charge to define how much big is the risk the company may afford to take and consequently define the maximum duration for each task.

5. DISCUSSION

The case study pinpoints how the indicators of the dashboard can be used for process design and control in food catering industry. The four families of indicators of the dashboard are strictly linked, and trade-offs are found between cost, time, energy and environmental impact of a production task. By controlling these indicators, it is possible to define benchmarks for each production cycle and compare similar tasks aiming at the definition of the best production standard (RQ1). The outcome of these indicators are the economic and environmental sustainability and the level of service delivered to the final consumer. Above all, the degree of quality is linked with the values of the KPIs since major investments and processing time (e.g. for hot-holding) may increase the degree of quality. The definition of standard processing time for slicing, packing and delivery tasks allows decision makers to estimate production cost and safety risks maintaining competitive economic edges and complying with HACCP regulation and hygiene controls (RQ2). Montecarlo simulation is a suitable methodology to model risk predicting which will be the expected temperature after a given time horizon. This has been used to set limits to processing time of task which previously has undefined duration (RQ3).

In addition to this, the analysis of the dashboard on single processing task uncovers interesting consideration to design food service operations. Considering task descriptions in Figure 5, cooking tasks result to be always over-demanded compared with other types and this lead the system to predictable bottlenecks. For this reason, it is a good practice for menu designer and production scheduler to avoid using the same resource for too many products on the same shift. Developing rule of thumbs to differentiate the request of resources may help to smooth production operations avoiding the duplication of the number of asset (e.g. a portion of the meals are cooked in steamers, another portion in the boilers). The analysis of the temperature profiles identifies prioritization rules for critical product families on specific production tasks. For example, meat products should have the priority on slicing and packing tasks since their temperature rapidly decreases. Steamed vegetables have a similar behaviour while pasta profile is almost linear, and its temperature tends to remain more stable than other products. As a last concern, Figure 4 unveils which tasks are less demanded (i.e. the ones with a small or null time bubble); recipe and process designer are encouraged to design preparation involving these tasks to provide a higher utilization of the resources able to perform these tasks since they probably are under-saturated. A better saturation of these resources may lead to a smoother production with lower depreciation costs.

6. CONCLUSION

This paper proposes a dashboard of KPI to control and benchmark food batch job-shop production processes. The aim of the indicators is to evaluate a production cycle and its tasks by four different points of view (i.e. cost, time, energy and environmental impact). Montecarlo simulation is used to estimate the value of these KPIs in presence of uncertainty (e.g. in the choice of the production equipment or resources) and results are used to investigate cost, quality and level of service delivered to the final consumer. As a proof of the potential of simulation, a case study from an Italian food service industry is illustrated from data collection to calculation and results interpretation discussing the managerial implication in the definition of standard production cycles for a food service network.

REFERENCES

Elmasry, Mohamed, and Fatma Tarek. 2016. “Discrete Event Simulation for Sustainable Batch Production in Food Processing.” In *International Food Operations and Processing Simulation Workshop*, 5–10.

Erdogdu, Ferruh, Fabrizio Sarghini, and Francesco Marra. 2017. “Mathematical Modeling for Virtualization in Food Processing.” *Food Engineering Reviews* 9 (4). Food Engineering Reviews:295–313. https://doi.org/10.1007/s12393-017-9161-y.

Europe Food Service. 2017. “European Industry Overview.” 2017. http://www.ferco-catering.org/en/european-industry-overview.

European Parliament. 2004. *REGOLAMENTO (CE) N. 852/2004 DEL PARLAMENTO EUROPEO Sull’igiene Dei Prodotti Alimentari*.

Fusi, Alessandra, Riccardo Guidetti, and Adisa Azapagic. 2015. “Evaluation of Environmental Impacts in the Catering Sector: The Case of Pasta.” *Journal of Cleaner Production* 132. Elsevier Ltd:146–60. https://doi.org/10.1016/j.jclepro.2015.07.074.

Huda, Abu M, and Christopher a Chung. 2002. “Simulation Modeling and Analysis Issues for High-Speed Combined Continuous and Discrete Food Industry Manufacturing Processes.” *Computers & Industrial Engineering* 43 (3):473–83. https://doi.org/10.1016/S0360-8352(02)00120-1.

Jacxsens, L., P. A. Luning, W. J. Marcelis, T. van Boekel, J. Rovira, S. Oses, M. Kousta, E. Drosinos, V. Jasson, and M. Uyttendaele. 2011. “Tools for the Performance Assessment and Improvement of Food Safety Management Systems.” *Trends in Food Science and Technology* 22 (SUPPL. 1). Elsevier Ltd:S80–89. https://doi.org/10.1016/j.tifs.2011.02.008.

Jansen, Derrien R., Arjen Van Weert, Adrie J M Beulens, and Ruud B M Huirne. 2001. “Simulation Model of Multi-Compartment Distribution in the Catering Supply Chain.” *European Journal of Operational Research* 133 (1):210–24. https://doi.org/10.1016/S0377-2217(00)00204-6.

Lemus-Mondaca, Roberto A., Antonio Vega-Galvez, and Nelson O. Moraga. 2011. “Computational Simulation and Developments Applied to Food Thermal Processing.” *Food Engineering Reviews* 3 (3–4):121–35. https://doi.org/10.1007/s12393-011-9040-x.

Medina-Marin, Joselito, Gilberto Perez-Lechuga, Juan Carlos Seck-tuoh-mora, Norberto Hernandez Romero, and Isaias Simon-Marmolejo. 2011. “Plant Capacity Analysis in a Dairy Company , Applying Montecarlo Simulation.” In *European Modeling and Simulation Symposium, EMSS 2011*, 690–95.

Mittal, Anuj, and Caroline C. Krejci. 2017. “A Hybrid Simulation Modeling Framework for Regional Food Hubs.” *Journal of Simulation*. Palgrave Macmillan UK, 1–14. https://doi.org/10.1057/s41273-017-0063-z.

Mullineux, Glen, and Mark J H Simmons. 2007. “Effects of Processing on Shear Rate of Yoghurt.” *Journal of Food Engineering* 79 (3):850–57. https://doi.org/10.1016/j.jfoodeng.2006.03.005.

Penazzi, Stefano, Riccardo Accorsi, Emilio Ferrari, Riccardo Manzini, and Simon Dunstall. 2017. “On the Design and Control of Food Job-Shop Processing Systems. A Simulation Analysis in Catering Industry." *The International Journal of Logistics Management* 28 (3):782–97.

Pérez-Rodríguez, Ricardo, S. Jöns, Arturo Hernández-Aguirre, and Carlos Alberto-Ochoa. 2014. "Simulation Optimization for a Flexible Jobshop Scheduling Problem Using an Estimation of Distribution Algorithm." *The International Journal of Advanced Manufacturing Technology* 73 (1–4):3–21. https://doi.org/10.1007/s00170-014-5759-x.

Taylor, Eunice. 2008. "A New Method of HACCP for the Catering and Food Service Industry." *Food Control* 19 (2):126–34. https://doi.org/10.1016/j.foodcont.2007.02.013.

AUTHORS BIOGRAPHY

Alessandro Tufano

Alessandro is a Ph.D. student at the Department of Industrial Engineering at the University of Bologna since November 2017. He has a bachelor's and a master's degree in management engineering. His research field revolves around storage, production systems and distribution network with a special emphasis on data-driven techniques for strategic and tactical optimization. He studies clustering techniques applied to the design of large capacitated networks. He develops profiling techniques for items processed in production or storage areas and predictive techniques to deal with uncertainty and risk in the production of perishable products.

Riccardo Accorsi

Riccardo Accorsi is an Assistant Professor in the Department of Industrial Engineering at the University of Bologna, Italy. In 2013, he defended his PhD in Mechatronics and Industrial Systems at the University of Padua, Italy. He received his Master degree in Management Engineering at the University of Bologna, Italy, in 2009. His main fields or research are modelling and simulation applied to industry and supply chain context, with particular focus on warehousing systems and distribution networks enabling product lifecycle management.

Andrea Gallo

Andrea Gallo is a Ph.D. Student at the Department of Industrial Engineering of Alma Mater Studiorum – Bologna University. Previously, he worked at KPMG S.p.A. and as a research assistant at the Department of Industrial Engineering. His main research field concerns the design, redesign and optimization of complex distribution networks and storage systems for perishable products. He studies and develops innovative mathematical models to virtualize, optimize and simulate the food supply chains considering the degradation of products due to environmental conditions. He also studies maintenance strategies and data mining techniques to reduce downtimes in high-performance production systems

Riccardo Manzini

Riccardo Manzini is a Professor of Logistics in the Department of Industrial Engineering at the University of Bologna, Italy. His academic research deals with planning, design, optimization and control of production systems with particular reference to logistics systems, storage systems, supply chain and distribution networks, reliability modelling and maintenance system management. His research interests are scientific and technical papers and contributions on logistics, maintenance and reliability engineering, production systems design and optimization. He is the editor and first author of the book Warehousing in the Global Supply Chain (2012) for Springer. He is the Director of the 'Food Supply Chain Center & LAB' at Bologna University –

IMPROVING INTEGRATION IN SUPPLY CHAIN TRACEABILITY SYSTEMS FOR PERISHABLE PRODUCTS

Andrea Gallo[(a)], Riccardo Accorsi[(b)], Riccardo Manzini[(c)], Daniele Santi[(d)], Alessandro Tufano[(e)]

[(a),(b),(c),(d),(e)] Department of Industrial Engineering (DIN), Alma Mater Studiorum - University of Bologna, Viale del Risorgimento, 2, 40122 – Bologna – Italy

[(a)] andrea.gallo7@unibo.it, [(b)] riccardo.accorsi2@unibo.it, [(c)] riccardo.manzini@unibo.it, [(d)] daniele.santi4@unibo.it, [(e)] alessandro.tufano2@unibo.it

ABSTRACT

Traceability represents a major concern in supply chains of perishable products. Progress enables complex and integrated monitoring systems based on Internet of Things (IoT), continuous monitoring and real-time alerting. However, the adoption rate of these innovations is not fast enough due to the need of expensive equipment and a robust digital infrastructure. The use of inappropriate technology and the lack of standardization between different monitoring systems often causes data leakage during storage and transportation. The lack of a standard in the traceability tools also causes difficulties in merging the output preventing the formation of a seamless cold chain. This paper presents a decision support tool that helps practitioners to track and trace the perishable products at each stage of the supply chain. The tool gathers data from multiple sources with different data structures, merge the files and fill missing data with the aid of a routing tool and weather forecasting databases. The output of this tool is a unique file containing all the traceability data about the product during its life-cycle. The tool also visualizes the traceability data through the use of a Geographic Information System (GIS) based on OpenStreetMap.

Keywords: traceability, perishable products, integration, decision support tool, data estimation

1. INTRODUCTION

Traceability represents a major concern in supply chains of perishable products (e.g. food and pharmaceutical) Firstly, the use of traceability is essential to assure the quality and safety of products in order to mitigate potential risks of contamination for the consumers (Beulens, Broens, Folstar and Hofstede 2005; Jones, Poghosyan, Gonzalez-Diaz and Bolotova 2004; Qi, Xu, Fu, Mira and Zhang 2014). Policy makers dictate strict regulations to ensure products safety and quality to protect citizens' health (Regattieri, Gamberi and Manzini 2007; Abad, Palacio, Nuin, de Zárate, Juarros, Gómez and Marco 2009). The use of sensors to track products during storage and distribution and the use of databases to stock these data can prove the compliance to the regulations and standards (Shanahan, Kernan, Ayalew, McDonnell, Butler and Ward 2009). To assure products' quality, logistics providers are adopting traceability systems to comply with HACCP method and ISO 9001:2000 protocol (Hajnar, Kollár and Láng-Lázi 2004).

Secondly, traceability is seen as a value-added activity for consumers. Because of their increased awareness on products' quality, customers are concerned about where the products they have bought are produced, processed and packaged (Storøy, Thakur and Olsen 2013; Zhang and Wang 2009).

Finally, traceability is useful to control products and to manage effectively the supply chain. It permits (1) to control the supply chain and know where products are stored and shipped (track) and (2) to monitor their quality and other characteristics backwards and forward along the chain (trace) (Salomie, Dinsoreanu, Pop and Sciu 2008).

Progress enables complex and integrated monitoring systems based on IoT, continuous monitoring and real-time alerting (Accorsi, Bortolini, Baruffaldi, Pilati and Ferrari 2017). In addition to barcodes (Galimberti, De Mattia, Losa, Bruni, Federici, Casiraghi, Martellos and Labra 2013), temperature and humidity sensors and RFID tags (Bibi, Guillaume, Gontard and Sorli 2017), new traceability systems integrate wireless sensor networks to continuously transmit their data to the control and alerting systems (Li, Peng, Zhang, Wei, Li 2015; Xiao, Fu, Zhang, Peng, Zhang 2016). These innovative methods allow practitioners to follow products within the infrastructures (e.g. ports, multimodal hubs) and nodes (e.g. manufacturer, suppliers, customers) of the supply chain (i.e. internal traceability) and during the distribution between different stages of the chain (i.e. external traceability).

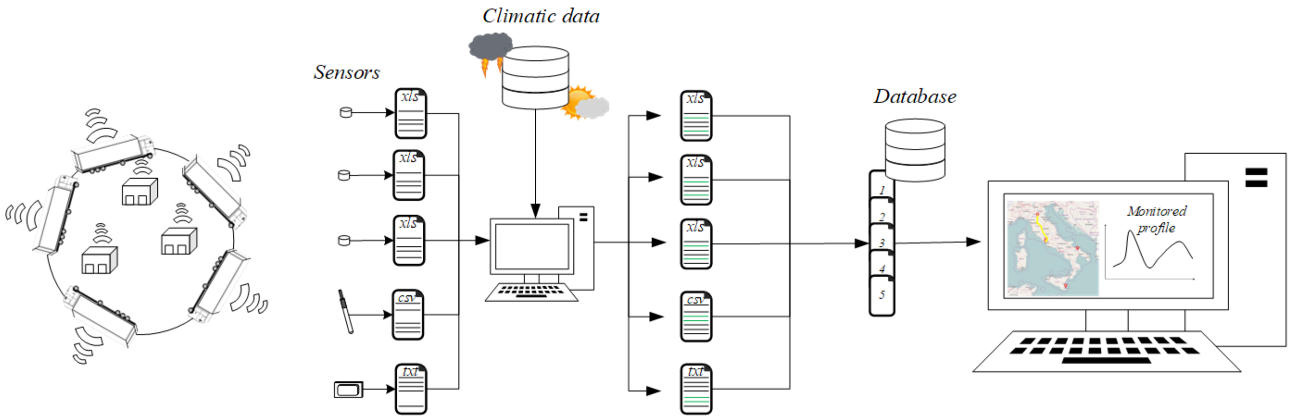


Figure 1: Traceability tool functionalities

However, the adoption rate of these innovations is not fast enough. The traceability systems require expensive equipment to be settled-up (Sun, Wang and Zhang 2017) and a robust digital infrastructure for data collection. The prohibitive costs and the complexity of the infrastructures frequently incite companies to adopt inadequate solutions (Hardt, Flett, and Howell 2017). The use of inappropriate technology and the lack of standardization between different monitoring systems often cause missing data during storage and transportation. In addition, companies often outsource different logistics stages to third part logistics providers. As the commercial software for traceability does not follow standardized protocols, the output of these tools cannot be merged easily (Bosona and Gebresenbet 2013). Furthermore, companies are reluctant to exchange traceability data between different stages of the supply chain to integrate them in a unique database.
This results in heterogeneous, not aligned monitoring systems along supply chain (Muljarto, Salmon, Charnomordic, Buche, Tireau and Neveu 2017), preventing the formation of a seamless cold chain (Li, Peng, Zhang, Wei and Li 2015). The consequences of not aligned monitoring systems can threaten products' safety and quality, weakening the trust between producers and consumers.
A data integration tool represents a practical solution to improve integration in traceability of perishable products throughout the supply chain. It merges data from different, autonomous (i.e. belonging and based on the need of a single company) and heterogeneous data sources (i.e. with a different data structure) into a unique, comprehensive and robust database.
This paper presents a decision support tool, developed in C# .NET language, that helps practitioners to track and trace the perishable products at each stage of the supply chain. This system reads and merges data from different monitoring systems sources. As each monitoring system contains a minimum set of information (e.g. data, time and a monitored parameter such as position or temperature), these data are gathered from the different commercial tools and unified in a unique data structure that allows to monitor products from production to the retail stores.

The tool allows final users to monitor the position and the environmental stresses experienced by products during their whole life cycle from a unique data source. Complete traceability data are provided without requiring manual integration and the knowledge of the different traceability software and data structures used at different stages of the supply chain.
In addition, the tool provides a procedure to fill missing data. Missing data can be due to errors during the writing process of sensors or whenever they run out of power or memory. Furthermore, different traceability sensors can provide monitoring data at different sampling intervals. The filling process infers automatically missing data from a routing tool and from weather forecasts services. It also integrates rules about usual distribution patterns followed by carriers and an estimation of the monitored values to level out data with different sampling intervals. Data are uniformed to the minimum available sampling interval to maximize the amount of information provided to the final users.
Through the use of a Geographic Information System (GIS) based on OpenStreetMap, users can monitor the route followed by the fleet of vehicles during distribution and reconstruct the profile of the monitored parameters (e.g. temperature and relative humidity) during the entire products' life-cycle.
This visualization aids users by highlighting criticalities during storage and distribution. This supports practitioners in perceiving the need for better storage and distribution solutions (e.g. using better insulating materials during the distribution, change the temperature set-point in warehouses).
The output of the tool is a unique database containing all the traceability data about the product during its life-cycle. This includes both internal and external traceability data. These data can help to assure product's safety, estimate products' quality and can improve consumer's confidence resulting in a more transparent system.
To the extent of our knowledge, there are not similar approaches in literature to merge different traceability data into a continuous monitoring system managing missing data with the integration of climate databases and a GIS.

However, there are some attempts to improve traceability systems in a supply chain by applying individually some of the functionalities presented in this data integration tool. Xiao-dong and Jian-zhen (2009) propose a data schema and an Object-Oriented Model to create a virtualized data integration system to integrate heterogeneous data sources. As the data sources are not physically integrated into a unique database, the queries must be broken down into sub-queries for each independent data source, then the results must be integrated into a unique answer to the user. Alfian, Ree, Ahn, Lee, Farooq, Ijaz and Syaekhoni (2017) present a a traceability system using RFID and wireless sensors network including data mining techniques to predict the missing data. The data mining techniques estimate missing temperature and humidity values from sensors using a neural network. It provides an estimation of the environmental stresses without recurring to weather forecasts or historical data, neither uses prediction to estimate the location of the products during transportation. Wang, Yue and Zhou (2017) included in their traceability system a quality evaluation method based upon fuzzy classification and neural network to classify the quality level of the products along with standard traceability data for food supply chains.

The remainder of the paper is organized as follows. Section 2 describes the methodology, both for data integration and for the estimation of missing values and the normalization of the sampling intervals. Section 3 presents and discusses the results. Section 4 concludes the paper.

2. METHODOLOGY

2.1. Data integration process

The dearth of a standardized data structure for traceability data causes a proliferation of data formats and schemas that cannot be easily integrated into a unique database. Each step of the supply chain is monitored into its own files. These files contain different information, sampling intervals and time horizons. In addition, they are stored in distributed positions located in several nodes of the supply chain. Users can easily visualize traceability information of a single step of the whole process from production to distribution. The existing tools for traceability systems allow them to monitor the position and the environmental stresses experienced by perishable products. A warning system alerts user whenever a criticality arises (i.e. the environmental conditions are far from the optimal storage conditions, causing potential safety issues) activating corrective actions to ensure consumers' safety. However, users can track and trace their products only for a single stage of the supply chain. The lack of visibility of the whole process can assure the compliance to the standards and the quality of products only focusing on a single stage. Users should have access to distributed data sources and manually uniform the data structure and integrate data whenever they want to monitor data for the whole life cycle of a single product.

The data integration process aims at integrating data from independent data source and store the results into a unique materialized data structure. A materialized data structure consists in a physical data source containing all the integrated data. The data source can be stored into a server and users can query the database to monitor a single product in each stage of the supply chain, from the production to the retail. As traceability information concerns many actors, from producers to distributors, retailers and final consumers, a materialized data structure is preferred. As the information is physically stored in the server, it is not necessary to continuously access the distributed data sources and the queries do not require neither to be subdivided into subqueries directed to the single data sources nor to be aggregated to set up the final result.

Fig. 2 schematizes the data integration process for a simplified supply chain network and represents traceability data for a product. The traceability data for the product start with the production stage. Once the product is produced, it is shipped to a storage node and stocked in a cold storage room. According to the demand, the product is distributed to the retailer where it stays until it is sold to the consumer. The traceability data gathered in each stage of the supply chain contains a similar set of data with the monitored profiles, hereafter called relevant data (i.e. date, time, coordinates of the location, temperature, relative humidity), and additional data (e.g. data about sensors, additional notes). The data types and formats are different as there is not a standard format and some of them are stored into a database and other are saved into files (e.g. Excel, csv, text files).

Firstly, it is necessary to map the different schemas of the data sources. The additional data are filtered out and only the relevant data are retained. The relevant data are extracted from the data sources. The different data schemas are analyzed and potential differences in the units of measurement and in the data format are solved. The result of this normalization is a unique data structure that constitutes the global schema adopted for the creation of the integrated data source. Once the global schema has been defined, data are added to the integrated data source. This phase consists of the ex-post reconstruction of the monitored profiles for a single product. Data are ordered chronologically. The aim of this phase is to extract from each data source only the data referring to the time period pertaining to the product in a specific stage of the supply chain (i.e. extracting data from a warehouse only when the product was stored into it). Traceability data from nodes (i.e. production plants, warehouses, retailers) usually do not provide useful information to identify the time in which the product enters or leaves the node. For this reason, relevant data are identified starting from the ones of the transportation stages. Analyzing the time and the GPS monitoring values of the transportation stage it is

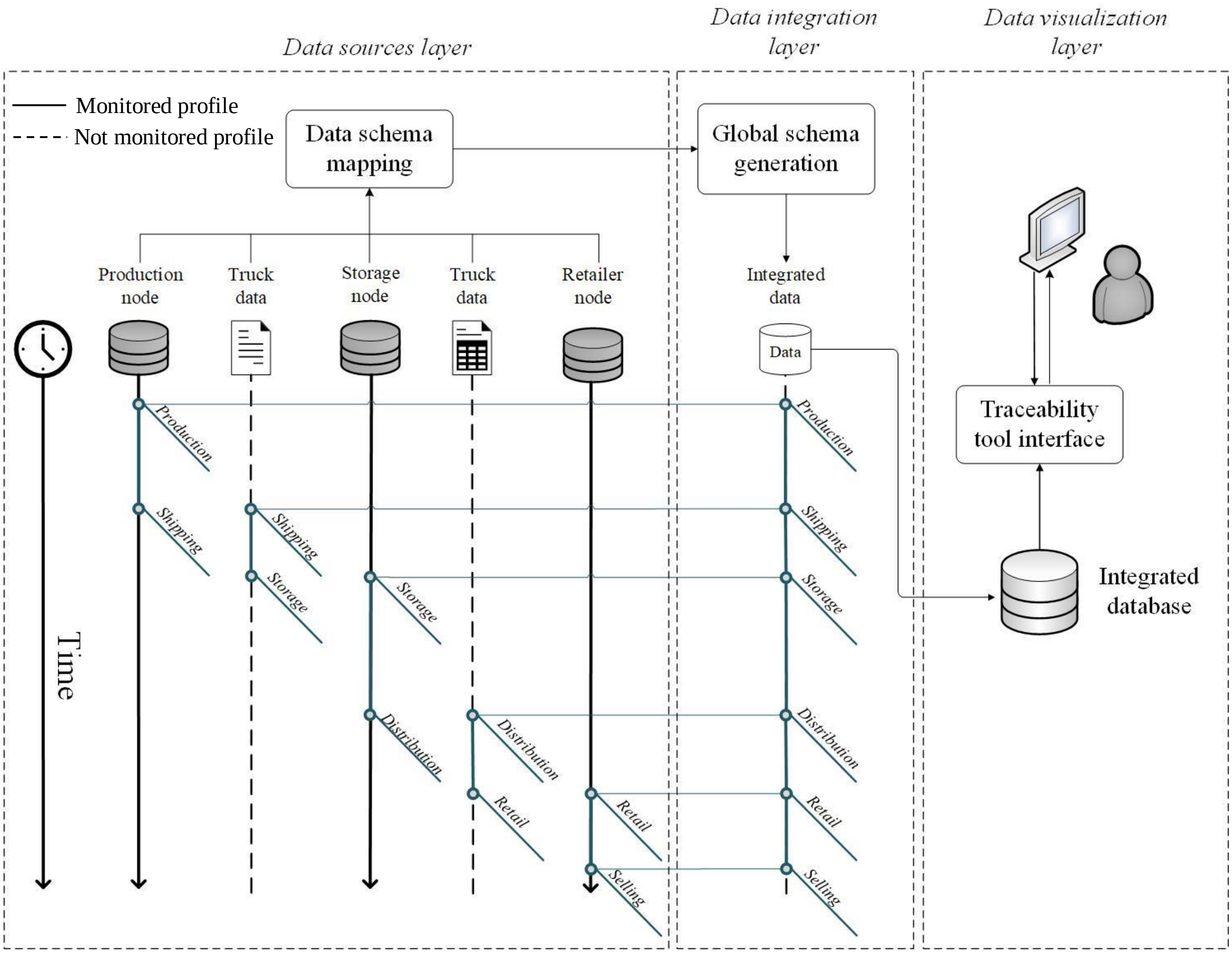


Figure 2: Data integration process

possible to realize when the product is loaded on the vehicle from the previous node of the supply chain and when it is unloaded in the next node. Repeating this step for each transportation stage of the supply chain and knowing when the products enters and leaves the system (i.e. the timestamp associated with its production and its sale in the database), it is possible to retrieve the traceability data for the product in its entire life cycle.

This process is repeated for each product sold in order to create a single data source containing all the traceability data.
The aforementioned process represents an ETL (Extract, Transform, and Load) process that realizes the materialized data structure. The tables of the integrated database are represented in Fig. 3.

The output of this process is an integrated database that can be easily accessed by users to retrieve traceability data for a single product in order to know the place of its origin, where it has been processed and packed, stored and the location visited during transportation. Users can also monitor the environmental stresses experienced by products and can be alerted whether safety issues have occurred. Furthermore, the integrated database represents the input data for the data visualization module of the traceability tool.

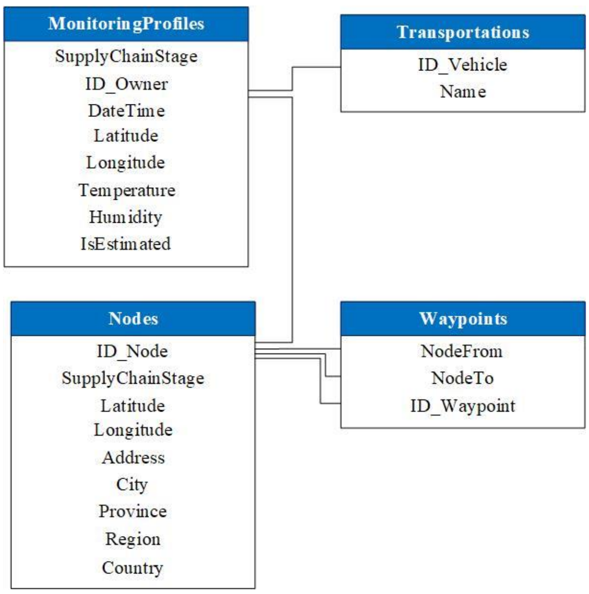


Figure 3: Representation of the integrated database

2.2. Data estimation process

The data integration process has chronologically reconstructed the monitoring sequence creating a seamless profile of the movements and the environmental stresses of the product. However, differences in the data sources still persist. The sampling intervals of different sensors could not correspond and missing values can cause a traceability blackout.

The data estimation process aims at solving these issues creating normalized traceability profiles. A normalized profile is characterized by the same sampling interval from the production to the retail, without missing values and certifies the respect of standards and regulations for the entire product's life cycle.

The data estimation process fills missing location values and climate values (i.e. temperature, humidity). Differences in the sampling intervals of sensors are solved with the adoption of the minimum sampling interval in order to guarantee the maximum detail of the output data. Intermediate values for sensors with higher sampling interval are estimated with the same procedure of the other missing data.

The steps of the estimation process are presented in Fig. 4.

2.2.1. Missing location data

The procedure that fills missing location data is based upon the combination of the past experience on the commonly adopted routes and on the application of a routing module. The routing module is based upon the open source maps of OpenStreetMap and on the open source route planner Itinero.

Analyzing past distribution patterns, it is possible to fill missing values by identifying whether the transportation between the departing and the arrival node usually entails the visit of an intermediate point (e.g. a secondary distribution center of the supply chain), known as waypoint. Furthermore, waypoints are not only a mere transit point as the trucks can also wait in the waypoint for some time.

Analyzing the location of the previous monitored location value, the location of the next value and the time of the missing value, it is possible to estimate whether the product could be at a waypoint, before reaching it or after it has been left. If at the time of the missing value the product is estimated to be at the waypoint, then the location of the waypoint is used to fill the missing value. If based on the estimation the product has not reached the waypoint yet, the missing value is estimated applying the routing function between the previous monitored value and the location of the waypoint. Conversely, the missing value is

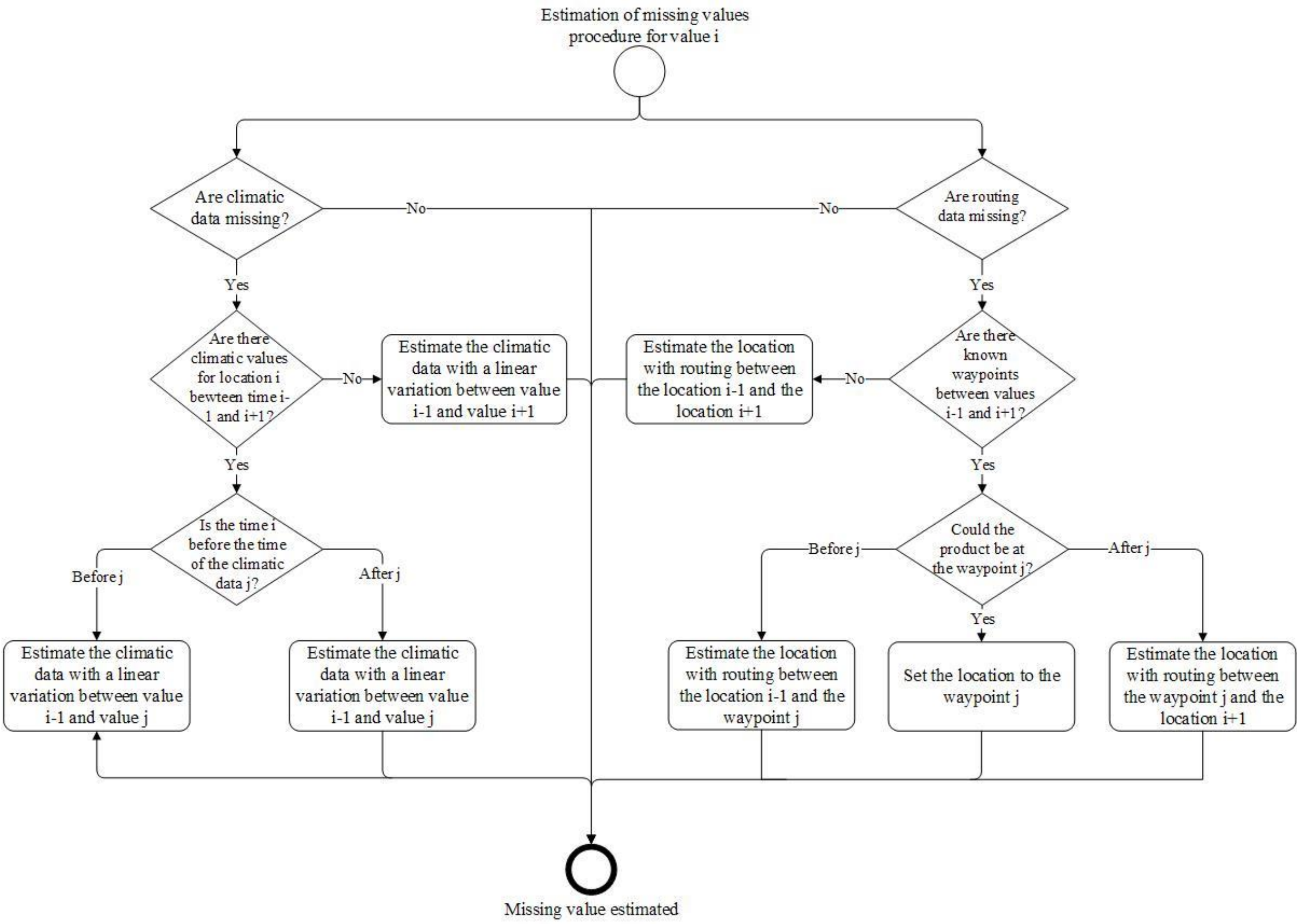


Figure 4: Data estimation process

estimated with the routing between the waypoint and the next monitored value whether the truck has already gone beyond the waypoint. Finally, if there is not a waypoint between the two monitored values, the missing value is estimated through the routing module applied to the locations of the previous and the next monitored values.

As the routing module is able to calculate the exact route between two locations and the time associated, it is possible to estimate each missing value without other approximations. The repetitiveness of the distribution routes also allows to consider the waypoints as a good approximation, as the same distribution plan is usually performed in the same way.

2.2.2. Missing climate data

The filling procedure for missing climate data is based upon the data of online weather forecasts services. These services offer weather forecasts and also have a database containing historical weather data to retrieve climate data from the past. The traceability tool presented use the World Weather Online's historical weather data. This service provides hourly data about temperature, relative humidity and many other data. As the change in the temperature and relative humidity values is not so relevant within a single hour, the missing weather data adopts linear variation of the values as follows:

1. If there are not climate data available between the previous monitored value and the next monitored value, then a linear variation between these values is considered for the estimation;
2. If the time of the missing value is included between the previous monitored value and the historical climate data, then the missing value is filled with a linear variation between these values;
3. Conversely, if the time of the missing values is included between the historical climate data and the next monitored value, then a linear variation between these two values is used.

As the climate estimation module needs the location to retrieve climate data, if both the position and the environmental stresses are unknown, the tool estimates the position before filling climate data.

3. RESULTS AND DISCUSSION

The integrated database contains all the traceability data, both monitored and estimated. It allows the reconstruction of a seamless cold chain also when the different actors store their data in different formats, with different data type and adopting different sampling intervals for their sensors.

The traceability tool presented in this paper provide methods for the creation of the integrated database starting from the heterogeneous data sources. The results of this normalization and integration is the creation of a unique data source that hides the heterogeneity of the data sources to the final users. Users can track and trace the products in each stage of the supply chain, monitoring their position and the environmental stresses and highlighting potential safety issues in the whole products' life cycle. The traceability system is unique and integrated and do not require a

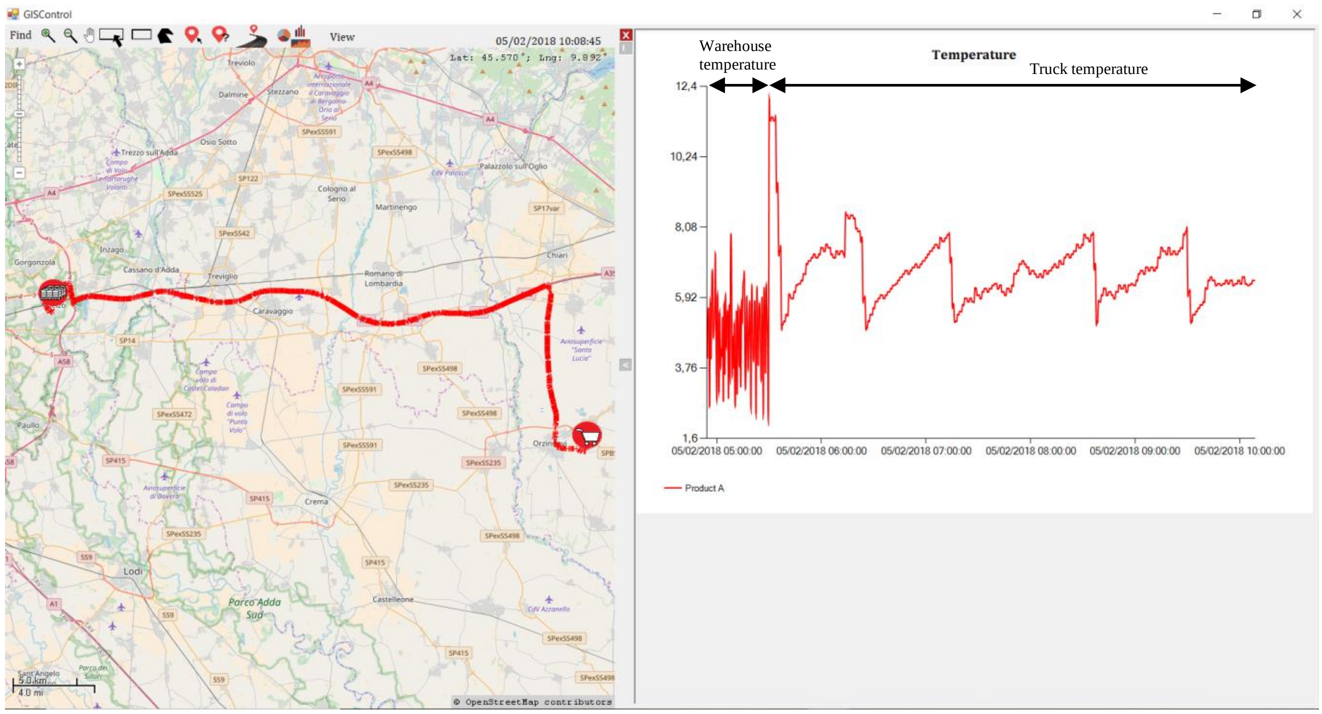


Figure 5: Main interface of the traceability tool

manual comparison and integration of unstandardized data.
When the integrated data source has been created, the tool visualizes the results of the monitoring process displaying the position and the monitoring profiles associated to a specific product or a batch of products (Fig. 5). An interactive map displays the real-time position of the product and its provenience reconstructing the flow of materials from production to the retail. Firstly, the tool acquires and displays the position of the nodes of the supply chain. Then the user can choose to follow a specific product throughout the chain. The application acquires the sampling interval as the minimum sampling intervals of all the sensors monitoring the position and the environmental stresses experienced by the product. This time interval is used to increase the time of the clock associated to the visualization. 300 real milliseconds correspond to a single time interval. As the tool has already filled missing data, each time interval corresponds to a monitored or estimated value for the product. This value is acquired and displayed on a chart showing the monitoring profile. When the clock of the tool reaches the end of the monitoring, every movement and all the monitored profile is visible on the display and users is aware of whether, when and where safety issues occurred and take corrective actions to protect consumers.

The use of the proposed traceability tool enhances considerably the integration of the traceability system of the supply chain and can be used by practitioners as a certification of the compliance to standards and regulations. The aim of its application is to reconstruct all the stresses experienced by perishable products during their life cycle to certify the delivery of high quality products to the consumers, proving that the products is followed in each stage of the supply chain and that recommended storage and transportation conditions are respected from the production to the retail. Furthermore, it can be integrated with models to estimate the shelf life decay of perishable products (Accorsi, Gallo and Manzini 2017) and the real time energy consumption (Gallo, Accorsi, Baruffaldi and Manzini 2017). Practitioners can also follow their products and trucks throughout the supply chain, tracking their routes and tracing the environmental conditions. This procedure gives them a complete control also over single products or batches of products.
The use of these tool improves the integration in the traceability systems of the supply chain without requiring expensive instruments and sensors or complex hardware changes. It takes advantage of the existing technologies combining the output of different traceability software and providing an integrated database that stores the results of the integration process and filling missing values.

4. CONCLUSIONS

Traceability is essential to guarantee consumers' safety, to certify the respect of standards and regulations and to track and trace products throughout the supply chain. This study presents a traceability tool that enhances the integration of the existing traceability systems. As there is not a standard for traceability tools and companies in the same supply chain frequently adopt different traceability systems, the proposed tool integrates the output of all the traceability systems and fills missing values, normalizing the sampling intervals of the sensors. The integration is realized through a materialized data structure containing the uniformed data. Missing values are filled with the aid of a routing module that performs routing between known nodes of the chain and waypoints and with historical weather and weather forecasts online databases. The output of the tool is a unique database that can be used for further analysis and the visualization of the position of the products and the environmental stresses they have experienced during their entire life cycle.
Further research will include the application of data mining techniques to estimate data when the time interval is lower than the one of the available climate information to improve the estimation of missing values. Other improves could entail the use of models to better estimate the environmental stresses of a single product within a monitored environment (e.g. warehouse, truck), as its temperature and relative humidity are not uniform and the sensors cannot cover each single position within the monitored environment

REFERENCES

Abad E., Palacio F., Nuin M., de Zárate A.G., Juarros A., Gómez J.M., Marco S., 2009. RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. Journal of Food Engineering, 93, 394-399.

Accorsi, R., Bortolini, M., Baruffaldi, G., Pilati, F., Ferrari, E., 2017. Internet-of-Things paradigm in food supply chains control and management. Procedia Manufacturing 11, 889-895.

Accorsi, R., Gallo, A., Manzini, R., 2017. A climate driven decision-support model for the distribution of perishable products. Journal of Cleaner Production, 165, 917-929.

Alfian, G., Ree, J., Ahn, H., Lee, J., Farooq, Ijaz, M.F., Syaekhoni, M.A., 2017. Integration of RFID, wireless sensor networks, and data mining in an e-pedigree food traceability system. Journal of Food Engineering, 2012, 65-75.

Beulens, A.J.M., Broens, D.-F., Folstar, P., Hofstede, G.J., 2005. Food safety and transparency in food chains and networks Relationships and challenges. Food Control, 16, 481-486.

Bosona, T., Gebresenbet, G., 2013. Food traceability as an integral part of logistics management in food and agricultural supply chain. Food Control, 33, 32-48.

Bibi, F., Guillaume, C., Gontard, N., Sorli, B., 2017. A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products. Trends in Food Science & Technology, 62, 91-103.
Galimberti, A., De Mattia, F., Losa, A., Bruni, I., Federici, S., Casiraghi, M., Martellos, S., Labra, M., 2013. DNA barcoding as a new tool for food traceability. Food Research International, 50, 55-63.
Gallo, A., Accorsi, R., Baruffaldi, G., Manzini, R., 2017. Designing Sustainable Cold Chains for Long-Range Food Distribution: Energy-Effective Corridors on the Silk Road Belt. Sustainability, 9, 2044.
Hajnar É., Kollár G., Láng-Lázi M., 2004. IT support and statistics in traceability and product recall at food logistics providers. Periodica Polytechnica Ser. Chem. Eng., 48 (1), 21-29.
Hardt, M.J., Flett, K., Howell, C.J., 2017. Current Barriers to Large-scale Interoperability of Traceability Technology in the Seafood Sector. Journal of Food Science, 82 (S1), 3-12.
Itinero, 2018. http://www.itinero.tech/
Jones, E., Poghosyan, A., Gonzalez-Diaz, F., Bolotova, Y, 2004. Traceability and Assurance Protocols in the Global Food System. International Food and Agribusiness Management Review, 7 (3), 118-126.
Li Y., Peng Y., Zhang Z., Wei J., Li D., 2015. Quality Monitoring Traceability Platform of Agriculture products Cold Chain Logistics Based on the Internet of Things. Chemical Engineering Transactions, 46, 517-522.
Muljarto, A.R., Salmon, J.-M., Charnomordic, B., Buche, P., Tireau, A., Neveu, P., 2017. A generic ontological network for Agri-food experiment integration – Application to viticulture and winemaking. Computers and Electronics in Agriculture, 140, 433-442.
OpenStreetMap, 2018. www.openstreetmap.org
Qi, L., Xu, M., Fu, Z., Mira, T., Zhang, X., 2014. C2SLDS: A WSN-based perishable food shelf-life prediction and LSFO strategy decision support system in cold chain logistics. Food Control, 38, 19-29.
Regattieri A., Gamberi M., Manzini R., 2007. Traceability of food products: General framework and experimental evidence. Journal of Food Engineering, 81, 347-356.
Salomie I., Dinsoreanu M., Pop C.B., Suciu S.L., 2008. Model and SOA Solutions for Traceability in Logistic Chains. Proceedings of iiWAS2008.
Shanahan, C., Kernan, B., Ayalew, G., McDonnell, K., Butler, F., 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.
Storøy, J., Thakur, M., Olsen, P., 2013. The TraceFood Framework – Principles and guidelines for implementing traceability in food value chains. Journal of Food Engineering, 115, 41-48.
Sun, S., Wang, X., Zhang, Y., 2017. Sustainable Traceability in the Food Supply Chain: The Impact of Consumer Willingness to Pay. Sustainability, 9, 999.
Wang, J., Yue, H., Zhou, Z., 2017. An improved traceability system for food quality assurance and evaluation based on fuzzy classification and neural network. Food Control, 79, 363-370.
World Weather Online, 2018. https://www.worldweatheronline.com/
Xiao X., Fu Z., Zhang Y., Peng Z., Zhang X., 2016. Developing an intelligent traceability system for aquatic products in cold chain logistics integrated WSN with SPC. Journal of Food Processing and Preservation, 40, 1448-1458.
Xiao-dong, C., Jian-zhen, L., 2009. Research on heterogeneous data integration in the livestock products traceability system. Proceedings - 2009 International Conference on New Trends in Information and Service Science, NISS 2009, 969-972.
Zhang, Z.Y., Wang, L. Research on traceability integrated logistics system of diary products. Proceedings - International Conference on Management and Service Science, MASS 2009.

AUTHORS BIOGRAPHY

Andrea Gallo is a Ph.D. Student at the Department of Industrial Engineering of Alma Mater Studiorum – Bologna University. Previously, he worked at KPMG S.p.A. and as a research assistant at the Department of Industrial Engineering.

His main research field concerns the design, redesign and optimization of complex distribution networks and storage systems for perishable products. He studies and develops innovative mathematical models to virtualize, optimize and simulate the food supply chains considering the degradation of products due to environmental conditions.

He also studies maintenance strategies and data mining techniques to reduce downtimes in high-performance production systems.

Riccardo Accorsi is an Assistant Professor in the Department of Industrial Engineering at the University of Bologna, Italy.

In 2013, he defended his PhD in Mechatronics and Industrial Systems at the University of Padua, Italy. He received his Master degree in Management Engineering at the University of Bologna, Italy, in 2009. His main fields or research are modelling and simulation applied to industry and supply chain context, with particular focus on warehousing systems and distribution networks enabling product lifecycle management.

Riccardo Manzini is associate professor of Logistics and Industrial & Manufacturing Systems at the Department of Industrial Engineering, Alma Mater Studiorum – Bologna University. He is the director of the 'Food Supply Chain Centre & LAB' at Bologna University – http://foodsupplychain.diem.unibo.it, and of the 'Warehousing Center' at Bologna

University http://warehousing.diem.unibo.it. He is a special issue guest editor for the International Journal of Production Economics 'Sustainable Food Supply Chain Management: Strategy, Operations and Technology'. He is the first author of the book: Manzini R., Regattieri A., Pham H., Ferrari E. (2010) Maintenance for Industrial Systems. London: Springer London Ltd., 978-1-84882-574-1, and also the author and co-author of about 130 scientific works including papers for international journals, books and books chapters, conference proceedings, etc.

Daniele Santi is a Business Process Engineer at CSE Group, specialized in RPA. Previously, he worked as a research assistant at the Department of Industrial Engineering of the Alma Mater Studiorum – Bologna University.

His main research field concerns the optimization of storage systems. He developed algorithms and tools to optimize the storage allocation and assignment and to redesign the storage systems for 3PL companies in several industrial sectors. He also developed traceability tools to improve the awareness of producers and consumers about travelling and storage conditions of perishable products.

Alessandro Tufano is a PhD student at the Department of Industrial Engineering of the University of Bologna since November 2017. He has a bachelor's and a master's degree in management engineering.

His research field revolves around storage, production systems and distribution network with a special emphasis on data-driven techniques for strategic and tactical optimization. He studies clustering techniques applied to the design of large capacitated networks. He develops profiling techniques for items processed in production or storage areas and predictive techniques to deal with uncertainty and risk in the production of perishable products.

SUSTAINABILITY EVALUATION OF LAST MILE FOOD DELIVERY: PICKUP POINT USING LOCKERS VERSUS HOME DELIVERY

Sameh M. Saad [(a)], Ramin Bahadori [(b)]

[(a), (b)] Department of Engineering and Mathematics,
Sheffield Hallam University, City campus Howard street Sheffield S1 1WB, UK

[(a)]S.Saad@shu.ac.uk, [(b)]b2047010@my.shu.ac.uk,

ABSTRACT
The Last mile delivery is known as one of the most costly and highest polluting stages within the food supply chain where food companies deliver the food products to the final consumers. As a new approach in this area, currently, a few food retailers offering pick up point service delivery using lockers. This paper provides a comprehensive comparison of the sustainability performance between home service delivery and picks up point service delivery using lockers. Hypothetical last mile food models for both approaches are developed. A Vehicle Route Problem with Time Window (VRPTW) is developed to minimise the CO_2 emission and implemented using the simulated annealing algorithm which is programmed in MATLAB software. Supply Chain GURU Software is adapted to implement the Greenfield analysis to identify the optimal number and the location of the locker facilities through a Greenfield service constraint.

Keywords: modelling and simulation, home service delivery, pick up point service delivery, last mile food delivery sustainability, food retail supply chain

1. INTRODUCTION

Supply chain management has often been viewed in the traditional and operational manner with a major focus on cost reduction. Over the past decade, enterprises have found that they need more effective strategies to increase the competitiveness of their supply chains. Hence, the supply chain sustainability was developed to meet customers, stakeholders and government's expectation through the three dimensions of sustainable development including economic, environmental and social (Seuring and Müller 2008; Closs et al 2011) in various policies of the organization, such as purchasing, design, manufacturing, distribution, logistics, etc.

Today, optimisation of the final step of the business-to-consumer delivery service -knows as Last Mile Problem (LMP) - has become a significant challenge for operation managers within the supply chains (Boyer et al 2009). LMP is identified as the main step of the order fulfilment process which means deliver the purchased items to end customers' physical address from the place (e.g. Warehouse) where the items are kept (Bromage 2001; Lee and Whang 2001). Last mile delivery is determined as one of the most costly and highest polluting segments within the supply chain (Gevaers et al 2011; Ülkü 2012) which around 28% of all transportation costs are incurred within this step.

The food supply chain is one of the most complex and largest sectors of the world's industry. In the food supply chain, focusing on sustainability issues often involves the production of agricultural products because this area causes the most significant environmental impacts. Therefore, the need for comprehensive attention to food systems is more needed. Thus, the awareness of food retail firms in procuring green supply chain promotes high consciousness in delivering sustained food products to end customers. The food industry is the biggest user of transportation which constantly increases pollution by generating the Greenhouse Gases (GHG) emissions. Validi et al (2014) also commented that the downstream distribution of food products through transportation is known as one of the major sources of environmental concern within food supply chains.

Currently, such as most non-food products there are two approaches to making a food retail purchase; online shopping and common shopping. E-commerce channels provide the opportunity for customers to make the purchase electronically without visiting the stores and receive the purchased food at their home delivery address by sellers, however, in common shopping approach customers need to visit stores physically to pick up foods and subsequently self-delivers the foods to their home. Both of these approaches have their own impact on the environment through the generation of GHG emissions during the delivery of the purchased food (see Brown and Guiffrida 2014; Siikavirta et al. 2003). Although, increasing home delivery may make more freight traffic (Weltevreden and Rotem-Mindali 2009) it is expected to be less than traffic related to common shopping as a move to a physical store is substituted by a delivery at home (Visser et al 2014). However, home delivery is received very much welcome by consumers this service is not free of issues. For instance, not delivery at the right time and place, excessive delivery cost, long delivery time and forced to stay at home have been raised from customer's perspective and extra costs for redelivery and inaccessible goods from carrier's viewpoint.

Picking up purchased goods that are ordered through the internet from lockers (Pickup points) also is the new option for making a retail purchase which rarely used in food retail sector and just currently received attention by a few retailers. For example, Waitrose in the United Kingdom provided the temperature-controlled lockers on a small scale to offer a convenient way for its customers to collect their shopping at a time and a place that fits around their schedule (TRB 2014). Thus, investigating the sustainability performance of pickup point using lockers versus home delivery in the food retail sector drives the main purpose of this study.
To achieve the aim of this study, two methodologies are utilised; at the first, Greenfield analysis is used to identify the optimal number and location of pick up points (lockers) through a specified service constraint. This method of analysis is quite frequently used in industry to determine the best location for a new and existing facility by which the location is indicated by latitude and longitude (Saad et al 2017).
The second, Vehicle Route Problem with Time Window (VRPTW) is developed to minimise the CO_2 emission and implemented using the simulated annealing algorithm which is programmed in MATLAB software. The integer linear programming model of the problem is described in the next section.

2. VRPTW MATHEMATICS MODEL

For a better articulation of the proposed mathematical model, at first, the input parameters and decision variables of the model is provided, then, the objective function and its constraints are presented. Also, essential descriptions of the details of the mathematical model are provided.

2.1. Input parameters

V= Total number of nodes; with vertex set $V= \{0, 1, \dots, n\}$; Where node 0 corresponds to the depot and the other nodes in this set of vertex represent the customers.
A= sets of edges; $A= \{(i,j) \mid i, j\} \in V$ and $i \neq j\}$.
K= Number of available vehicles; $K= \{1, ..., k\}$ and the number of vehicles is unlimited.
Q_k= Capacity of the k^{th} vehicle ($k \in K$).
D_i = Customers demand ($i \in V$).
dij = Length of edge between the nodes i and j $(i,j) \in A$
At_{ik}= Arrival time of k^{th} vehicle to i^{th} customer/locker
$t1_i$= Lower bound in the hard time window of i^{th} customer/locker
$t2_i$= Upper bound in the hard time window of i^{th} customer/locker
C_{ijk} = CO_2 emission of moving the k^{th} vehicle ($k \in K$) between the nodes i and j
Where:

$$C_{ijk} = \left(\left(T_{wk} + W_{ijk}\right) \times R_{ck}\right) \times d_{ij}$$

And
T_{wk} =Tare weight of the k^{th} vehicle, which is the weight of empty vehicle.
W_{ijk} = Weight of shipments on board of k^{th} vehicle between the nodes i and j
R_{ck}= CO_2 emission rate of kth vehicle

2.2. Decision variables

$$x_{ijk} = \begin{cases} 1 \text{ if } j^{th} \text{ customer is served by } k^{th}\ vehicle \\ \quad \text{after } i^{th} \text{ customer} \\ 0 \quad otherwise \end{cases}$$

y_{ik}= the quantity of the demand of the i^{th} customer which is delivered by the k^{th} vehicle.

2.3. Home service Delivery Formulation

$$Min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} C_{ijk} x_{ijk} \ , \quad i \neq j \tag{1}$$

Subject to

$$\sum_{i=0}^{n} \sum_{k=1}^{K} x_{ijk} = 1, \quad j = 0, \dots, n, \tag{2}$$

$$\sum_{i=0}^{n} x_{ipK} - \sum_{j=0}^{n} x_{pjK} = 0 \ , \ p = 0, \dots, n; \ k = 1, \dots, K, \tag{3}$$

$$y_{ik} = D_i \sum_{j=0}^{n} x_{ijk} \ , \quad i = 1, \dots, n; \ k = 1, \dots, K \tag{4}$$

$$\sum_{k=1}^{K} y_{ik} = 1, \quad i = 1, \dots, n \tag{5}$$

$$\sum_{i=1}^{n} y_{ik} \leq Q, \quad k = 1, \dots, K \tag{6}$$

$$\sum\nolimits_{i,j \in S} x_{ijk} \leq |S| - 1, (S \subset \{1, \dots, n\}); \ |S| \geq 2 \tag{7}$$

$$t1_i \leq At_{ik} \leq t2_i, \quad i = 1, \dots, n; k = 1, \dots, K \tag{8}$$

$$x_{ijk} \in \{0,1\}, \quad i = 0, \dots, n \ ; \ j = 0, \dots, n; k = 1, \dots, K \tag{9}$$

$$y_{ik} \geq 0, \quad i = 1, \dots, n; \ k = 1, \dots, K \tag{10}$$

The objective function represents minimisation of the total CO_2 emission produced by using the transportation fleet. Constraints (2) ensure that each customer is visited exactly once. Constraints (3) mean that any vehicle that enters each node will definitely leave it. Constraints (4) ensure that the i^{th} customer's demand is completed if exactly one vehicle passes through it. Constraints (5) indicate that all customers demand is entirely fulfilled. Constraints (6) impose that the loading process on any route should not exceed the capacity of the vehicle. Constraints (7) present the sub tour elimination constraints. Equation (8) indicates hard time window constraints.

2.4. Pickup point Formulation

In order to formulate pickup point delivery using lockers, constraints (2) and (4) in the above formulation can be replaced with equations 11 and 12 respectively:

$$\sum_{i=0}^{n}\sum_{k=1}^{K} x_{ijk} \geq 1, j = 0, \dots, n, \quad (11)$$

Equation (11) presents that each locker is visited at least once.

$$y_{ik} \leq D_i \sum_{j=0}^{n} x_{ijk}\,, \quad i = 1, \dots, n; \; k = 1, \dots, K \quad (12)$$

Equation (12) indicates that the i^{th} locker's demand is completed if at least one vehicle passes through it.

However, in this research, environmental sustainability received more authors' attention, other transportation performance measures including transportation cost, transportation time and route utilization also are investigated to provide a more comprehensive comparison of sustainability performance between pickup point using lockers and home delivery in the last mile food deliveries. Mathematical relationships governing the aforementioned problems are described as follows:

$$T_C = \sum_{i=0}^{n}\sum_{j=1}^{n}\sum_{k=1}^{k} d_{ijk} \times A_{TC} \quad (12)$$

Where

T_C= Total transportation cost

A_{TC} = Average transportation cost per km

d_{ijk}= The length of the edge between nodes i and j travelled by vehicle k

$$T_t = \sum_{i=0}^{n}\sum_{j=1}^{n}\sum_{k=1}^{k} \frac{d_{ijk}}{F_{vk}} \quad (13)$$

Where

T_t = Total transportation time route

F_{vk} = Fleet velocity (km/h) of vehicle k

$$R_u = \frac{\sum_{i=0}^{n}\sum_{j}^{n}\sum_{k=1}^{K} d_{ijk} \times W_{ijk}}{T_d \times Q_k} \quad (14)$$

Where

R_u= Route utilization

T_d= Total distance

3. HYPOTHETICAL LAST MILE FOOD DELIVERY MODELS DEVELOPMENT

Generally, in home delivery approach, vehicles depart from a company central depot to deliver purchased food to end customers who are ordered through e-commerce channels. In order to model this service delivery, a number of 125 customers are considered and distributed stochastically within the urban region. Figure 1 displays the GURU snapshot of the customers' distribution in one of the UK cities (red circles) with a single depot.

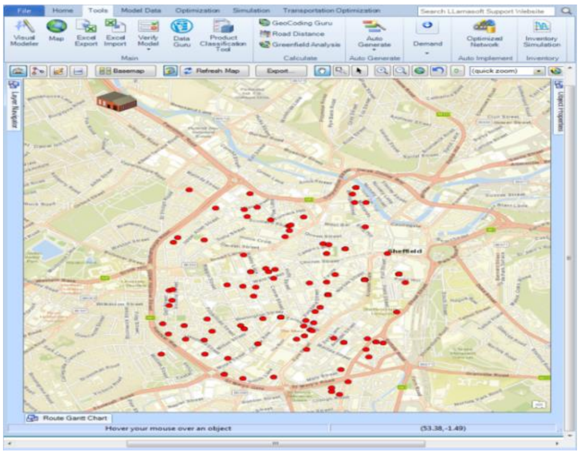


Figure 1: Supply Chain Guru Screen Shot of the Customers' distribution

Subsequently, the following assumptions are adopted:

1. The customers' demand weights (kg) are randomly determined from n (10, 30).
2. Travel distance is measured in kilometre (km).
3. There is a homogeneous fleet available at the company with the capacity of 600 (kg) and CO_2 emission rate of 0.00028324 kg per km.
4. The primary number of the vehicle is considered to be equal to the number of the customers (Limitation of the number of vehicles are ignored).
5. Average transportation costs, average vehicle's velocities and vehicle's tare weight are considered to be £2 per km, 30m/h and 1000 respectively.
6. Time available for delivery is assigned to each customer randomly through four categories: 9am-12 pm, 12-15 pm, 15-18 pm, 18- 21 pm
7. Vehicle waiting time in both customer's points and depot's point is ignored.
8. Limitation of the number of lockers' boxes is not considered.

The obtained results from MATLAB Software for the home service delivery model are displayed in Table 1. In order to meet all customers' demands through specified time window, the numbers of 9 routes (R) are generated with associated results in terms of the mean values of: millage (*M*), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u) were 6.38(km), 2.05(kg), 12.77(£), 0.21(h) and 21(%) respectively.

Table 1: Vehicle Route Optimisation Results for Home Service Delivery Model

Routes	M (km)	CO_2 (kg)	T_c (£)	T_t (h)	R_u (%)
R 1	5.93	1.91	11.86	0.20	23
R 2	4.60	1.41	9.21	0.15	13
R 3	4.88	1.47	9.76	0.16	10
R 4	4.81	1.49	9.63	0.16	16
R 5	11.33	3.73	22.66	0.38	27
R 6	5.91	1.87	11.81	0.20	19
R 7	6.50	2.14	12.99	0.22	27
R 8	6.12	1.92	12.24	0.20	18
R 9	7.38	2.51	14.76	0.25	34
Total	**57.46**	**18.45**	**114.92**	**1.92**	**-**
Mean	**6.38**	**2.05**	**12.77**	**0.21**	**21**

To develop a pickup point service delivery by using lockers; Supply Chain GURU Software is adapted to implement Greenfield analysis to identify the optimal number and location of pick up points (lockers) through a service constraint. The Greenfield service constraints enable to specify the percentages of customers or demand to be served within specified distances from the Greenfield sites. In this research, the distance between 100% of customers and pick up points (lockers) is generated to not be more than 400 meters. The obtained results from GURU Software are displayed in Table 2 which ten potential lockers (L) facilities with their assigned customers (A_c) are determined with average distance (A_d) between customers and lockers is 0.168 (km). Figure 2 also displays the snapshots of the GURU results.

Table 2: Greenfield Analysis Result

L	Latitude	Longitude	A_c	A_d
L1	53.3811	-1.4664	35	0.202
L2	53.38485	-1.47267	9	0.152
L3	53.38432	-1.48193	3	0.077
L4	53.38655	-1.47877	6	0.198
L5	53.37625	-1.47529	17	0.251
L6	53.38054	-1.47545	12	0.177
L7	53.37766	-1.48139	13	0.215
L8	53.37293	-1.46917	5	0.086
L9	53.37669	-1.46897	19	0.213
L10	53.38762	-1.4674	6	0.112
Mean				**0.168**

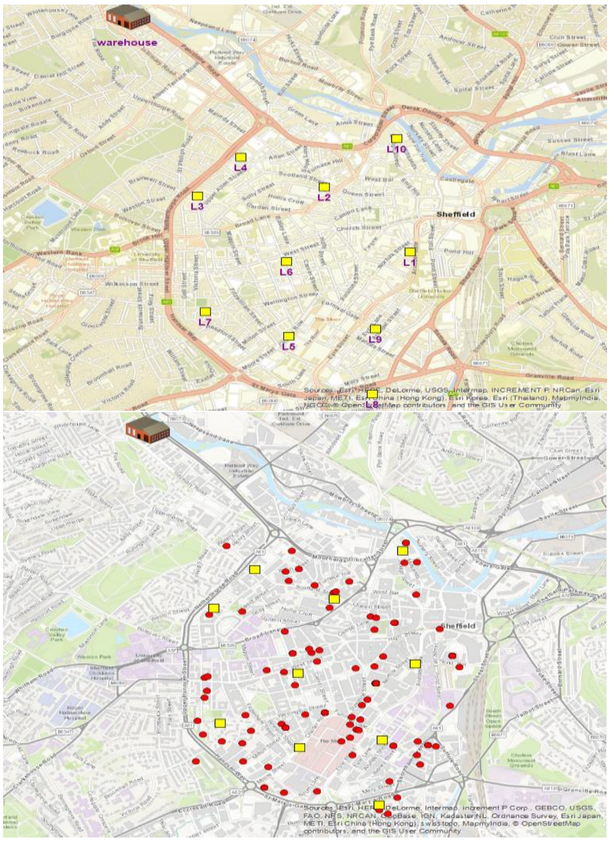


Figure 2: Supply chain Guru Screen Shot of the Greenfield Analysis Result

As shown in Table 3, six routes are generated during the simulation of pick up point service delivery model to meet all customers' demands through the specified time window. On average, millage (*M*), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u) were 5.43 (km), 1.87(kg), 10.87(£), 0.18(h) and 34(%) respectively.

Table 3: Vehicle Route Optimisation Results for Pick up Point Service Delivery Model

Routes	M (km)	CO_2 (kg)	T_c (£)	T_t (h)	R_u (%)
Route 1	6.25	2.16	12.51	0.21	37
Route 2	5.87	2.13	11.75	0.20	47
Route 3	5.67	1.92	11.34	0.19	33
Route 4	6.98	2.51	13.95	0.23	45
Route 5	4.33	1.48	8.66	0.14	34
Route 6	3.50	1.04	6.99	0.12	08
Total	**32.60**	**11.24**	**65.21**	**1.09**	-
Mean	**5.43**	**1.87**	**10.87**	**0.18**	**34**

4. SUSTAINABILITY COMPARISON RESULTS: PICKUP POINT USING LOCKERS VERSUS HOME DELIVERY

As illustrates in Figure 3, the comparison of the results revealed that the obtained values from the pickup point service delivery are improved in terms of the millage (M), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u):

- The mileage was reduced by 43% from 57.46 (km) in home service delivery service to 32.6(km) in pickup point service delivery.
- The CO_2 emissions were fallen by 39% from 18.45 (kg) in home service delivery to 11.24(kg) in pickup point service delivery.
- The transportation cost was decreased by 43% from 114.92 (£) in home service delivery to 65.21(£) in pickup point service delivery.
- The transportation time was dropped by 43% from 1.92 (h) in home service delivery to 1.09 (h) in pickup point service delivery.
- The route utilisation was improved by 161% from 21% in home service delivery to 34% in pickup point service delivery.

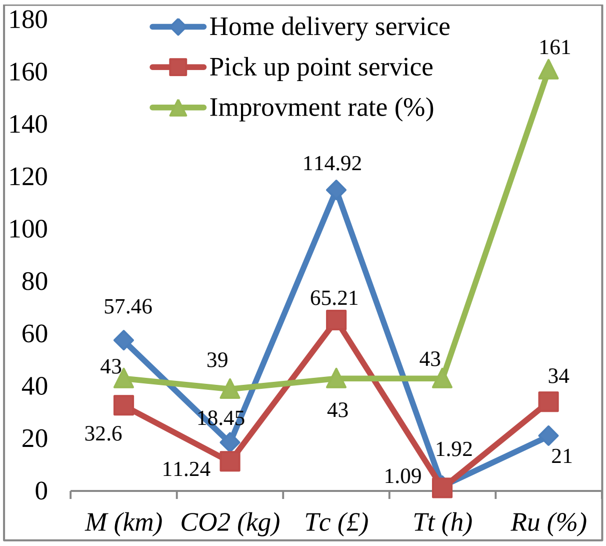


Figure 3: Pickup Point Delivery Versus Home Delivery Sustainability Comparison Results

5. CONCLUSION

In this paper, the sustainability performance through two last mile food delivery approaches; home service delivery and pick up point service delivery using lockers were evaluated. Both approaches were developed hypnotically and implemented and validated using Supply Chain GURU Software and MATLAB software. Greenfield analysis was used to identify the optimal number and location of potential locker facilities with a single service constraint. Moreover, vehicle route optimisation was applied to minimising CO_2 emission.

The output data was used to investigate sustainability performance of both home service delivery and pick up point service delivery through some performance measures such as millage, CO_2 emission, transportation cost, transportation time and route utilisation.

This work provided a systematic method to quantify the differences in sustainability performance between home service delivery and pickup point service delivery. The results proved that the pickup point outperformed the home service delivery in all the performance measures considered in this study.

REFERENCE

Boyer, K. K., A. M. Prudhomme, and W. Chung., 2009. The Last Mile Challenge: Evaluating the Effects of Customer Density and Delivery Window Patterns. Journal of Business Logistics, 30(1), 185–201.

Bromage, N., 2001. Keep the Customer Satisfied. Supply Management, 6(10), 34–36

Brown, J.R. and Guiffrida, A.L., 2014. Carbon emissions comparison of last mile delivery versus customer pickup. International Journal of Logistics Research and Applications, 17(6), 503-521.

Closs, D.J., Speier, C. and Meacham, N., 2011. Sustainability to support end-to-end value chains: the role of supply chain management. Journal of the Academy of Marketing Science, 39(1), 101-116.

Gevaers, R., E. Van de Voorde, and T. Vanelslander., 2011. Characteristics and Typology of Last-Mile Logistics from an Innovative Perspective in an Urban Context. City Distribution and Urban Freight Transport: Multiple Perspectives, Edward Elgar Publishing, 56-71.

Lee, H. L., and S. Whang., 2001. Winning the Last Mile of E-Commerce. MIT Sloan Management Review, 42(4), 54–62.

Saad, S., Bahadori, R., Ravisankar, J., 2017. Modelling the sustainable distribution system in food retail sector- A simulation approach. In: Bruzzone AG, Piera MA, Longo F, Vignali G, editors. FoodOPS2017: Proceedings of the International Food Operations and Processing Simulation Workshop. 2017 Sep 18-20; Barcelona, Spain. Red Hook, NY: Curran Associates, Inc, 45-50.

Seuring, S. and Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of cleaner production, 16(15), 1699-1710.

Siikavirta, H., M. Punakivi, M. Karkkainen, and L. Linnanen., 2003. Effects of E-Commerce on Greenhouse Gas Emissions. Journal of Industrial Ecology, 6(2), 83–97.

TRB, 2014. Waitrose trials temperature controlled click & collect lockers available at: https://www.theretailbulletin.com/news/waitrose_trials_temperature_controlled_click_collect_lockers_20-10-14/

Ülkü, M. A., 2012. Dare to Care: Shipment Consolidation Reduces Not Only Cost, But Also

Environmental Damage. International Journal of Production Economics, 139(2),438–446.
Validi, S., Bhattacharya, A. and Byrne, P.J., 2014. A case analysis of a sustainable food supply chain distribution system—A multi-objective approach. International Journal of Production Economics, 152, 71-87.
Visser, J., Nemoto, T. and Browne, M., 2014. Home delivery and the impacts on urban freight transport: A review. Procedia-social and behavioral sciences, 125, 15-27.
Weltevreden, J.W. and Rotem-Mindali, O., 2009. Mobility effects of b2c and c2c e-commerce in the Netherlands: a quantitative assessment. Journal of Transport Geography, 17(2), 83-92.

AUTHORS BIOGRAPHY

Professor Sameh M Saad, holds a BSc (Honours), MSc, PhD, PGCHE, CEng, MIET, MILT, FHEA, FCILT. He is the Professor of Enterprise Modelling and Management and also a Postgraduate Research Coordinator and MSc/MBA Course Leader in the Department of Engineering, Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, UK. His research interests and experience include fractal supply chain, modelling and simulation, design and analysis of manufacturing systems, production planning and control, reconfigurable manufacturing systems and next generation of manufacturing systems including fractal and biological manufacturing systems. He has published over 150 articles in various national and international academic journals and conferences, including keynote, address a book and four patents.

Ramin Bahadori is a PhD candidate in the Department of Engineering, Sheffield Hallam University, UK. He received his BSc in Industrial Management from Persian Gulf University, IRAN and MSc degree in Logistics and Supply Chain Management from Sheffield Hallam University, UK in 2010 and 2014 receptively. His research interest is in the field of fractal supply chain, modelling and simulation, logistics capabilities, inventory optimisation, logistics cost optimisation, information system, food supply chain, green Vehicle routing problem, last mile delivery, supply network integration, supply chain sustainability, communication and collaboration within supply network, and multi-criteria decision-making fuzzy AHP.

APPLICATION OF REA-METHOD TO A CONVECTIVE DRYING OF APPLE RINGS AT AMBIENT TEMPERATURE

D. Bulegenov [a], S. Saliyeva [b], A. Sekerbayeva [c], S. Spotar [d]

[(a),(b),(c),(d)] Chemical Engineering Department, School of Engineering, Nazarbayev University, 53 Kabanbay batyr Ave., Astana 010000, Kazakhstan

[(a)] dinmukhamed.bulegenov@nu.edu.kz, [(b)] ssaliyeva@nu.edu.kz, [(c)] aigerim.sekerbayeva@nu.edu.kz, [(d)] sergey.spotar@nu.edu.kz

ABSTRACT

This study focuses on the convective drying of apple rings without any extra-heating of the processing ambient air. The lumped reaction engineering approach (REA) model has been employed to determine the rate of drying for the apple rings under forced convection considered as a normal processing regime. The algorithm implies determination the activation energy curve from the accurate 'reference' measurements of the drying rate under natural convection conditions. The required for the model implementation mass transfer coefficients for the apple ring samples under natural and forced conditions were obtained in the series of customized experiments. The study does extend the application of REA for the limiting simplest case of convective drying of thick samples under ambient temperature condition.

Keywords: convective drying, apple rings, reaction engineering approach (REA)

1. INTRODUCTION

Nowadays apples are one of the most widely-produced fruits in the world (Statista, 2014). The *Malus domestica* apple's domestication history originates from at least 6,000 years ago from *Malus sieversii* in the Tien Shan Mountains of Central Asia. An apple has been identified as one of the main dietary sources of fibre and phenolic compounds that have antioxidant properties thus helping to improve people's health (Boyer and Liu, 2004, Raudone et al., 2016).

In order to provide a year-round supply of nutrients, there is a need to preserve fruits while when they are high in a season. Drying is one of the oldest simple and safe methods to increase the storage time without considerable changes in flavour, colour and essential nutrients. Moreover, drying increases storage time and reduces costs of packaging, transportation and storage as well as environmental footprint associated with these processes (Arslan and Musa Özcan, 2010).

During long historical development variety of drying methods such as natural drying by convective air, freeze-drying, superheated steam drying, microwave-aided drying and others have been developed (Zhang et al., 2017, Sagar and Suresh Kumar, 2010). As far as drying of products and their storage is concerned, commonly it faces compromises between process technology and product quality.

Due to extreme continental climate in Kazakhstan the typical indoor air humidity ranges within approximately 10 - 30 %. Unlimited naturally occurring dry air prompts to consume this environment benefit by carrying out the convective drying process. At the ambient temperatures, the driving force of the mass transfer manifests through the water vapour concentration gradient. This paper is a part of an ongoing project targeting exploration of the drying process specifics at the conditions described above. Without application of heating, the drying at the ambient temperature is attractive not only from the energy saving and economics perspective but also from environmental sustainability point. The resultant high-quality product could be classified coming from 'green technology' process. Figure 1 demonstrates rather convincing samples of the dried apple ring obtained by drying at ambient temperature without application of any preservative substances (like sulphur dioxide). The question that occurs within the frame of the project is how to calculate (evaluate, estimate, predict) the rate of the drying process of the apple rings.

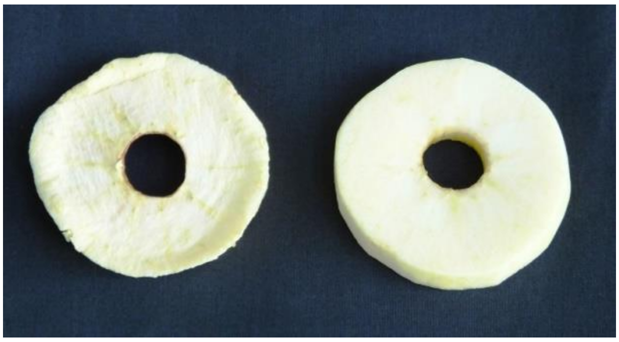


Figure 1: Samples of fresh (on the right) and dried (on the left) apple rings; drying has been carried out at 25°C of ambient dry air.

The lumped reaction engineering approach (REA) model (Chen 2008, Putranto, Chen and Webley 2011, Chen and Putranto 2013) has been employed in this study. In comparison with predecessors (a characteristic drying rate curve model, the distributed-parameter model, and the empirical models) REA has several advantages; in particular, it bridges experimental drying curves data with the Arrhenius fundamental equation in terms of evaporation. The implementation of the activation energy as an additional energy barrier brought proximate physical rationale into the interpretation of particulars of the specified drying process and allows rationalising prediction of the drying rate. Moreover, application of REA model reduces the volume of the experimental data required to calculate the rate of drying under a variety of air flow rates.

Initially, the application of REA modelling was suggested for prediction of the drying rate of 'thin' objects (lumped system) with a value of 'standard' Bi number less than 0.1 (Chen 2008). More recently, Chen and Putranto (2013) suggested the modified Bi accounted for the processes with a phase change, and accordingly, justifies the range of the applicability of a lumped system approach.

The objective of this paper is a further support application of the REA modelling in the case of convective drying of 'thick' objects (apple rings herewith). Besides, carrying out the drying process at ambient temperature (without heating of air) we highlight the limiting simplest case of REA approach without the necessity to determine the temperature profile.

2. MATERIALS AND METHODS

2.1. Requirements and inputs for the REA model application

With REA concept (Chen 2008, Putranto, Chen and Webley 2011, Chen and Putranto 2013), under quasi-isothermal conditions we have the following set of equations:

$$m_s \frac{dX}{dt} = -h_m A\left(\rho_{v,s} - \rho_{v,b}\right),$$

the drying rate of a material (1)

$$\rho_{v,s} = exp\left(-\frac{\Delta E_v}{RT_s}\right)\rho_{v,sat}(T_s),$$

surface vapour concentration (2)

$$\rho_{v,sat} = K_v\left(-\frac{E_v}{RT}\right),$$

saturated vapour concentration of water (3)

$$\Delta E_v = -RT_s ln\left(\frac{-m_s\frac{dX}{dt}\frac{1}{h_m A}+\rho_{v,b}}{\rho_{v,sat}}\right),$$

the activation energy (4)

$$\frac{\Delta E_v}{\Delta E_{vb}} = f(X - X_b),$$

the dependence of activation energy on moisture content (5)

$$\Delta E_{vb} = -RT_b \ln(RH_b),$$

the 'equilibrium' activation energy (6).

When drying apple rings using ambient air, the temperature difference across product surface and bulk flow certainly do present, however, its value is rather small. Hence, the physical properties of the product and drying air were estimated at the same ambient temperature; under this assumption, the process heat balance equation is not addressed.

Since derivation, meaning and significance of the system (1) – (6) are provided in the original papers (Chen 2008, Putranto, Chen and Webley 2011, Chen and Putranto 2013), herewith we focus on some specifics associated with the implementation of REA method in our experiments.

Thus, Eqn. (4) has to be used to determine the activation energy function $\Delta E_v(X)/\Delta E_{vb}(X)$ from the experimental data $X = X(t)$ via numerical differentiation which requires an accurate continuous measurement of the drying rate. The experimental procedure of accurately recorded data of the apple ring samples takes an essential role in implementation of the REA model.

In addition, the determination of the value of the mass transfer coefficient, h_m, in Eqn. (4) needs to be accounted for. In cases of convection, for the objects of canonical geometry like spheres and cylinders, the relevant correlations are readily available in literature and can be used straightforward (Chen 2008, Putranto, Chen and Webley 2011, Chen and Putranto 2013). However, in the absence of such equations for the samples of arbitrary geometry, the value of mass transfer coefficient should be found under the customised experimental procedure.

2.2. Material preparation and drying conditions

Apple of *Golden Delicious* variety has been used in experiments. The fruit was washed with tap water, wiped to dry and the peel was removed. Rings ≈ 10 mm in thickness, ≈ 60 mm in outer diameter, and ≈ 10 mm in inner diameter were cut from apple. All procedures are conducted in the laboratory under room temperature (25°C - 27°C) and humidity (8% - 12%); during each experiment temperature and relative humidity data were measured using the ТКА-ПКМ20 metering system the and recorded accordingly. The accuracy and precision of the measurement is ±5.0% for the relative humidity (RH) measured value and ±0.5°C for the room temperature. There were no appliances for stabilisation of the temperature and humidity of the convective media like it was arranged in the closed-loop facility [10], hence slight variations of the ambient temperature and humidity were averaged to be used in the following calculations.

2.3. Natural convective drying, determination of activation energy

Under REA-method hypothesis, for similar drying conditions and initial water content, it is possible to obtain the necessary REA parameters for the specified product, expressed in the relative activation energy $\Delta E_v/\Delta E_{vb}$ in one accurate drying experiment (Putranto, Chen and Webley 2011). Drying of the apple ring under the condition of natural convection has been selected for determination of the activation energy for these apple rings. The schematic of the experiment is shown in Figure 2.

The loss of mass of the sample due to the drying process has been measured using the KERN EG-N mass balance with 1 mg accuracy grade. Measurements were recorded each 30 s with the application of the compatible software. The experiments under natural convection lasted 30 hours until apple rings approached to equilibrium moisture consent state. Afterwards, for calculation of the moisture content on the dry basis, Xi:

$$X_i = (m_i - m_s)/m_s \quad (7)$$

the dry residue has been determined by drying of the apple ring sample at 105°C ±5°C for 30 min in PN60 Carbolite oven to constant mass, m_s. The measured relationship $X_i = X_i(t)$ has been used in the calculation of the activation energy.

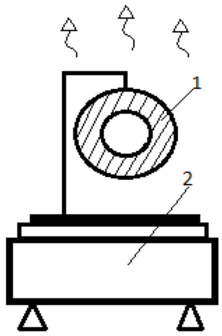


Figure 2: Drying of the apple ring under natural convection; 1 – apple ring sample, 2 – mass balance.

2.4. Forced convection drying

Drying under forced convection condition has been accomplished in the unrestricted open space using the conventional fan as shown in Figure 3. The free stream velocities near the sample were measured with Testo 416 anemometer equipped with the miniature vane sensor with the accuracy of ±(0.2 m/s + 1.5 % of measured value). Continuous monitoring of the sample's mass loss with the KERN EG-N mass balance was not possible due to the disturbing dynamic impact of the flow on the mechanism of balance if placed in the airstream. Therefore the apple ring samples were periodically taken from the airstream for mass loss measurements. Actually, it was not a problem since under REA method the activation energy function Eqn. (5) was evaluated in 'an accurate' experiment under natural convection.

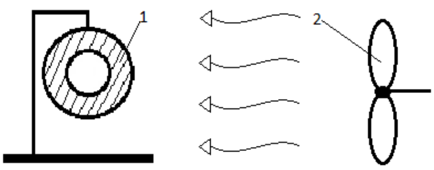


Figure 3: Drying of the apple ring under forced convection; 1 – apple ring sample, 2 – air mover (fan).

2.5. Determination of mass transfer coefficients

Experimental determination of mass transfer coefficient, h_m, required to use in Eqn. (4) has been accomplished using the geometrically similar rings which were cut out from the porous floral foam material. These rings were soaked in water and arranged as shown in Figure 2 and Figure 3. It was assumed that the drying of the fully water-soaked ring can be described as the evaporation from the completely wet surface as:

$$dm/dt = h_m A(\rho_{v,sat} - \rho_{v,b}) \quad (8).$$

Eqn. (8) enables calculation of the values of mass transfer coefficient, h_m, via the recording of the evaporation rate and evaluation of other terms. It is worth to point out that we assumed that initially and within 20 – 30 min of the transient period of measurement the surface temperature of these soaked ring could be approximated to the value of the ambient temperature due to the relatively large thermal capacity of a water-soaked ring. Therefore, the surface saturated water vapour concentration, $\rho_{v,st}$, was determined at the ambient temperature. In the opposite to the limiting situation of mass transfer from the water thermo-insulated film the surface wet bulb temperature might be noticeably lower than the temperature of the surrounding.

3. RESULTS AND DISCUSSION

3.1. Experimental data and determined inputs for REA model

The raw experimental data for the mass transfer coefficient determination is presented in Figure 4. Linear behaviour of the mass loss corresponds to the constant rate drying process that implies completely wet surface. Data input and application of Eqn. (7) yields to $h_m \approx 0.003$ m·s^{-1} for natural convection condition and $h_m \approx 0.0093$ m·s^{-1} for the forced convection under 1.5 m·s^{-1} airstream velocity.

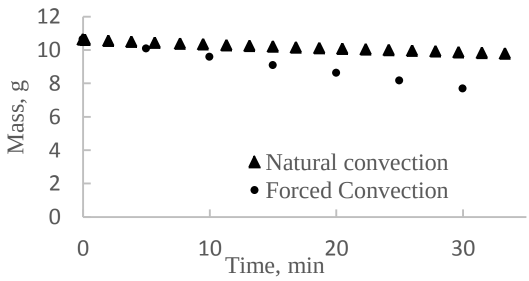


Figure 4: Loss of mass due to evaporation from the saturated surface of the floral foam rings under natural and forced convection.

Figure 5 represents raw data and the processed parameters for the accurate drying of the apple rings under natural convection. This was done to obtain the activation energy function for the apple rings that in a turn was used to calculate the drying rate for the forced convection condition.

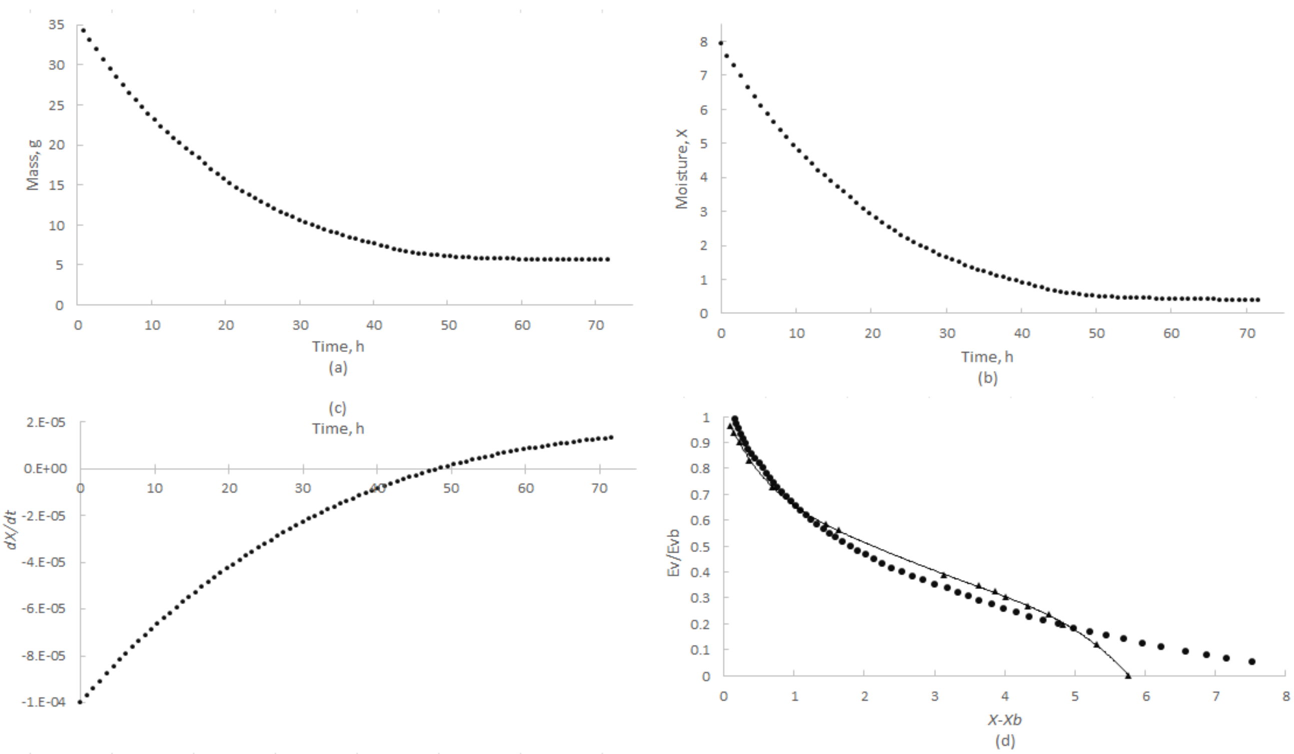


Figure 5: Drying of the apple ring under natural convection. (a) – apple ring mass loss, (b) – moisture content change, (c) – change of drying rate; (d) – the relative of activation energy of the apple ring sample (circles) and apple cylinder sample (triangles) (Putranto, Chen and Webley 2011).

Apple samples drying curves $X = X(t)$ behaviour generally corresponds to the results published in the earlier works (Putranto, Chen and Webley 2011, Zlatanovic, Komatina and Antonijevic 2013); the scheduled differences can be attributed to the variety of apples, the shape of the samples, temperature and humidity of the drying air. Most probably, due to these reasons, we observe some discrepancy in the relative activation energy curves $\Delta E_v/\Delta E_{vb} = f(X - X_b)$ obtained in our work (shown in Figure 5(d)) and in the previous study (Chen and Webley 2011).

3.2. Estimation of the forced convective drying rate as the outcome of the REA model

As it was already mentioned, the main benefit of REA-method is a reduction of the required experimental data needed to calculate the drying rate curves by using the conservative properties of the relative activation energy. As to the same material being dried under the different drying conditions, Chen and Putranto (2013) prognosticate more or less the same trend quantitatively. The experimental results of the change in the moisture content of the apple ring samples and the relevant calculated curve are depicted in Figure 6. The accuracy of prediction is rather satisfactory taking into account the arguable issue of the drying at the same ambient temperature and humidity but under the natural and forced convection can be regarded as 'similar drying conditions' (Putranto, Chen and Webley 2011, Chen and Putranto 2013). Perhaps, more data is required to be accumulated to clarify this matter. Additionally, it is worth to point out the simplicity of the setup and process of carrying out the experiment for obtaining the data for activation energy estimation under natural convection regime.

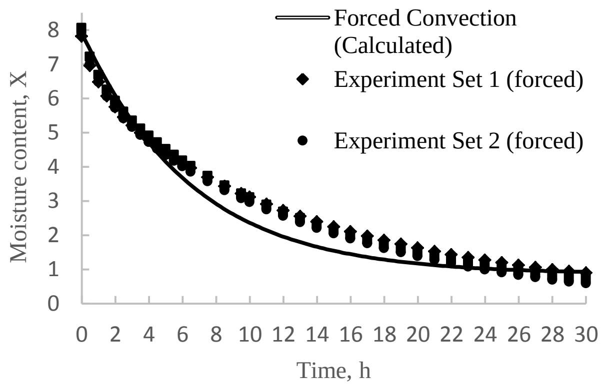


Figure 6: Experimental and calculated drying curves for the apple rings placed in the airstream characterised with T ≈ 27°C, RH ≈ 12% and u ≈ 2 ms-1.

4. CONCLUSION

Application of the reaction engineering approach (REA) has been used in this study to predict the moisture content profile of convective drying of apple rings. The activation energy was evaluated in the experiment under natural convection via accurate measurement of the sample mass loss with a precision balance. The activation energy and the saturation vapour concentration were determined at the ambient temperature. The mass transfer coefficients for the ring shape samples have been estimated in the set of customised experiments. Therefore, this work extends the application of REA for convective drying of thick samples under ambient temperature condition (without heating of air).

NOMENCLATURE

A surface area of the sample (m2)
h_m mass transfer coefficient ($m \cdot s^{-1}$)
m apple ring sample mass (kg)
m_s dried mass sample of material (kg)
RH relative humidity of drying air
T temperature (K)
t time (s)
X average moisture content on a dry basis ($kg \cdot kg^{-1}$)
X_b equilibrium moisture content on a dry basis ($kg \cdot kg^{-1}$)
E_v activation energy for pure water evaporation ($J \cdot mol^{-1}$)
ΔE_v activation energy ($J \cdot mol^{-1}$)
$\Delta E_{v,b}$ 'equilibrium' activation energy ($J \cdot mol^{-1}$)
K_v apparent reaction frequency, ($kg \cdot m^{-3}$)
$\rho_{v,b}$ vapour concentration in drying air ($kg \cdot m^{-3}$)
$\rho_{v,s}$ concentration of water vapour at surface ($kg \cdot m^{-3}$)
$\rho_{v,sat}$ saturated vapour concentration ($kg \cdot m^{-3}$)

ACKNOWLEDGMENTS

This research was supported by Small Research grant scheme at Nazarbayev University (090118FD5323).

REFERENCES

Arslan D., Musa Özcan M., 2010. Study the effect of sun, oven and microwave drying on quality of onion slices. LWT - Food Science and Technology, 43 (7), 1121–1127. Available from: http://www.sciencedirect.com/science/article/pii/S0023643810000794 [accessed 14 December 2017]

Boyer J., Liu R.H., 2004. Apple phytochemicals and their health benefits. Nutrition Journal, 3 (5). Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC442131/ [accessed 14 December 2017]

Chen X.D., Putranto. A., 2013. Modelling Drying Processes. New York: Cambridge University Press.

Chen X.D., 2008. The Basics of a Reaction Engineering Approach to Modeling Air-Drying of Small Droplets or Thin-Layer Materials. Drying Technology, 26, 627–639. Available from: https://doi.org/10.1080/07373930802045908 [accessed 14 December 2017]

Putranto A., Chen X.D., and Webley P.A., 2011. Modelling of Food Materials with Thickness of Several Centimeters by Reaction Engineering Approach (REA). Drying Technology, 29, 961–973. Available from: https://doi.org/10.1080/07373937.2011.557793 [accessed 14 December 2017]

Raudone L., Raudonis R., Liaudanskas M., Viskelis J., Pukalskas A., Janulis V., 2016. Phenolic Profiles and Contribution of Individual Compounds to Antioxidant Activity of Apple Powders. Journal of Food Science, 81 (5), C1055–61. Available from: http://dx.doi.org/10.1111/1750-3841.13277 [accessed 14 December 2017]

Sagar V.R., Suresh Kumar P., 2010. Recent advances in drying and dehydration of fruits and vegetables: a review. Journal of Food Science and Technology, 47 (1), 15–26. Available from: https://doi.org/10.1007/s13197-010-0010-8 [accessed 14 December 2017]

Statista, 2014. Fruit: world production by type 2014. Available from: https://www.statista.com/statistics/264001/worldwide-production-of-fruit-by-variety/ [accessed 14 December 2017]

Zhang M., Chen H., Mujumdar A.S., Tang J., Miao S., Wang Y., 2017. Recent developments in the high-quality drying of vegetables, fruits, and aquatic products. Critical Reviews in Food Science and Nutrition, 57 (6), 1239–1255. Available from: http://dx.doi.org/10.1080/10408398.2014.979280 [accessed 14 December 2017]

Zlatanović I., Komatina M., Antonijević D., 2013. Low-temperature convective drying of apple cubes. Applied Thermal Engineering, 53, 114–123. Available from: https://doi.org/10.1016/j.applthermaleng.2013.01.012 [accessed 14 December 2017]

AUTHORS BIOGRAPHY

Dinmukhamed Bulegenov and Aigerim Sekerbayeva are fourth-year Chemical Engineering students at Nazarbayev University, Kazakhstan.

Sayara Saliyeva is a PhD Candidate at UCL, UK. She also holds a post of a teaching and research assistant within the Chemical Engineering Department at Nazarbayev University. Sayara graduated with an MEng in Chemical Engineering from University of Sheffield, UK. Sayara's research interests lie at the interface between environmental risk assessment and techno-economic analysis of gasification processes, particularly in relation to policy formation and the establishment of novel or emerging technologies.

Sergey Spotar began his research career in 1975 in the Institute of Thermo-Physics of Russian Academy of Sciences. His PhD thesis focused on the specifics of transport phenomena in confined swirled flows. In 1998 Sergey Spotar went to Malaysia where he worked in industry and taught in universities. Since 2012 Sergey Spotar holds a position of Associate Professor within Chemical Engineering Department at Nazarbayev University. His research interests relate to heat/mass transfer; food freezing, drying and thermo-processing; air pollution control and industrial ventilation; supercritical carbon dioxide applications; handling of bulk solids; diagnostics of turbulent boundary layers and vortex flows using non-intrusive laser dopler anemometry technique.

DESIGN AND TESTING OF MODIFIED ATMOSPHERE PACKAGING OF COW'S RICOTTA

Ugolotti Sara[(a)], Vignali Giuseppe[(b)]

[(a)]CIPACK Interdepartmental Center, University of Parma, Parco delle Scienze 181/A, 43124 Parma (Italy)
[(b)]Department of Engineering and Architecture, University of Parma, Parco delle Scienze 181/A, 43124 Parma (Italy)

(a) sara.ugolotti2@studenti.unipr.it , (b)giuseppe.vignali@unipr.it

ABSTRACT

The aim of this work is to evaluate the shelf life of cow's ricotta under MAP (Modified Atmosphere Packaging). MAP is a packaging technique commonly used in the food industry in order to control the microbial growth. After the extraction of the air present in the headspace of the package, a mixture of CO_2, O_2 and N_2 in different percentage is usually introduced before the packaging sealing.
Based on these premises, a design of experimental tests has been created in order to evaluate the effect of each process parameters. To perform these test, it is also required the creation of thermoformed trays (made with a multilayer material using PET/EVOH/PE) in which the ricotta was inserted and packaged in a modified atmosphere.
After the time intervals established in the experimental program, the analysis of the MAP was carried out using a special instrument ("Oxybaby" made by Witt SpA), able to measure the quantity of gas present in the headspace of the thermoformed trays. Then a statistical analysis of the obtained results was carried out.
The results showed that after 10 days the product was edible for all types of atmosphere, but at 20 and, especially, at 30 days, even in the trays wrapped with CO_2, the product was not acceptable for human consumption.
One of the possible solutions, in order to lengthen the shelf life of cow's ricotta, consists in the pre-sterilization of the trays before the product packaging with a solution of H_2O_2.

Keywords: cow's ricotta, MAP, gas mixture, trays.

1. INTRODUCTION

The term "Ricotta" derives from the Latin "recoctus", that is "cooked twice", to indicate the technology used to produce this dairy product. Ricotta is obtained from the heating of the residual whey from the processing that has already undergone cooking for the production of cheese. Not coming directly from the milk but from the whey of cheese making and not being the coagulation of proteins due to rennet, the ricotta cheese cannot fall into the product definition of cheese, and it is therefore described generically as a dairy product. Considered, in fact, by many people as a cheese (often called Ricotta cheese), it is, instead, the classic by-product of cheese making. The milk, made coagulate with veal rennet or with the other types of agents, available coagulants (animals, vegetables, microbial, chemical) gives rise to the curd, which is recovered and become cheese, rich in noble protein, ie casein. The remaining liquid, or dairy serum, can be heated to at least 72 and often up to 90 ° C; in such conditions the serum proteins (lactalbumin, lactoglobulin, etc.) solidify and are exploited. This material is ricotta, whose composition is extremely variable; the humidity varies from 60 to 75%, the fat from 4 to 15% and more. Borba et al. (2013), in their research, state that the use of whey did not compromise its texture or result in sensory negative characteristics. Indeed, data suggest that whey of cheese, may be used as the main ingredient in creamy ricotta cheese production, adding value to this by-product and providing a promising alternative for the reuse of whey generated by the dairy industry. The grow in consumption and imports of dairy products in international markets is expected to continue in the coming years due to both economic development and the gradual urbanization of most population currently residing in rural areas (Mantione and Vignali 2017). Within ten years the consumption of cheese will grow altogether by an average of 17% world-wide, with an increase that will reach 41% in Asian countries (Nomisma 2015). For this reason, it is necessary that cheese producers devote time and resources to improve the technologies and production methods in order to obtain a better and longer shelf life product. Consumer demand is increasingly turning towards products without chemical preservatives, with high nutritional characteristics and low fat content. Cow's ricotta reflects this type of product, in fact, it is low in fat and salt and it contains many proteins. Fresh ricotta, however, is characterized by short shelf life because of its high moisture level, high concentration of residual sugars and an initial pH above 6.0 which, make this product an excellent growth medium for a wide range of microorganisms (Mancuso et al. 2014). In dairy products there are some microorganisms that, growing up, change appearance and quality of the products. The presence and quantity of these depends on the initial microbial contamination and on the hygienic rules practiced during the production. Most of the indigenous microorganisms, like Enterobacteriaceae and E. coli, are not able to survive at thermal treatment of the whey, to this purpose their presence in ricotta is, usually, due to secondary contamination, closely related to precarious hygiene conditions. Secondary contamination occurs after the cooking phase, especially during packaging, then during the storage phase the microorganisms grow and multiply. Given the high moisture, elevated pH, the water activity and the refrigerated storage, ricotta is an excellent substrate for the possible growth of several psychotropic pathogenic and spoilage microorganisms. Common contaminants of ricotta include Pseudomonas spp., Enterobacteriaceae, Listeria monocytogenes, B. cereus and Arcobacter spp., yeast and moulds. Pseudomonas spp. represents the main obstacle to extend ricotta shelf life, because it benefits of the selective advantage of the combination of low temperature and long storage (Spanu et al. 2018).

To lengthen the shelf life, as much as possible, the ricotta is packaged using the modified atmosphere. MAP is packaging technique frequently used in food industry to control the microbial growth (Peelman et al. 2014; Spanu et al., 2016), different mixtures of gas can be used, usually are combined percentages of Oxygen, Carbon Dioxide and Nitrogen.

The ability of MAP to extend the shelf life of a traditional regional product guarantees consumers a quality product and provides opportunities for manufacturers to expand their markets beyond national boundaries (Mancuso et al, 2014). It is, also, important to use high-barrier packaging to avoid excessive leakage of gas from the tray.

It is necessary to underline that the presence of environmental contaminants implies that the use of MAP without an appropriate decontamination of the packaging film and the headspace is not sufficient to extend the durability of cow's ricotta. For this reason, it is always necessary to equip the working environment with adequate hygienic protection systems, e.g. air filtration.

Some recent studies concern the use of biopreservatives to control microbial proliferation in MAP packed ricotta. Fresh ricotta, intended for large scale retail, is commercialized in modified atmosphere packaging, under refrigeration temperature, with a shelf life varying from 14 to 21 days (Spanu et al. 2017). The improvement of the hygiene management procedures it is one of the possible solutions to reduce the level of initial microbial contamination. The use of biopreservatives has been proposed to compete with contaminants and to preserve the quality of dairy products. The genus Carnobacterium, is able to produce bacteriocins, therefore, it has been used as protective cultures to provide durability and safety to various types of food. The use of this biopreservative was effective in reducing Pseudomonas ssp concentration respectively (Sobrino-Lopez and Martin-Belloso 2008, Elsser-Gravesen 2013). The remainder of this article is composed as follows. The second chapter describe the experimental program, materials and procedures. In the third one there is a description of the collected data. The second to last chapter consists in the discussion of the results obtained. Finally, section five contains conclusions and reflections of the work carried out.

2. MATERIAL AND METHODS

2.1 Samples

The study was conducted on 143 trays, 135 of which with the selected gas mixture inside. The remaining 8 trays are filled only with air in their head space and they serve as control samples. The samples consist on thermoformed trays of rectangular base, made with a multilayer material using PET/EVOH/PE, sealed with high barrier peelable laminated films and weighing approximately 300g. After packaging they were transported to the refrigerated storage (4°C). The analyzed samples present three variables:

- Time. Microbial analyzes were done after 10, 20 and 30 days.
- Trays depth. Three different trays depths have been tested: 20, 30 or 40 mm.
- Gas mixture. Three different mixture of gas were inserted:
  - 100% N_2
  - 75% N_2 and 25% CO_2
  - 50% N_2 and 50% CO_2

Tests were done in different moments to evaluate the conservation state of the product. Another variable is the headspace of the trays, that determine the gas quantity in contact with ricotta. Three different gas mixtures were analyzed to evaluate which one leads to a better conservation of the food.

2.2 Experimental design

The samples were divided into 45 trays with map composed by 100% N_2, in particular 15 trays for each type of breakthrough (20,30,40 mm); the same thing was done for the other two mixtures, that are 75% N_2-25% CO_2 and 50% N_2-50% CO_2. There are also 8 control vessel fill with environment air. A map check is performed with "Oxybaby" for the various time intervals set by the experimental program. This is a special instrument made by Witt SpA, through a needle, it pierces the film that seals the tray so as not to let out the gas present inside and analyzes the percentages of the gases of the MAP.

3. RESULTS

3.1 Microbiological profile

Table 1: Intrinsic properties and microbiological profile after 10 days.

10 Days

Mixture	Depth	pH	Fecal coliforms	Enterobacteriaceae	Total mesophilic bacterial load	Yeast and moulds	Lactic bacteria	Micrococcaceae	Sulphite-reducing clostridia
Aria	-	6,23	<10	<10	10.000	<10	1.120	<10	<10
100% N2	20	6,26	<10	<10	5.000	<10	30	<10	<10
100% N2	30	5,81	<10	130	94.000	<10	54.000	30	<10
100% N2	40	5,82	<10	<10	188.000	<10	165.000	10	<10
75%N2 - 25%CO2	20	6,09	<10	<10	38.000	<10	48.000	<10	<10
75%N2 - 25%CO2	30	6,28	<10	<10	10.000	<10	44.000	30	<10
75%N2 - 25%CO2	40	6,17	<10	2000	750.000	<10	850.000	210	<10
50%N2 - 50%CO2	20	6,29	<10	<10	42.000	<10	5.000	<10	<10
50%N2 - 50%CO2	30	6,14	<10	<10	120.000	<10	166.000	10	<10
50%N2 - 50%CO2	40	6,15	<10	<10	176.000	<10	184.000	30	<10

Table 2: Intrinsic properties and microbiological profile after 20 days.

20 Days

Mixture	Depth	pH	Fecal coliforms	Enterobacteriaceae	Total mesophilic bacterial load	Yeast and moulds	Lactic bacteria	Micrococcaceae	Sulphite-reducing clostridia
Aria	-	5,98	<10	<10	34.000.000	300	1.440.000	10	<10
100% N2	20	5,78	<10	<10	14.000.000	1.000	20.000.000	10	<10
100% N2	30	5,85	<10	<10	24.000.000	2.000	13.500.000	60	<10
100% N2	40	5,89	<10	<10	16.000.000	1.000	12.000.000	400	<10
75%N2 - 25%CO2	20	5,87	<10	<10	4.200.000	<100	2.500.000	40	<10
75%N2 - 25%CO2	30	6,17	<10	<10	24.000.000	200	9.600.000	180	<10
75%N2 - 25%CO2	40	5,73	<10	<10	38.000.000	200	12.000.000	270	<10
50%N2 - 50%CO2	20	5,94	<10	<10	28.000.000	<100	16.000.000	800	<10
50%N2 - 50%CO2	30	6,09	<10	<10	34.000.000	100	15.000.000	100	<10
50%N2 - 50%CO2	40	6,03	<10	<10	48.000.000	400	13.500.000	90	<10

As can be seen from Tables 1 and 2, there is a decrease in PH over time and an average increase in the total mesophilic bacterial load of 3 log_{10} cfu, greater increase occurs for lactic bacteria, yeasts and molds. Microbilogical analysis is not detailed as it does not reflect the objective of our paper.

3.2 MAP composition at T_{10}, T_{20}, T_{30}

Tests of the MAP composition were carried out after different days of refrigerated storage, respectively 10 (T_{10}), 20 (T_{20}), 30 (T_{30}).

From Table 3 it can be noted that in trays with a thickness of 20 mm and an initial MAP 100% N_2, there is a trend of N_2 decreasing in time, CO_2 and O_2 decrease between the analysis at T_{10} and T_{20} and then go back at T_{30}.

In trays with depth of 30 mm, percentage of N_2 and O_2 is stable, instead, CO_2 increases from T_{10} to T_{30}; the same is true for the deep trays 40 mm. The values shown in red are anomalous data with respect to those expected.

In Table 4 is clear that for the first vessels type the behavior of N_2 is fluctuating, at first it is increasing and then between T_{20} and T_{30} it decreases slightly. O_2 have a small increase between T_{10} and T_{30}, while CO_2 has a trend contrary to N_2, decreases and then increases. For the 30 mm deep trays, CO_2 and O_2 stay almost unvaried, but N_2 shows a small increase in the last 10 days. For the last pack type the values of the gases remain approximately constant at T_{10} and T_{20}, but at T_{30} it can be noted an important decrease for N_2 and a dramatic increase for CO_2.

In Table 5 results of the analyzes for the deep trays 20 mm describe a constant trend of N_2 up to T_{20} and then there is a rapid decline, while CO_2 presents the opposite trend. For the other two types of packaging CO_2 increases between T_{20} and T_{30}.

Regarding to the control trays with inside air, the performance of the gas remains constant during all the duration of the storage, except for CO_2 which increases dramatically at T_{30} and O_2 which decreases.

4. DISCUSSION

The data collected in tables 3, 4 and 5 were then inserted into a "DOE" software, able to generate graphs that shows the trend of the gas level inside the MAP according to the experimental variables. The software output consists of 9 graphs, 3 for each gas (N_2, CO_2 or O_2), which shows the curve that expresses the percentage of that specific gas at a given moment (T_{10}, T_{20}, T_{30}) and in relation to the depth of the trays (20,30,40 mm). Graphical results have been shown in Figures 1, 2, and 3

Figure 1: CO2 trend at T10, T20 and T30

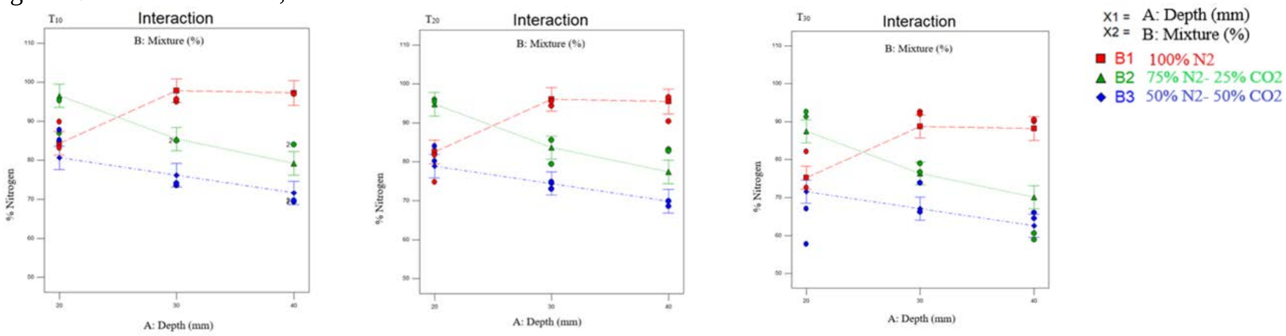


Figure2: CO2 trend at T10, T20 and T30.

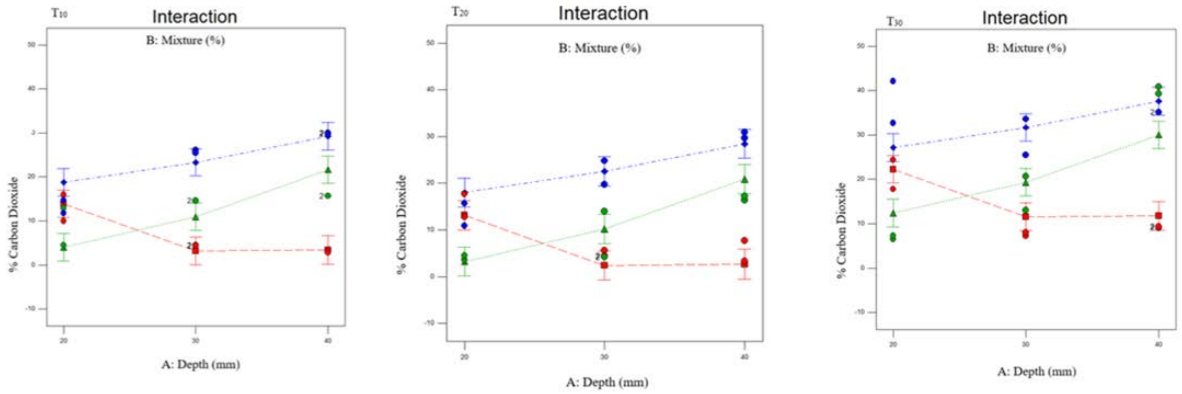
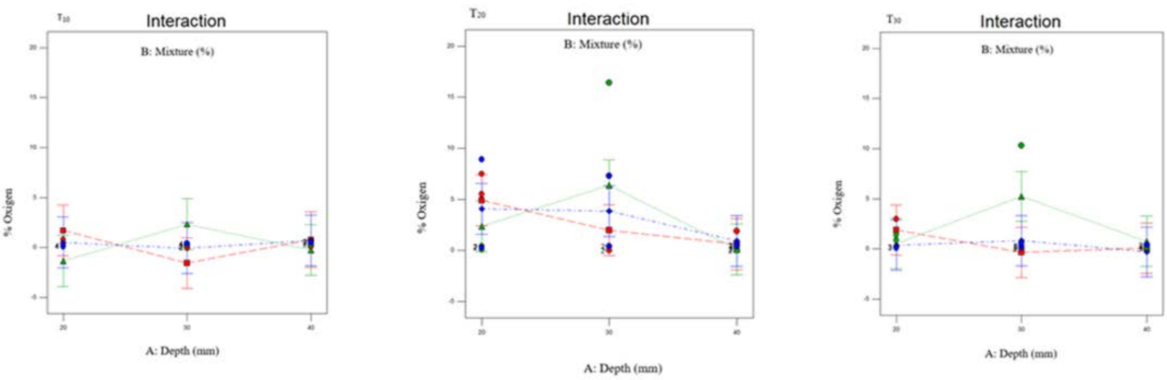


Figure3: O2 trend at T10, T20 and T30



The MAP gas concentration does not stay constant during the storage period, but their level can show increasing, decreasing or fluctuating trends. With a MAP composed of 100% N_2, the percentage of nitrogen increases with the increase of the depth of the trays between 20 and 30 mm and then stabilizes. Instead, the trend is decreasing for the other two types of MAP. Furthermore, it can be noted that the final levels of N_2 at T_{30} are lower than the values measured at T_{10} and T_{20}.

In the second graphic group (Figure2), CO_2 level decreases as the depth of the trays increases until it stabilizes after 30 mm. In 75% N_2- 25% CO_2 and 50% N_2- 50% CO_2 MAP, the percentage of CO_2 increases as the depth of the packs

increases. In this case, the values of CO_2 detected at T_{30} are greater than those measured at T_{20} and T_{10}.

In the last one graphic group (Figure3), oxygen has a fluctuating trend, decreases as the depth of the trays increases between 20 and 30 mm and then returns to grow between 30 and 40 mm in 100% N_2 MAP, instead the opposite trend is noted for the other two types of mixtures. The percentage of O_2 increases in the detection at T_{20} and then returns to the initial value at T_{30}. This could be explained with the release into the head space of O_2 incorporated in the food matrix at first, than successive reduction is attributable to the consumption of O_2 during the successive growth of the microorganism. The fluctuating trend of CO_2 could be due to the fact that, at first, the gas is absorbed in the product, while the subsequent increase maybe due to the decomposition of microorganisms inside the product. In percentage this increase is small and it could be related to permeability of the plastic lidding film.

5. CONCLUSION

In this paper, we carried out an experimental project with the aim of verifying the effectiveness of the use of MAP in the packaging of cow's ricotta. From the results obtained it can be said that the product is edible up to 20 days, beyond which the analyzed ricotta is not suitable for human consumption. It can be said that the use of modified atmosphere is essential to ensure that the product remains fresh and good for up to 20 days as it is able to contain microbial growth. It is also true, however, that it is essential for the correct maintenance of the product to have a low level of microbial contamination in the initial phase. It is fundamental the strict application of good hygiene and good manufacturing procedures, especially during the packaging phases until the closure of the trays.

One of the possible adoptable solutions to lengthen the shelf life of the product is to sterilize the trays with a solution of H_2O_2 before filling them, in addition to a more accurate training of the personnel regarding the respect of the hygiene rules. There is, indeed, an association between secondary contamination with Pseudomonas ssp. and the level of the implementation of the food safety management system at plant level (Pala et al. 2016). Obviously, this is not enough if the goal is to extend the deadline beyond 20 days, for this we could think to exploit the recent studies on biopreservatives or find other type of treatment of the packaged products. As above described, it has been tested that the use of biopreservatives has a positive impact on extending shelf life, especially in industrial MAP cows ricotta.

REFERENCES

1. Borba, K., Silva, F., Madruga, M., Queiroga, R., Souza, E., Magnani, M. The effect of storage on nutritional, textural and sensory characteristics of creamy ricotta made from whey as well as cow's milk and goat's milk (2013) International Journal of Food Science and Technology, pp.1279-1286.
2. Elsser-Gravesen, D., Elsser-Gravesen, A. Biopreservatives. In: Biotechnology of Food and Feed Additives, Springer Berlin Heidelberg, pp. 29 and 49
3. Mancuso, I., Cardamone, C., Fiorenza, G., Macaluso, G., Arcuri, L., Miraglia, V., Scatassa, ML. Sensory and microbiological evaluation of traditional ovine ricotta cheese in modified atmosphere packaging (2014) Ital J Food Safety 3:22-4.
4. Mancuso, I., Cardamone, C., Fiorenza, G., Macaluso, G., Arcuri, L., Miraglia, V., Scatassa M. Sensory and microbiological evaluation of traditional ovine ricotta cheese in modified atmosphere packaging (2014) Italian Journal of Food Safety, art. no. 1725, pp. 122-124.
5. Mantione, R., Vignali, G. Market analysis of dairy products produced in the Parmigiano Reggiano area (2017) International Food Operations and Processing Simulation Workshop, FoodOPS 2017, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2017, pp. 82-91.
6. Nomisma, Società di studi economici (2015) Relazione di accompagnaento alla prposta di piano produttivo del consorzio di tutela del formaggio Grana Padano DOP.
7. Pala, C., Scarano, C., Venusti, M., Sardo, D., Casti, D., Cossu, F., Lamon, S., Spanu, V., Ibba, M., Marras, M., Paba, A., Spanu, C., De Santis, E.P.L. Shelf life evaluation of ricotta fresca sheep cheese in modified atmosphere packaging (2016) Italian Journal of Food Safety, 5 (3), art. no. 5502, pp. 134-139.
8. Peelman, N., Ragaert, P., Vandemoortele, A., Verguldt, E., De Meulenaer, B., Devlieghere, F. Use of biobased materials for modified atmosphere packaging of short and medium shelf life food products (2014) Innov Food Sci Emerg Technol 26:319-29.
9. Scatassa, M.L., Mancuso, I., Sciortino, S., Macaluso, G., Palmeri, M., Arcuri, L., Todaro, M., Cardamone, C. Retrospective study on the hygienic quality of fresh ricotta cheeses produced in Sicily, Italy (2018) Italian Journal of Food Safety, 7 (1), art. no. 6911, pp. 68-71.
10. Sobrino-Lopez, A., Martin-Belloso, O. Use of nisin and other bacteriocins for preservation of dairy products (2008) Int. Dairy J. 18 (4), 329 and 343.
11. Spanu, C., Piras, F., Mocci, A.M., Nieddu, G., De Santis, E.P.L., Scarano, C. Use of Carnobacterium spp protective culture in MAP packed Ricotta fresca cheese to control Pseudomonas spp (2018) Food Microbiology, 74, pp. 50-56.
12. Spanu, C., Scarano, C., Piras, F., Spanu, V., Pala, C., Casti, D., Lamon, S., Cossu, F., Ibba, M., Nieddu, G., De Santis, E.P.L. Testing commercial biopreservative against spoilage microorganisms in MAP packed Ricotta fresca cheese (2017) Food Microbiology, 66, pp. 72-76.
13. Spanu, S., Mosna, D., Vignali, G. CFD Analysis of Coffee Packaging in Capsules using Gas Flushing Modified Atmosphere Packaging (2016) International Journal of Food Engineering, 12 (9), pp. 875-887;
14. Tognella R. Ricotta vaccina (2011) Il Latte.

APPENDIX

Table 3: Test results with map 100% N_2.

100% N2	Time 10			Time 20			Time 30		
	N2	CO2	O2	N2	CO2	O2	N2	CO2	O2
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	79,4	0,3	20,3						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	83,2	16	0,8						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				81,7	12,8	5,5			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				74,8	17,7	7,5			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							72,6	24,4	3,0
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							82,1	17,8	0,1
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	89,9	10	0,1						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	95	4,5	0,1						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	95,6	4,4	0						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				94,4	5,6	0			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				95,5	4,5	0			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							92	8	0
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							92,6	7,3	0,1
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	79,6	0,7	19,7						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	79,5	0,6	19,9						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				90,4	7,7	1,9			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				96,6	3,3	0,1			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)							90,9	9,1	0
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)							90,5	9,4	0,1
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	97	2,9	0,1						

Table 4: Test results with map composed by 75% N_2 and 25% CO_2.

75% N2 25% CO2	Time 10			Time 20			Time 30		
	N2	CO2	O2	N2	CO2	O2	N2	CO2	O2
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	79,6	0,4	20						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	95,3	4,5	0,2						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				96	3,6	0,4			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				95,4	4,5	0,1			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							92,6	6,5	0,9
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							91,3	7,3	1,4
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	86,9	12,9	0,2						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	80	0,1	19,9						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	85,1	14,6	0,3						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				79,4	4,2	16,4			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				85,6	14	0,4			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							76,7	13	10,3
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							79	20,7	0,3
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	79,5	0,6	19,9						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	85,1	14,6	0,3						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	84	15,7	0,3						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	84	15,7	0.3						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				83,2	16,4	0,4			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				82,8	17,2	0			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)							58,9	40,9	0,2
40 mm,ATM (vuoto: 15mbar,P: 650 mbar)							78,5	21,4	0,1
40 mm,ATM (vuoto: 15mbar,P: 650 mbar)							60,6	39,3	0,1

Table 5: Test results with map composed by 50% N2 and 50% CO2.

50% N2 50% CO2	Time 10			Time 20			Time 30		
	N2	CO2	O2	N2	CO2	O2	N2	CO2	O2
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	87,8	11,8	0,4						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	85,2	14,7	0,1						
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				80,2	10,9	8,9			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)				84	15,7	0,3			
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							57,8	42,1	0,1
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)							67,1	32,7	0,2
20 mm,ATM (vacuum: 15mbar,P: 650 mbar)	74,1	25,5	0,4						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	73,5	26,1	0,4						
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				74,8	24,8	0,4			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)				73	19,7	7,3			
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							66,2	33,6	0,2
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)							73,9	25,5	0,6
30 mm,ATM (vacuum: 15mbar,P: 650 mbar)	69,4	30	0,6						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)	69,7	29,8	0,5						
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				68,6	30,9	0,5			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)				69,9	29,7	0,4			
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)							64,5	35,1	0,4
40 mm,ATM (vacuum: 15mbar,P: 650 mbar)							66	33,6	0,4

Table 6: Test results with map composed by air.

Air	Time 10			Time 20			Time 30		
	N2	CO2	O2	N2	CO2	O2	N2	CO2	O2
20 mm, ARIA (no vacuum, no gas)	79,5	0,6	19,9						
20 mm, ARIA (no vacuum, no gas)				80,1	0,8	19,1			
20 mm, ARIA (no vacuum, no gas)							81,1	3,3	15,7

LIFE CYCLE ANALYSIS AND ENVIRONMENTAL IMPACT OF MANUFACTURING CHATEAU AND BURGUNDY WINE BARRELS

Flor Montalvo, FJ[(a)], Jiménez-Macías E[(b)], Pérez de la Parte M[(b)], Latorre-Biel JI [(a)], Martínez-Cámara E[(b)], Blanco-Fernández J[(b)]

[(a)] Public University of Navarre, Tudela, Navarre, Spain
[(b)] University of La Rioja, Logroño, Spain

[(a)] francisco.flor@outlook.es , [(b)] emilio.jimenez@unirioja.es , [(b)] mercedes.perez@unirioja.es,
[(a)] juanignacio.latorre@unavarra.es , [(b)] eduardo.martinezc@unirioja.es, [(b)] julio.blanco@unirioja.es

ABSTRACT
In the process of red wine aging, the barrel plays a fundamental role both in the contribution of aromas and in the stabilization of the wine and its color. There are, however, different types of barrels, depending on materials, species and origin of the oak, morphology and geometry, and capacity (from 225 liters to larger formats of 300 and 500 liters).
The purpose of this work is to perform the Life Cycle Assessment (LCA) of these barrel formats and compare them with the 225-liter Bordeaux barrel, providing detailed information on these products that can serve as a reference for their use in the calculation of the impact of its application in the wine aging processes.
We will consider, for the realization of the present LCA, all the phases of process and manufacture of the barrel that cover from the contribution of materials and their processing until the final storage.

Keywords: wine barrels, production modeling, environmental impact, live cycle assessment

1. INTRODUCTION

In the process of aging of red wine, the barrel plays a fundamental role both in the contribution of aromas and in the stabilization of the wine and its color. There are, however, different types of barrels, depending both on the materials from which they are manufactured and especially the species and origin of the oak used (Quercus Alba, Quercus Peatrea, Quercus Robur, ...), as well as their morphology and geometry, varying their capacity from 225 liters to larger formats of 300 and 500 liters (Ancín et al. 2004 ; Cutzach et al. 1999 ; Singleton, 1995).

The effect of varying the relative contact surface with the wine, the thickness of the staves or the origin of the oak, make clearly different the influence of the barrel in the aging of the wine. The most commonly used barrel format is the 225 liter Bordeaux barrel (Garde-Cerdán and Ancín-Azpilicueta 2006 ; Ribéreau-Gayon, 1999). There are, however, other types of barrel of similar capacities widely used, among which we must highlight the Burgundian barrel of 228 liters and the chateau barrel of 225 l (Towey and Waterhouse, 1996a, 1996b; Wolf-Crowther et al. 2011).
The purpose of this work is to perform the Life Cycle Assessment (LCA) (Leiva et al. 2015, 2016; Leiva-Lázaro et al. 2015) of these barrel formats and compare them with the 225-liter Bordeaux barrel for different oak origins, providing detailed information on these products that can serve as a reference for their use in the calculation of the impact of its application in the wine aging processes (Arapitsas et al. 2004; Schmid et al. 2011; Vidal et al. 2016).
We will consider, for the realization of the present LCA, all the phases of process and manufacture of the barrel that cover from the contribution of materials and their processing until the final storage (Carrillo et al. 2006; Chatonnet and Dubourdieu, 1998a, 1998b).
In this way, all the critical phases of the production process will be segregated and defined (Chira and Teissedre, 2013a, 2013b, 2014).
The methodology selected to obtain the LCA model will be CML-IA baseline V3.04 / EU25, using the software Simapro 8.3 for its development.

2. MATERIALS AND METHODS

2.1. Objectives

Throughout this article a gate-to-gate Environmental Impact Analysis will be developed for the process of making barrels for aging in "Burgundy" formats of 228 l and "Chateau" 225 l. and in the oak varieties Q. Peatrea and Q. Robur (Turturică et al. 2016).
The analysis included all the processes associated to wine barrels manufacturing, from the reception of the wood, sawing operations and drying, to the manufacturing of the barrel and including all the accessory tasks, which included the hours of personnel assigned to the manufacturing, direct and indirect consumption of materials, energy consumption and any other consumption that is incurred until the completion of the finished barrel (Del Alamo et al. 2006; Fernández de Simón et al. 2010).

2.2. Functional unit

For this paper, the functional unit was defined as the aging of 1 l. of red wine during four months in "chateau" and "borgoña" French (Q. Peatrea) and European (Q. Robur) oak.
Chateau oak barrels are characterized by less oak wood thickness. They use 22 m. staves instead of classical 25 mm. staves.
Staves thickness reduction also means a reduction in the useful life for the barrel because of the reduction for the useful amount of wood and consequently, a reduction for transfer compounds from wood to wine.
This also suppose a faster evolution for chateau barrels aging wines because of the increase for the micro-oxygenation process.
Borgoña barrels are wider and lower than classical barrels. If they are transport barrels (historically used for long way transport), they use 27 mm. wide staves.
We considerate that these barrels are used for singular wines, so the selection for the functional (specially 4 months period) unit is according to a high expression wine aging (with a higher quantity of process and wine transfers form barrels).
For the development of the LCA model and the CMLIA baseline, the Simapro 8.3 baseline V3.04 / EU25 software has been used.
Selected impact categories were:

- Abiotic Depletion (AD);
- Abiotic Depletion (fossil fuels) (AD-FF);
- Global Warming-GWP100 (GWP);
- Ozone Layer Depletion (ODP);
- Human Toxicity (HT);
- Fresh Water Aquatic Ecotoxicity (FWAE);
- Marine Aquatic Ecotoxicity (MAE);
- Terrestrial Ecotoxicity (TE);
- Photochemical Oxidation (PO);
- Acidification (AC);
- Eutrophication (EU).

2.3. System boundaries

System boundaries were designed for this analysis including all process associated to barrels production on "Chateau 225 l" and "Borgoña 228 l" made on Q. Robur/Q. petraea oak Wood and the aging of red wine for four months long.
Oak barrels fabrication process are are divided into 4 phases:
First phase, named Wood treatment, includes next process:

- Wood reception
- sawing
- drying.

Second phase, named Head manufacture, includes next process:

- Jointing
- Head toasting
- Planning
- Beveling
- Heat branding

Third phase, named oak barrel assembly, includes next process:

- End trimming
- Hollowing
- Jointing
- Staves toasting
- Pressing (first stage)
- Craze cutting
- Hole drilling
- Hoop manufacturing and insertion
- Pressure test
- Pressing (second stage)
- Head sanding
- Body sanding

Fourth phase, named Storage, includes next process:

- Barrel packaging
- Barrel controlled conditions storage.

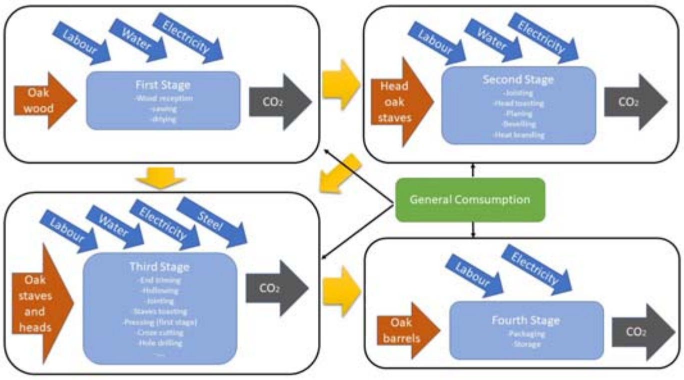


Figure 1. Oak barrels manufacturing process

There is a fifth phase, named wine aging that considered all aging process using oak barrels for red wine. Includes next process.

- Barrel filling and emptying
- Barrel rinsing and cleaning
- Additional aging operations

Next activities were considered out- side the scope of this project:

- Wood transport from origin to barrel production factory
- Another input transport from origin to barrel production factory
- Barrel transport from the barrel production factory to the winery.
- installing and dismantling for the barrel production company
- installing and dismantling for the winery
- wine production (after the aging process)
- maintenance and auxiliary operations in barrel production company and winery.
- managing and treating waste produced throughout the life cycle
- wine distribution process

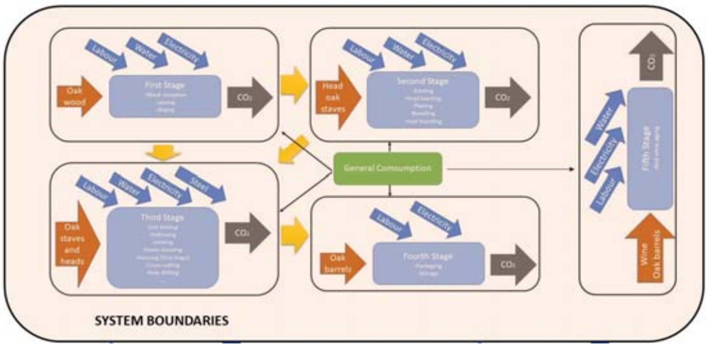


Figure 2. System boundaries

2.4. Assumptions.

Conditions and inputs are constants in the study. They have the same properties and they don´t change during the analysis.
Chateau and borgoña barrels are not standard aging barrels used in Spain.
They are used for singular and high expression wines.
That´s why the time between rackings are faster than in traditional aging wines, so the medium time between them are 4 moths long.
Aging process implies wine losses because of the evaporation and they are specially important if the humidity and temperature conditions are not right.
Relative humidity values must be higher than 80% and temperatures lower than 15°C.
Under these conditions, ullage reduces wine by 3% per year for barrels of 225L (14, 15, 16).
For the analysis we use 22 m. thickness chateau 225 l oak barrel staves instead of classical 25 mm. 225 l bodelesa barrel.
Staves thickness reduction means a reduction in the useful life for the barrel because of the reduction for the useful amount of wood so this barrels longlife will be 5 years long instead of 6 years traditional barrels longlife.
We also study 25 m. thickness borgoña 228 l oak barrel staves instead of classical 25 mm. 225 l bodelesa barrel.
This barrels longlife will be 6 years old, the same longlife than traditional barrels.
Sanitation process will be the same for all barrels.
This process consist in a water low pressure rinse (2 to 15 bars), for mechanical cleaning, a hot water water high-pressure rinse cleaning (over 100 and 60-80 ºC) to get satination effect and deep mechanical cleaning.
The waste wood produced during barrel manufacturing is used again to get enologic toasted products.

3. RESULTS AND DISCUSSION

3.1. Global environmental impact analysis.

We have 2 different process in this study: barrel construction and red wine aging.
Barrel construction involves phases 1 to 4, including oak wood reception, wood process, drying, sawing, staves production (heads and body staves), staves mechanization, barrel assembly, finishing process and controlled conditions storage.
Wine aging process involves phase 5, including barrel filling and emptying, barrel rinsing and cleaning and other wine aging operations.
Global phases analysis shows that phase 1 has the higher global impact.
This phase is associated to oak Wood reception, sawing and drying. These processes have great electricity and water consumption so they are cause of the high impact.

3.2. Environmental impact analysis by phases.

In spite of the different volumes of the barrels analyzed, the difference derived from volume is very small.
There are small differences between same format barrels constructed with different oak origins. That is because the great similarities between the species Q. Peatrea and Q. Robur, that both are European oaks species.
Difference should be bigger if we had used other origins of oak Woods (Q. Alba) but these barrels are usually constructed from this oak origins Wood.
However, the difference between different barrel formats is very important because their half-life is very different. Chateau barrels have 5 years old medium longlife while Borgoña barrels have 5 years old medium longlife.
Obviously, wood origin does not influence phase 5 impacts because these processes are associated to red wine aging and there is no influence from Wood origin.

4. CONCLUSIONS

In this paper we studied Life Cycle Analysis for red wine aging using not traditional barrel formats.
Q. Robur and Q. Peatrea 225 l. Chateau format and 228 l. Borgoña format barrels have been studied.
Functional unit was defined as the aging of 1 l. of red wine during four months in “chateau” and “borgoña” French (Q. Peatrea) and European (Q. Robur) oak.
The global analysis of processes shows that the greatest impacts correspond to phase 1, associated to oak wood reception and processing, especially because of the electrical consumption on sawing cutting process.
It is also representative electrical consumption associated to Wood toasting in phases 2 (heads manufacturing) and 4 (barrel manufacturing).
Impact analysis show us that wood origin has no influence in impact result.
However, barrel geometry is really important because of the different quantity of wine liters that a barrel can process in its life.
This effect is low representative because of the different volume of chateau 225 l. and borgoña 228 l. but the different long life associated to different stave thickness are really important.

Proceedings of the International Food Operations and Processing Simulation Workshop
ISBN 978-88-85741-18-8; Bruzzone, Longo, Piera and Vignali Eds.

Table 1. Barrel Borgoña 228 l. / Q. Peatrea

Impact Category	Unite	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	General consumptions	Total
Abiotic depletion	kg Sb eq	1,53742E-08	9,27415E-10	3,00211E-09	6,28421E-10	6,37732E-09	5,93191E-09	**3,22414E-08**
Abiotic depletion (fossil fuels)	MJ	0,131211076	0,007957682	0,026342384	0,005172591	0,041661347	0,048826115	**0,261171195**
Global warming (GWP100a)	kg CO2 eq	0,010482138	0,000643247	0,002095251	0,000415467	0,003423986	0,003921756	**0,020981845**
Ozone layer depletion (ODP)	kg CFC-11 eq	1,37801E-09	8,52697E-11	2,2616E-10	5,70651E-11	4,4022E-10	5,3866E-10	**2,72539E-09**
Human toxicity	kg 1,4-DB eq	0,00327356	0,000202986	0,000784176	0,000131827	0,001464532	0,001244371	**0,007101453**
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,002674089	0,000166873	0,002400898	0,000106597	0,001074284	0,001006215	**0,007428956**
Marine aquatic ecotoxicity	kg 1,4-DB eq	12,43452119	0,826722935	3,006839041	0,534106601	4,430674933	5,041641683	**26,27450638**
Terrestrial ecotoxicity	kg 1,4-DB eq	8,54848E-05	4,71347E-06	1,02825E-05	3,17995E-06	3,02323E-05	3,00168E-05	**0,00016391**
Photochemical oxidation	kg C2H4 eq	5,41057E-06	1,76198E-07	6,90935E-07	1,15393E-07	9,71371E-07	1,08924E-06	**8,4537E-06**
Acidification	kg SO2 eq	6,81599E-05	4,40339E-06	1,21176E-05	2,88636E-06	2,38328E-05	2,72455E-05	**0,000138646**
Eutrophication	kg PO4--- eq	1,49935E-05	8,97834E-07	3,39763E-06	5,66367E-07	1,18661E-05	5,34616E-06	**3,70676E-05**

Table 2. Barrel Borgoña 228 l. / Q. Robur

Impact Category	Unite	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	General consumptions	Total
Abiotic depletion	kg Sb eq	1,62037E-08	9,30617E-10	3,0081E-09	6,28421E-10	6,37732E-09	5,93191E-09	**3,30801E-08**
Abiotic depletion (fossil fuels)	MJ	0,139658312	0,008092046	0,026593655	0,005172591	0,041661347	0,048826115	**0,270004066**
Global warming (GWP100a)	kg CO2 eq	0,011142213	0,000655399	0,002117976	0,000415467	0,003423986	0,003921756	**0,021676798**
Ozone layer depletion (ODP)	kg CFC-11 eq	1,45124E-09	8,59117E-11	2,2736E-10	5,70651E-11	4,4022E-10	5,3866E-10	**2,80046E-09**
Human toxicity	kg 1,4-DB eq	0,003459483	0,00020647	0,000790691	0,000131827	0,001464532	0,001244371	**0,007297375**
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,002834476	0,000170601	0,002407872	0,000106597	0,001074284	0,001006215	**0,007600045**
Marine aquatic ecotoxicity	kg 1,4-DB eq	12,97824824	0,842275601	3,035923792	0,534106601	4,430674933	5,041641683	**26,86287085**
Terrestrial ecotoxicity	kg 1,4-DB eq	9,20683E-05	4,73652E-06	1,03256E-05	3,17995E-06	3,02323E-05	3,00168E-05	**0,00017056**
Photochemical oxidation	kg C2H4 eq	6,32425E-06	1,78754E-07	6,95714E-07	1,15393E-07	9,71371E-07	1,08924E-06	**9,37471E-06**
Acidification	kg SO2 eq	7,14094E-05	4,46601E-06	1,22347E-05	2,88636E-06	2,38328E-05	2,72455E-05	**0,000142075**
Eutrophication	kg PO4--- eq	1,6046E-05	9,21385E-07	3,44167E-06	5,66367E-07	1,18661E-05	5,34616E-06	**3,81877E-05**

Table 3. Barrel Chateau 225 l. / Q. Peatrea

Impact Category	Unite	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	General consumptions	Total
Abiotic depletion	kg Sb eq	1,86951E-08	1,12808E-09	3,62161E-09	7,64159E-10	6,46235E-09	7,2132E-09	**3,78845E-08**
Abiotic depletion (fossil fuels)	MJ	0,159552669	0,009691085	0,031869383	0,006289871	0,042216832	0,059372556	**0,308992395**
Global warming (GWP100a)	kg CO2 eq	0,012746279	0,000783504	0,002534653	0,000505208	0,003469639	0,004768855	**0,024808139**
Ozone layer depletion (ODP)	kg CFC-11 eq	1,67567E-09	1,03757E-10	2,73616E-10	6,93912E-11	4,4609E-10	6,5501E-10	**3,22353E-09**
Human toxicity	kg 1,4-DB eq	0,00398065	0,000247208	0,000946207	0,000160302	0,001484059	0,001513155	**0,008331581**
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,003251692	0,000203321	0,002870955	0,000129622	0,001088607	0,001223558	**0,008767755**
Marine aquatic ecotoxicity	kg 1,4-DB eq	15,12037776	1,006978539	3,630163255	0,649473627	4,489750598	6,130636287	**31,02738007**
Terrestrial ecotoxicity	kg 1,4-DB eq	0,00010395	5,73408E-06	1,24708E-05	3,86682E-06	3,06354E-05	3,65004E-05	**0,000193157**
Photochemical oxidation	kg C2H4 eq	6,57925E-06	2,14534E-07	8,33073E-07	1,40317E-07	9,84322E-07	1,32451E-06	**1,0076E-05**
Acidification	kg SO2 eq	8,28824E-05	5,3613E-06	1,46764E-05	3,50981E-06	2,41506E-05	3,31305E-05	**0,000163711**
Eutrophication	kg PO4--- eq	1,82321E-05	1,09432E-06	4,11228E-06	6,88702E-07	1,20243E-05	6,50093E-06	**4,26527E-05**

Table 4. Barrel Chateau 225 l. / Q. Robur

Impact Category	Unite	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	General consumptions	Total
Abiotic depletion	kg Sb eq	1,97E-08	1,13209E-09	3,62751E-09	7,64159E-10	6,46235E-09	7,2132E-09	**3,8903E-08**
Abiotic depletion (fossil fuels)	MJ	0,169824507	0,009859319	0,032117297	0,006289871	0,042216832	0,059372556	**0,319680382**
Global warming (GWP100a)	kg CO2 eq	0,013548932	0,000798719	0,002557075	0,000505208	0,003469639	0,004768855	**0,025648428**
Ozone layer depletion (ODP)	kg CFC-11 eq	1,76471E-09	1,04561E-10	2,74801E-10	6,93912E-11	4,4609E-10	6,5501E-10	**3,31456E-09**
Human toxicity	kg 1,4-DB eq	0,004206732	0,000251571	0,000952635	0,000160302	0,001484059	0,001513155	**0,008568454**
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,003446722	0,00020799	0,002877835	0,000129622	0,001088607	0,001223558	**0,008974334**
Marine aquatic ecotoxicity	kg 1,4-DB eq	15,78154987	1,026451731	3,658859468	0,649473627	4,489750598	6,130636287	**31,73672158**
Terrestrial ecotoxicity	kg 1,4-DB eq	0,000111955	5,76294E-06	1,25133E-05	3,86682E-06	3,06354E-05	3,65004E-05	**0,000201234**
Photochemical oxidation	kg C2H4 eq	7,69028E-06	2,17733E-07	8,37789E-07	1,40317E-07	9,84322E-07	1,32451E-06	**1,1195E-05**
Acidification	kg SO2 eq	8,68339E-05	5,43971E-06	1,4792E-05	3,50981E-06	2,41506E-05	3,31305E-05	**0,000167856**
Eutrophication	kg PO4--- eq	1,9512E-05	1,1238E-06	4,15574E-06	6,88702E-07	1,20243E-05	6,50093E-06	**4,40054E-05**

REFERENCES

Ancín, C., Garde, T., Torrea, D. & Jimenez, N. (2004). Extraction of volatile compounds in model wine from different oak woods: Effect of SO2. Food Research International, 37, 375-383.

Arapitsas, P., Antonopoulos, A., Stefanou, E. & Dourtoglou, V. G. (2004). Artificial aging of wines using oak chips. Food Chemistry, 86, 563-570.

Boidron, J. N., Chatonnet, P. & Pons, M. (1988b). Influence du bois sur certaines substances odorantes des vins. Connaiss. Vigne Vin, 22, 275-294.

Carrillo, J. D., Garrido-Lopez, A. & Tena, M. T. (2006). Determination of volatile oak compounds in wine by headspace solid-phase microextraction and gas chromatography–mass spectrometry. Journal of Chromatography A, 1102, 25-36.

Chatonnet, P. & Dubourdieu, D. (1998a). Comparative study of the characteristics of American white oak (Quercus alba) and European oak (Quercus petraea and Q. robur) for production of barrels used in barrel aging of wines. American Journal of Enology and Viticulture, 49, 79-85.

Chatonnet, P. & Dubourdieu, D. (1998b). Identification of substances responsible for the 'sawdust' aroma in oak wood. Journal of the Science of Food and Agriculture, 76, 179-188.

Chira, K. & Teissedre, P. L. (2013a). Extraction of oak volatiles and ellagitannins compounds and sensory profile of wine aged with French winewoods subjected to different toasting methods: behaviour during storage. Food Chemistry, 140, 168-177.

Chira, K. & Teissedre, P. L. (2013b). Relation between volatile composition, ellagitannin content and sensory perception of oak wood chips representing different toasting processes. European Food Research and Technology, 236, 735-746.

Chira, K. & Teissedre, P. L. (2014). Chemical and sensory evaluation of wine matured in oak barrel: effect of oak species involved and toasting process. European Food Research and Technology, 240, 533-547.

Cutzach, I., Chatonnet, P., Henry, R. & Dubourdieu, D. (1999). Identifying new volatile compounds in toasted oak. Journal of Agricultural and Food Chemistry, 47, 1663-1667.

Del Alamo Sanza, M. & Nevares Domínguez, I. (2006). Wine aging in bottle from artificial systems (staves and chips) and oak woods: Anthocyanin composition. Analytica Chimica Acta, 563, 255-263.

Fernández de Simón, B., Cadahía, E., del Álamo, M. & Nevares, I. (2010). Effect of size, seasoning and toasting in the volatile compounds in toasted oak wood and in a red wine treated with them. Analytica Chimica Acta, 660, 211-220.

Garde-Cerdán, T. & Ancín-Azpilicueta, C. (2006). Review of quality factors on wine ageing in oak barrels. Trends in Food Science & Technology, 17, 438-447.

Leiva, F., Saenz-Díez, J.-C, Martínez, E, Jiménez, E, Blanco, J. (2016). Environmental impact of mushroom compost production. Journal of the Science of Food and Agriculture.

Leiva, F.J., Saenz-Díez, J.C., Martínez, E., Jiménez, E., Blanco, J. (2015). Environmental impact of Agaricus bisporus cultivation process. European Journal of Agronomy. Volume 71, November 01, 2015, Pages 141-148.

Leiva-Lázaro F.J., Blanco-Fernández J., Martínez-Cámara E., Latorre-Biel J.I., Jiménez-Macías E. (2015). Mushroom cultivation process, agaricus bisporus variety: comparison between traditional and climate controlled cultivation and identification of environmental impacts of the production processes. The 3nd International Workshop On Simulation For Energy, Sustainable Development & Environment SESDE 2015, Bergeggi, Italy. 21 – 23 September 2015.

Ribéreau-Gayon, P. (1999). Observations related to the causes and consequences of stuck fermentation in vinification. Journal International des Sciences de la Vigne et du Vin, 33, 39-48.

Schmid F, Grbin P, Yap A and Jiranek V. 2011. Relative efficacy of high-pressure hot water and high-power ultrasonics for wine oak barrel sanitization. Am J Enol Vitic 62:519-526.

Singleton, V. L.. 1995. Maturation of wines and spirits:comparaisons, facts and hypotheses. Am. J. Enol. Vitic., 46, 98-115.

Towey, J. P. & Waterhouse, A. L. (1996a). Barrel-to-barrel variation of volatile oak extractives in barrel-fermented Chardonnay. Am. J. Enol. Vitic., 47, 17-20.

Towey, J. P. & Waterhouse, A. L. (1996b). The Extraction of volatile compounds from French and American oak barrels in chardonnay during three successive vintages. American Journal of Enology and Viticulture, 47, 163-172.

Turturică, M., Stănciuc, N., Bahrim, G. & Râpeanu, G. (2016). Effect of thermal treatment on phenolic compounds from plum (prunus domestica) extracts – A kinetic study. Journal of Food Engineering, 171, 200-207.

Vidal, L., Antúnez, L., Giménez, A., Medina, K., Boido, E. & Ares, G. (2016). Dynamic characterization of red wine astringency: Case study with Uruguayan Tannat wines. Food Research International, 82, 128-135.

Wolf-Crowther, M., Mozes, C. & Laczko, R. (2011). Forestry in the EU and the World: A Statistical Portrait. Publications Office of the European Union. Luxembourg. DOI, 10, 13022.

Author's index