Novel Processing Methods for the Production and Distribution of High-Quality and Safe Foods

Project no. 015710
Integrated project
Priority 5 Food Quality and Safety

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1 Introduction to NovelQ

1.1 Introduction to project

Since March 1 2006, thirty seven project partners have joined forces in the EU-funded Integrated Project "NovelQ" which was designed to stimulate innovations in novel food processing and packaging. In this project, integrated strategic solutions for technical and basic research hurdles have been formulated for complex, real food products rather than food constituents.

Enhancements to the state-of-the-art in novel processes focused on high pressure processing (HPP) for preservation of food, quantitative studies on the effect of pulsed electrical fields (PEF) on food pathogens and cold plasma as a surface disinfecting method. Other innovative topics included coupling of new packaging concepts to novel processing and solving R&D hurdles in implementation of advanced heating technologies.

Key scientific emphasis has been placed on plant-based products, both solid and liquids, including carrot, tomato, strawberry, apple and broccoli. These commodities were selected because they integrate (i) food structure issues, (ii) colour and flavour-related aspects, (iii) health-related components, including allergens, and (iv) food safety issues. However, the results have broad applicability to other type of products, to the level of whole meals – including regional recipes that are typical of the rich and diverse European cuisine. To most effectively address these opportunities, further knowledge on consumer perception is crucial and therefore studied in NovelQ.

The integrated approach of new technologies, the objectives striving for fresh-healthy convenience foods – responding to the demands of consumers – the unique novel processes investigated and the strength of the cross-sectorial consortium together represented an opportunity to maintain and enhance Europe's current competitive advantage in the global market place. EU policy relevance was further underlined via the production of eco-friendly, healthy and safe food – including convenience e.g. for the aging population in Europe – and through the context of incremental innovation.

1.2 Overall objectives

The overall objective of this transnational, inter-sectorial Integrated Project was to formulate strategic solutions for technical and basic research hurdles in order to develop and successfully demonstrate novel processing (NP) schemes. The exploitation of potentially unique novel processing characteristics aimed to improve quality, facilitate (incremental) innovation and further increase the added value of the EU food sector through:

- **substantially extending shelf-life** (without compromising safety) of, especially, fresh-like convenience foods of plant origin. This is generally the limiting factor in maintaining the shelf-life of prepared whole meals. A solution to this problem will maintain the value (quality and export) of regional recipes and, hence, contribute to promotion of the rich and diverse European cuisine;
- **responding to the demands of consumers for food with fresh characteristics** close to those of the raw material (taste, aroma, texture, healthy ingredients). This goal is not achievable using conventional processing;
- **responding to the demands of consumers for foods that contribute to individual health and wellbeing.** Such foods help to lower the levels of diet-related disease and reduce associated health and social costs across the European Union;
- enhancing **eco-friendly innovative processing**, as a direct consequence of reducing:
  (a) current wastage of fresh produce (~35%) via extended shelf-life,
  (b) energy inputs, via low-temperature and low-energy processing,
  (c) usage of water and chemicals, through applications of new hygiene approaches, and
  (d) migration problems and packaging materials, via in-pack processing (thereby avoiding any need for repackaging).

NovelQ was set up using the food chain approach. This required that plant-based raw materials, new processing concepts, packaging, shelf life and consumer evaluation were considered in a holistic manner and that development and exploitation of novel technologies were placed within the broad food chain perspective.
The project aimed to enable the benefits of individual NP technologies to be identified and evaluated at different stages along the food chain (e.g. as pre-processing technologies and as actual processing-preservation unit operations); examples included pre-processing with NP followed by pasteurisation based on classical heating technologies or advanced heating technologies.

1.3 Working approach and structure

NovelQ represents an integrated interdisciplinary research, demonstration and dissemination project designed to overcome current bottlenecks that exist across the entire R&D chain. These bottlenecks inhibit the introduction of NP technologies in the European food industry. In order to achieve this ambitious goal, fully interacting approaches have been adopted:

- firstly, in Sub-projects 1 and 2 a comprehensive knowledge base was developed offering mechanistic and kinetic insights into the effect of NP and packaging materials on the safety and quality of complex (regional) food products (solids and liquids) of plant origin. This approach was adopted as opposed to the examination of model systems (e.g. buffer systems); although the latter is simpler, its results are less readily transferred to industry. Sub-project 1 focused on mechanistic and kinetic insights in changes of food components and food products during processing with NP. Novel processing schemes include high pressure (HP), pulsed electric field (PEF) and (cold) plasma. Sub-project 2 focused on the effects of NP on packaging materials and food package material interactions with the food itself (e.g. migration).

- secondly, an integrated product/process development and demonstration approach (embracing reversed chain thinking) have been developed for the range of products mentioned above. These products include a number of regional products subjected to NP. Sub-project 3 focused on consumer perceptions of NP; Sub-projects 4, 5 and 7 on pan-European innovation, demonstration, dissemination and training. Both advanced heating and novel processing schemes (HP, PEF, cold plasma) have been further developed and demonstrated. Therefore, cross-sectorial co-operation between food and equipment manufacturers was a feature of this project (SMEs and multinationals), being strongly supported by partner research institutes. Over 80 food and equipment manufacturers became member of the Industry Advisory Platform (see Table 1.3). Finally in Sub-project 6, the project management and administration was outlined, emphasis was placed on managing innovation processes in R&D projects.
- finally, to extend the study of edible coatings on different food products in the existing NovelQ project a TTC project (Nanocom) focused on novel raw materials that are required for inclusion into coatings and films. As part of the Nanocom project (incorporated in Sub-project 2), the raw materials were agro-proteins that are available commercially or isolated, from whole grains and cereal by-products of the milling (bran) and brewing (spent-grain) industry, which are not available commercially. The inclusion of nanoparticles to improve material properties and films on pilot plant scale processing was performed.

NovelQ contained seven fully interconnected Sub-projects [SPs], one of which has been an overarching management task:

- **Sub-project 1**: Basic research: mechanisms and kinetics of the impact of novel technologies on food safety and quality as a basis for process and product development
- **Sub-project 2**: Strategic basic material research for packaging foods through novel technologies
- **Sub-project 3**: Consumer perception and socio-economic background of novel processing methods
- **Sub-project 4**: Development and demonstration of novel food processing technologies
- **Sub-project 5**: Dissemination, technology transfer and training
- **Sub-project 6**: Project management
- **Sub-project 7**: Cold plasma, packaging and HP demonstration activities

SP 1 addressed basic food science; SP2 material science, SP3 consumer issues; SP4 applied research, development and demonstration; SP5 focused on dissemination, technology transfer, and training and career development of young scientists from NovelQ; the project management and administration activities were clustered in SP 6 (see Figure 1.1.); SP7 included demonstration activities (resulting from NovelQ competitive call) on cold plasma, packaging and high pressure.

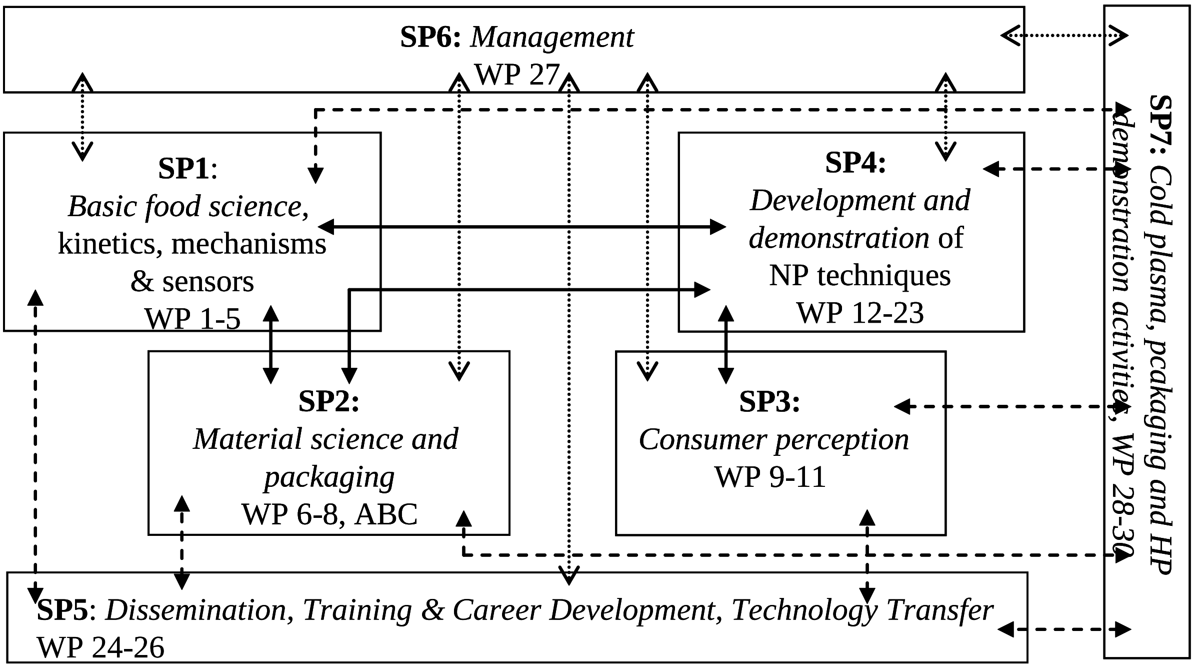


Figure 1.1 Relations among all Sub-projects

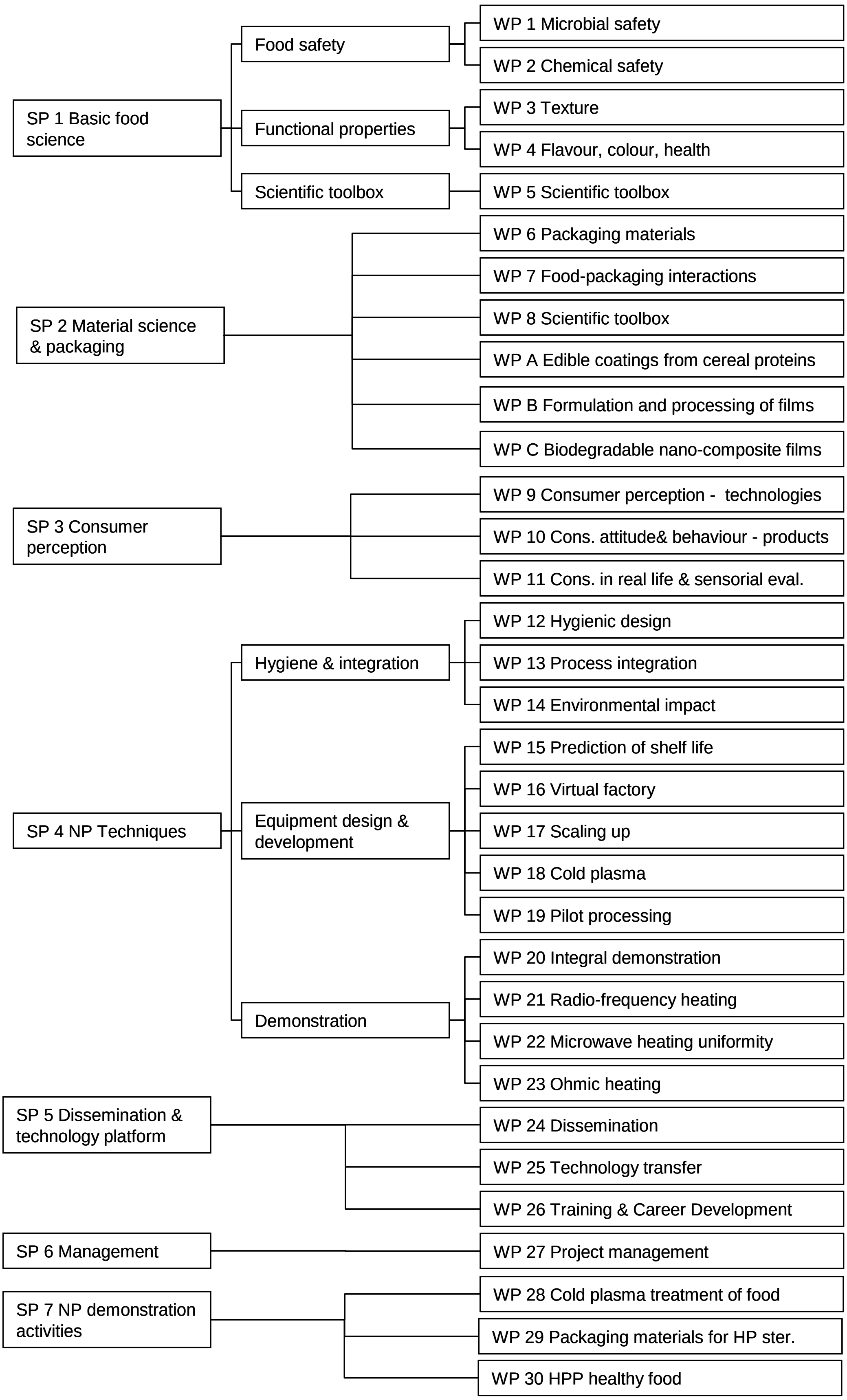
The activities within NovelQ were strongly linked to one another. To guarantee interaction especially between R&D, demonstration and training activities, the workpackages were grouped within subprojects. Table 1.1 shows the position of the different WPs within the subprojects. Each workpackage consisted of one type of activities, either R&D, demonstration, training or management.

Table 1.1 Position of WPs within the subprojects

Subproject	R&D	Demonstration	Training	Management
Subproject 1	WP 1-5	-	-	-
Subproject 2	WP 6-8, ABC	-	-	-
Subproject 3	WP 9-11	-	-	-
Subproject 4	WP 12-19	WP 20-23	-	-
Subproject 5	WP 24	-	WP 25-26	-
Subproject 6	-	-	-	WP 27
Subproject 7	-	WP 28-30		

Figure 1.2 presents a tree of the subprojects and workpackages within NovelQ to explain the structure of NovelQ.

Figure 1.2 (next page). NovelQ Structure of subprojects and workpackages.


SP 1 Basic food science
Food safety
Functional properties
Scientific toolbox
WP 1 Microbial safety
WP 2 Chemical safety
WP 3 Texture
WP 4 Flavour, colour, health
WP 5 Scientific toolbox
SP 2 Material science & packaging
WP 6 Packaging materials
WP 7 Food-packaging interactions
WP 8 Scientific toolbox
WP A Edible coatings from cereal proteins
WP B Formulation and processing of films
WP C Biodegradable nano-composite films
SP 3 Consumer perception
WP 9 Consumer perception - technologies
WP 10 Cons. attitude& behaviour - products
WP 11 Cons. in real life & sensorial eval.
SP 4 NP Techniques
Hygiene & integration
Equipment design & development
Demonstration
WP 12 Hygienic design
WP 13 Process integration
WP 14 Environmental impact
WP 15 Prediction of shelf life
WP 16 Virtual factory
WP 17 Scaling up
WP 18 Cold plasma
WP 19 Pilot processing
WP 20 Integral demonstration
WP 21 Radio-frequency heating
WP 22 Microwave heating uniformity
WP 23 Ohmic heating
SP 5 Dissemination & technology platform
WP 24 Dissemination
WP 25 Technology transfer
WP 26 Training & Career Development
SP 6 Management
WP 27 Project management
SP 7 NP demonstration activities
WP 28 Cold plasma treatment of food
WP 29 Packaging materials for HP ster.
WP 30 HPP healthy food

1.4 Description of consortium

Table 1.2 (next page) gives an overview of the NovelQ partners.

In addition, an Industry Advisory Platform (IAP) was established by the NovelQ project to enhance the involvement of industry. The role of the IAP consisted of:

- Participation in annual IAP meetings, at which also the project partners were present in order to exchange latest insights in NovelQ (except for the confidential information originating from research and demonstration projects);
- Providing input based on industrial experience of IAP members with novel processing and packaging in order to optimise knowledge transfer as well as the development process;
- Consideration of participation in demonstration projects (via competitive call procedure and proof of principles demonstration call), together with other IAP-members or NovelQ participants, depending on the topics.

By the end of the project, 89 IAP members (from industries and other interested organisations) joined the Industry Advisory Platform. See Table 1.3.

Table 1.3 demonstrates that small and medium enterprises from all over Europe supported the IAP in order to increase their opportunity for growth and extension of the market share as well as to extend their international network. In this way, SMEs were linked to the project via the IAP activities. Reviewing the industrial partners and IAP members, it can be concluded that both food manufacturers as well as food machinery equipment suppliers were actively involved in NovelQ to enhance incremental innovations and implementation.

Table 1.2 NovelQ partners

Name of the organisation	Type of organisation	Country	Contact person	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7	Role in the activities/project
Wageningen UR Food & Biobased Research	Research	Netherlands	Dr. H.S.M. de Vries Ms. Ir. A.M. Matser	X	X		X	X	X	X	**Project co-ordinator, co-ordinator SP6, SP5, SP7** **Co-ordinator SP4**, SP1 plasma activities, SP4 development of HP, PEF, plasma, SP5 training and internet site, SP7 demonstration activities on cold plasma, packaging and HP
TU Berlin	University	Germany	Prof. D. Knorr	X			X		X		**Project science manager** **Co-ordinator SP1**, SP1 PEF, HP activities, models, SP4 modelling
KU Leuven	University	Belgium	Prof. M. Hendrickx	X			X	X	X	X	**Co-ordinator SP1**, HP/thermal effects on endogenous properties
IFR	Research	U.K.	Ds. S. Astley Prof. R. Fenwick Prof. T. Brocklehurst	X					X		**International Relationship Co-ordinator**, SP5 Training & Career Development, SP1 food safety
University Lleida	University	Spain	Ms.Prof. O. Martin	X							Sub-project 1, flavour and colour effects
VTT	Research	Finland	Ms. M. Lille	X							Sub-project 1, functional properties
LIFE-UC	University	Denmark	Prof. H. Sorenson	X							Sub-project 1, allergens, functional properties
UNIZAR	University	Spain	Prof. J. Raso	X							Sub-project 1, microbial safety, PEF
IMCB-CNR	Research	Italy	Prof. S. Iannace		X		X		X	X	**Co-ordinator SP2**, interaction HP with packaging, novel packaging concepts
UNINA	University	Italy	Prof. G. Mensitieri		X						Sub-project 2, packaging models
CFRI	Research	Hungary	Ms. Prof. D. Bánáti			X		X	X		**Co-ordinator SP3**, consumer research, SP5 Dissemination, TCD
SCA	Platform	Europe	Ms. M. Peterman			X		X			Sub-project 5, dissemination
Nofima	Research	Norway	Ms. Dr. N. Veflen Olsen			X					Sub-project 3, consumer research
Aarhus Univeristy	University	Denmark	Prof. K. Grunert			X					Sub-project 3, consumer research
SIK	Research	Sweden	Ms. Dr. L. Ahrné	X	X		X		X	X	**Co-ordinator SP4 and SP7**, SP2 integration of packaging concepts, SP4 hygienic design, development advanced heating technologies, SP7 demonstration activities on cold plasma, packaging and HP
CTCPA	Research	France	Dr. F. Zuber				X				Sub-project 4, process hygiene
Campden BRI	Research	UK	Dr. J. Holah				X				Sub-project 4, process hygiene, SP5 Dissemination
TNO-QoL	Research	Netherlands	Ms. F. Boon				X				Sub-project 4, predictive modelling

Name of the organisation	Type of organisation	Country	Contact person	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7	Role in the activities/project
FRIP	Research	Czech Rep.	Dr. M. Houska				X				Sub-project 4, demonstration and implementation
USAL	University	U.K.	Prof. J. Gray				X				Sub-project 4, demonstration, development and implementation
Resato	Industry SME	Netherlands	Mr. H. Bijmolt				X				Sub-project 4, specialised equipment
I&L Invest	Industry SME	Belgium	Mr. L. v. Schepdael				X				Sub-project 4 ,demonstration and implementation
Unilever	Industry LE	Netherlands	Ir. H. Hoogland				X	X			SP4 demonstration, SP5 technology transfer, **Chairman IAP**
A&F-EFFoST	Platform	Europe	Ing. H. Lelieveld			X		X	X		SP5 dissemination and interaction with industry
Struik	Industry LE	Netherlands	Mr. M. Lor				X				SP4, demonstration project radio frequency heating
Procordia	Industry LE	Sweden	Ms. U. Stöllman				X				SP4, demonstration project microwave
OPAL	Industry SME	France	Mr. A. Besnardeau				X				SP4; demonstration project ohmic heating technology
PENY	Industry SME	France	M.Dejean/D.Vivien				X				SP4; demonstration project ohmic heating technology
Univ. Montpellier	University	France	Ms. Prof.N. Gontard		X						Sub-project 2, migration studies
FAU	University	Germany	Prof. A. Delgado	X							Sub-project 1, integrated models
INTI	Research	Argentina	Ms.Dr. P .Eisenberg		X						Sub-project 2, Nanocom INCO
CSIR	Research	South Africa	Ms. S. Buchner		X						Sub-project 2, NAnocom INCO
Koldsteril	Industry SME	Switzerland	Dr. W. Glettig							X	SP 7, demonstration cold plasma
Icimendue	Industry	Italy	Dr. M. Mensitieri							X	SP 7, demonstration packaging
TOP	Industry SME	Netherlands	Ir. W. de Heij							X	SP 7, demonstration high pressure
NC Hyperbaric	Industry	Spain	Ms.Dr. C. Tonello							X	SP 7, demonstration high pressure
USFD	University	U.K.	Prof. J. Gray				X				Sub-project 4, demonstration, development and implementation

Note: dissemination was also key topic within and across all Sub-projects (not restricted to Sub-project 5).

Table 1.3 Industry Advisory Platform members

Company	Country
Abba Seafood	Sweden
Agro Alimentaire Innovation Recherche	France
AH-Automation	Sweden
Ahold	Netherlands
Aldia	Belgium
Alpro NV	Belgium
Angulo General Quesera, S.L.	Spain
Anova Seafood	Netherlands
Arla Foods	Sweden
Asesoria Industrial Zabala	Spain
August Cieszkowski Agricultural University	Poland
Avure	Sweden
Bakalland S.A.	Poland
Barilla	Italy
Beskyd Frycovice	Czech Republic
Campina	Netherlands
Campofrio Alimentación, S.A.	Spain
CLARANOR	France
CNTA	Spain
Coca-Cola Europe	Belgium
Cocker Consulting Ltd.	Ireland
Congelados de Navarra S.A.	Spain
Coopbox	Italy
C-Tech Innovation Ltd	U.K.
CRITTMECA	France
Danish Meat Research Institute	Denmark
European Hygienic Engineering & Design Group	EU
European Space Agency	EU
Flanders' FOOD	Belgium
Food-Processing Initiative e.V	Germany
Fonterra Daily for Life	Australia
Fortunate Ltd.	Hungary
Friesland Foods	Netherlands
Fromageries Bel S.A.	France
GEA TDS GmbH	Germany
General Mills International	France
Gernal NV	Belgium
HAK B.V.	Netherlands
Heineken	Netherlands
HK Ruokatalo Oy	Finland
Hero	Switzerland/Netherlands
Hoogesteger	Netherlands
I&L Invest	Belgium
ICIMENDUE	Italy
Indulleida	Spain
Innowise GmbH	Germany
ISEKI	EU

Company	Country
Lantmännen Cerealia	Sweden
Lineum AB	Sweden
Litfood	Lithuania
Koldsteril	Switzerland
Kraft Foods	Germany
Marel Food Systems ehf	Iceland
Marfo BV	Netherlands
McCain Foods Belgium N.V.	Belgium
Marin Gimenez Hnos S.A.	Spain
Mars Food Europe C.V.	Netherlands
NC Hyperbaric	Spain
Novozymes	Spain
Numico	Netherlands
Nutreco	Netherlands
OMVE	Netherlands
OPAL	France
OLUS Tecnologia S.L.	Spain
PENY	France
PepsiCo	Germany
Philips Technologie GmbH	Germany
Premier Foods	England
Procordia Foods	Sweden
Promatec Food Ventures	Netherlands
Provalor	Netherlands
Resato	Netherlands
Rudolf Wild GmbH & Co. KG	Germany
SAIREM	France
Silliker	France
Sopgrape Vinhos	Portugal
Stork FDS	Netherlands
Struik	Netherlands
Tetra Pak Processing	Sweden
TOP B.V.	Netherlands
Total Fruit	Netherlands
Unilever	Netherlands
VMEngineering	Netherlands
Wipak	Germany
Wokke Food Systems	Netherlands
Xendo	Netherlands
Zdas	Czech Republic
Zeeland's Roem	Netherlands
Zwanenberg Food Group BV	Netherlands

1.5 Main deliverables and end results

The **main deliverables** of NovelQ were the development and demonstration of NP schemes; the design of eco-efficient production chains based on NP and novel packaging concepts.

In addition to this main deliverable, the following ***specific deliverables*** were foreseen:

- Over **50 draft manuscripts describing clear scientific answers, based on mechanistic and kinetic insights**, to unresolved open questions regarding the opportunities of NP (HP/T, PEF, plasma) to address key safety, health and quality issues of plant-based food products, including: (i) qualitative and quantitative answers to questions relating to chemical safety, allergens, food structure changes, stability of colour, flavour and health compounds, and (ii) new models (including databases) and sensors (indicator systems) to evaluate the safety and quality impact of NP (HP/T, PEF, advanced heating) on plant-based food products.

- Over **12 draft manuscripts and reports describing clear scientific answers, based on mechanistic and kinetics insights**, on open question related to the possibility of using innovative packaging materials (biodegradable, edible, active), as well as common polymeric systems in combination with NPs treatments. This includes (i) qualitative and quantitative answers to open question related to the effect of NPs technology on the properties of materials and on the food packaging interactions and (ii) mathematical models for predicting the evolution and changes of structural and functional properties of the polymeric materials utilised in package treatments with NP. Several software tools were foreseen for prediction of functional properties of packaging materials before and during NP-T treatments. Finally, a device will be developed based on optical fibres suitable for on-line analysis of material properties under HP/T.

- **three validated (prototype) and demonstrated (pilot-scale) NP implementation schemes** for SMEs; applications of novel technologies will be developed in co-operation with SMEs and will include the entire chain from raw material, processing, transport, packaging and consumer acceptance; where possible, these will focus on regional product development.

- **two validated and demonstrated products of HP and PEF**; development of HP and PEF applications for industry, including (pilot) equipment, product packaging, environmental impact, safety and quality of treated products and consumer acceptance.

- **elucidation of cold plasma** as a decontamination method for surfaces at the laboratory scale (food and packaging materials).

- **creation of one unified Platform for public and private bodies** that will regularly discuss the impact and potential of NP schemes and provide feedback for NovelQ.

- **creation of a strategic Novel Technology Knowledge Chain** that links basic science and its implementation, including training: in this way, an effective expertise base will be in place to enable Europe to better respond to, adopt and implement novel schemes for successful applications at the broader EU level (see affiliation of partners).

The project was expected to deliver a fully-integrated approach in quantifying reaction- and diffusion rates in foods and packaging materials, and in determining food-package interactions as influenced by NP schemes. These results will be integrated in the food chain as a basis for new integrated processing concepts showing an incremental innovation in food quality (including packaging and shelf life issues).

For the first time, using the principle of equivalence, the incremental innovation of quality of food products processed by different integrated technologies were foreseen to be demonstrated (in the demo-projects and applied research projects like WP 19 and 20), so as to optimise the quality-safety balance of food products.

Below, a short overview is given of the main deliverables:

Development and demonstration of NP schemes

Novel processing schemes have been developed and demonstrated for:

- *Novel applications of advanced heating technologies*
    - Minimal pasteurisation/sterilisation technology by application of water immersed radio-frequency heating for food products in consumer packages resulting in new pilot-scale equipment.
    - Design of ready-to-eat meals compositions for uniform microwave heating resulting in a simulation model that is now commercially available.
    - Ohmic heating technology of highly viscous pumpable foods with particles resulting in a new Mediterranean vegetable dish being marketed in the South of France.
- *Novel technologies*
    - Cold plasma treatment equipment for inactivation of micro-organisms on food surfaces.
    - Packaging materials for high pressure sterilisation resulting in new packaging materials that are commercially available now.
    - High pressure processing of healthy, complex food products resulting in a new range of fruit and vegetable products that are now produced in the Benelux countries.

Three demonstration activities were started after a competitive call procedure (see also Sub-project 6, management issues).
The activities in Sub-projects 4 and 1 resulted in the development of a lab-scale unit for cold plasma processing that that will be sold worldwide.
10 short demonstration trials have been carried out in collaboration with members of the Industry Advisory Platform as described in the results of Sub-project 4, revealing the wider applicability of NP to a range of not yet tested products

Design of eco-efficient production chains based on novel processing and novel packaging concepts

The design of eco-efficient production chains based on novel processing and novel packaging concepts was presented in models for life cycle analysis, shelf life, hygiene and decision support systems.

- Life cycle analysis studies have been performed and showed that novel processing technologies provide great opportunities to improve the sustainability of food systems by reducing energy use in processing (especially shorter treatment times) and waste in the food chain (results obtained together with the WP on shelf-life models). It is important to consider the entire life cycle of a product when designing the process to avoid increasing environmental impact from, for example, new packaging, which comes with the technology, or overlooking benefits from options made possible by new technology. Raw material utilisation and waste reprocessing was therefore also studied to design sustainable food production systems.
- The hygienic designs of high pressure and pulsed electrical field pilot- and industrial-scale equipment were analysed. Major hurdles were not discovered. For high pressure, emerging risks may be found in the pressuring fluids; however, this may not encounter any problems. For pulsed electric field, the risks are similar as for heat pasteurisation, namely in the aseptic part of the processing line. The insights from NovelQ were summarised in the guidelines for hygienic processing that were made available for the members of the Industry Advisory Platform.
- Decision support system: at the start of the project, the industry emphasised the importance of implementation of novel processing tools in processing lines and full production chains. In order to guide the applicator with making the right choice, a decision support system was developed taking into account product chain aspects.
- Shelf-life models have been developed allowing getting insight in the shelf-life of a specific product treated with novel processing and to reduce product loss. The model can be applied to predict shelf life based on microbial and enzymatic spoilage, and determination of processing conditions to obtain a desired shelf life. The model combines microbial inactivation and growth with enzyme inactivation, enzyme rest activity and quality. A user-friendly interface was developed and demonstrated to the members of the Industry Advisory Platform.
- Other examples of eco-friendly results are e.g. room temperature disinfection of packaging materials and food products using cold plasma's, novel biodegradable packaging materials, models for homogenously treating products in HPP and PEF chambers, PEF water disinfection unit, etc.

Improved understanding and mechanistic insights of NP

At the start of the project, series of knowledge gaps were identified for high pressure high temperature (HPHT), pulsed electric field, cold plasma, and packaging in relation to novel processing. Major breakthrough was achieved in understanding kinetics and mechanistic insights, especially in the areas of food texture, food chemistry, microbiological inactivation mechanisms, bio-chemical side-effects and risks, allergy in relation to HPHT, (bio-degradable) material characteristics facing HPHT and cold plasma conditions (including changes in glass transition temperature, crystallisation phenomena, multi-layer tensions, etc.), migration and

scalping considerations at novel processing conditions, and consumer science regarding novel processing and products produced by using novel processing.
These insights are described in more detail in Chapter 2, especially in subprojects 1, 2 and 3.
In total, over 120 scientific publications have been written, including two special issues.
The establishment and steering of the Training and Career Development Network (over 40 members) had also a very positive impact both for the members themselves as well as for the integration of project activities. The tailor-made TCD meetings were of high quality, mainly due to the organisational talent and willingness of its members to exchange views. The forthcoming TCD-alumni network received a warm welcome and was embedded as Special Interest Group within EFFoST.

In addition to the main deliverables, the following ***specific deliverables*** were foreseen:

- Over 50 draft manuscripts describing clear scientific answers, based on mechanistic and kinetic insights, to unresolved open questions regarding the opportunities of NP (HP/T, PEF, plasma) to address key safety, health and quality issues of plant-based food products, were foreseen. 97 scientific publications were published and 14 scientific publications were submitted, including two special issues.
- Over 12 draft manuscripts describing clear scientific answers, on questions related to the possibility of using innovative packaging materials as well as common polymeric systems in combination with NPs treatments were foreseen. 17 scientific publications were published and 7 submitted.
- Three validated (prototype) and demonstration (pilot-scale) NP implementation schemes for SMEs were foreseen. Within NovelQ, 6 demonstration workpackages and 10 demonstration trials were performed to demonstrate novel applications of advanced heating technologies and novel technologies.
- Two validated and demonstrated products of HP and PEF were foreseen including development of HP and PEF applications for industry. Within NovelQ, integral demonstrations were performed on orange juice (HP pasteurisation, PEF, mild heat treatment), carrot pieces (HP and heat pasteurisation, HP and heat sterilisation) and ready-to-eat meals and dips (HP and heat pasteurisation, HP and heat sterilisation). In the demonstration trials, other products were validated and demonstrated for novel processing.
- Elucidation of cold plasma as a decontamination method for surfaces at the laboratory scale (food and packaging materials) was foreseen and resulted in a commercially available lab-scale unit for cold plasma processing.
- Creation of one unified Platform for private bodies to discuss on regular basis the impact and potential of novel processing schemes and to provide feedback for NovelQ was foreseen. The Industry Advisory Platform of NovelQ was set up at the start of the project and had 89 industrial members when the project has been finalised. The following activities were organised for the IAP: industry-oriented workshops and meetigns, special part of the NovelQ website, newsletters, business cases featuring novel processing technologies, decision support tool to select the most appropriate novel processing technology, etc. At the start of the project 12 regional meetings were promised. Over 20 public workshops were held in different regions in Europe. The workshops were organised alongside large international events to attract a large group or as stand-alone workshops for a specific audience.

- Creation of a strategic novel technology knowledge chain that links basic science to its implementation, including training sessions. To stimulate interaction between young scientists within and outside the NovelQ consortium, and to stimulate them to communicate their results, the TCD Network was established following the NovelQ kick-meeting in 2006. This network turned out to be very successful with over 40 members. TCD activities included a TCD section at the NovelQ website, newsletters, workshops/conferences, and scientific and soft-skill trainings. In September 2010, a very successful, large PhD conference was organised at TU Berlin at which PhD students from NovelQ and other EU projects presented their project results. The TCD Network was recognised by the EC as an important tool within the European projects and resulted in a specific FP6 call for projects on this topic.

It should also be mentioned that NovelQ contributed to a new activity on pulsed electric field for safe water. The aim was to make safe drinking water - via a small, robust PEF unit - available for third countries, in particular for disastrous areas. A safe-water workshop on this topic was organised and a small prototype of a PEF unit for safe drinking water was constructed.

In conclusion, the NovelQ project team was able to show incremental innovations with an active industrial involvement. Even though the direct financial contributions of companies in the project was limited, as compared to the ones from research institutes, the indirect spending by companies such as OMVE and NC Hyperbaric has been substantial and leading to new prototypes.

It should be emphasised that especially the SMEs has been actively involved. The 10C SME approach, described in the NovelQ Special of New Food in more detail, is recommended to be used in other EU projects:

- Combined basic science and applied research
- Construction of an Industry Advisory Platform
- Cross-sector involvement of SME
- Combined workshop with more EU projects
- Communication with SME
- Competitive call for SME to join projects (with low bureaucratic burdens)
- Compact proof of principles for SME
- Company visits to SME
- Continuity of SME in a dynamic, open, platform
- Co-ordinated feedback to the EC on new topics relevant for SME

1.6 References

Project website: www.novelq.org

2 Description of main results

2.1 Mechanisms and kinetics of impact of NP on food safety and quality: description of main results of SP1

2.1.1 Introduction to SP1 incl. main objectives, contractors involved

Situating the SP
Within the field of novel processing and preservation technologies, **high pressure processing** and **pulsed electric field processing** are key technologies which are in an advanced state of maturity (both in terms of their food science basis and their technology development) and have recently been introduced or are likely to be introduced in the near future at an industrial scale. On the other hand, the food science basis of **cold plasma treatments**, to a large degree, remains to be developed.

This Sub-project has concentrated on the **strategic basic (food) research that is required to demonstrate, at industrial level, the introduction of novel technologies**. On a long-term basis, a strong multi-disciplinary scientific and technological basis must guarantee successful implementation of new technologies in Europe to provide safe, nutritious and high quality foods through environmentally friendly production methods. Building on the available knowledge base, this SP focussed on missing links that could jeopardise the European food industry against other competing economic communities, such as the United States and Japan.

Focus points were:
Food safety aspects requiring further documentation and understanding. These safety aspects included microbial and chemical targets (spore inactivation, pathogens – vegetative cells, inactivation of existing allergens, chemical compounds with negative health effects).
Food quality (functionality) aspects including nutritional/health-related targets as well as sensory aspects such as texture, colour and flavour - with a particular focus on freshness.

The key targets were 1) mechanistic insight, 2) understanding of kinetics and 3) translation of kinetic data and models into a toolbox (consisting of **mathematical models and indicator systems** allowing performance evaluation of processes and products. These key targets provided a unique basis for identifying, evaluating and optimising processes in demonstration activities (performed in SP4).

This Sub-project focused on plant based foods (solids and liquids) and used **carrots, tomatoes, strawberry, apple and broccoli as raw materials (fresh and processed foods) as study vehicles**; these have been selected because they integrate (i) food safety issues (both microbiological and processing related chemical safety), (ii) food structure issues, (iii) colour and flavour-related aspects, (iv) health-related compounds, and (v) allergens. In addition, they afford study of low acid- and acid foods (allowing study of processing intensities targeting pasteurisation and sterilisation) and, crucially, they are economically important in European fruit and vegetable chains.

From the processing standpoint, SP1 examined processing variables such as time, temperature, pressure, electric field strength, pulse frequency, total energy input. Understanding the **mechanistic and kinetic effects** of such variables provided a necessary basis for demonstrating high pressure/thermal processing and high electric field pulse treatment. The intensity of the processing conditions were chosen such that different unit operations based on novel technologies were considered such as pre-processing, intermediate and final processing/preservation steps along the food chain from raw materials to final consumption.

These strategic choices were motivated directly by the state of the art in the field at the beginning of the project, as largely described in a set of review papers (**Delgado et al. 2008, Gerlach, et al. 2008, Oey et al. (2008a) Oey et al. (2008b), Sila, et al. (2008), Van der Plancken et al. (2008), Wilson et al. (2008)**) and by the key objective of demonstration in this IP.

Research objectives
Considering the state of the art in this field, the key unresolved scientific questions to be answered in this Sub-project on the effect of new processing technologies on food safety and quality were:

Microbial safety (WP1):

- What are the target bacterial spores, in particular pathogens, in relation to high pressure sterilisation (HP/T)? What are the inactivation kinetics of the key targets and what are the mechanisms of action? How does the food matrix influence these phenomena?
- What are the target pathogens in relation to pulsed electric field pasteurisation? What are the inactivation kinetics of the key targets? What is the influence of the food matrix?
- Can cold plasma be used to decontaminate food surfaces? What are the target bacteria? What are the kinetics and mechanisms involved?

Chemical safety (WP2):

- Can high pressure/thermal or pulsed electric field processing change the allergenicity of existing allergens in plant based foods? What are the mechanisms and kinetics of these processes? What is the effect of the food matrix?
- Does high pressure/thermal processing or pulsed electric field processing evoke chemical reactions affecting product safety/quality? What are the mechanisms and kinetics of these processes? What is the effect of the food matrix?

Food quality aspects, freshness character (WP3 and WP4):

- How can texture, firmness, consistency and viscosity aspects of plant-based food products be optimised (maintained or improved) during high pressure thermal treatments? Is there a role of exogenous enzymes to maintain or improve texture of delicate plant structures? What are the kinetics and mechanisms involved?
- What is the effect of high pressure thermal processing or pulsed electric field processing on health related compounds, freshness related flavour compounds and colour aspects of plant based foods?
- What are the kinetics and mechanisms involved?

Considering the scientific and technical state of the art, and the kinetics on microbiological food safety, chemical food safety and food quality aspects to be obtained in this IP, **process impact evaluation tools developed in this sub-project (WP5)** were:

Tools, available as software and sensors (indicator systems), that allow determination of process impact in phases of design, validation and optimisation including analysis of process uniformity for *high pressure thermal processes*.

Tools, available as software and sensors (indicator systems), that allow determination of process impact in phases of design, validation and optimisation including analysis of process uniformity for *pulsed electric field processing*.

Expected impact

By successfully addressing these objectives the following needed to be achieved (as compared to the state of the art at the beginning of the project):

To understand and quantify the effects of high pressure thermal processing on all quality and safety aspects of foods in the context of processing intensities covering pasteurisation and sterilisation levels.

To understand and quantify the effects of pulsed electric field processing on all safety (pathogens) and quality aspects in the context of processing intensities covering pasteurisation levels.

To explore, understand and quantify *the effects of cold plasma* on microbial food safety aspects.

To develop the first sensors and models for design, validation and optimisation of novel processing technologies based on high pressure thermal and pulsed electric field processing.

Contractors involved

SP1 consisted of a highly interdisciplinary research team, all key experts in the areas of novel food processing, food microbiology, analytical biochemistry, nutrition, food allergens or process modelling.

#	Partner	Expertise	Involvement in SP1	
1	A&F	Novel processing technologies: HP, cold plasma, PEF, Equipment design, process research, microbiology, quality, consumer attitude	WP1	Spore inactivation by HPHT processing Cold gas plasma decontamination (kinetics)
2	TUB	Basic research related to Processing effects on cellular levels of plants and microorganisms Production of plant and microbial metabolites Stress responses of plants and micro-organisms Process development in the area of PEF, HP, ultrasound and thermal processing	WP2	Provision of PEF processed samples for LIFE UC and IFR Data analysis
			WP4	Generation of health related compounds by mild PEF and HP processing Kinetic modeling
			WP5	Model development for PEF processing Development of indicator systems for PEF processing
3	KULeuven	Effect of conventional and novel processing technologies on food properties of technological, organoleptic or nutritional importance	SP1	**coordinator**
			WP2	Provision of HP(HT) processed samples for LIFE UC and IFR Data analysis

#	Partner	Expertise	Involvement in SP1	
		related to (bio)chemical and chemical changes. Mechanistic and kinetic approach Process design, evaluation, optimisation Sensors for process impact evaluation	WP3	**WP leader** Mechanism and kinetics of textural changes under HP(HT) processing
			WP4	Effect of HP(HT) processing on anthocyanins Effect of HP(HT) processing on glucosinolate-myrosinase system Kinetic modeling
			WP5	Development of indicator systems for HP(HT) processing
4	IFR	Food structure Microbiology Allergens	WP1	**WP leader** Mechanism of HPHT spore inactivation Mechanism of PEF microbial inactivation Cold gas plasma decontamination
			WP2	**WP leader** Allergen inactivation by PEF and HP(HT) processing
			WP3	Cellular disruption by processing Development of probes
5	UdL	Effect of PEF processing on food quality related enzymes and food quality aspects	WP4	**WP leader** Effect of PEF processing on food colour component availability and stability Effect of PEF processing on food flavour component availability and stability
6	VTT	Effect of HP processing on food texture and health and flavour compounds Enzymatic applications for industrial processes	WP4	Effect of HP(HT) processing on food colour component availability and stability Effect of HP(HT) processing on food flavour component availability and stability
7	LIFE UC	Analytical biochemistry Development of qualitative and quantitative methods of analysis	WP2	Analytical-biochemical evaluation of chemical reactions with negative health implications related to PEF and HP(HT) processing
			WP4	Analytical-biochemical evaluation of generation and retention of flavours, colours and health compounds related to PEF and HP(HT) processing
8	UNIZAR	Effect of novel and conventional preservation technologies on microbiology (microbial resistance, sublethal injury, kinetic modelling, ...)	WP1	Microbial inactivation by PEF processing (kinetics and mechanistic aspects)
9	FAU	Theoretical and experimental fluid mechanics CFD modelling High pressure in situ measurement techniques Energy balances	WP5	**WP leader** Model development for HP(HT) processing Model development for PEF processing

2.1.2 Working approach

The central approach in SP1 was the integration of all key safety and quality aspects from both a mechanistic and kinetic point of view (Figure 2.1.1). Research was conducted following a **five-level approach**, considering (i) microbial inactivation (WP1), (ii) allergen inactivation (WP2), (iii) chemical safety (WP2), (iv) improved food structure (WP3) and (v) improved colour, flavour and health functionality (WP4).

SP1 followed a **five-step research innovation approach**, consisting of (i) identification of processing conditions and food matrix, (ii) detailed kinetic studies based on a common methodological approach, (iii) development of predictive models, (iv) mechanistic understanding of the phenomena observed (WP1-4) and (v) compilation of all information obtained in integrated models and specific sensors (WP5). As a consequence, common and specific windows of processing conditions and food matrices were defined, allowing not only maximal interaction between the work packages, but also comparison of (novel) unit operations on a quantitative basis and from a viewpoint of true equivalence.

Figure 2.1.1 Five-level, five-step innovation research approach.

2.1.3 Main results achieved

References mentioned in bold result from SP1 research and are listed separately bellow, together with all other SP1 papers. References from outside the project (not in bold) are mentioned to contextualise the NovelQ results.

High pressure (high temperature) processing

Microbial safety

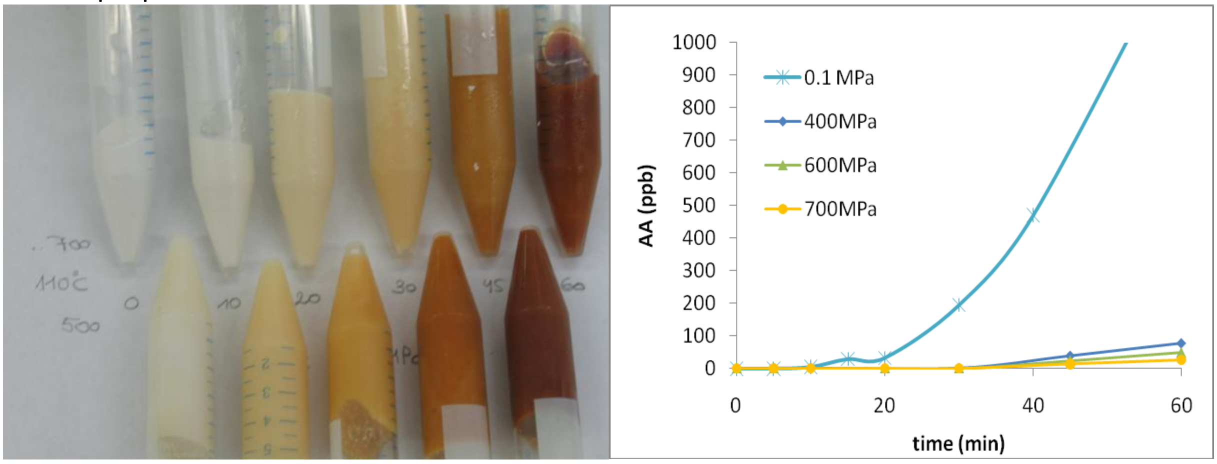
While in earlier research spore inactivation with high pressure was attempted by using a cycle approach involving spore germination at relative low pressures followed by inactivation of the germinated spores at elevated pressure, in recent years, the interest of researchers has focussed on a combination of high pressure and temperature. Nevertheless, insight in the mechanisms of HP/HT spore inactivation is far from complete (Wilson et al., 2008).
In SP1, *C. sporogenes* strain NCIMB 8053 (=PA3679) was used as the model organism in a detailed kinetics study. The methodology of choice to enumerate the surviving spores was that of the most probable number (MPN) because of its very low detection level (factor 10-100 lower as compared to conventional plate counting methods), the possibility to detect spores which are not completely killed but only reversibly inactivated and sometimes capable to grow out only months after treatment and the low risk of post-treatment contamination of the spore samples. The aim of the study was to distinguish the pure pressure effect from the thermal effect of HPHT induced spore inactivation. Little difference in spore inactivation was observed between thermal inactivation at 121°C and the combined thermal/pressure inactivation at 121 °C and 600 MPa. At pressures above 600 MPa, inactivation occurred faster for the combined pressure/thermal inactivation. However, from the matrix of conditions tested, $Z_{121°C}$ (pressure increase required to obtained 10-fold faster inactivation at 121°C) was determined to be 267 MPa. This pressure increase above 600 MPa cannot be reached as the current constraint for industrial scale processes is that a maximal pressure of 800 MPa is feasible.

<u>Conclusion</u>:
Therefore, the data suggest that possibilities to enhance inactivation rates by increasing the **pressure for an industrial scale process are limited. Nevertheless, because of the strong** effect of pressure on heating and cooling rates, UHT-like processes can be designed for packed foods, which will positively affect the overall quality of the product.

Chemical safety

Thermal processing of carbohydrate-rich foods, such as potato and cereal products can lead to the formation of the potential human carcinogen acrylamide, predominantly through the Maillard reaction between the amino acid asparagine and a reducing sugar. The Maillard reaction is also responsible for the formation of desired as well as undesired colour and flavour compounds and is therefore considered one of the most important chemical reactions in determining the quality of heated foods.

Limited information is available on acrylamide formation during HP/HT processing. Within SP1 (**De Vleeschouwer et al., 2010**), the impact of HP/HT-conditions (100-115 °C, 400-700 MPa, 0-60 min) on the different stages of the Maillard reaction was elucidated in equimolar asparagine-glucose model systems, measuring the concentration of acrylamide, reactants, hydroxymethylfurfural, organic acids, and melanoidins, as well as pH before and after treatment. The retarding effect of high pressure on the overall Maillard reaction was demonstrated (Figure 2.1.2), although the rate at which acrylamide was formed strongly depended on the buffer system used and the temperature and pressure dependence of its pK_a. Based on the results obtained in model systems, it could be demonstrated that maximal acrylamide concentrations generated (~1700 ppb) during a 60 min HP/HT-treatment at 115 °C and 600 MPa are considerably lower than during a conventional heat treatment (~6500 ppb). Moreover, the time frame that is relevant for high pressure sterilisation applications is much shorter (3-5 min holding time at 121 °C) than the frame selected in the study for kinetic purposes.



A. Brown colour of equimolar 0.1M aspargine-glucose mixture (16% water content, MES buffer pH 6.0) after pressure treatment at 110°C and 500 or 700 MPa

B. Acrylamide concentration in equimolar 0.1M aspargine-glucose mixture (80% water content, phosphate buffer pH 0.6) after treatment at 110°C and atmospheric or elevated pressure.

Figure 2.1.2 High pressure processing at elevated temperature, not only retards browning (A), but also acrylamide formation (B).

In addition, methods to analyse effects of HP processing were developed in SP1. Analytical fingerprinting was based on chemometric analysis of electropherograms from capillary electrophoresis of LMW containing raw extracts of the various processed and non-processed plant materials. Principal component analysis (PCA) was performed to see whether specific degradation patterns could correlate to the processing parameters. PCA analyses of data on all water-soluble LMW compounds detected by MECC from HP/HT processing of carrots lead to an unidentified marker for HP processing in combination with high temperature (**unpublished results**).

Conclusion:
Based on these considerations and the fact that only high water content products are relevant for high pressure processing applications, it was concluded that acrylamide formation is not expected to pose a major hazard to this type of products.

The major results obtained in SP1 with regard to high pressure/high temperature processing and chemical safety are reviewed in **Van der Plancken et al. (2011)**.

Allergens

Allergens pose another safety risk for susceptible consumers. It is known that the secondary and tertiary structure of food allergens is crucial to their allergenic potential. Processing techniques affecting this structure, like HP treatment, can thereby possibly reduce the allergenicity of foods. Several studies have been performed on the effect of HP at ambient to moderate temperature on different food allergens. In SP1, the effects of temperature and/or high pressure (150-800 MPa) treatments were studied on three selected, purified plant allergens: Ara h 2,6 (peanut 2S albumins) and the predominant apple allergens, Mal d 1 and Mal d 3.

High pressure treatment had little effect on the structure of the 'prolamin-fold' proteins Ara h 2 and 6 from peanut at either room temperature or at 80°C, as shown by FTIR-spectroscopy. In the case of apple Mal d 3, changes in secondary structure due to pressure processing at 80°C were observed and attributed to the temperature, rather than the pressure. These changes were also reflected in the antibody recognition of Mal d 3. The heterologously expressed Mal d 1 showed small changes in secondary structure following high pressure treatment at 20°C with rather more alteration at 80°C. The secondary structure of Mal d 1, whilst less stable, was able to refold after heat treatment and showed no consistent changes after treatment. The changes that were observed were attributed to changes in aggregation state and thus concentration. However, these observations may not be representative of what happens when the allergens are heated in the fruit, where the chemical environment of the proteins is very different (Johnson et al., 2010).

Therefore, Husband et al. (2010) studied the impact of thermal and high pressure processing on the immunoreactivity of the two main allergens in apple (Mal d1 and Mal d 3), as well as the Bet v 1 homologue Api g 1 in celeriac. The results showed that Mal d 1 was subject to chemical modification as soon as the apple tissue was disrupted although it was remarkably resistant to both thermal (10 min at 115°C) and HP/HT (10 min at 115°C and 700 MPa) processing. This is in contrast to the Bet v 1 homolog from celeriac, Api g 1 that was susceptible to thermal processing at either pressure. The other major allergen in apple, Mal d 3 was found to be resistant to chemical modification and thermal processing in apple, which is in contrast to its behaviour in solution. This study also showed that pectin protected Mal d 3 from thermal denaturation in solution and is one possible candidate for the protective effect of the fruit matrix towards heat susceptibility. The combination of pressure and temperature significantly reduced its immunoreactivity. The conclusion to be drawn from these results is that HP/HT processing is an effective method to reduce the allergenicity of both apple and celeriac but for allergen-specific differing reasons. Mal d 1 will have its allergenic potential reduced by disruption of the apple cell structure either prior to or during the processing. The celeriac allergen Api g 1 will have its immunoreactivity reduced by thermal processing at ambient or elevated pressure, while the apple allergen Mal d 3 requires HP/HT processing.

Conclusion:
In conclusion, HP/HT processing makes apple safer to eat with respect to allergens as the Mal d 3 is modified by the process and the Mal d1 allergen is modified by the disruption of the tissue. It is difficult to draw a general conclusion on the effect of HP/HT processing, as there is clearly an effect of the matrix on allergen inactivation and the mechanism seems to differ between allergens.

The major results obtained in SP1 with regard to high pressure/high temperature processing and food allergens are reviewed in Van der Plancken et al. (2011).

Textural functionality

In edible fruits and vegetables, texture is mainly determined by the structure of their parenchyma cells which are weak and non-specialised. The structural integrity of the primary cell wall and middle lamella, in addition to the turgor pressure generated within the cells due to osmosis, determine the texture of such tissues. Loss of this structural integrity, for instance during processing, can mainly be attributed to depolymerisation of cell wall pectic polysaccharides, leading to weakened cell adhesion. During processing, pectin, particularly abundant in the middle lamella, is susceptible to both chemical and biochemical conversions that can either be beneficial (demethoxylation) or detrimental (depolymerisation) to the texture of the fruit or vegetable.

While the effect of high pressure processing on texture at ambient pressure has been studied extensively, the number of investigations on the effect of HP/HT processing on texture is limited. In SP1, carrots were selected as a case-study as they have high pectin content and their textural changes largely depend on pectin modifications.

In an exploratory study on the effect of processing on texture of carrots, De Roeck et al. (2008) observed that although both heated (at 80 or 100°C) and HP/HT processed (at 80°C and 600 MPa) carrots showed an initial texture loss attributed to loss of turgor pressure, HP/HT treated carrots, unlike HT treated, did not undergo further softening as the process continued. Two possible explanations were suggested for the improved retention of hardness under pressure: (i) inhibition of the beta-eliminative depolymerisation, either directly by pressure or indirectly by the observed extensive demethoxylation and (ii) formation of fortifying networks of the low methoxylated pectin with endogenous Ca^{2+} ions.

It was confirmed in pectin model systems that beta-eliminative depolymerisation occurred at a lower rate and demethoxylation at a higher rate during HP/HT processing (90°C, 500-700 MPa), in comparison to during heating at ambient pressure (De Roeck et al., 2009). The retarding effect of pressure at elevated temperature on the texture of carrots was also demonstrated in a kinetic study (De Roeck et al., 2010). Both for thermal and HP/HT processing, the changes in texture after processing could be described by a fractional conversion model. Although the residual level of hardness at long treatment times did not differ between treatments, the rate constants were significantly higher for heat treatment

at ambient pressure. Extensive pectin demethoxylation during the HP/HT pre-process (heating to the initial temperature at ambient pressure and pressure build-up phase) could be responsible for a retarded beta-elimination, which is considered to be the main cause of thermal softening of carrots. The formerly established pre-treatment strategy of lowering the DM and adding exogenous Ca2+ for texture improvement of thermally processed fruits and vegetables, was also successful in case of HP/HT processing. However, an almost identical outcome was obtained by HP/HT treating the carrots directly in a calcium chloride solution without applying a pre-treatment. Given the strong demethoxylation, the HP/HT dynamic build-up phase can be regarded as an implicit HP pre-treatment. Obviously, excluding a separate pre-treatment step will lead to time savings and a lower cost.
Furfaro et al. (2009b; 2009a) showed using two-dimensional NMR cross-correlation relaxometry in combination with optical microscopy that rapid pressurisation to 600 MPa immediately following a pre-cooking step at 60°C (20 min) results in intact cell wall structure of both carrot phloem and xylem without evidence for cell wall separation or extracellular pectin-filled domains, while compartmentalised gelatinisation does occur. This study also revealed that carrot phloem is richer in pectin that can be thermally or high pressure gelatinised than xylem, so that texture is more affected by processing in the former. This also suggests that in processed tissues, the texture is predominantly determined by cell wall strength and degree of biopolymer cross-linking rather than by turgor pressure.

Finally, De Roeck et al. (2010) showed that for processing conditions leading to the same microbial impact, both for pasteurisation and sterilisation purposes, high pressure processes were the better option in retaining carrot hardness. In the case of HP pasteurisation, only limited texture loss was observed as processing temperatures were not high enough to support beta-eliminative pectin degradation. Both thermal and HP sterilisation processes were accompanied by significant hardness loss, although less pronounced in case of HP sterilisation. The latter could be attributed to two effects: (i) faster heating and cooling rates corresponding to shorter treatment times and (ii) enhanced pectin demethoxylation during combined HP/HT processing resulting in low methoxylated pectin which is less susceptible to beta-eliminative depolymerisation and can form fortifying networks with Ca2+ present. This pronounced loss of texture was reflected in carrot microstructure where extensive cell separation and polymer solubilisation was observed. During consecutive storage of the treated carrots, the hardness did not change within 9 days (Figure 2.1.3).

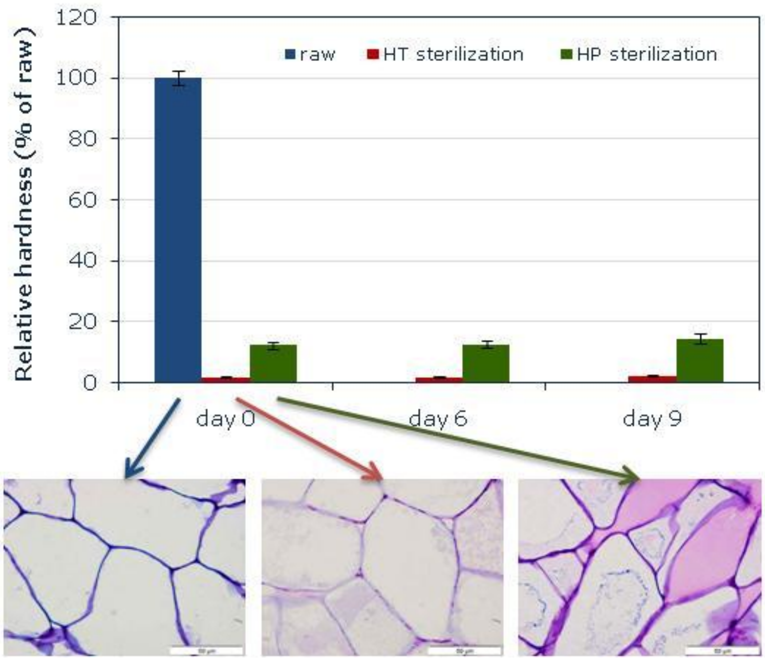


Figure 2.1.3: Carrot relatve hardness and microstructure after equivalent HT and HP sterilisation

The clear effect of HP/HT processing on the texture and structure will not only affect the consumer's appreciation of the food, but might also alter its nutrient bioavailability.

Conclusion:
In conclusion, HP/HT processing leads the way to new and even unexpected or different textures and structures for products having the same microbial safety as those treated with conventional thermal processing.

The major results obtained in SP1 with regard to high pressure/high temperature processing and textural functionality are reviewed in Van der Plancken et al. (2011).

Colour, flavour and health functionality

Generation of health-related compounds due to stress reactions

In SP1, the effect of mild HP treatment on the **stress induction** of different plant (apples) and plant cell cultures (apple, tomato and carrot) has been investigated through external stimulation of cell metabolic activity and subsequent production of secondary metabolites (phenolic compounds). Plant cell and tissue cultures were used as model systems for plant tissue in particular to acquire more information about biosynthetic pathways that were investigated through alterations of polyphenolic content as well as related enzyme activity (Phenylalanine ammonia-lyase (PAL)). Additionally the cell permeabilisation was examined in order to obtain information whether the treatment resulted in a extraction process (high cell disintegration index) or a stress response was measured. In connection with the studies of effects on enzymes and chemical reactions processing, highly specific methods for online determination of substrate transformation and production of products have been developed based on MECC. This has been the case for the enzyme systems PAL, PPO, POD and myrosinase.

A wide range of treatment intensities has been performed to achieve a response from plants or cell cultures. Not every treatment caused specific changes in plant tissue that could have been characterised as a stress response. Apples treated with 50MPa for 20s showed a significant increase in phenolics right after treatment as well as after a stress reaction time of 24h, whether longer treatment times and/or higher pressures resulted in a sharp decrease within 48h. For the treatment of plant cell culture (e.g. apple) even lower pressure and treatment times were needed. A positive stress reaction (eustress) was observed after a treatment for 30s at 25MPa. This reaction was approved by corresponding enzyme activity as well as a negligible cell permeabilisation grade.
A biological tissue of other treated plants and cell cultures used within this project underwent similar specific changes in metabolic activity, after different treatment intensities and/or stress reaction time, indicating that changes were product and treatment specific. It is most likely that mechanisms for phenolic production were triggered by HP treatment and our results confirmed that changes in phenolic content after certain treatment condition, stress reaction time, or storage condition were related to changes of PAL activity (unpublished results).

Food colour and flavour stability

High pressure processing enhances reactions that are associated with a volume decrease. As the change in volume upon breaking of covalent bonds is small, its effect on low-molecular mass compounds such as vitamins and flavour compounds is expected to be limited. This is corroborated by many studies, as reviewed by Oey et al. (2008b). Nevertheless, loss of nutritional value during consecutive storage occur, for instance due to limited enzyme inactivation by high pressure. In HP/HT processing, the additional process parameter temperature can nonetheless be responsible for loss of nutrients, as shown by a limited number of studies prior to the NovelQ project (Taoukis et al., 1998; Kim et al., 2001; Oey, et al., 2006). Flavour is the sensory impression of a food that is determined mainly by taste and smell. Even small changes in the flavour-active components can alter the overall flavour of the fruit or vegetable to a large extent. High-pressure as such is considered to have a limited effect on low-molecular-weight flavour compounds, but as on health-related compounds, high-pressure processing may result in undesired changes in the overall flavour of plant-based foods for example during storage if enzyme inactivation has been incomplete. Although several studies have been performed describing the limited change in flavour immediately after high pressure treatment of fruit and vegetable products, as reviewed by Oey et al. (2008a), in only one was the additional effect of temperature considered (Krebbers et al., 2002).

In SP1, next to flavour compounds, health related compounds with an additional colour (carotenoids and anthocyanins) or flavour functionality (glucosinolates) were studied.

Dietary carotenoids play a role in reducing the risk of various diseases, including certain cancers, cardiovascular disease and eye diseases. The review paper by Oey et al. (2008b) already indicated that studies on carotenoid stability towards pressure are limited to ambient temperatures. These showed that carotenoids are relatively pressure stable and that extraction yields can be improved. In the NovelQ project, the processing window under investigation was expanded to HP/HT processing. Carrots are a major source of α-carotene, β-carotene and lutein. No major losses in α-carotene or β-carotene occurred when carrot puree was heat-treated at atmospheric pressure (0.1 MPa) at 40-74°C or high pressure-treated at 800 MPa and 40-74°C. Lutein was slightly more sensitive to high-pressure processing than α- or β-carotene. Also in tomato puree, a major source of lycopene, no losses of this carotenoid were observed after a pressure treatment of 30 min at 800 MPa and 55°C.

It is generally accepted that vegetables of the *Brassicaceae* family have a health promoting effect, mainly due to the presence of high concentrations of glucosinolates. Although the latter by themselves are biologically inactive their hydrolysis products show anti-carcinogenic potential. In intact tissue, myrosinase and glucosinolates are separated, necessitating cell disruption (for instance by processing) for the active hydrolysis products to be formed. However, the thermolabile enzyme is often already inactivated before the health related compounds are formed. On the other hand, strong hydrolysis is associated with bitter taste, calling for a good control of the myrosinase activity. Furthermore, any health related compound formed, such as isothiocyanates, needs to be stable during the process as well. The stability of both myrosinase and isothiocyanates under high pressure was poorly described prior to the NovelQ project.
In a series of papers, Van Eylen and co-workers (2007; 2008a; 2008b; 2009) investigated on a kinetic basis how the different aspects of the glucosinolate-myrosinase system could be affected through targeted HP processing (100- 600 MPa) at mild temperatures (20-50°C) to obtain optimal formation and stability of the health related glucosinolate hydrolysis products. Myrosinase activity and inactivation, cell leakage and glucosinolate conversion reaction products were assessed. Preliminary experiments indicated that high pressure processing at high temperatures was not relevant for optimal functionality of this system. The integrated effect of HP processing at mild temperatures on the glucosinolate-myrosinase system clearly illustrated that by proper selection of processing conditions specific hydrolysis products, with potentially higher health beneficial effects can be obtained in pressure processed broccoli.

In addition to being responsible for the red colour of strawberries, anthocyanins are important due to their role as bioactive antioxidants. These compounds are relatively stable during HP processing at moderate temperature, although this treatment can not prevent their enzymatic degradation during storage because of insufficient inactivation of the endogenous enzymes.
Verbeyst et al. (2010) compared the degradation kinetics of the major anthocyanin in strawberry paste (pelargonidin-3-glucoside) during HP/HT treatments (80–130°C and a pressure range of 200–700 MPa) to similar temperature conditions at ambient pressure. For

all processes, the degradation of pelargonidin-3-glucoside followed a first-order kinetic model. A positive effect of both temperature and pressure on the degradation rate was observed, although the effect of increasing pressure was smaller than that of increasing temperature. Temperature dependence of the degradation rate constants was higher at atmospheric pressure than at elevated pressures, while only a small pressure dependence of the reaction rate constants was demonstrated. A model describing the combined temperature–pressure dependence of the degradation rate constants was proposed as a tool to design and optimise HPHT processes. Although pressure plays an additional role in enhancing the degradation rate of anthocyanins, the shorter treatment times during these processes (due to fast heating and cooling rates), might lead to a lower integrated process impact in comparison to an equivalent thermal process.

The typical flavour of strawberries is contributed to a complex mixture of furanones, esters, aldehydes, alcohols and sulphur compounds. Some compounds have a greater impact on overall flavour than others due to differences in the characteristic odour thresholds of the compounds. Previous studies (Lambert et al., 1999; Zabetakis et al., 2000) have shown that high pressure treatment does induce some changes in the amounts of volatile compounds, although to a lesser extent than thermal processing, and probably due to insufficient enzyme inactivation. However, because of differences in odour thresholds, these changes might exert only a limited effect on the actual appreciation of the overall strawberry flavour. Furthermore, there are no known studies on the combined effect of pressure and temperature on this quality attribute.

Combing descriptive sensory analysis, GC-olfactometry (Figure 2.1.4) and GC-MS of volatile compounds, Lille et al. (2011) concluded that HP/HT treatment affects the overall flavour of strawberry purée. They were able to link many of the volatile compounds to specific verbal descriptions. Nevertheless, there were some descriptions that remained without a positively identified volatile, probably due to differences in odour threshold and GC-MS detection limits.

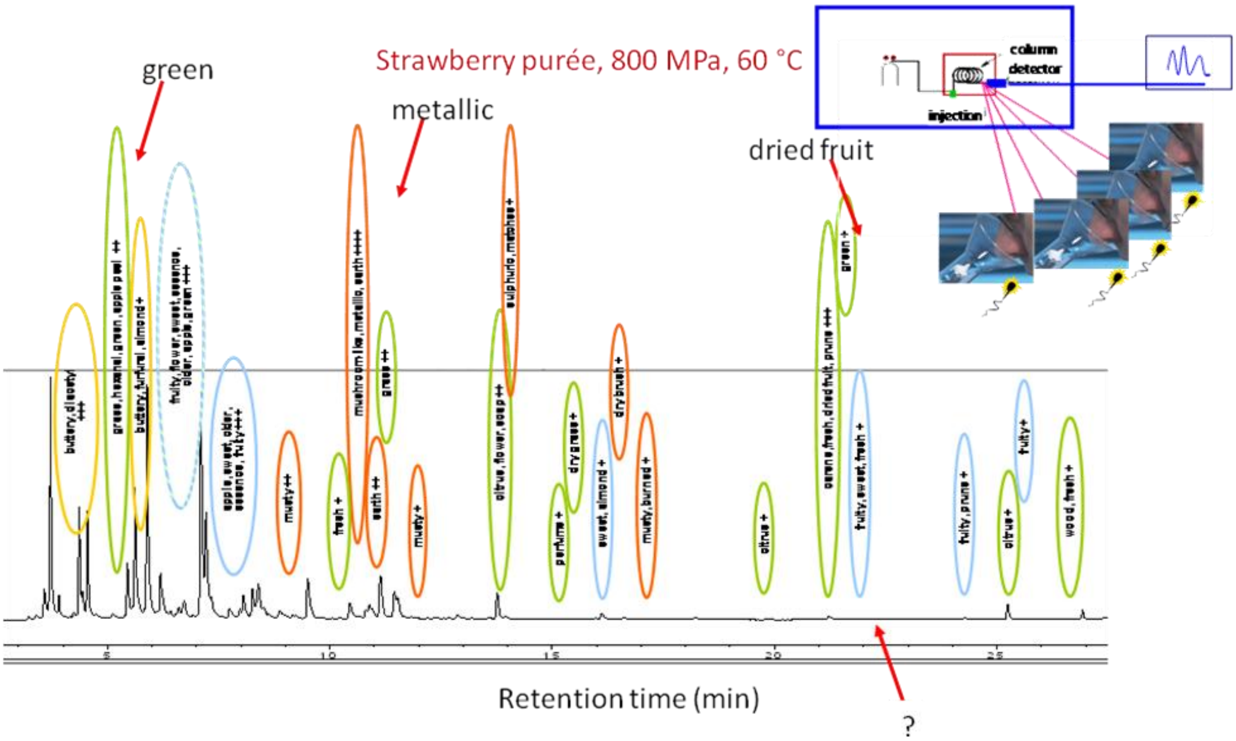


Figure 2.1.4. GC olfactometry links volatile compounds to aroma perceived by humans

HP-processing at the most intense conditions (10 min at 800 MPa, 60 °C) resulted in a clear increase in dried fruit- and tea-like odour and a loss in acidity. The odour of the strawberry purée treated at 800 MPa at ambient temperature was perceived very similar to that of the untreated purée (0.1 MPa, 20 °C).
An intense resin or dried fruit resembling odour was also detected by GC-olfactometry in the strawberry samples treated at 60°C (at 0.1 or 800 MPa). This odorous event also appeared in the sample treated at 800 MPa, 20°C, but at a lower intensity. The volatile compound responsible for the dried fruit-like odour remained, however, unknown (Figure 2.1.4).

GC-MS revealed that high-pressure processing at 800 MPa (20 or 60°C), as well as heating at 60 °C at atmospheric pressure, resulted in increased concentrations of many aldehyde and ketone compounds, which are typical lipid oxidation reaction products. Lipid oxidation is initiated already when the strawberries are homogenised, but it appeared to be enhanced during processing at the above mentioned conditions. Many of the aldehydes, which showed increased concentrations due to high-pressure processing at 20°C, are known to be responsible for green or grass-like notes. An increase in the intensity of green notes in the high-pressure processed samples was also detected by GC-olfactometry, but not in the sensory evaluation of overall odour. This might be due to the fact that GC-olfactometry splits the odour to its odorous components, whereas the overall odour is perceived as its entity in sensory assessment.
High-pressure processing at 800 MPa (20 or 60°C) did not, according to GC-MS, cause significant losses in ester compounds, which are important compounds in fresh strawberries since they are responsible for fruity and sweet notes in the overall flavour. By GC-

olfactometry, however, a reduction in the intensity of fruity notes was detected as a result of high-pressure processing (800 MPa, 20 or 60°C) or heating at 60 °C (0.1 MPa).
By GC-olfactometry, an additional metallic odour was detected in the high-pressure processed strawberry purée (800 MPa, 20 °C and 800 MPa, 60 °C). This odour was absent in the untreated (0.1 MPa, 20 °C) and heat-treated (0.1 MPa, 60 °C) samples. The compound(s) responsible for the metallic odour could not be identified in the study.
In conclusion, HP/HT processing does not appear to be the ideal substitute for thermal processing with regard to strawberry flavour.

More than 30 volatiles have been identified that probably contribute to the typical tomato flavour. The flavour is not only directly reflected by the sum of the volatile and non-volatile components, but also depends on their relative amounts and interactions (Buttery et al., 1987; Buttery, 1993). The knowledge on the effect of high pressure processing on the flavour of tomato is limited, although the concentration of hexanal, has been shown to increase due to high pressure treatment, leading to a rancid aroma (Porretta et al., & Vicini, 1995). Lipoxygenase and hydroperoxide lyase, naturally present in many vegetables and fruits, were held partially responsible for the increased concentration of this lipid derived volatile compound (Oey et al., 2008a).
In SP1, Viljanen et al. (2011) observed that the effect of HP/HT processing on the amount of volatile compounds could mainly be attributed to the heat treatment rather than to the high pressure treatment itself. The levels of most aldehydes decreased as the temperature increased (20°C to 60°C). Most significant decreases were observed in hexanal, E-2-hexenal and 1-penten-3-one, which are important volatiles in fresh tomato flavour. In tomato purée treated at 800 MPa (20°C and 60°C) for 10 min a reduction in the intensity of fresh tomato odour was coupled with a decrease in the amounts of enal aldehydes, 1-penten-3-one, 1-penten-3-ol, 1-pentanol and 2-pentylfuran. Simultaneously with the loss of fresh tomato odour, an increased intensity of cooked tomato odour and tea aroma was perceived in samples treated at 800 MPa and 60°C. On the basis of the observed changes in volatile composition and perceived odour, the authors concluded that high-pressure processing, at least under the conditions studied, is not suitable for preserving fresh tomato flavour.

Conclusion:

In conclusion, while high pressure processing at ambient temperature has a limited effect on **health related compounds**; the additional process parameter temperature in HP/HT processing can induce losses in some nutrients. This strongly depends on the type of nutrient. The results obtained within the NovelQ project suggest that fat soluble nutrients are less sensitive to HP/HT processing than water soluble, at least for the ones studied (carotenoids versus anthocyanins). In addition, HP/HT processing for a long time has detrimental effect on the fresh flavour of strawberries and tomatoes. However, because of the shorter treatment times during these processes (due to fast heating and cooling rates), integrated process impact might be lower in comparison to an equivalent thermal process.
By proper selection of processing conditions specific hydrolysis products, with potentially higher health beneficial effects can be obtained in pressure processed broccoli.

The major results obtained in SP1 with regard to high pressure/high temperature processing and colour, flavour and health functionality are reviewed in Van der Plancken et al. (2011).

Modelling and impact measurement of HP(/HT) processing

One of the targets of SP1 has been the development of methods to evaluate quantitatively the process impact and uniformity of high pressure (HP) thermal processing of foods. Such methods serve as a basis for design, evaluation and optimisation of processes. Two approaches for temperature uniformity mapping in HP reactors were adopted: (i) computational thermal fluid dynamics modelling and simulation of temperature fields and (ii) use of protein-based, extrinsic, isolated pressure-temperature-time indicators for experimental temperature uniformity mapping.

In numerical simulations, HPP uniformity can be evaluated regarding flow fields, temperature fields and, based on experimentally determined kinetics, the resulting process impact on food quality or safety. For that purpose, specifically adapted mathematical balance equations based on the governing equations of thermofluiddynamics were solved (Delgado et al., 2008; Rauh et al., 2009; Rauh & Delgado, 2008; Rauh & Delgado, 2010a; Rauh & Delgado, 2010b). Validation of the mathematical models and numerical simulations has been done based on comparison with experimental measurements of temperature and velocity fields applying measurement techniques specially developed for HP conditions (Song et al., 2010; Song et al., 2008a; Song et al., 2008b; Song et al., 2009) and analytical considerations (Rauh & Delgado, 2010a; Rauh & Delgado, 2010b). In SP1, a quantitative analysis of uniformity of temperature distributions and impact of HP treatment using three-dimensional numerical simulations taking into account several pressure generation systems (e.g. cylinder-piston systems, injection systems) was developed (Rauh et al., 2009; Rauh & Delgado, 2008; Rauh & Delgado, 2010a; Rauh & Delgado, 2010b).
Thermal boundary conditions and process media were varied and examined concerning their ability to reduce temperature heterogeneities in HPP (Rauh et al., 2009). In addition, kinetic data of several biochemical conversion reactions were used to predict the effect of temperature heterogeneities on process impact uniformity. Different aspects of the approach used were new, since before, contributions in literature modeled HPP either with injection or plunger system for pressure build-up leaving aside the movement of the plunger (Denys et al., 2000; Hartmann et al., 2004; Hartmann & Delgado, 2002a). In this context, symmetrical flow and temperature fields throughout the whole process were assumed and two-dimensional numerical simulations were conducted. Investigations of the flow in a cylindrically shaped vessel with walls cooler than the liquid delivers unstable and asymmetrical flow patterns during the pressure holding phase due to unstable thermal layering at the top of the vessel (Baars et al., 2007; Rauh et al., 2009). Hence, three-dimensional numerical simulations were required and implemented. Regarding this, the pressure generation was considered by a free jet of pressure transmitting medium (indirect compression) or by prescribing the movement of a plunger located at the bottom of the vessel (direct compression). The pressure build-up and release rates resulted from these two measures. In the simulations at the vessel walls, corresponding thermal and fluiddynamical boundary conditions were described (e.g. heat fluxes, temperature conditions, etc).

Using a step-wise, kinetics-based research strategy consisting of (i) selecting and evaluation of candidate sensors, (ii) screening of the p,T sensitivity, (iii) kinetic calibration for isothermal conditions and (iv) validation of the kinetics under dynamic conditions, four different protein-based, extrinsic, isolated pTTIs (based on *Bacillus amyloliquefaciens* amylase, *Bacillus subtilis* amylase or ovomucoid), spanning the pressure-temperature domain of HP pasteurisation and sterilisation, were developed in SP1 (Grauwet et al. 2009, 2010a,b,c). At step 2 and 3, solvent engineering was used as a corrective feedback action. Hereby, the protein solvent condition (e.g. buffer pH, buffer type, protein concentration, addition of sugars, etc.) was purposely modified to obtain the desired indicator characteristics and to reach three objectives: (i) the read-out windows of the protein systems coincides with the application window; (ii) the read-out windows of all indicator systems differs; (iii) the p,T-sensitivity of inactivation is adjusted.
The potential of these 4 systems for use in uniformity mapping was investigated at two levels: pilot (both for pasteurisation and sterilisation conditions) and industrial scale (only available for pasteurisation conditions) and two orientations (horizontal or vertical). Differences in pTTI read-outs at different locations in the vessel illustrated low and high temperature zones (Grauwet et al. 2009, 2010a,b,c). The former could be attributed to combinations of conduction phenomena and free convection phenomena as evidenced by CFD modelling (Grauwet, Rauh et al. 2011). The zone of lowest temperature needs to be addressed in relation to the food safety objective (Figure 2.1.5).

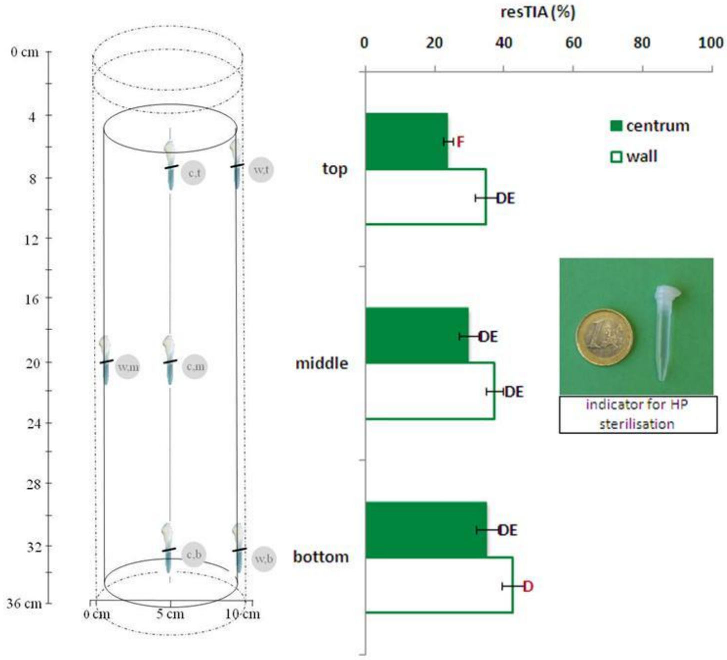


Figure 2.1.5 Use of a prototype indicator for HPHT applications: detection of zones of lowest temperature in a pilot scale HPHT vessel.

Conclusion:
pTTIs and CTFD modelling are complementary methods for documenting HPP conditions. In this context, CTFD modelling can be a method to compare the temperature distribution of different equipment designs in combination with different pressure media, food packages, isolating materials, etc. before the HP equipment is actually built. In addition, the thermofluiddynamical characterisation of the HP vessel by CTFD modelling enables definition of critical vessel positions that have to be checked with pTTIs to validate the process impact. When the most uniform set-up has been selected and has been constructed, pTTIs can be a fast and easy way to document and validate the HP process in terms of temperature uniformity during actual processing.
Some recommendations can be made to improve the temperature uniformity: (i) selecting components with comparable compression heat behaviour, either (ii) promotion of heat transfer between vessel content and wall, resulting in a homogenous vessel-content temperature or (iii) prevention or reduction of heat transfer between vessel content and wall, to obtain uniform temperature approaching the process temperature as much as possible, for instance by fast pressure build-up, use of isolation, control of both the vessel content temperature and the vessel wall temperature.

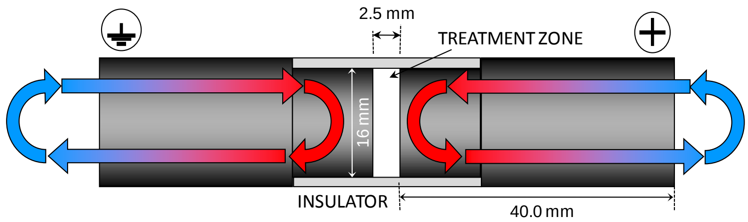
The major results obtained in SP1 with regard to modelling and impact measurement are reviewed in Grauwet, Rauh et al. (2011).

PEF processing

Microbial safety

In SP1, first the PEF resistance of five strains of *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli,* and *Salmonella* Typhimurium were investigated in order to identify microbial targets for PEF pasteurisation. The screening study (Saldaña et al., 2009) demonstrated that the PEF resistance of strains of a given bacteria and of strains of different bacteria may vary greatly. As the most resistant strains at low pH are not necessarily the most resistant at neutral pH, the target microorganisms for PEF pasteurisation could be expected to be different for foods, depending on their pH. The most PEF-resistant strains found in this study was taken into consideration in the kinetic studies. Saldaña et al. (2010a, 2010b) developed predictive models that described the PEF inactivation of the most resistant strains of each microorganism selected in the screening study in the range of pH of most foods (3.5-7.0), a wide range of electric field strengths (15-30 kV/cm), and treatment times (0-500 µs). They observed that the relationship between the Log_{10} of survivors and the time for constant electric field strength and pH was not linear for the four strains investigated. A primary model based on the Weibull distribution was used to describe the concave upwards survival curves obtained. Secondary models were based on quadratic equations that described the relationship between the two parameters of the Weibull model (p and δ values) and the three parameters investigated (E, t, pH) and permitted comparing the PEF resistance of the four strains under a wide range of treatment conditions. The PEF resistance of *E. coli* O157:H7 at pH 5.5 was similar to that of *S. aureus* 4459 and *Salmonella* Typhimurium 878. However, *E. coli* O157:H7 showed a slightly lower resistance than *L. monocytogenes* 5672 at pH 4.5 and 7.0 and a slightly higher resistance at pH 3.5. Based on these results, strains of *L. monocytogenes* 5672 and *E. coli* O157:H7 could be used as target microorganisms of public health concern for design of PEF pasteurisation processes. However, the highest level of inactivation achieved in these two strains, which was approximately 1 Log_{10} cycle reduction, was too low to reach an appropriate level of public health protection. Increasing the process temperature or combining PEF with other preservation methods could be feasible approaches to achieve the sufficient microbial destruction required for designing PEF pasteurisation processes.

In SP1, a static parallel-electrode treatment chamber with tempered electrodes (Figure 2.1.6) that permitted to obtain data at different temperatures under quasi-isothermal conditions and uniform electric field strength was designed in order to obtain a better understanding of the influence of the temperature on PEF microbial inactivation. Saldaña et al. (2010c) showed that microbial inactivation by PEF is highly dependent on the temperature, even when the treatments are applied at temperatures that are not lethal for the microorganisms. Therefore, the temperature during treatment is a critical parameter that should be considered in future studies in order to characterise microbial PEF resistance and to obtain reliable kinetics data to design predictive models.



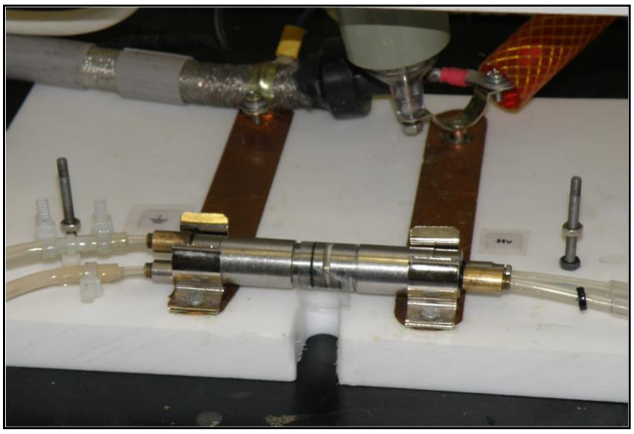


Figure 2.1.6 Scheme and picture of static parallel-electrode treatment chamber with tempered electrodes

The SP1 study on the combined effect of PEF and antimicrobials showed (Figure 2.1.7) that the application of PEF in the presence of LAE (N^{α}-lauroyl ethylester) at moderate temperatures has a great potential for achieving effective control of pathogenic microorganisms. The lack of synergy between nisin and PEF to inactivate Gram-negative bacteria makes this combination an ineffective application for pasteurising foods in which both Gram-positive and negative microorganisms are present (**Saldaña et al., 2011a, 2011**).

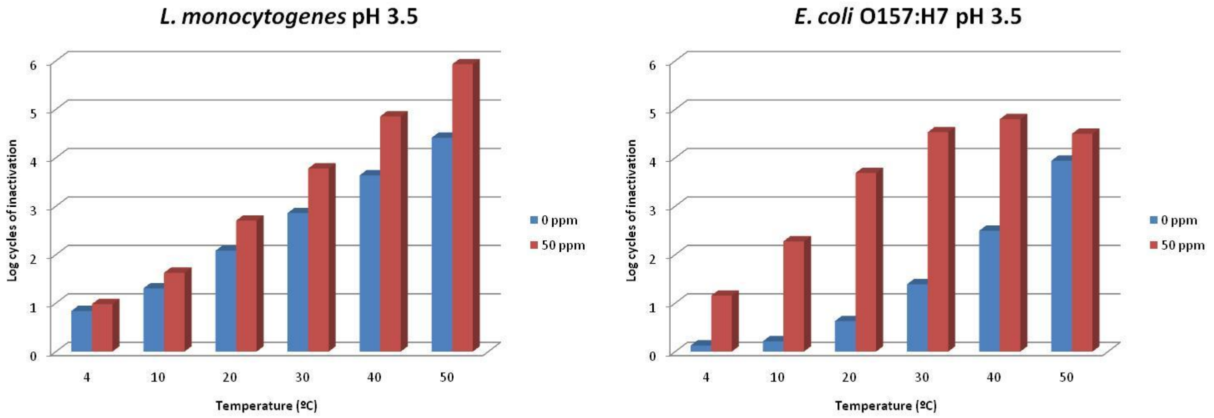


Figure 2.1.7. Resistance of Listeria monocytogenes and Escherichia coli O157:H7 to PEF treatments (30 kV/cm, 100 µs) applied at different temperatures in McIlvaine buffer of pH 3.5 added with 50 ppm of LAE (N^{α}-lauroyl ethylester).

As commercialisation of PEF processing for liquid food pasteurisation requires the application of continuous flow treatments, results obtained in a batch treatment need to be validated in a continuous flow before they can be successfully implemented on a large scale. In SP1, inactivation of the strain of *E. coli* O157:H7 in apple juice was investigated using a parallel electrode treatment chamber in which the maximum temperature was between 55 and 60°C to avoid microbial inactivation due exclusively to heat. An inactivation of 3 Log_{10} cycles was obtained at 25 kV/cm with a treatment time of 80 µs when the initial temperature was 20ºC, 48 µs when the initial temperature was 30ºC, and 36 µs when the initial temperature was 40ºC. The presence of LAE at a concentration of 50 ppm drastically increased the efficacy of PEF treatments in flow. A reduction in the *E. coli* O157:H7 population of 6 Log_{10} cycles or higher was observed when the initial treatment temperature was 20, 30, or 40°C.

Conclusion:

Results obtained during the Novel Q project indicate that there is a considerable variation in the susceptibility of different strains of pathogenic microorganisms to PEF treatments. This must be taken into consideration in studies that aim at defining a process criterion to achieve a given performance criterion. If studies are not conducted with the most PEF-resistant strains selected in previous screening studies, results should be validated with different strains.

In addition, when operating at room temperature, PEF process conditions that are commercially applicable are not sufficient to obtain substantial inactivation in the most PEF-resistant strains of pathogenic microorganisms.

Furthermore, microbial inactivation by PEF is highly dependent on the temperature of the treatment medium. Therefore, kinetic studies on microbial inactivation by PEF at different temperatures are required to evaluate the real potential of this technology for food preservation because the incremental lethality of PEF treatments at moderate temperatures introduces the possibility of pasteurising liquid foods using short treatments at moderate electric field strengths.

Combining the PEF treatment at moderate temperatures with the presence of an antimicrobial, which was effective against Gram-positive and Gram-negative pathogenic bacteria, such as LAE at 50 ppm, would permit reducing the number of pulses and the outlet temperature, and consequently the energy costs would be lower, but one could obtain an even higher level of inactivation in the four strains investigated.

The major results obtained in SP1 with regard to PEF processing and microbial safety are reviewed in Saldaña et al. (2011).

Allergens

Allergens pose another safety risk for susceptible consumers. It is known that the secondary and tertiary structure of food allergens is crucial to their allergenic potential. Processing techniques affecting this structure can thereby possibly reduce the allergenicity of foods. Studies of the effect of PEF on protein structure are limited in number. It is reported to affect protein denaturation, aggregation and structure attributed to conformational change, although the contribution from indirect effects (e.g. associated Ohmic heating) should not be ruled out in these studies.

In SP1, the effect of PEF processing on three selected, purified plant allergens: Ara h 2,6 (peanut 2S albumins) and the predominant apple allergens, Mal d 1 and Mal d 3 was studied (Johnson et al., 2010). PEF treatment did not significantly affect the secondary structure of any of the plant allergens in this study. However, the scarcity of studies on the effects of PEF on protein structure in general means that it is difficult to predict whether other allergens may be affected under similar processing conditions. It is, however, difficult to imagine a mechanism by which PEF treatment could directly influence the structure of allergenic proteins. It is more probable that highly localised thermal fluctuations in the treatment cell are responsible for the minor observed structural changes.

Further investigations were performed to see whether juice extraction after PEF treatment of apple pulp yielded a higher allergen (Mal d3) content. It was found that Mal d3 was associated with the cellular material i.e. the pulp and pomace. PEF treatment of apple mash induces higher protein content in the juice; depending on the variety (Idared, Piros, Elstar, Roter Gravensteiner, Royal Gala and Jonagold), this also resulted in a higher ratio of Mal d3. There was little or no correlation between either the processing conditions and the amount of protein released, or between the amount of protein released into the juice and the amount of Mal d 3 found in the juice. Neither was there a correlation between the hardness of the apple on the one hand and the amount of protein or Mal d 3 released into the juice (unpublished results).

<u>Conclusion</u>:
Pulsed electric field treatment does not induce any significant changes in the structure of any of the allergens studied, nor does it clearly increase the allergen content following extraction of apple juice.

Chemical safety

Chemical reactions in the processed fruits and vegetables occur in the native matrix systems at room temperature and atmospheric pressure, when enzymes and their substrates come into contact in appropriate reaction media. The biomolecules-LMW-components and their enzymes are physically separated by membranes in the undamaged tissues. However, at some processing conditions, enzymes and their substrates are mixed, and this give basis for initiation of autolysis processes i.e. degradation or transformation of the native components in non-enzymatic or enzyme catalysed reactions.

PEF processes operate at relatively low temperatures, but still at conditions where unwanted chemical reactions can occur. The potential chemical reactions resulting from PEF processing depend on the type of components in the matrix systems, and for the allelochemicals their occurrence are chemotaxonomic defined. This mean that the components and their chemical reactions are different for the different plants and plant families considered.

Methods to analyse effects of PEF processing were developed in SP1. Analytical fingerprinting was based on chemometric analysis of electropherograms from capillary electrophoresis of LMW containing raw extracts of the various processed and non-processed plant materials. Principal component analysis (PCA) was performed to see whether specific degradation patterns could correlate to the processing parameters. For PEF treated carrot samples no specific processing related (electrical field strength, pulses, temperature) variations were observed, only variations due to matrix (unpublished results).

Conclusion:

Under the conditions of the study (food matrix, processing conditions, compounds studied), PEF processing does not seem to result in water soluble compounds that are typical for the treatment.

Colour, flavour and health functionality

Generation of health-related compounds due to stress reactions

In SP1, the effect of mild PEF treatment on the stress induction (as evidenced by lycopene, amino acid and polyphenolic content as well as related enzyme activity (peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase)) of different plants (apples, grapes, tomatoes and carrots) and plant cell cultures (apple, grape, tomato and carrot) has been investigated. In connection with the studies of effects on enzymes and chemical reactions processing, highly specific methods for online determination of substrate transformation and production of products have been developed based on MECC. This has been the case for the enzyme systems PAL, PPO, POD and myrosinase.

A wide range of treatment intensities has been performed to achieve a response from plants or cell cultures. When PEF treatment of 300 V/cm was applied, no changes in polyphenolic content could have been observed. When increasing treatment intensity to 1600 V/cm, phenolic content of PEF treated tomato cell culture observed immediately after treatment (referred as 0 h stress reaction time) was much lower than in referent sample. Consequently, polyphenolic content measured in cell media increased, suggesting

permanent permeabilisation of the cell membrane, and release of phenolic substances out of the cells. After 3, 6, 24 and 48 hours stress reaction time, decline of phenolic substances was observed in PEF treated cells, whereas corresponding increase was observed in cell growth/treatment media. PAL activity was suppressed as well after such a treatment, indicating cell damage and inability to perform vital functions.
Biological tissue of other treated plants and cell cultures used within this project underwent similar specific changes in metabolic activity, after different treatment intensities and/or stress reaction time, indicating that changes were product and treatment specific. It is most likely that mechanisms for phenolic production were triggered by PEF treatment and the SP1 results confirmed that changes in phenolic content after certain treatment condition, stress reaction time or storage condition were related to changes of PAL activity (unpublished results).

Food colour and flavour stability

Other work conducted in SP1 has aimed at evaluating the effect of PEF treatments on the concentration and stability of different health-related phytochemicals, as well as on flavour compounds of treated fruit and vegetable juices. Also the effect of the treatments on enzymes having an incidence on these compounds has been assessed. At the same time, PEF applications have been compared with heat-processing to offer a comparison with conventionally used treatments.

Higher retention of health-related compounds having an impact on colour of fruit juices was generally observed for PEF-treated products. The stability of these compounds through storage is dependent for each case on the residual amounts of enzymes involved in their degradation.

Carotenoids: SP1 studies on tomato (Odriozola-Serrano et al., 2007, 2008ab, 2009a) and carrot juice (Quitão-Teixeira et al., 2008, 2009), have demonstrated that PEF processing can better maintain the initial content in carotenoids than thermal processing, or even cause significant increases in tomato and carrot juices, ranging from 1.0% to 46.2% in the case of PEF-treated tomato juice. A look into individual carotenoids seems to point that the observed increase in lycopene could be, at least partially, a consequence of the conversion of some carotenoids acting as precursors of this compound. On the other hand, an increase in the availability of the carotenoids could be caused in comparison to an equivalent thermal treatment. No substantial losses in carotenoids were observed through storage of PEF samples, thus leading to a better colour preservation (Aguiló-Aguayo et al., 2009a). PEF-processing succeeded in inactivating almost completely peroxidase in tomato juice samples, whereas lipoxygenase was only slightly inactivated (20%) (Aguiló-Aguayo et al., 2008a, 2008b, 2009b). As shown in Figure 2.1.8, enzymatic activities in PEF-treated juices greatly differed upon enzymes.

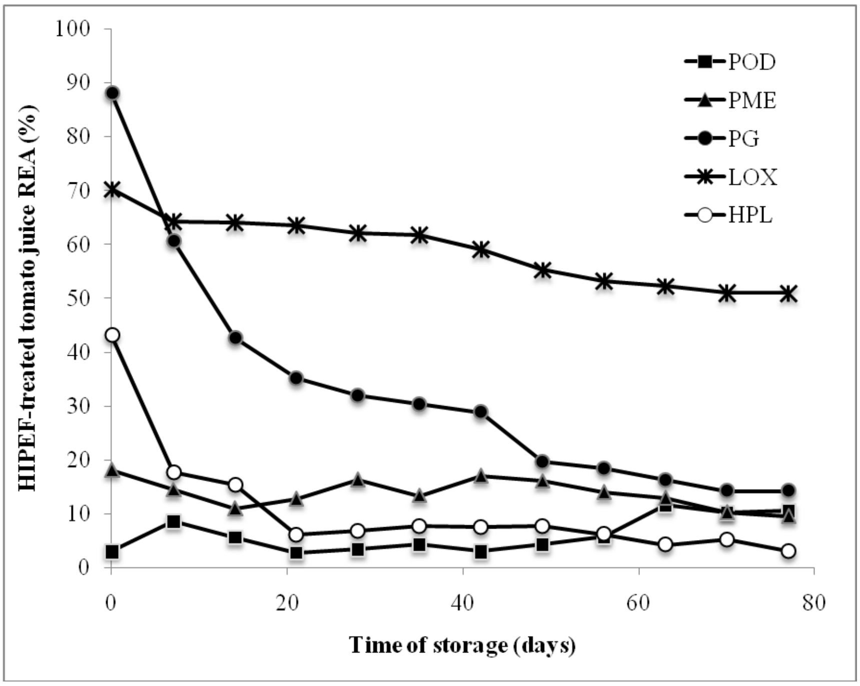


Figure 2.1.8. Residual activities of some of the main quality-deleterious enzymes during storage of a HIPEF-pasteurised tomato juice.

Phenolic compounds: Changes in anthocyanins content were minimal in PEF-treated strawberry juices. Results achieved within the project (Odriozola-Serrano et al., 2008c,d, 2009b,) suggest that anthocyanin retention inversely depends on treatment intensity. However, some inconsistent results have been found, because not all anthocyanins appear to respond equally to the effect of various degrading agents. Treatments of high-intensity have been found to induce the conversion of proanthocyanins into anthocyanins. The concentration of anthocyanins after a PEF pasteurising treatment was found to be 38.1 mg/100 mL, which is slightly higher than that found for an equivalent thermal treatment (36.2 mg/100 mL). In the untreated juice, the content of anthocyanins was 29.5 mg/mL. Regarding storage, it was observed that the main anthocyanins, pelargonidin-3-glucoside and pelargonidine-3-rutinoside, were depleted in both PEF and thermally-treated strawberry juices. These changes in the PEF treated juices have been associated to the residual amounts of β-glucosidase (Aguiló-Aguayo et al., 2008c, 2009c). In this case, PEF treatments failed at inactivating the totality of this hydrolytic enzyme.

Regarding other phenolic compounds, it has been found that PEF-treated juices (tomato and strawberry) exhibit higher concentrations of phenolic acids and flavonols than heat-treated juices (Odriozola-Serrano et al., 2008c, 2009a). These observations are consistent for the main individual compounds from each group. Changes in minor phenolic acids such as ferulic acid, p-coumaric acid and caffeic acid were also observed in tomato juice through storage. Caffeic acid content was slightly increased over time, which was directly associated with residual hydroxylase activities. Regarding strawberry juice, ellagic and *p*-coumaric acids were found to be in greater concentrations after a PEF treatment and over storage, in comparison to heat-treated products.

Chlorophylls: PEF treatments have been also shown to cause a little impact on the chlorophyllic content of broccoli juices. Products derived from the degradation of chlorophylls, such as pheophytin and pheophorbide, are formed in the PEF-treated samples in lower amounts than in heat-processed. Hence, the original green color of broccoli is preserved through PEF processing. However, chlorophyll stability through storage was poor. The reason for that was that maximum chlorophyllase activity was found to be 74%. Because of its conductive properties, PEF-processing does not seem to be an option for broccoli juice (unpublished results).

In the same context of health-related compounds, it was shown that PEF processing results in a significantly greater vitamin C retention, apparently independent of the food matrix (tomato: Odriozola-Serrano et al., 2007, 2008a,c; carrot: Quitão-Teixeira et al., 2009; strawberry: Odriozola-Serrano et al., 2008c,d, 2009b). In addition, vitamin C depletion during consecutive storage was diminished in comparison with thermally treated juice, as evidenced by the smaller rate constants.

PEF-processed juices initially exhibited higher concentrations of the main flavour compounds. Certain flavour compounds contributing to strawberry juice flavour such as 2,5-Dimethyl-4-hydroxy-3(2H)-furanone and ethyl butanoate were better maintained by PEF- than by thermal-processing. Therefore, no differences in the aromatic impact of just processed juices, measured in terms of the olfactive activity values of the different individual compounds, were found when comparing untreated and PEF-treated juices. In contrast, heat-treated juices exhibited a loss in their aromatic profile caused by processing. An increase in the concentration of 1-butanol in heat-treated samples was also found through storage, leading to an unpleasant flavor to the product. In conclusion, flavor stability during storage of PEF-processed strawberry juice was greater than for heat-processed juices, even though enzymes contributing to the generation of flavours and off-flavours in the juice, such as lipoxygenase and β-glucosidase, were scarcely inactivated (Aguiló-Aguayo et al., 2008c, 2009d).
A parallel study has been undertaken for tomato juice (Aguiló-Aguayo et al., 2008a,b, 2009b, 2010). Similar levels of residual lipoxygenase activity were observed for PEF- and heat-treated juices. In contrast, PEF-processing inactivated roughly a 50% of the initial hydroperoxide lyase activity, in front of the complete inactivation reached with a thermal treatment. Regarding flavour, PEF-treated juices exhibited higher concentrations of compounds contributing to tomato aroma than untreated and heat-treated juices throughout storage.

Conclusion:
PEF can induce stress related responses and the phenolic content after certain treatment condition, stress reaction time or storage condition are related to changes of PAL activity.
PEF processing results in better retention and storage stability of carotenoids, phenolic compounds and flavonols, in comparison to thermal processing.
PEF processing can be industrially implemented to render juices that better resemble the freshly squeezed, especially in what regards to their aroma profile.

The major results obtained in SP1 with regard to PEF processing and microbial safety are reviewed by Odriozola-Serrano et al. (2011).

Modelling and impact measurement of PEF processing

Pulsed electric field (PEF) processing of liquid foods has been numerically and experimentally evaluated in SP1 in order to improve process efficiency in terms of microbial inactivation while keeping heat sensitive compounds. Optimisation procedures have been applied to reduce process parameters inhomogeneity, reduce the thermal load and ensure a safe and high quality food product. Modifications of insulator shape geometry, impact of process parameters, finding optimal treatment conditions, insertion of static mixing devices, implementation of electrode cooling devices, numerical simulation of process parameters, enzyme inactivation and pH-shifts during the PEF processing have been investigated (Jaeger et al., 2010, Meneses et al. 2010, 2011a-d., Moritz et al., 2011, Saldaña et al., 2010).

The results of computational simulation showed how an adequate treatment chamber design can increase the electric field strength, resulting in an improvement of the microbial inactivation. Process parameters, such as the flow rate also affected the microbial inactivation, which was improved when increasing the flow velocity of the product. Furthermore, it was shown that enzymes can be used as integrators of temperature-time domains under dynamic conditions, as coupled to the multiphysic simulation of PEF processing.

The SP1 results clearly showed that numerical optimisation can be extended to more complicated insulator geometries, and multiple residual activity models, which in combination with temperature considerations, depicted that process parameters should be properly selected so that valuable food contents are minimally damaged. Furthermore, it was shown that to reach reasonable level of inactivation a high number of PEF chambers should be serially connected.

It was revealed that a large part of the microbial and enzyme inactivation was related to the overall thermal load to which the product was exposed during the PEF processing considering the temperature increase due to ohmic heating. A model capable to distinguish between thermal and PEF effects was built.

The modification of the treatment chamber by inserting static mixing devices provided a possibility to improve electric field strength and temperature distribution resulting in an increased microbial inactivation and retention of heat sensitive components. The insertion of grids of the dimension used in the study has shown applicability for the treatment of low viscosity products like milk or clarified fruit juices. The implementation of jacket heat exchanger surrounding the electrode was shown to provide a capable tool in order to reduce thermal effects and to improve the retention of heat sensitive compounds.

Due to the high inhomogeneities present during a continuous PEF processing with a co-linear treatment chamber configuration, PEF treatments should be characterised in terms of the electric field strength, treatment time and specific energy input (for a given initial temperature). An average value from the previously mentioned parameters with their respective standard deviation, maximal and minimum value should be given for the whole process. The lowest value of electric field strength, treatment time and energy input will be the limiting factors for food safety reasons and the maximum value for the resulting product temperature should be considered with regards to product quality.

Regarding PEF treatment within parallel plate electrodes and batch systems, it was concluded and demonstrated that controlling the temperature at quasi-isothermal conditions is the basis to study PEF inactivation kinetics. These systems are less affected by superimposing temperature effects occurring in continuous systems and are more suitable to investigate synergetic effects of PEF and temperature under defined conditions. Finally, a numerical simulation was performed in order to describe the shift of pH during PEF treatment. The numerical simulation was based on the Nernst-Plank and general heat transfer equations including a time-dependent solution in a batch treatment chamber with parallel plate configuration.

Conclusion:

Computational simulation showed that PEF processing can be optimised to improve process homogeneity, reduce the thermal load and ensure a safe and quality food product by increasing the flow velocity, using serial PEF chambers, inserting static mixing and implementation of jacket heat exchanger.

Controlling the temperature at quasi-isothermal conditions is the basis to study PEF inactivation kinetics using parallel plate electrodes and batch systems.

pH changes need to be taken into account in conventional small scale batch systems when evaluating the PEF effect on microorganisms, enzymes or other food constituents.

The major results obtained in SP1 with regard to modelling and impact measurement are reviewed by Meneses et al. (2011d).

Cold plasma decontamination

Microbial safety

Plasma treatment is envisioned as a versatile disinfection agent that can be applied by a jet of carrier gas at reduced temperatures. Despite the large R&D efforts that have been made so far the mechanism of the bacterial action has remained unknown. The SP1 approach was focused on identification and quantification of the critical parameters of a plasma treatment and unraveling the interaction mechanism of micro-organisms with the plasma by thermodynamic assessment of the gas.

To this end, inactivation kinetics of *Salmonella enterica* serovar Typhimurium 4/74 subjected to distinct charge transfer processes were determined and an overall decimal inactivation time for *Salmonella* of 2.85 +/- 0.16 min as a result of charge transfer in a nitrogen based plasma was detected.

Two distinct electron exchange processes of electron transfer processes were measured in situ and discrimination between events of the uptake of negative charge (reduction) and the release of negative charge (oxidation) of the system as a whole could be made. Results showed that no differences occur in the inactivation rate of Salmonella exposed to either reductive or oxidative stress when exposed to (elastic) charge transfer processes. It is therefore suggested that the inactivation occurs through a common factor in the reduction and oxidation process that is invoked by the plasma. In addition to the elastic electron-electron scattering process, the (inelastic) recombination processes of electron uptake and electron release that are known to occur in closed redox cycles. These types of charge transfer processes are the only candidates that can explain the observed inactivation (unpublished results).

Another SP1 study (Fernandez et al., 2011) showed that the rate of inactivation of S. Typhimurium is inversely proportional to initial bacterial concentration, with the D-value observed at the highest cell concentration assayed (108 CFU/filter) being 14 fold higher than seen at the lowest starting concentration (105 CFU/filter). Addition of increasing concentrations of *Pseudomonas fluorescens* cells to a *Salmonella* population of 105 CFU/filter resulted in an exponential decrease in the rate of killing of the *Salmonella* cells. However, whilst the addition of heat-killed S. Typhimurium cells to 105 CFU/filter live S. Typhimurium cells resulted in a significant decrease in the killing rate, this effect was dose independent. This suggests that although biomass plays a role in the protection against cold atmospheric gas plasma inactivation seen at high cell densities, dead cells and their components released during the heating period are not as effective as viable cells. Fluorescence microscopy showed that, unlike the single dispersed cells observed at low cell densities, at higher cell densities bacteria were present in a multilayered structure. This phenomenon could explain the reduced inactivation by the plasma, since the top layer may present a physical barrier that protects underlying cells.

Conclusion:

The microbial inactivation by cold plasma is evoked by (inelastic) recombination processes of electron uptake and electron release occurring in closed redox cycles.

Cell density strongly affects the efficacy of cold plasma processing as upper layers of bacterial multilayer structures can act as a physical barrier to the underlying cells. This should be taken into account in both further studies and in the practical application of this technique to food industry.

2.1.4 Main dissemination activities

SP1 dissemination activities were performed at different levels. An overview is given in the table on the next page.

Overview of dissemination in SP1

Type of dissemination	Total number[1]	Category	Number[1]
Peer review publication	95 (12)	Published	87 (9)
		Submitted	14 (4)
Conferences & workshops	182 (10)	Oral	106 (4)
		Poster	84 (6)
TCD	88	Oral	41
		Poster	47
Book chapters	16		
Other	25 (2)		
Awards	13		
PhD	15		

[1] joint dissemination activities are indicated between brackets

The major disseminative outputs were scientific publications and presentations. The promised number of 50 draft publications was more than doubled, with 87 published and 14 submitted peer review papers (draft papers not included). At the beginning of the project, 6 review papers were published in a NovelQ-dedicated issue of Trends in Food Science and Technology, describing the then state-of-the-art in all research levels considered in SP1 with regard to high pressure processing. These reviews were well-cited (between 7 and 20 times), with one even leading the journal's "Most downloaded" list at the time of publication. Also on the subject of pulsed electric field processing, 3 review papers were submitted. A book chapter was devoted to cold plasma in food processing. At the end of the project, the major results obtained in SP1 were reviewed in 5 multi-partner review papers submitted to be published in yet another special issue of Trends in Food Science and Technology.

The subproject was also well represented at scientific conferences (106 oral and 85 poster presentations). The quality of the research performed was recognised with 13 awards.
SP1 young scientists made up a large part of the TCD network. They accounted for 47 poster presentations and 41 oral presentations at TCD activities. A highly successful TCD activity, organised by SP1 partner TUB, was the PhD symposium in Berlin (September 2010). Eight oral presentations at this conference were of SP1 signature, in addition to 7 posters. 2nd and 3rd prise of the best oral presentation were awarded to two SP1 researchers (one in cooperation with SP4). Within SP1, 15 PhDs were and two will be obtained.
Dissemination activities in SP1 not only targeted a scientific public, but also the general public with 13 publications in professional magazines.

2.1.5 Interaction with other Sub-projects

Sub-project 2: Specification of a common set of processing conditions, as packaging materials need to perform under the same conditions as the foods are treated.

Sub-project 3: The products and processes considered were the same in both sub-projects. SP 3 based its activities on the product/process framework identified in SP1.
Sub-project 4: Interactions occurred at two levels:
In the initial phase of the project, technical aspects related to *small scale equipment for detailed kinetic studies at high pressure high temperature conditions* were studied in SP4 forming the basis for adjusting existing equipment towards specific needs for kinetic studies, in particular short duration high pressure high temperature conditions.
SP1 formed the *scientific product/process knowledge base* for demonstration activities in SP4. Direct deliverables of SP1 flowed as input into SP4 (different aspects of WP 12-14, WP15-19 and WP20-23). For instance, SP1-developed indicators were applied in evaluation of the homogeneity of HP treatments (WP19). Information on kinetics was used to establish processing conditions for the integral demonstration of product improvement using NP technologies in WP20. Knowledge obtained on HP non-uniformity in WP5 was translated into industry guidelines in WP12 . This resulted in several papers (e.g. Landfeld et al. 2011, Vervoort et al., 2011 and Timmermans et al., 2011)
Sub-project 5: SP1 delivered all necessary input for dissemination activities at all levels of SP5. There was a strong participation of SP1 scientists in the TCD activities.

2.1.6 Conclusions and future research needs

The **major conclusions** of the individual topics investigated in SP1 have been drawn after the description of the corresponding major results (section 2.1.3).

In general, the approach applied in SP1 (section 2.1.2) allowed to perform highly controlled kinetic studies to fully quantify and understand the effects of high pressure thermal processing and pulsed electric field processing on quality and safety aspects of foods in the context of processing intensities covering pasteurisation and sterilisation (in case of HP processing) levels. As the same study vehicles were used throughout the sub project, comparison of (novel) unit operations on a quantitative basis and from a viewpoint of true equivalence became within reach (as for instance undertaken in SP4).
Furthermore, the first sensors and models design, validation and optimisation of novel processing technologies based on high pressure thermal and pulsed electric field processing were developed. Finally, a step forward has been made in the understanding and quantification of the effects of cold plasma on microbial food safety aspects. Thereby, the objectives of this subproject have been reached.

Although major progress was made in the knowledge on the effect of novel processing on plant-based foods, some **future research needs** could still be identified in SP1:

High pressure (high temperature) processing

- ***Experimental set-up:*** Proper experimental set-up and description thereof is vital to compare kinetic information obtained by research groups. The proportion between the processing time (including pressure build-up time, holding time, temperature equilibration time) and the time constants of the kinetics (microbe, enzyme, nutrient) complicate model discrimination for kinetics. In case of fast inactivation kinetics, the processing-induced changes can be masked by the dynamic processing effects if not properly taken into account during the data analysis.

- Comparison between HP/HT processing and conventional thermal processing needs to be made for processing conditions that result in equivalent microbial safety.
- ***Microbial safety:*** HP/HT inactivation kinetics of target strains need to be performed in different media. Kinetic models of microbial inactivation by HP/HT need to be validated in real food systems. Furthermore, the mechanism of spore inactivation needs to be further elucidated.
- ***Allergens:*** The influence of matrix on allergen reduction by HP/HT needs to be studied in real food systems. The mechanism of allergen reduction by HP/HT needs to be further elucidated.
- ***Chemical safety:*** The effect of HP/HT on chemical risk reactions such as acrylamide formation also needs to be studied in matrices of lower water content. Furthermore, there is a need for "in vitro" tests for toxicological assessment of HP/HT treated foods.
- ***Textural functionality:*** The consequences of the different food textures obtained during HP/HT processing on the nutrient bio-accessibility need to be determined.
- ***Colour, flavour and health functionality:*** To fully unravel the stress response of plant tissue to HP treatments, a better insight into the different branches of phenylpropanoid pathway (lignin, salicylic acid and flavonoid production with related enzyme activity) is necessary. Regarding the treatment of plant cell cultures it might be useful to screen the material for additional parameters e.g. vitality and different ages.
- In order to completely grasp the effect of HP/HT processing on flavour and colour, mechanistic insight in flavour development and colour changes during post-treatment storage is required.
- ***Modelling of HP(/HT) processing:*** CTFD models require experimental information about the pressure and temperature dependent thermophysical properties of the treatment media (e.g. transmitting medium, food product). However, the knowledge of the combined effect of temperature and pressure on these properties is far from complete.
- ***Impact measurement of HP(/HT) processing:*** Indicators are characterised by a specific temperature sensitivity. Consequently, uniform read-outs evaluated at different coordinates in a HP vessel do not necessarily prove that no temperature differences existed. Consequently and if possible, it is important to link the temperature sensitivity of the targets to the temperature sensitivity of the indicator applied. To this end, kinetic data on the target attributes are needed.

Pulsed electric field processing

- ***Microbial safety:*** The lack of uniformity in the distribution of the temperature and electric field strength can impair the evaluation of the treatment lethality. An approach to estimating the microbial inactivation in a continuous PEF treatment is to assume that the inactivation in an in-homogeneous PEF process is a function of the momentary electric field strength and temperature in the different zones of the treatment chamber. To validate this approach the integration of numerical simulation techniques in order to know the distribution of temperature and electric field strength in continuous treatment chambers with the development of predictive models generated from microbial inactivation data obtained under uniform conditions of temperature and electric field strength should be required.

- PEF at moderate temperatures and treatments conditions commercially applicable has proven to be effective to obtain substantial inactivation of very PEF-resistant strains in continuous treatments of apple juice. These process criteria should be considered in the future during studies on the impact of PEF on quality attributes of foods.
- ***Colour, flavour and health functionality:*** To fully unravel the stress response of plant tissue to PEF treatments, a better insight into the different branches of phenylpropanoid pathway (lignin, salicylic acid and flavonoid production with related enzyme activity) is necessary. Regarding the treatment of plant cell cultures it might be useful to screen the material for additional parameters e.g. vitality and different ages.
- ***Modelling of PEF processing:*** The presented investigations suggest further studies under homogeneous process conditions. Kinetics data of microbial and enzyme inactivation or other components of interest at a uniform distribution of electric field strength, homogeneous treatment time and homogeneous and isothermal conditions are desired in order to validate and standardise PEF processing between research centres and make a successful industrial scale-up.

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2.2 Material research for packaging foods through NP: description of main results of Subproject 2

2.2.1 Introduction to SP 2 incl. main objectives, contractors involved; Material research for packaging foods processed through NP

Sub-project 2 focused on the analysis of the effect of NP treatments on structural and functional properties of polymeric materials used for packaging and on the assessment of the suitability of novel materials for these technologies. As far as novel materials are concerned, SP2 focused on the development of biobased sustainable materials for packaging and on the effects of NP on packaging materials and package material interactions with the food itself (e.g. migration/scalping). Specific objectives are described below:

- Extraction, purification, and structural understanding of alcohol-soluble (prolamin), non-allergenic proteins from cereal grains (oats and pearl millet) and one cereal processing waste stream (sorghum beer spent grain) to be used as novel biopolymers for the development of coating and films.
- To develop formulations and processing technologies for the preparation of novel films and edible coatings.
- To develop biodegradable nano-composite packaging materials suitable for the development of packaging films with improved mechanical and barrier properties.
- To study the effect of high pressure (HP/T) treatments on the relevant functional and structural properties of commercial packaging materials and novel packaging systems
- To study the effect of the HP/T treatments on migration and scalping phenomena during processing and storage
- To extend the shelf life of plant foods by combining (i) High Pressure Processing (HP) with edible coatings and (ii) combination of microwave drying and edible coatings.
- To develop mathematical models as well as their numerical implementation for predicting the change of physical/chemical properties of packaging materials subjected to HP/T conditions and for predicting the effect of HP/T treatments on migration phenomena

Considering the state of the art in this field, the key open scientific questions addressed in this Sub-project were:

Formulation and processing for the preparation of novel packaging materials

- How can plasticization/formulation be optimised to produce biodegradable films and/or edible coating with appropriate mechanical and barrier properties that are suitable for HP/T processing?
- What are the components and the processing conditions in order to enhance compatibility between natural polymers and plasticizers for the preparation of coatings and films?

- How to incorporate active substances that can have an antimicrobial action during HP/T as well as during shelf-life?

Effect of novel technologies on material properties

- What is the influence of HP/T treatments on structural and functional properties on packaging materials?
- How does HP/T modify the chemical-physical, mechanical and barrier properties of biodegradable films and edible coating compared to common polymeric systems?

Food packaging interactions

- How do new materials and existing materials interact with food and food additives during HP/T treatments and advanced heating and during shelf life, with a particular emphasis on migration/scalping issues?
- How can edible coatings be used prior to advanced heating and HP/T treatments, i.e. microwave-assisted drying to extended shelf-life of semi-dried plant foods?
- How can edible/active coatings or biodegradable packaging be used on NP processed food to trigger and/or control migration of moisture, gases, vapours (i.e. aroma compounds) and specifically added active compounds (i.e. antimicrobial or antioxidant) and act as active packaging?

This sub-project is also aimed to the *development of a mathematical model as well as to its numerical implementation* (*WP8*) for predicting the change of physical/chemical properties of packaging materials subjected to NP conditions and for predicting the effect of NP treatments on migration/scalping phenomena.

Contractors involved and their role are described below:

Organisation	Participant short name	Country	Role
Wageningen UR Food & Biobased Research	A&F	The Netherlands	HP treatments
IMCB-CNR	IMCB	Italy	Novel biodegradable films, structural characterisation
University of Naples	UNINA	Italy	Commercial films, functional properties, modelling
SIK	SIK	Sweden	Edible and bioactive coatings, combination of novel packaging concepts and NP treatments
University Montpellier II	UM2	France	Food/packaging interactions, bioactive films
INTI-Plasticos	INTI	Argentina	Spread coating, nanocomposites
CSIR	CSIR	South Africa	Extraction and use of novel protein formulations

2.2.2 Working approach

The food packaging materials investigated were i) commercially available common films, ii) commercially available biodegradable films, iii) novel polymeric materials developed in the research project.

High pressure Pasteurisation (HP/LT) (temperature increase from 20 to 40 °C during treatment) and high pressure sterilisation (HP/HT) (temperature from 90 to 115 °C during treatment) were applied on packaging films alone and on packaged foodstuff. The selection and analysis of the effects of HP Pasteurisation and Sterilisation on properties of common packaging materials were done on monolayer as well as on multilayer packaging films (see table below). Laminated structures differ for a) types of layers used obtaining different ratios of mechanical and thermal expansion properties of the components layer; b) type of adhesive layers characterised by different mechanical and thermal properties. Multilayer co-extruded structures were also analysed for comparison to laminated structures.

Table 2.2.1. Packaging structures employed for HP Pasteurisation and sterilisation of packaged foodstuff

Material identification	**Material type**	HP Pasteurisation	HP Sterilisation
A1) LLDPE	Monolayer commercial	**X**	**X**
A2) PLA	Monolayer commercial biodegradable	**X**	**X**
A3) PET-PPcast (adh.1)	Multilayer laminated commercial	**X**	**X**
A4) PET-LLDPE (adh.1)	Multilayer laminated commercial	**X**	**X**
A5) PETmet-LLDPE (adh.1)	Multilayer laminated commercial	**X**	**X**
A6) PET/PA/Aluminum foil/LLDPE	Multilayer laminated commercial	**X**	**X**
A7) PCL/Zein(TPZ)+PCL (60%,40%)/PCL	Novel material	**X**	**X**
B1) PPcast	Monolayer commercial		**X**
B2a) PET-PP (adh. 2)	Multilayer laminated commercial		**X**
B2b) PET-PP (adh. 3)	Multilayer laminated commercial		**X**
B2c) PET-PP (adh. 4)	Multilayer laminated commercial		**X**
B3) PP-EVOH-PP	Multilayer coextruded commercial		**X**
B4) PP cast-PET-PVDC coated	Multilayer laminated commercial		**X**
C1) PA cast-PP cast (adh. 2)	Multilayer laminated commercial	**X**	**X**
C2) PA cast-ink-PP cast (adh. 2)	Multilayer laminated commercial	**X**	**X**
C3) PA cast-PP cast (adh. 6)	Multilayer laminated commercial	**X**	**X**
C4) PA cast-PP cast (adh. 6)	Multilayer laminated commercial	**X**	**X**
C5) PA cast-PP cast (adh. 5)	Multilayer laminated commercial	**X**	**X**
C6) PA cast-ink-PP cast (adh. 5)	Multilayer laminated commercial	**X**	**X**
C7) OPA-PP cast (adh. 2)	Multilayer laminated commercial	**X**	**X**
C8) OPA-PP cast (adh. 6)	Multilayer laminated commercial	**X**	**X**
C9) OPA-PP cast (adh. 5)	Multilayer laminated commercial	**X**	**X**
C10) PET-PP cast (adh. 2)	Multilayer laminated commercial	**X**	**X**
C11) PA cast-PP cast (adh. 7)	Multilayer laminated commercial	**X**	**X**
C12) PP-EVOH (3 μm)-PP	Multilayer coextruded commercial	**X**	**X**
C13) PP-EVOH (10 μm)-PP	Multilayer coextruded commercial	**X**	**X**
C14) PP-PA-PP	Multilayer coextruded commercial	**X**	**X**

Legenda:

EVOH: ethylenevinylalcohol; **LLDPE**: linear low density polyethylene; **OPA**: bi-oriented polyamide; **PA cast**: polyamide cast; **PCL**: polycaprolactone; **PET**: bi-oriented polyethyleneterephthalate; **PETmet**: metallised (aluminium) bi-oriented film with optical density 2.2 (it measures the amount of deposited aluminium layer); **PLA**: polylacticacid; **PP cast**: polypropylene cast; **PVDC**: polyvinylidenechloride; **Zein (TPZ)**: thermoplasticized zein

Adhesive 1: E735 +C2. NCO terminated polyurethane adhesive [100 parts:110 of diisocianate (MDI, E735) 10 parts:110polyol (high m.w. polyester, C2)] produced by Rohm&Haas.

Adhesive 2: 811A + CatF. OH terminated polyurethane adhesive [100:110polyol (811A) + 10:110NCO terminated hardener (Cat F)]. Produced by Rohm&Haas.

Adhesive 3: L719 + CR719C1. NCO terminated aliphatic polyurethane adhesive [100:110diisocianate (L719) + 10:110polyol (high m..w. polyester CR719C1)]. Produced by Rohm&Haas.

Adhesive 4: L719 + CR719C4. NCO terminated aliphatic polyurethane adhesive [100:110diisocianate (L719) +10:110 polyol (high m..w. polyester with silane CR719C4)]. Produced by Rohm&Haas.

Adhesive 5: FP44A+FP75. OH terminated polyurethane adhesive [100:110 polyol (FP44A) + 10:110 toluene-diisocianate (TDI, FP75)]. Produced by Sapici.

Adhesive 6: FP45B+ FP45C. NCO terminated polyurethane adhesive[100:110 toluene-diisocianate (TDI, FP45B) + 10:110 polyol (FP45C)]. Produced by Sapici

Adhesive 7: L050. Water based, acrylic adhesive. Produced by Rohm&Haas

The novel polymeric materials that were developed during the project are summarised below:

1) **Biodegradable polymeric films**. Materials based on blends of biodegradable polymers, i.e. natural polymers from renewable resources including both proteins and polysaccharides and/or polymers obtained through chemical synthesis (e.g. polylactides (PLA) and polycaprolactones (PCL)).
2) **Edible coatings**. These materials were investigated with the objective to explore the potential of extending the shelf-life of solid foods by combining in the proper way edible coatings, HP treatments and microwave drying.
3) **Bioactive materials**. In this case, biodegradable films and edible coatings were modified with additives (preservative and antioxidant) that inhibit microbial or oxidative deterioration.
4) **Bio-nanocomposites**. Nanoparticles were added to biopolymers to improve process and properties of the packaging material in view of their potential use for HP treatments.

2.2.3 Main results achieved

Formulation and processing for the preparation of novel packaging materials based on bio-polymers

Biodegradable films, edible coatings and bio-active packaging materials based on polymers from renewable resources were developed. Both thermoplastic (dry) and solvent (wet) based technologies were employed. Selected packaging systems were used in combination with HP treatments to improve shelf life of selected food systems.

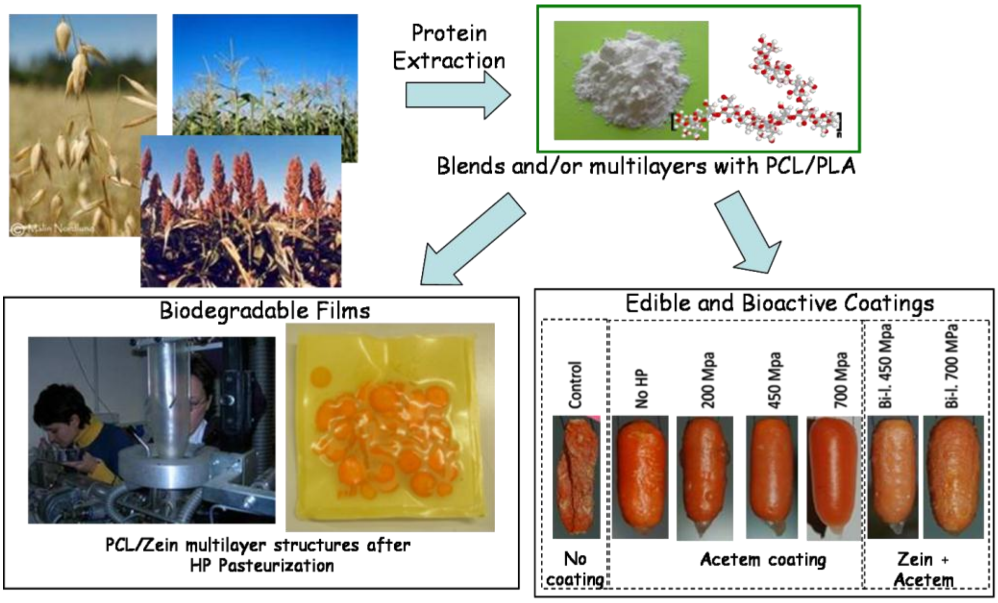

Figure 2.2.1 Examples of novel films and edible coating developed for HP treatments.

Thermoplastic based technologies

While thermoplastic synthetic polymers can be melt-processed by simply applying heat and shear; unfortunately, the high crystallinity and the strong intermolecular interactions present in the proteins and polysaccharides lead to thermal degradation of the material before achieving melt flow. The flow of these natural occurring macromolecules is however possible if a thermoplasticization process, based on a combination of heat, mechanical shear and suitable plasticizers occurs. In this way, several products can be formed by using traditional shaping methods, such as extrusion, compression molding, thermoforming, calendering, injection molding and film blowing. The material compositions and the technological procedures to prepare novel biodegradable films based on synthetic and natural polymers were developed. The activities were focused on the thermoplastic processing of plastic materials based on zein, wheat gluten, proteins from spent grain (kafirin and zein), starch, and on the development of technologies aimed to prepare multilayer films and nano composites with improved functional properties.

A variety of thermoplastic zein (TPZ), wheat gluten (WG) and thermoplastic starch (TPS) materials were prepared and characterised in order to evaluate the correlation between material composition, thermoplasticization conditions and extensional rheology. In particular Oliviero et al. (2010) studied the feasibility of preparing thermoplastic films of zein by film blowing without the time consuming and expensive solubilisation step of the proteins in suitable solvents. The zein powder was plasticized directly in the extruder, without the use of solvent and of a premixing phase. Blown films from zein plasticized with PEG 400 were produced and sufficiently low thickness (80 µm) were achieved. The preparation of films based on thermoplastic starches (TPS) by using the film blowing technique was also challenging. Zullo & Iannace (2009) investigated different varieties of starch in order to study the suitability of these materials to be processed in a film blowing line. As for the materials based on TPZ, the increase of the melt deformability and the elongational properties of the melt were assessed to be crucial in the film blowing process of TPS.

Multilayer films based on TPZ with tailored barrier to oxygen and water vapour were successfully developed for HP Pasteurisation treatments. In these multilayer systems, TPZ was employed for the high barrier properties to oxygen and carbon dioxide while PCL was used as a water barrier layer. The important requisite for the preparation of multilayered novel biodegradable films based on TPZ and PCL was the adhesion between the hydrophilic layer (TPZ) and the hydrophobic layer (PCL) This was successfully obtained by developing TPZ/PCL blends. HP Pasteurisation performed on carrot juice and solid carrots packaged with multilayer TPZ-PCL structures, revealed the compatibility of such packaging structure with this type of process. In fact, HP treatment up to 700 MPa did not promote any detectable change in mechanical properties as well as of oxygen and water vapour barrier properties (Gontard ed al. 2010, Mensitieri et al., 2011)

Nanocomposite packaging films

Bio-nanocomposites based on nanoclay and POSS dispersed in several biopolymeric matrices were investigated with the aim of improving barrier, thermal and mechanical properties of packaging films. Nanocomposites from montmorillonite (MMT) and wheat gluten as well as from MMT and zein were prepared by using thermo-mechanical processing. In the range of studied glycerol contents (25–42.8 wt %), it has been shown that glycerol had no significant effect on the mechanical properties or water sensitivity of WG-based films. Increasing the thermoforming temperature from 60 to 120°C led to considerable improvements of the mechanical properties (increases in both the stress and strain at break) and a significant reduction of the water sensitivity. The introduction of MMT (up to 5 wt %) allowed the achievement of mechanical properties that were not possible by just the variation of the glycerol content and the processing temperature. The film stiffness (Young's modulus) could be increased more than three times on addition of 5 wt% MMT and the stress at break was almost doubled (Angellier-Coussy et al. 2008).

Bio-nacomposites were successfully obtained also from TPZ and MMT. In this case, MMT without any organic modification was first mixed with the plasticizer and then added to the zein powder directly in the mixing chamber employed for the thermoplasticization process at controlled heat and shear conditions. The efficient dispersion of the inorganic reinforcement, as proved by X-ray diffraction, allowed for an effective improvement of thermal, rheological and mechanical properties of the bionanocomposites with respect to the neat TPZ. A significant increase of the storage modulus in the whole temperature range was observed in dynamic-mechanical experiments (Nedi et al. 2011). A dramatic increase of mechanical properties has been observed, with Young's modulus increasing from 296 MPa for neat TPZ to 1205 MPa at 5%wt of clay and to 1478 at 10%wt of clay (Mensitieri et al., 2011). Little increase of tensile properties were observed in some cases after HP treatments.

Other main results achieved within the NovelQ project are summarised below:

- Biodegradable clay nanocomposite films based on PHB, PCL, PHB/PCL blends, commercial PLA blends (BIO-FLEX®) showed a remarkable increase of mechanical properties. The use of clay allowed for a better phase morphology of the blends.
- Formulation based on wheat gluten, nanoclay and crosslinking agents were specifically developed for the spread coating technology.
- Development of PHB and wheat gluten nanocomposite based on polyhedral oligomeric silsesquioxanes (POSS). PHB composites (PHB–MA –POSSGPTS) showed better mechanical performance but did not contribute on material thermal stability improvement.

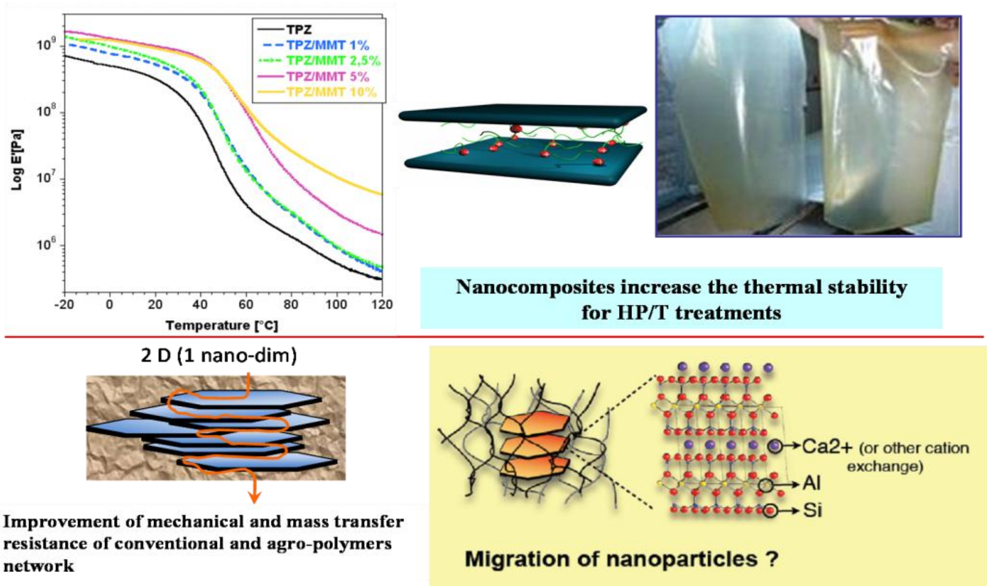

Figure 2.2.2 Examples of bio-nanocomposite based on nanoclay for HP treatments. Films have been developed with improved mechanical and dynamic-mechanical properties. The following matrices were employed: thermoplastic zein (TPZ), TPZ/PCL blends, wheat gluten, PHB, PCL and their blend.

Formulations for solvent based technologies: edible and spread coatings

Proteins and polysaccharides have been used in combination with suitable plasticizers to produce coatings for the relevant application together with high pressure/temperature (HP/T) treatment. Formulations for coatings of zein from maize, starch and acetoglycerides were developed for improved combined properties and improved appearance. Other formulations were based on avenin and kafirin extracted from South African cereals. Barrier and mechanical properties of these edible coatings have been determined and evaluated

Zein, the main seed storage protein of maize, has been widely studied as a possible source of material for the production of biodegradable plastic films. Plasticization of zein is critical to make functional films. While there have been a number of publications which report the behavior of systems with a wide variety of plasticizers, there have been few which attempt to examine the interactions of protein and plasticizer at the molecular level. The plasticizing effects of water, glycerol, and 2-mercaptoethanol were examined by a combination of spectroscopy (FTIR and dielectric) and thermomechanical methods. The results suggest that both water and glycerol are adsorbed onto the protein and form hydrogen bonds with the amide groups. The plasticizer then builds up in patches on the protein surface. 2-Mercaptoethanol only exhibited a weak plasticizing effect due probably to disulfide bond breaking (Gillgren at al., 2009)

The mechanical properties of zein based films were all dependent on the plasticizer content with higher strain at break and lower modulus and max stress with higher plasticizer content. Prolamins are known to be difficult to plasticize and a set of different plasticizers were screened. Food grade plasticizers for the protein films were developed and a mixture of glycerol and either citric or ascorbic acid were displaying good functional properties. Ascorbic and citric acid gave equivalent plasticization but ascorbic acid produced darker films. The best formulation for zein coatings was an aqueous ethanol (70 wt%) solution containing citric acid and glycerol (2:1) with a total plasticizer/protein ratio of 0.3

A food approved lightly hydroxypropylated oxidized potato starch was mixed with glycerol and was applied on the foods by dipping. The coatings were transparent and it was possible to produce “invisible” coatings with a texture similar to the fruit and vegetable itself. The coatings were hydrophilic and therefore easily plasticized and swollen by water. The best formulation for starch coatings was water solution of 3 wt% starch and glycerol with a total glycerol/protein ratio of 0.3.

Acetem™, a mixture of **mono and di-glycerides** (Danisco Ingredients, Brabrand, Denmark), was used due to its hydrophobic character and good water vapor properties. An Acetem with dripping point at 35°C was chosen to give good mouth feel. The coating was applied by dipping from a melt and the melt temperature and dipping time were adjusted to give a thin coating. The Acetem coatings had a waxy appearance and were therefore also mixed with zein to produce more “invisible” coatings. The WVP was shown to be proportional to the amount of zein and could therefore be regulated accordingly.

Model waxes. Two waxes were characterized in a separate study as a basis to understand the moisture migration through crystalline, waxy structures similar to the Acetem. Confocal laser scanning micrographs of the petrolatum sample showed a more open microstructure with coarse crystals separated from each other, whereas the microcrystalline wax appeared to have a more networked crystalline structure consisting of somewhat finer crystals. The petrolatum sample, however, had higher water vapour permeability than the microcrystalline sample. Both waxes melted and crystallised over a broad temperature range. Their melting and crystallisation characteristics were however quite different, probably owing to a different oil content. The microcrystalline wax melted and crystallised through two steps, whereas thepetrolatum melted and crystallised through only one step (Petersson et al., 2008)

Novel protein coatings and films: Coatings and films were prepared from avenin, zein and kafirin (sorghum prolamin). Avenin displayed potential, although it did not exhibit the mechanical qualities of wheat gluten, which resembles avenin at the molecular level. However, avenin has the advantage in edible applications of less allergenicity compared to wheat gluten. Compared to kafirin and zein, avenin was more extensible at low plasticizer contents, while kafirin and especially zein were more extensible at the highest plasticizer content. Avenin was far weaker than the other two at all plasticizer contents. Kafirin and zein displayed similar barrier properties, whereas avenin was notably more permeable (Gillgren et al., 2008).

Other main results achieved in the NovelQ project are summarised below:

- Development of extraction methods for cereals proteins at lab and pilot scale: protocols for extraction and purification of pennisetin (from pearl millet), zein (from maize) kafirin (from sorghum) and proteins from spent grain.
- Development of novel formulations of edible coatings based on the extracted cereal proteins for carrots, broccoli and strawberries.
- Development of agro proteins formulations with suitable physical-mechanical properties, gas permeability and mass transfer to be processed to obtained films by spread coating processing. In particular, spread coating formulations with crosslinking agents (glyoxal, ferulitic acid, tannic acid) were successfully developed. Decrease of water solubility and permeability as well as improvement of mechanical properties were obtained.

Active packaging films and coatings

Edible films and coatings consisting of polysaccharides, proteins or lipids can be used to preserve the quality of food by acting as a barrier between the food and the environment. By incorporating a preservative or an antioxidant, the film or coating can contribute, in a more active way, to food safety and quality. The release of active substances, as well as the release of functional coating components, from edible coatings was investigated on three different coatings. The two first coatings had matrices consisting of only one material; respectively the maize protein zein and a mixture of acetylated monoglycerides referred to as acetem. The third coating consisted of zein dispersed in an acetem matrix. The active substances used were sorbic acid, sodium propionate and ascorbic acid. In addition, the release of the plasticizers citric acid and glycerol, mixed into the zein coatings, was studied. The coatings were all covering a model food consisting of a gelatin gel with a water activity similar to the one of semi-dried fruits. The results show that all active substances, as well as plasticizers, were released from the coatings and the coatings can thus be used for controlled release of active substances to food. The active substances released from the acetem or mixed coatings were present in a high concentration close to the surface at all times. The coatings containing acetem can consequently be used in situations where the risk of microbial growth and contamination is highest at the food surface.

An additional challenge of the NovelQ project was the investigation of the potential interest of the combination of novel packaging concepts and novel processes for shelf life extension. In this way a new active antimicrobial biopolymer was designed based on PLA as polymer matrix containing volatile active agents (carvacrol or allylisothiocyanate, two naturally occurring antimicrobial compounds found respectively in Oregano and in plants from the *Cruciferea* family) for an action by direct or indirect contact with food. The objective was to assess the antimicrobial properties of the processed materials on *Botrytis cinerea*, a widely spread crop pathogen in combination or not with high pressure treatments of increasing intensity. The assessment of the effectiveness of combined treatments was carried out with the processed material that displayed the best antimicrobial properties. The combined action of active packaging and HP treatment was proved to be a promising antimicrobial system for inhibiting *Botrytis cinerea* growth during at least 10 days at 22°C. Moreover, combining mild HP treatment (at 300 MPa) and use of active film of PLA including AITC previously encapsulated in cyclodextrins was more efficient than either a HP pasteurisation-like treatment (800 MPa) or the antimicrobial packaging alone (Raouche et al., 2011). This combined action between pressure and antimicrobial agent could be used to reduce the intensity of the HP treatment and/or the quantity of antimicrobial compound added in the film and consequently would permit to reduce the impact on food and the cost of the treatment.

Table 2.2.2 **:**Antimicrobial activity on *Botrytis cinerea* of bio-active packaging combined with high pressure treatment

	0.1 MPa	300 MPa	600 MPa	800 MPa
Ctrl	+	+	+	+
PLA/AITC	+	+	-	-
PLA/AITC encaps	+	-	-	-

+ microbial growth / - no microbial growth after 10 days exposure

Effect of HP/T treatments on material properties

Packaging materials for HP treatments have to be flexible enough to withstand the compression forces while maintaining physical integrity without losing the properties which guarantee the adequate protection of packaged food. In fact, HP treatment can promote changes in crystallinity, density and orientation of plastic packaging materials that could affect, in turn, mechanical and mass-transfer (vapour and gas barrier, migration/scalping) properties of the package in a significant extent. Moreover, interfacial stresses arising between the different elements of multilayer structures as a result of the high pressure, could bring about delamination and extensive detachment of the layers. A systematic analysis has been therefore performed to investigate the behaviour of flexible single materials and multilayer commercial plastic structures used to package selected foodstuff (i.e. tap water, carrot juice, carrot puree and solid sliced carrots) to be HP treated.

Effect of mechanical action of pressure in HP pasteurisation and sterilisation treatments

Pouches made of single and multi-layer commercial film structures used to package tap water, solid carrots, carrot puree and carrot juice were subjected to the following high pressure treatments 1) Pasteurisation (25-40°C) at 200, 500 and 700 MPa; 2) Sterilisation (90-115°C) at 200, 500 and 700 MPa.

As a result of these tests, it was found that:

1) all single layers and multilayer structures are able to mechanically withstand *HP pasteurisation*, at least up to 700MPa. The only exception being multilayer structures containing aluminium foil or metallised layers which present extensive delamination phenomena;

2) single layer commercial films were able to mechanically withstand *HP sterilisation*, at least up to 700MPa, with the exclusion of PLA which embrittles and shows a partial phase

change, likely due to hydrolysis phenomena induced by water, which is the main component of the pressure transmitting fluid used in HP treatment ;
3) only multilayer structures with layers having *close mechanical properties are able to mechanically withstand HP Sterilisation*, at least up to 700MPa, without delamination phenomena. This behaviour has been rationalised by using analytical and numerical (finite element methods) modeling of the behavior of multilayer pouches under high pressure, as detailed later in this document. It has been theoretically predicted and experimentally verified that, in the cases where delamination occurred, it is essentially due to development of very high interlayer mechanical stresses and not to the different thermal expansion properties of the layers composing the film structure.

In fact, best results have been obtained with laminated *PAcast/PPcast* films with adhesive 5 and 6 (samples C3, C4, C5 and C6), in view of close values of mechanical moduli of PAcast and PPcast: these film structures are compatible with HP sterilisation even with a demanding foodstuff as is solid carrots. Satisfactory results were also obtained with a) *PAcast/PPcast* laminated samples C1 and C2 with adhesive 2, as well as with *OPA/PPcast* films samples C7, C8 and C9. Worse results have been obtained with *PET/PP* cast (sample C10) laminated bi-layer, in view of the significant difference in mechanical moduli of the various layers. PP/EVOH 3 µm/PP (sample C12) and PP/EVOH 10 µm/PP (sample C13) coextruded tri-layer film and PP/PA/PP (sample C14) coextruded tri-layer film also displayed unacceptable performances in HP sterilisation. Multilayer structures containing aluminium foil or metallised layers are unsuitable also for HP sterilisation.

Figure 2.2.3 Examples of multilayers films subjected to HP sterilization: i) delamination occurring after HP sterilization in PET/PP bilayers and ii) structural integrity after HP sterilization in PA/PP and OPA/PP bilayers. PP: Unoriented Polypropylene; OPA: Biaxially oriented polyamide; PA: Unoriented polyamide

Analysis of the possible changes of relevant functional and structural properties of commercial packaging films to be used for HP/T treatments

Permeability (Oxygen, carbon dioxide and water vapour), *Sorption Isotherms* (Oxygen, carbon dioxide and water vapour) and *Dynamical-Mechanical* analysis were performed both before and after the HP treatments to assess the occurrence of possible changes of functional and mechanical properties of packaging structures due to HP treatments. It was found that:

1) HP (both sterilisation and pasteurisation) *do not promote any significant change in functional (barrier) properties* of tested *single layer films* (PP, LLDPE), for any kind of packaged foodstuff (tap water, solid carrots, carrot puree and carrot juice). PLA properties are affected only in the case of HP sterilisation process.

2) *In the cases in which the commercial multilayer structure are able to mechanically withstand the effects of the stress field* associated to HP pasteurisation and sterilisation, without displaying delamination, *the functional properties* (e.g. thermal and mechanical properties, oxygen and carbon dioxide permeability and diffusivity, water permeability and diffusivity) *also are practically unchanged* as compared to starting materials. Hence, the mechanical integrity remains, in general, the main point of attention when considering suitability of commercial multilayer packaging structure for use in HP sterilisation/Pasteurisation.

Understanding of the phenomena involving structure/morphology of the materials that occur as a consequence of HP treatments.

Changes of structure/morphology occurring in the packaging materials during HP treatment could, in turn, promote changes in functional properties of packaging structures. The experimental evaluation of structure/morphology changes have been conducted for single layer films (PP, LLDPE, PLA) also with the purpose of gathering information to be used in theoretical modeling of the changes of functional properties of packages after HP treatments. For these reasons it was important to evaluate a) the density evolution of the amorphous regions for the case of PLA; b) the evolution of the degree of crystallinity and of average orientation for the case of PP, LLDPE and PLA. This evaluation regarding the changes of structure/morphology of polymeric films has been achieved through the use of advanced characterisation techniques such as: i) Modulated Differential Scanning Calorimetry**;** ii) Thermo-mechanical analysis (thermal dilation at atmospheric pressure), iii) Measurement of PVT behaviour (from room temperature up to the molten state, from 10 to 200 MPa, iv) X-ray scattering; v) Raman confocal microscopy; vi) Density measurement, vii) polarised FTIR microscopy, viii) Differential interference contrast microscopy.

As an example, HP sterilisation and pasteurisation treatments can possibly induce several changes in structural and morphological properties of PLA and, in turn, in its functional properties. The pasteurisation and sterilisation HP treatments are proved to induce in PLA packaging films some changes in crystallinity, density, orientation and the action of water (used as main component in pressure transmitting fluid) promotes, during sterilisation, hydrolysis of PLA. HP pasteurisation has rather limited consequences on functional properties of PLA packaging films which remain substantially unchanged. On the other hand, HP sterilisation promote unacceptable embrittlement and opacification likely due to hydrolysis phenomena (ref. New Food).

Identification of processing windows for several materials of interest in food packaging applications

A procedure to assess the processing windows of commercial materials (single and multilayer) has been identified which is based on the following points:

a) processing conditions should not exceed the actual glass transition temperature (Tg, which is pressure dependent) of any plastic layer, which is glassy at ambient conditions, to avoid possible wrinkling and deformation due to polymer shrinking.

b) processing conditions should not exceed the actual melting temperature (Tm, which is pressure dependent) of any plastic layer, to not compromise structural integrity of the packaging.

c) interlayer stresses under pressure should not exceed the mechanical resistance of adhesive layers.

On the basis of the experimental evaluation in a PVT apparatus of Tg and Tm increase as a function of pressure up to 200 MPa on single layer films, for the case of *LLDPE, PP, PLA, PET,* it is possible, by extrapolating data with theoretical models, to estimate Tg and Tm increase with pressure up to 700 MPa.

As far as multilayer commercial structures are concerned, packaging films usually adopted in food packaging are generally able to with stand HP pasteurisation treatments with the notable exception of structures containing metallised films, which display delamination. On the other hand, only some of the possible multilayer structures are suitable for HP sterilisation, as is the case of cast nylon/cast polypropylene films. Other common structures, such as bioriented polyethylenterephthalate / cast polypropylene films are unable to withstand the state of stress and delaminate during HP sterilisation. However, all the multilayer structures which do not display delamination, are also suitable for HP treatments in terms of their functional (e.g. barrier) properties since display very limited or virtually no change in these properties as a consequence of treatment. (Gontard et al., 2010)

Food packaging interactions

Migration and scalping related to HP/T treatments

The interactions between the food product and the packaging material include both (i) the sorption or "*scalping*" by the packaging material of substances contained in the food product (aroma compounds generally) and (ii) the *migration* of substances from the packaging material (monomers, process aids and additives as plasticizers, antioxidants or light stabilisers) to the food product. Unlike other stabilisation technologies, high pressure treatments require the food product to be packaged during the treatment (at least in its primary packaging). Therefore, assessment of the food/packaging interactions must necessary be investigated under the conditions of the treatments in order to be in compliance with the legislation on food contact materials (FCM)[1] with the goal to carry out a complete assessment of the potential impact on packaging of high pressure treatments, both performing a pasteurisation treatment with a temperature increase from 20 to 40 °C

[1]Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food.

(HP/LT) and a sterilisation from 90 to 115 °C (HP/HT). The study of migration and scalping of relevant model molecules was conducted to simulate the conditions that the FCM undergoes during all the service life of the packed novel food i.e. the HP/T treatment and a further storage of 26 days.

The apparition of directive 2002/72/EC[2] allowing the use of models to determine the compliance of food contact materials was a turning point in the approach of migration tests. In the NovelQ framework, a specific effort was made on the development of software tools for prediction of migration and scalping phenomena within polymer and Food Simulating Liquid (FSL). Four different mathematical models depending on the type of set-up used to obtain experimental data were developed and implemented in MATLAB® software. The toolboxes requiring the diffusion coefficient (D) of the targeted compound in the packaging material as main input (in addition to the partition coefficient), new approach was developed using non-destructive spectroscopic methods to quickly determine D values. FTIR and Raman micro-spectroscopies turned out to be especially adapted for gathering kinetic profiles of average concentration (FTIR) and even concentration profiles in the polymer thickness (Raman) (Mauricio *et al.,* 2009, 2011c). By this way, the characterisation of diffusion coefficient is achieved within a few hours.
This approach was successfully applied to fully assess a range of common and innovative packaging materials, using the same conditions for high pressure pasteurisation and high pressure sterilisation. Two already commercialised materials (LLDPE and PLA) were selected so that they represent different characteristics of packaging materials, *i.e.* at ambient temperature LLDPE is above its glass transition temperature (Tg) while PLA is below; LLDPE is very apolar whereas PLA shows a moderately polar character. Finally LLDPE comes from fossil resources whereas PLA is currently the most available bio-sourced material.
The results show that the temperature was indeed the most critical factor during the treatments. Both materials, polyethylene and PLA were found suitable for high pressure pasteurisation. Concerning migration, *no detrimental effect was demonstrated as a consequence of the high pressure treatment* since migration levels of targeted additives (Uvitex OB and Irganox 1076) measured on HP treated samples were not significantly different from the control (Mauricio *et al.,* 2010a).

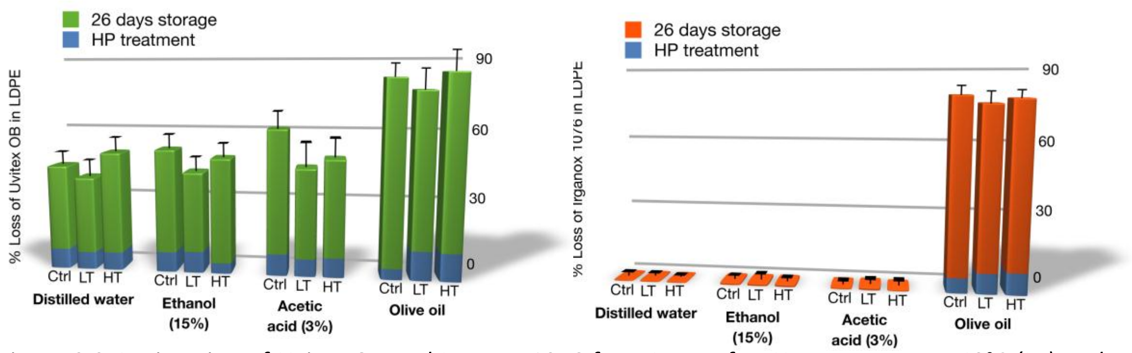

Figure 2.2.4 migration of Uvitex OB and Irganox 1076 from LDPE after HP treatment at 40°C (LT) and 115°C (HT) and subsequent 26 days of storage

[2]Commission Directive 2002/72/EC of 6 August 2002 relating to plastic materials and articles intended to come into contact with foodstuffs

As for scalping, the uptake of aroma compounds did not increase for both materials during the high pressure pasteurisation. Moreover, it decreased significantly for PLA. The impact of temperature was particularly clear for PLA. The migration of the selected surrogate (Uvitex OB) was still non-detectable but the uptake of low molecular weight aroma compounds after HP/T sterilisation was significantly higher than the control (at 115°C and 0.1 MPa, atmospheric pressure). Compared to the HP/T pasteurisation at 40°C, the aroma uptake increased nearly eight folds after HP/T sterilisation (Mauricio et al., 2011a). Furthermore, after the treatment in aqueous FSL, PLA became brittle, whitish and opaque what made it unfit for packaging purposes. Therefore, PLA undergoes a glass transition during at least a part of the HP sterilisation process which appears to be a critical factor. According to Di Maio *et al.* (2008) the increase in opacity and brittleness observed for samples HP sterilised in aqueous media is caused by an increase of crystallinity, but also hydrolysis phenomena are expected to play a role. In particular, water could act as an inductor of crystallisation, which takes place between the glass transition temperature and the melting point of a polymer.

It is interesting to compare the behaviour of LLDPE towards a conventional thermal sterilisation (121°C, 20 min) and a HP/T sterilisation (115°C, 5 min, 800 MPa). HP/T sterilisation did not have a significant effect on the migration of two different additives (Irganox 1076 and Uvitex OB), even compared to control samples at 40°C (Mauricio et al., 2010a). However, the uptake of aroma compounds of HP/T treated LDPE showed a three to five-fold increase compared to control at 115°C and atmospheric pressure (Mauricio *et al.,* 2011a). As for the conventional sterilisation, LLDPE did not even withstand the treatment and melted. Actually, the melting point of a polymer also increases with pressure, allowing thus to extend the temperature range of use of LLDPE. As consequence, *LLDPE could be used for HP/T sterilisation whereas it does not stand a conventional thermal treatment*.
In addition to the investigation performed on commercial packaging material, a novel nano-composite material based on wheat gluten/montmorillonite[3] (WG/MMT) was subjected to a HP/T treatment (800 MPa, 40°C, 5 min) and subsequently assessed in terms of migration/scalping phenomena. The analysis of compliance of the upcoming FCM was performed according the conditions recommended by the directive relating to plastic materials with a particular attention on the nanoparticule behaviour after treatment and during subsequent storage. While no effect of HP/T treatments was observed on overall migration and proteins migration from the WG nanocomposite films into the four standards simulating liquids (FSL) the release of nanoparticles was particularly issued but the influence of HP/T treatments on the release of MMT could not be clarified. The investigation of the respective migrations of silicon and aluminum used as tracers of MMT revealed two important results :*(i)* the content of silicon was higher in aqueous FSL in contact with samples containing montmorillonites (MMT) and *(ii)* the HP treatment led to a significant increase of the content of silicon compared to the untreated samples (Mauricio *et al.,* 2010b). Structural analyses by X-ray diffraction, FTIR and differential thermogravimetrical analysis, carried out to clarify the effect of HP on the structure of MMT, showed that

[3]Montmorillonite is alumino-silicate minerals organised in tetrahedral sheets. The addition of MMT is generally performed for enhancing the mechanical properties and water sensitivity of bio-sourced materials.

important modifications took place, mainly focused on the tetrahedral sheet of MMT (Mauricio *et al.,* 2011b). As a conclusion, *the use of nanocomposite materials for HP treatments should be assessed in a case-by-case basis that cannot based on the results for the untreated nano-composite.*

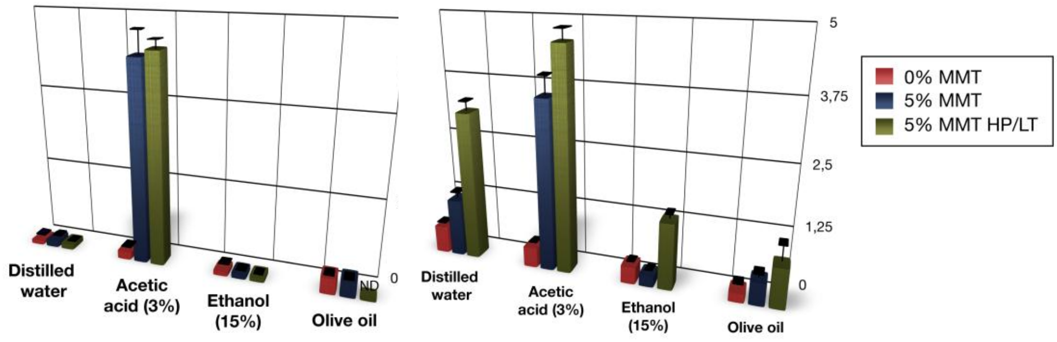

Figure 2.2.5 Migration of aluminium and Silicon from control and HP treated WG nanocomposites after 10 days of contact with the four food simulating liquids

Combination of novel packaging concepts and NP processes for shelf life extension

The work focused on: (i) combination of High Pressure Processing (HP) with edible coatings and (ii) combination of microwave drying and edible coatings. The work intended to develop and evaluate innovative concepts to extend the shelf life of plant foods.

Different types of coatings and HP conditions were tested, and the best way to combine high pressure processing with edible coatings was selected. A variety of fruits and vegetables were tested, and the most promising results were achieved for minicarrots and fruit-based candy. A lipid based edible coating (GrinsteadTM Acetem) alone or combined with zein showed to be a suitable coating for the selected products. Pressures of 700 MPa in combination with pure Acetem coating showed to have the best ability to prolong shelf life as it resulted in best appearance and less weight loss. Shelf life extension of 3 – 5 days could be reached using this method.

The same approach was applied to fruit-based candy (42 % apple, 42 % raspberry, 15 % pectin and 0.15 % CaCl2) and the shelf-life was determined based on visual appearance, texture, water loss and microbial growth changes during storage at 20°C and 50 % RH. Results showed that the combination of high pressure treatment and lipid based edible coating prolonged the shelf-life. The products were acceptable for consumption after 15 days. There was no significant difference between the two high pressure treated samples (at 400 or 700 MPa) in any of the test parameters.

Combination of microwave assisted hot air drying and edible coatings also resulted in the shelf-life increase of semi-dried plant foods. Quality changes of coated carrot and apple slices were evaluated during storage at 15°C and 30%RH and 20°C and 50%H in terms of weight loss, water content and colour and compared to uncoated carrots. Bi-layer coatings with zein as first layer covered with Acetem, had the best effects on water retention and

prevented carrot slices from microbial growth and shrinking. These kinds of bi-layer films were found to be the most effective edible coatings to extend the shelf-life of semidried carrots. The shelf-life of semidried apple and carrot can be extended by approximately one week, being microbial and enzymatic browning the main problems.
Active coatings in combination with microwave drying or high pressure was found to be a way to further extend shelf-life of fruit products such as semi-dried apples and fruit based jelly. For example, combination of high pressure (400 and 700 MPa) and active acetem (acid sorbic 0,5%) improve significantly quality and shelf-life during storage in air at 20C:50% RH. Water loss was reduced, colour is more stable, appearance is acceptable even after 14 days and the product is safe (no microbial growth).

Mathematical models and numerical implementation

Mathematical models and their numerical implementation have been developed to predict the evolution of structure/morphology and the barrier properties of polymeric materials employed for the realisation of flexible packaging structures subjected to HP/T treatments. In particular, a number of these numerical tools allow the prediction of several relevant structural properties such as i) the density evolution of the amorphous phase of glassy polymers, ii) the dependence of glass transition temperature on pressure, iii) the dependence of amount of crystallinity as a function of temperature and pressure, iv) the evolution of PVT properties. Other theoretical models and numerical tools use this information to predict sorption isotherms of gases and vapours and their diffusivity in glassy and rubbery polymers employed in food packaging, based on equation of state theories and free volume theories. As a whole, the different numerical tools implemented within the project are able to model and predict functional properties of starting materials and, on the basis of temperature/pressure histories, are also able to model and predict changes of functional properties promoted by HP treatments.
For example, the density evolution of semi-crystalline, glassy, Poly(lactic acid), used as biodegradable packaging material, under ultra/high pressure histories can be effectively modeled assuming that the volume relaxation kinetics involves only the amorphous part of the polymer. In particular, a scaling law for relaxation times is utilised in the framework of KAHR (Kovacs Aklonis Hutchinson and Ramos) phenomenological theory in order to model the volume relaxation behavior. With this approach and only two fitting parameters, it is possible to predict accurately the density evolution of the PLA during the HP sterilisation and pasteurisation treatments in HP industrial processes (Grassia el al, 2011)
Thermodynamic models for sorption of low m.w. compounds in polymers supply relevant information to predict barrier properties of packaging films both before and after HP treatments. In the case of water vapor sorption in poly-?-caprolactone (PCL), a semicrystalline and rubbery biodegradable polymer, a possible formation of water-polymer and water-water hydrogen bonding has to be accounted for. A very satisfactory modeling of sorption thermodynamics of water in PCL is in fact obtained by using an equation of state approach where, in the framework of a lattice fluid model, mean field and an hydrogen bonding contributions are combined in an additive fashion. This model, beside correctly predicting sorption isotherms, also supplies an accurate estimate of the number and types of hydrogen bonds formed in the PCL-water mixture (Scherillo et al. 2011).

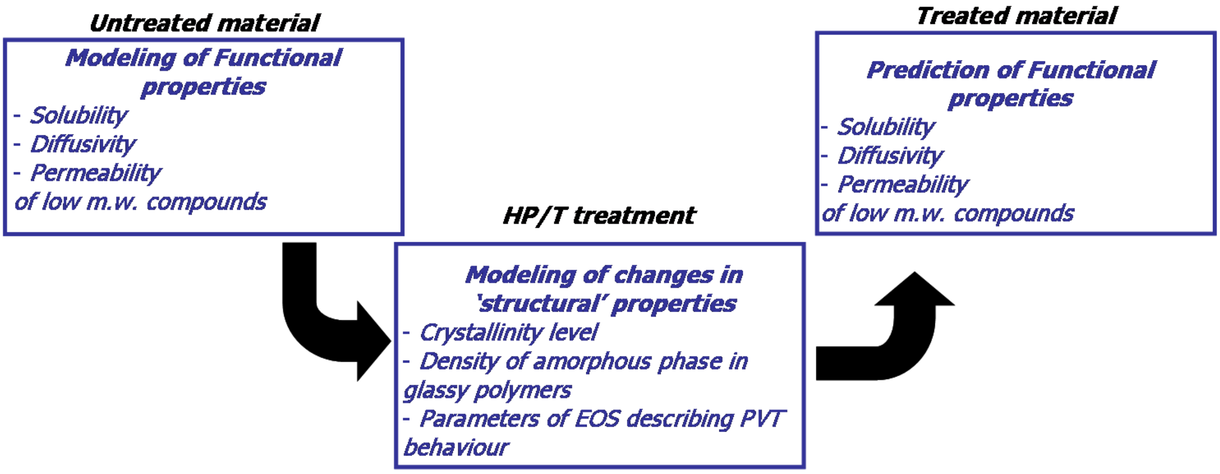

Figure 2.2.6. Development and validation of scientific toolboxes

Moreover, analytical and finite element approaches, can be used to evaluate the stress state which develops as a consequence of high pressure treatments in multilayer film structures. The stress developed in multilayer polymeric films, used to package foodstuff, when submitted to HP pasteurisation and sterilisation treatments can be calculated by using an analytical approach on simple idealised packaging shapes or, more in general, by adopting Finite Element (FE) methods that allow the calculation on more realistic package shapes. Quite interestingly, interlayer shear and normal stresses develop at the interface between the component layers of the multilayer structure, thus possibly determining delamination phenomena, as experimentally observed in the case of several multilayer films, if these stresses go beyond the resistance limit of the adhesive layers interposed between the single layers. This approach allow a proper design of multilayer structure in terms of the type of films to be coupled with ht aim of preventing delamination phenomena. In fact, it is demonstrated that these phenomena are more likely to occur in the cases in which mechanical moduli of the laminated layers differ significantly (Fraldi et al., 2011).

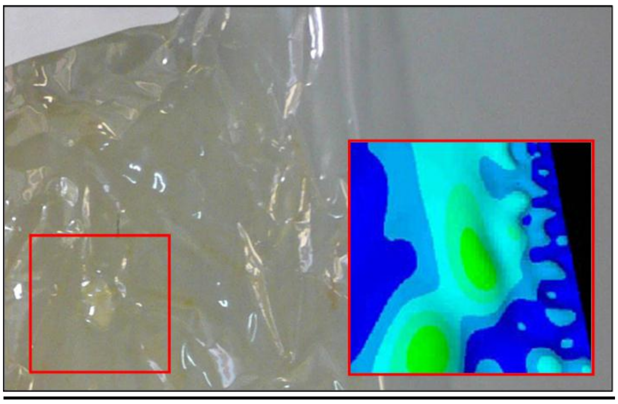

Figure 2.2.7 Comparison between experiment and FE analysis: similarity in terms of localized delamination phenomena.

Criteria for material selection, towards the design of packaging structures

The integration of numerical tools developed to model and to predict functional and structural properties of polymeric materials, represents a useful theoretical framework for the assessment of the suitability for use in HP treatments of certain polymers and multilayer structures and is of help also in designing package structures. In fact, these tools allow for the quantification i) of possible decrease of barrier properties as a consequence of treatment, ii) of development of inter- and intra-layer stresses as well as iii) of identification of HP processing windows for packaging materials in terms of compatibility of processing conditions with actual melting and glassy temperatures of polymeric films.
This supploes an important guidance for the selection of i) the multilayer materials, ii) their relative thickness and iii) the most appropriate adhesive (in the case of laminated structures) or, alternatively, given a certain structure, for the specification of the limiting conditions for its use.
To this aim, these tools have to be coupled with a proper database obtained by collecting experimental information on specific materials such chemical structure, crystallinity, glass transition temperature, density, PVT behavior, mechanical properties. In particular, in the frame of the NovelQ project, these data have been experimentally determined for some polymeric materials: PET, PP, LLDPE, PLA; PCL, PA.

2.2.4 Main dissemination activities

Sub-project 2	
Referred journal papers published	17
Referred journal papers accepted	-
Referred journal papers submitted	7
Technical articles submitted in magazines	3
Major international conference papers presented	39
Workshops/meetings organised	2
Other (video)	1
Thesis	13
TCD contributions (oral, posters)	10
Draft papers, planned papers, planned conferences	2

2.2.5 Interaction with other Sub-projects

- **Sub-project 1:** *Packaging materials treated with NP.* Strong interaction with Sub-project 1 on HP/T treatments. The set of processing conditions to treat packaging materials were harmonised with processing conditions utilised to process food to evaluate the packaging materials at relevant process conditions.
- **Sub-project 3:** Products and processes considered in both sub-projects were the same. Sub-project 3 set-up their work based on the product/process framework identified in Sub-project 2.

- **Sub-project 4:** *Decision support system.* Interaction between the scientific toolbox for process impact on structural and functional properties of packaging materials and the decision support system for implementation of NPs with the aim of supporting information to potential users on packaged food processed by NPs.
  Integrated hygienic product handling and packaging. Interaction includes process-packaging interaction and appropriate packaging following NP treatment, including hygienic handling.
  Demonstration project. Generation of product/process scientific data that were used for the demonstration project. Examples are: **(i)** hygiene handling following NP treatments; **(ii)** scaling-up problems related to optimal processing conditions; and **(iii)** interaction between NP methods as pre-treatments prior to HP/T and advanced heating treatments, such microwave-assisted drying to extended shelf-life of semi-dried plant foods using edible coatings as protective barrier.
- **Sub-project 5:** Sub-project 2 delivered all necessary input for dissemination activities.
- **Sub-project 7:** Sub-project 2 delivered all necessary input for the development of innovative packaging structures.

2.2.6 Conclusion

Major progress was made in the knowledge on the effect of novel processing on packaging materials through an extensive evaluation of the impacts of NPs on the performance of common and novel packaging materials and on their interaction with the packaged food. Particular emphasis was given to HP/T treatments and combination of novel packaging concepts (i.e biodegradable films and edible coatings, nanocomposites, bio-active polymeric systems) with novel processes that permitted to prolong the shelf-life above that accessible with currently available technologies.
Key issues such as the evolution of material properties with process conditions as well as food-packaging interactions associated with NPs were analysed and modelled through the development of integrated theoretical and numerical tools that allowed a) the prediction of functional and structural properties of the packaging materials, b) the prediction of the process/package-product interactions for simulating and controlling migration of unwanted compounds (for regulatory issues on undesirable compounds and quality maintenance by avoiding scalping), c) the assessments of the suitability for use in HP treatments of certain polymers and multilayer structures in view of designing specific package structures.

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2.3 Consumer perception and socio-economic background of novel processing methods: description of main results of Subproject 3

2.3.1 Objectives and contractors involved

The aim of the SP3 was to research and promote consumer acceptance of NP and NP products:

- Perception of consumers towards NP technologies
- Perception of consumers towards NP products
- Perception of consumers towards NP products in real life situations and sensory research

Successfully addressing these objectives allow the following to be achieved:

- To understand consumers' perception towards NP technologies and NP products and the perceived benefits and costs.
- To develop guiding principles for implementation of NP technologies to be used by for example SMEs in various regions in Europe.

These goals were achieved in the framework of three workpackages:

Workpackage 9: Innovation and consumer perception of novel technologies
WP leader: Prof. Dr. Diána Bánáti, CFRI
Partners: CFRI, A&F-EFFoST, SCA, Nofima, ASB

Workpackage 10: Consumer attitude and behaviour towards real products produced with novel technologies
WP leader: Mrs. Dr. N. Veflen Olsen (Nofima)
Partners: Nofima, CFRI, ASB, A&F-EFFoST

Workpackage 11: Consumer attitude and behaviour towards NP products in real life situation and sensorial evaluation
WP-leader: Mrs. Dr. N. Veflen Olsen (Nofima)
Partners: CFRI, ASB, A&F, A&F-EFFoST, Nofima

2.3.2 Working approach

Consumer perception of novel technologies

A systematic analysis of earlier research was conducted to investigate food consumer values, attitudes and behaviour according to the previous researches. A searchable database was created with free accessible scientific publications in the theme of consumer acceptance of novel technologies.

To discover the place of novel technologies (HPP, PEF) in the desires of consumers focus group interviews were conducted in Norway, Denmark Slovenia, Hungary, Serbia, Slovakia, and the Czech Republic.

Innovation in food industry

Our aim was to discover the barriers and facilitators for innovation in the food sector in the EU (Scandinavian and Central and Eastern European countries) with an internet based questionnaire survey.

Consumer attitude and behaviour towards real products produced with novel technologies

This work included studies on products produced by novel technologies in comparison with those produced conventionally. Consumer attitudes and actual behaviour towards such products were studied through two approaches: a qualitative means-end chains analysis method and a quantitative conjoint analysis method based on the results of the previous qualitative results. In the framework of means-end chains analysis 30-30 laddering interviews were conducted in Norway, Denmark, Hungary and Slovakia. The conjoint analysis was conducted to examine consumers' trade-off among different product attributes with 150-150 respondents in Hungary and Slovakia and in Denmark and Norway.

Consumer attitude and behaviour towards NP products in real life situation

A consumer observation study was carried out to evaluate the sensory characteristics of freshly pressed, mildly pasteurised and high pressure processed orange juices and assess the influence of different technologies on perceptual quality of the product. The second objective was to assess the influence of repeated exposure on the perception of sensory attributes of differently treated orange juices and to examine the consumer behavior in a real life out-of-home condition in the "Restaurant of the Future" of Wageningen UR in Wageningen, The Netherlands.

A quantitative consumer acceptance study was conducted in Denmark and in Hungary to obtain a better understanding of the mechanisms governing consumer acceptance of new food technologies and to investigate how trial of the product affects attitudes to the technology.

Sensorial evaluation of NP products

The sensorial evaluation of NP products compared to conventional products was examined. Assessors evaluated fresh, untreated, frozen control, HPP, heat treated and PEF treated samples during 28 day long storage period. PEF treated samples were not tasted in the framework of this study.
To refine the results of the sensory study additional sensory test with tasting was made on PEF, heat treated, and fresh samples later.

To rename of 'Pulsed Electric Field' to 'Micro Pulse'

The additional task was to examine the consumers opinion about the rename of 'Pulsed Electric Field' to 'Micro Pulse' with focus group interviews, because previous results show, that the name 'Pulsed Electric Field' make the fear of electricity in the consumers. Three focus group interviews were made with consumers (older age consumers, young adults and health conscious consumers) and one with the experts of different fields of food sciences.

2.3.3 Main results achieved

Consumer perception of novel technologies

A searchable knowledge database was created with 118 articles from 57 scientific journals that were collected systematically and elaborated electronically. In the database there are 95 articles about consumer perception of genetic modification, 22 articles about irradiation, 4 articles about high pressure treatment and 1 about pulsed electric field treatment derived from 239 authors. The database was continuously used during NovelQ.

The results of the focus group interviews regarding the place of novel technologies in the desires of consumers indicate that there are both top-down and bottom-up processes that affect consumers' attitudes towards the HPP and PEF technologies and the products manufactured by means of these. The attitudes towards the PEF and HPP processes are based both on general socio-political attitudes and on a risk/benefit trade-off of the product attributes. The main advantages of HPP and PEF perceived by the consumers were the products' expected naturalness, improved taste and high nutritional value, whereas the main disadvantage were lack of information about the PEF and HPP products. Environmental friendliness and the more natural products were seen as the main advantages, while concern for body and health, the more expensive products, lack of information about the technologies and a general scepticism were seen as the main disadvantages of the PEF and HPP processes. According to the respondents, in a potential buying situation the participants said that quality and especially taste play a critical role in accepting and maintaining the commercial marketability of these novel products. There were more negative attitudes and less positive attitudes towards the PEF process and the PEF products compared to the HPP process and the HPP products. The participants were sceptical towards PEF because of its name, which was not the case with HPP. This scepticism is partly due to the fact that the name generates a fear of electricity. In addition, PEF products are seen as negative as they are believed to trigger allergic reactions. By comparing potential differences between the North and East European consumers' attitudes towards the two technologies it can be seen that in general the North European consumers are a bit more sceptical towards PEF and HPP products than the East European consumers. Secondly, the North European consumers are a bit more sceptical towards the environmental benefits of the products, and thirdly many of the North European consumers think that there is a big lack of information about products produced by means of PEF or HPP. The East European participants see the higher price solely as negative, while some of the participants in the North European countries see the higher price as positive. The East European participants are more worried about allergy caused by PEF and HPP products.

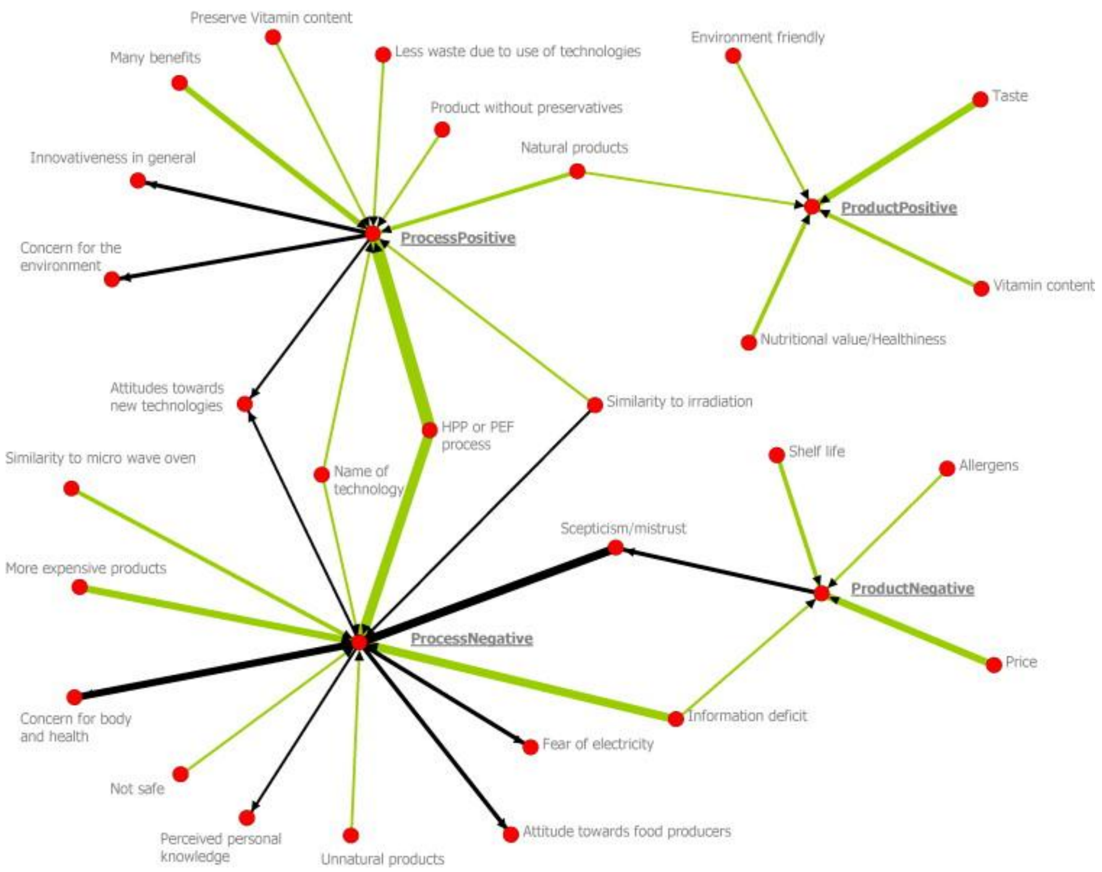

Figure 2.3.1: Consumer attitude formation model for juice, all countries and both technologies

Innovation in food industry

As forces and obstacles of process and product innovation internal and external factors were differentiated in the Scandinavian countries.

Internal factor 'financial resources' does not have a significant effect on the degree of innovation and none of the external factors influence the degree of innovation. A possible explanation for this finding may be that the companies are facing more or less the same external environment, which leads to homogenous answers. Results from the causal analysis in PLS show that the three variables 'management and culture', 'time' and 'organisation of product and process innovation' have a direct and significant influence on the degree of innovation in the food sector. These results indicate that the more open management and employees are towards changes the more innovative the company is likely to be. In the same manner it can be concluded that the more time the company dedicates to innovation activities the more innovative the company is likely to be. 'Knowledge sharing' and 'relations' have an indirect influence on degree of innovation in the Scandinavian

countries. Hence, it can be concluded that a company's management and culture, amount of time dedicated to innovation, knowledge sharing, customer orientation, organisation of product and process innovation as well as relations with external partners can act as barriers as well as facilitators to a successful implementation of new technologies, like HPP and PEF. If a company does not have the necessary basis with regards to these areas it can complicate the implementation of the technologies.
Regarding the Central-Eastern European Countries enterprises were classified into three groups: the first cluster's (18%) innovation forces were less successful, while the second and third's (41-41%) innovation forces were adequate. The second and third clusters collect information about consumers, the management sets great store by control, they have clear goals for new products, and the managers are personally committed to innovation. While the second cluster develops in a structured and systematic but rapid system, the third cluster's innovation system is less structured and systematic. According to the respondents the personal communications of people from trade, industry and consumer research were the most important sources of the information in the innovation processes.

Consumer attitude and behaviour towards real products produced with novel technologies

With the help of **means-end chain analysis** we could identify the most important product attributes, the main consequences of the use of the novel technologies and the main values connecting the consequences. With the help of the MEC analysis software the value-map of the examined technologies (pasteurisation, HPP, PEF) was designed (figure 2.3.2). Most frequent mentioned product attributes were 'nutritional value' and 'preserves taste' during selection of NP products. Most important consequence of the consumption is 'effect on health'. 'Environmental advantages' were also significant in the evaluation of the NP product. Most consumers are sceptical against PEF treatment in all 4 countries and refusal is even higher in Central - East Europe.

The results of the **conjoint analysis** indicates that consumers in all the four countries perceive PEF and HPP treated juice to be a better choice than pasteurised juice if the price and taste are right. But most of all consumers want freshly produced apple juice with a premium taste at an acceptable price. The finding that HPP juice is easier to accept than PEF juice is also in line with previous studies. The main aim of this study was to address an old challenge within MEC research, the documentation of the choice relevance of means-end chains. According to the PLS path model test, benevolence has a positive significant effect on environment and health in three out of four countries. Hedonism has a positive effect on the importance of taste when choosing apple juice in Norway, Denmark and Hungary, health concerned consumers choose fresh or HPP/PEF juice, not pasteurised juice. There seems to be a tendency towards stronger effects from the values benevolence and hedonism in the Northern Europe than in Eastern Europe. The consumers from Northern Europe are negative towards pasteurised juice and positive towards fresh juice, the Eastern European consumers are negative towards new treatment juices. Consumers from Eastern Europe – including health conscious consumers also – are more price sensitive.

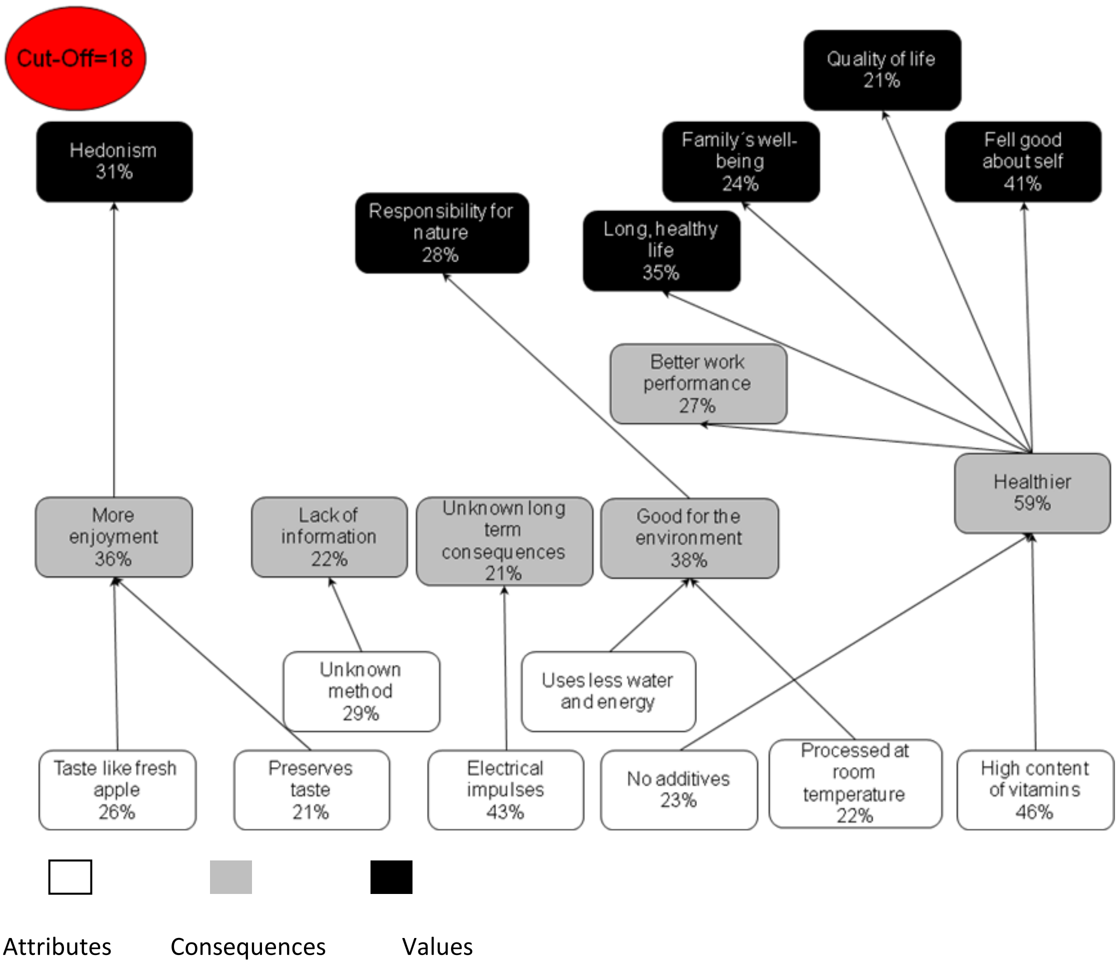

Figure 2.3.2: Hierarchical value map for HPP juice – all countries

Consumer attitude and behaviour towards NP products in real life situation

The results of the ***consumer observation study*** show, that the freshly pressed, mildly pasteurised and high pressure processed juices do not differ from each other on the tested attributes, except for sour. The average liking scores for the three juices were comparable. The bimodality of the liking scores for the juices suggests that two groups of consumers can be discerned. For all juices the collative attributes fresh and health were judged higher by the persons who like the juices better. Apparently a better taste goes along with the perception that the juice is fresher and healthier.
Regarding the examination of the effect of repeated exposure an increase in liking was noticeable in the case of all three juices. Some of the sensory attributes, especially sweet and sour, are perceived differently after repeated exposure to fresh and high pressure processed juice. It looks like that these juices are perceived as sweeter and less sour after repeated exposure. The collative attributes fresh and healthy are not perceived differently. Even this limited number of exposures in a limited time already affected the hedonic and

some sensory attributes. This indicates that the dynamics in perception are not to be ignored.
Only few repeat purchases of novel technology processed juices could be shown in the Restaurant of Future. Out of the 113 coupons, 59 coupons were used to receive a free juice. A reason for this might be the juice base which was relatively low sweet and rather pungent. The labels were hardly read, not even the first time, suggesting that the information about the applied processing technologies was not relevant for the customers to decide what juice to choose. This experiment did not change the choice patterns regarding drinks.

The ***quantitative consumer acceptance study*** shows, that the attitude change toward the technologies due to the sensory experience can be explained as an *affective conditioning* effect. Due to the pairing of the technology name with the sensory experience, the affective reaction elicited by the sensory experience is transferred to the technology name. The evaluation of the technology changed in a direction that corresponds to the valence of the elicited affect. Negative sensory experience (low quality product) influences attitude toward the technologies in a negative way, positive sensory experience (high quality product) influences in a positive way. Two product-technology pairings had bigger effect on attitude change, than one. According to the results of the evaluative conditioning, negative effect is easier conditioned, than positive. The attitude change effect remained stable after the product trial, and moreover the attitudes were more negative after three days.

Sensorial evaluation of NP products

The results of the ***sensorial examination of the novel products*** (HPP, heat treated, fresh, frozen control –odour and taste assessment; PEF – odour assessment) show, that the assessors were not able to make significant difference among the samples that have been made by novel and standard technology on the first examination day. The fresh sample got spoilt by the third examination day. On the last examination day the assessors felt significant distinction between the orange odour of the frozen and the heat treated samples. The odour intensity of the heat treated sample was constant by the third examination day but later on the assessors found significant distinction between the odour intensity of the third day and the fourth day sample. The after taste decreased in case of all samples during the storage period.
The fresh orange odour and the odour intensity decreased in case of the HPP, the PEF and the heat treated samples during the storage, furthermore the flavour intensity decreased in case of HPP and heat treated samples during the storage but these changes were not significant. Neither professional assessors nor consumers were able to find a significant difference among the samples produced by novel and standard technology on the last examination day. According to the examination, the fresher taste could not be demonstrated as the advantage of HPP and PEF treatments in contrast with mild pasteurisation. In general, this integral demonstration showed, that both pulsed electric field treatment and high pressure processing can result in a longer shelf life of fresh orange juice with maintaining the fresh characteristics.

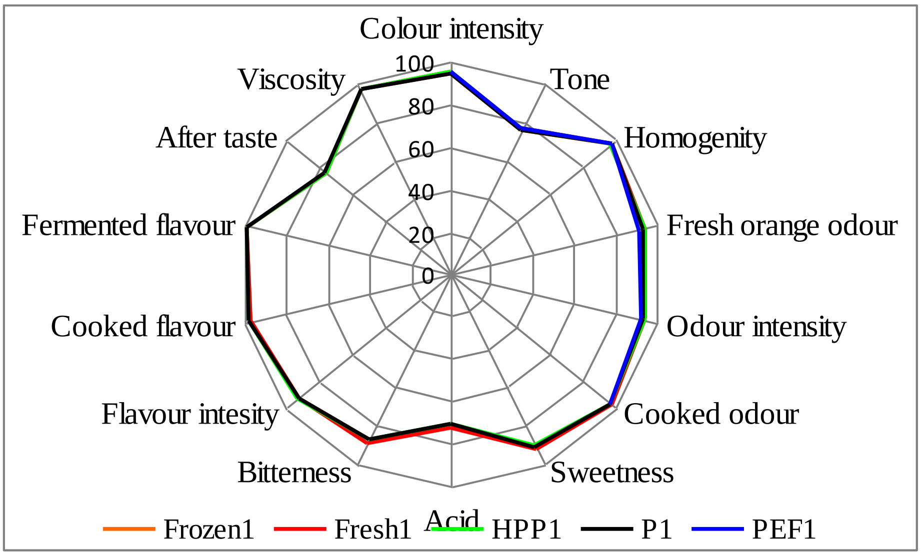

Figure 2.3.3: Results of the sensory profile on the last testing day (day 28)

The results of the ***additional examination on PEF***, heat treated and untreated samples (odour and taste assessment) show, that the expert profile analysis concerning the mean scores of the flavour intensity was 10% higher in case of the untreated samples, than the heat pasteurised juices. This result was supported by the ranking survey with 100 consumers: the consumers preferred the untreated juices more, than the heat pasteurised juices (sig<=0.01). The untreated products are fresher and richer in taste and flavour, but more acid, than the heat pasteurised juices, which were less intensive in flavour and which has cooked flavour. A paired sample test (N=26 test) was conducted by experts concerning the preference of the differently treated products. As the result of the paired sample test, there was no difference between the untreated and PEF products, but assessors preferred PEF products more, than the heat pasteurised products (sig<=0.05), which caused by the freshness of the PEF orange juice.

Figure 2.3.4: The sensorial evaluation of the samples by normal light and red light

The rename of ‘Pulsed Electric Field’ to ‘Micro Pulse’

The focus group interviews with consumers regarding the ***rename of the PEF technology to ‘micro pulse’ technology*** discovered, that 'micro pulse' name has better associations (indulgence, short, modern), than pulsed electric field (associated with radiation, unhealthy, unnatural, rough) and 'micropulse' is in no way associated with 'electricity' among then respondents. After getting information on the two technologies the name 'micro pulse' was also preferred in scoring to PEF. Consumers expressed their definite need of getting informed about the technologies even if this leads to uncertainty and distrust because of eventual lack of comprehensive knowledge. Young consumers are more opened toward both technologies.
Consumers’ judgment about the rename of the technology is divided: in the opinion of two focus groups, it does not misleading regard the name 'micro pulse' in comparison to PEF, though the electrical feature of the treatment should be mentioned. According to the respondents of the health conscious focus group, the rename of the technology is misleading, because the aim of the rename is the reduction of the consumers' fears. A deterrent technology name makes consumers more careful and motivates more conscious product choice.

The most important issues appeared during the expert focus group were that clear communication is important for the consumers, and it is needed to communicate for the consumers the nature of the technology (what kind of methodology based on the technology). The name ‘pulsed electric field’ is wrong and ‘micro pulse’ is not informative. Name ‘Micro electrical pulse’ can be acceptable, according to the experts. It is essential for the marketability of a new technology, that it have to offer unambiguous benefits for the consumers. It is important that the declared benefits of the new technologies have to be certified for the consumers. A communicational campaign is needed to the introduction of the new technologies. SMEs cannot finance the communication campaign. Beside of the product labels, the use of other communication tools is needed.

2.3.4 Main dissemination activities

Sub-project 3	
Referred journal papers published	16
Referred journal papers accepted	-
Referred journal papers submitted	-
Technical articles submitted in magazines	-
Major international conference papers presented	26
Workshops/meetings organised	17
Other (video)	-
Thesis	-
TCD contributions (oral, posters)	2
Draft papers, planned papers, planned conferences	4

2.3.5 Interaction with other Sub-projects

The objective of integral demonstration project was to evaluate the general application and viability of NP schemes by comparison of the effect of novel processing and conventional processing at equivalent processing level with respect to inactivation of micro-organisms and to provide a guiding document for application of NP schemes. In this research three parties and three sub-projects (SP1, SP3, SP4) were involved, Catholic University Leuven (Leuven, Belgium), Central Food Research Institute (Budapest, Hungary) and Wageningen University and Research (Wageningen, The Netherlands).

2.3.6 Conclusions for SMEs related to the implementation of HPP and PEF technologies

- Innovation possibilities of the Central and Eastern European and the Scandinavian food industries are highly diverse. Also the divergent consumers' reactions induce regional differences in the success of technological and product innovations. As Central and Eastern European consumers are quite price sensitive, its prospective consequence (e.g. tight market) should be considered.
- Interest of the Scandinavian consumers in products manufactured with new technologies is limited by the fact that also other freshly squeezed, slightly pasteurised and cool-storaged juices are offered on the market being very similar to HPP and PEF products. So newcomers have to differentiate their products form those existing already there.
- Considering that the sensory quality of freshly squeezed HPP and PEF treated fruit juices differs strongly from those circulated on the Central and Eastern European markets being rediluted from concentrates, introduction in these countries means not only new technologies but basically new products as well. It is highly important here to connect product introduction with tasting in order to make the new products known and popular.
- In every country consumers preferred HPP and PEF products to the pasteurised ones provided that prices and flavour were adequate (standard price with premium taste). So it is very important to highlight and communicate product advantages correctly.
- HPP and PEF treatments showed comparably sensory properties of orange juice compared to mild heat treatment, so further product specific tests should be conducted in this field also comparing more intense heat treatments.
- When the fresher taste cannot be verified at the HPP and PEF treatments, environment saving or the preserved nutritional and biological value could be focused in the communication policies for consumers. In this respect always the efficient EU legislation must be followed.
- Regardless of the EU regions, acceptance of HPP technology is better for the consumers than that of PEF technology. In addition to similar benefits consumers attach clearly higher risk to the PEF technology.

- Majority of health conscious consumers selected fresh as well as HPP and PEF products so in the product policies it would be practical to communicate better preservation of natural substances aiming at the health conscious consumer segments in this way.
- Concerning consumers' values the impact made by hedonism and benevolence on product selection was disclosed so it should be considered in product positioning (this effect is more vigorous in Scandinavia but weaker in the Central and Eastern European countries).
- Relation between environment consciousness and selection of technologies is not so strong that could significantly promote product introduction (this effect is more vigorous in Scandinavia but weaker in the Central and Eastern European countries).
- Consumers' difference making between the two examined technologies to the benefit of HPP remains even the designation „PEF treatment" is changed to „micro pulse". Renaming is opposed by the health conscious consumers being on the other hand the most important target group of HPP and PEF products. It means that outstanding emphasis should be laid on consumers information when introduce the new products.
- It should be contemplated to change the PEF name used in scientific life to „micro electric pulse treatment" in the consumer communication supported by an easy-to-understand and concise information on this technology.

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2.4 Development and demonstration of NP: description of main results from Subproject 4 and Subproject 7

2.4.1 Introduction to SP incl. main objectives, contractors involved

Activities in Sub-project 4 and 7 had the overall objective to facilitate and speed up the introduction of NP in the industry. It integrated applied R&D and demonstration activities to enhance the development and industrialisation of novel technologies, including novel thermal and advanced non-thermal processing methods.

Following basic researches in Sub-project 1 and 2, applied research focused on bottle necks currently limiting development of NP schemes and equipment for industrial applications of novel technologies. Results from Sub-project 3 helped to define consumer- perceived product and process characteristics. An additional part of the activities involved development of concepts for food products produced with NP schemes and research on hurdles currently hindering the development of large-scale pilot plant equipment. Pilot units were made accessible for demonstration projects, to facilitate technology transfer activities in Sub-project 5.

Within the project, 1.65M€ budget was reserved for demonstration projects to demonstrate the incremental innovation of quality of specific food products, including regional food products. A competitive call was organised (described in more detail in subproject 5) for these demonstration projects, resulting in three additional workpackages (WP28-30, organised in subproject 7) and four new industrial partners. In addition to this, integral demonstration activities were organised and short time demonstration trials.
In the first 18 months of the project, three demonstration projects were conducted (WPs 21-23); the other demonstration activities started after 18 months.

Objectives

- To facilitate and speed up the industrial exploration of NP by applied research and developing supporting technologies for industrial application and by performing extensive demonstration activities.
- To demonstrate the incremental innovation of specific food products and specific NP schemes by demonstration projects.

SP 4 Partners

Organisation	Country	Role
Wageningen UR Food & Biobased Research	The Netherlands	SP4 project co-ordinator, WP 16-21.
SIK	Sweden	SP4 project co-ordinator, WP 12, 13, 14, 17, 20, 23
TU Berlin	Germany	WP 15
KULeuven	Belgium	WP 19, 20
IFR	U.K.	WP 14
CTCPA	France	WP 13, 19, 22
CCFRA	U.K.	WP 12
TNO-QoL	The Netherlands	WP 15
FRIP	Czech Republic	WP 19
Resato	The Netherlands	WP 17
I&L Invest	Belgium	WP 17
Unilever	The Netherlands	WP 17, 20
Struik Foods	The Netherlands	WP 21
OPAL	France	WP 22
Procordia	Sweden	WP 22
CGPA PENY	France	WP 22
University of Sheffield	U.K.	WP 23

Workpackages within Sub-project 4

WP no.	Title
WP 12	Hygienic design and hygienic materials for NP equipment
WP 13	Integrated hygienic product handling and packaging
WP 14	Environmental efficient novel process production systems
WP 15	Prediction of shelf life of NP treated products
WP 16	Virtual factory approach for implementation of novel processes
WP 17	Research on specific scaling up problems relating to NP schemes (not incl. plasma)
WP 18	Research on specific scaling up problems relating to NP schemes: cold plasma
WP 19	Characterisation and specification of small scale pilot processing units
WP 20	Integral demonstration of product improvement using NP technologies
WP 21	Minimal pasteurisation/sterilisation technology by application of water immersed radio-frequency heating
WP 22	Optimisation of microwave heating uniformity of prepared food products
WP 23	Demonstration project: Ohmic heating technology of pumpable foods

SP 7 Partners

Organisation	Country	Role
Wageningen UR Food & Biobased Research	The Netherlands	SP7 project co-ordinator, contact point WP 28
SIK	Sweden	SP7 project co-ordinator,
KULeuven	Belgium	Contact point WP 30
ICMB-CNR	Italy	Contact point WP 29
Koldsteril	Switzerland	WP 28
Icimendue	Italy	WP 29
Top	The Netherlands	WP 30
NC Hyperbaric	Spain	WP 30

Workpackages within Sub-project 7

WP no.	Title
WP 28	Cold plasma treatment of food
WP 29	Packaging materials for high pressure sterilisation
WP 30	High pressure processing for healthy complex food products

The workpackages in SP 7 started in month 27

2.4.2 Working approach

These Sub-projects focused on the integral effects of NP schemes on the quality and shelf-life of food products showing the incremental innovation of the quality of food products that is possible by using NP processing schemes. Three important approaches were addressed, all being essential for successful implementation of NP by the European food industry parallel and after NovelQ.
The **first approach** (**WP 12-14**) focused on process hygiene of the entire process, including integrated hygienic product handling and hygienic design of the process and packaging. In these activities, the environmental efficiency of the NP processing schemes is also evaluated and compared with conventional technologies. In general, NP processes are much more energy efficient than conventional heating technologies, but Life Cycle Assessment is necessary to quantify this.

The **second approach** (**WP 15-19**) addressed the actual processing with NP processing schemes, focussing on equipment design and development of small-scale equipment for demonstration purposes. A virtual factory tool was developed to select appropriate technologies and process conditions for a specific food product and to predict the effects of these on shelf life and quality. Available equipment was systematically characterised to guarantee its correct use at equivalent process impact conditions. Specific scaling up problems were addressed to solve specific problems that currently limit the introduction of these technologies. For example, one important reason for the limited use of high pressure processing is the low reliability of the equipment currently available. State of the art reference processes and equipment were used to compare the impact of HPT, PEF and cold plasma on product quality. These included also advanced heating technologies.

The **third approach** (**WP 20-23 and WP 28-30**) demonstrated the potential impact of NP schemes on the product quality and shelf life. This was done in two ways. On one hand with an integral project demonstration where products were processed with different conventional and NP schemes and evaluated on quality, sensory characteristics and shelf life. On the other hand with a range of demonstration projects on NP schemes. These projects consisted of research partners in NovelQ and food industries and equipment manufacturers, including SMEs, coming from the Industrial Platform.

A competitive call was organised (described in more detail in subproject 5) for these demonstration projects, resulting in three additional workpackages (WP28-30, organised in subproject 7) and four new industrial partners. In addition to this, demonstration trials were organised. The main emphasis of these demonstration projects was on HP, PEF and cold plasma. However, at the start of NovelQ, pilot scale equipment for these technologies was only limited available. Therefore, the first demonstration projects (WP 21-23) focused on novel applications of advanced heating technologies, while later demonstration projects were on HP and cold plasma demonstration.

2.4.3 Main results achieved

This section gives an overview of the main results achieved. More information can be find in the periodic activity reports and the publications. This section is organised according to the approach described in the previous section.

First approach: hygiene, integrated product handling, environmental impact

Hygienic design and hygienic materials for NP equipment
Activities focused on hygienic design of NP equipment, including research on contact between food and equipment, and optimisation of hygienically acceptable food contacting materials in processing equipment and production systems to deliver safe foods with high quality. Hygienic design is very important for food safety because of its role in ensuring that the equipment does not harbour hazards, e.g. microorganisms, and can be effectively cleaned of material generated during production. For equipment that produces pasteurised/sterilised products, however, the most important function of the hygienic design is providing a barrier to avoid microbial re-contamination. There are three major vectors of microbial contamination: surfaces, liquids and air. Contamination from equipment surfaces can be exacerbated by its process performance e.g. ageing of selected materials during the process and its influence on both organic and microbial cleanability; also temperature, pressure and volume differentials during processing etc. (see table 2.4.1).
Assessments were performed on HP and PEF equipment in industrial and/or pilot processing lines to investigate the potential hygienic risks. Microbiological levels enumerated from the swabbed commercial HP units have been used to make a microbial contamination level database. PEF pilot plant chambers were researched on cleanability of parts and surfaces of insulators and electrodes (possible to dismantle).
Activities resulted in a guideline for hygienic high pressure processing.

Table 2.4.1 Potential sources of microbial contamination during processing

Vectors	**High pressure processing**	**Pulsed electric field processing**
Air	Water transmitting system	
Liquids	Pressure transmitting fluid	
Surfaces	Chamber Closure Carriers Lubricants External packaging	Chamber Electrodes Insulators Seals and joints
Process	Pressure changes Material changes	Material changes

Integrated product handling

For the successful use of NP schemes, it is essential that hygienic product handling can be done in the whole processing and packaging operation. Integration of process and packaging is crucial. For several NP, the product is in-flow treated and has to be packed afterwards. Research was performed to connect these operations, mainly focussing on extended shelf life packaging after ohmic heating treatment. Research activities addressed the specific problems related to products with particles in it. The findings were summarised in guidelines for solving problems of integration of processing and packaging operations.

As manual handling is a major source of food contamination, research was oriented on hygienic handling of food components and packaging utilising various robotic handling and gripping systems. Hygienic manufacturing encompasses the entire operation from the input of raw ingredients to the processing and packaging of the final product. A significant improvement in hygiene can be accomplished by removing, as far as possible, human operators from physical contact with food products and replacing their function with fully automated procedures. A complete demonstrator has been developed to better understand and demonstrate the potential offered by a flexible, hygienic handling system for fragile food products (Figure 2.4.1). Three design of grippers were developed and included in the prototype. This prototype has demonstrated that the concept is valid: with the force gripper and the data extracted from the vision system, each product type can be gripped with a specific set grip force to maintain the product quality under hygienic conditions.

Figure 2.4.1 Robot station during flexible production. Variable and fragile products arrive mixed to the robot and are individually handled and placed according to the layout designed.

Environmental impact of novel processing

Research involved designing environmental efficient production chains for NP taking into account the activities through the whole production chain from raw material to consumer use and waste handling. Environmental efficiency was evaluated using Life Cycle Assessment (LCA) methods (ISO 14040), with addition of socio-economical indicators. LCA studies have been applied to several cases where novel processing technologies have been compared with conventional processing. For example, the results of tomato salsa showed that HP processing has lower energy use (Figure 2.4.2), partly due to more energy efficient processing and as a result of the potential to use more energy efficient packaging. The energy use by the retailer was higher for HP sterilised and heat-treated products even when they are stored at ambient temperature as compared with fresh and HP pasteurised products, which demand refrigerated storage. This is explained by the much longer storage time for HP sterilised and heat-treated products (12 months). Transportation is a significant contributor to all four product life cycles (transportation includes all transport of packaging materials, raw materials and the product up to retailing), but there are only minor differences between the products.

In conclusion, novel processing technologies provide great opportunities to improve the sustainability of food systems by reducing energy use in processing and waste in the food chain. But it is important to consider the entire life cycle of a product when designing the process / system so as to avoid increasing environmental impact from, for example, new packaging, which comes with the technology, or overlooking benefits from options made possible with new technology. Raw material utilisation and waste reprocessing was therefore also studied to design sustainable food production systems.

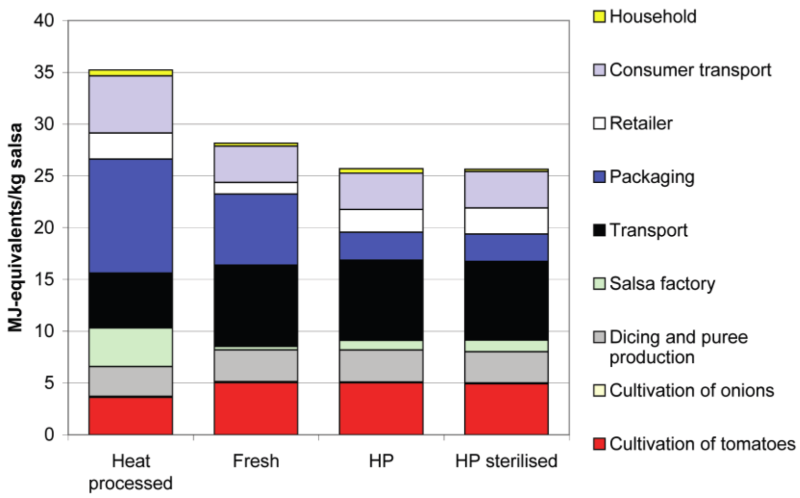

Figure 2.4.2 Use of primary energy in the production of a tomato salsa product.

Second approach: Equipment design and development of novel technologies using an applied and market oriented research approach

Predictive modelling of quality during shelf life

There is a clear need to predict the shelf life of NP treated products. Predictive modelling was performed including the entire production chain, e.g. ingredients (initial microbial load), effects of NP processing, packaging and storage. Shelf life was evaluated with respect to microbiology, quality and nutrients. The main factors determining quality and shelf-life were identified: initial quality and contamination, effect of NP, packaging and storage conditions.

By linking these factors in a model it was possible to predict quality and shelf-life. A shelf life model for PEF and HP treated orange juice was developed using data from the literature and insights from NovelQ (Figure 2.4.3). The model can be applied to predict shelf life based upon microbial and enzymatic spoilage, and determination of processing conditions to obtain a desired shelf life. The model combines microbial inactivation and growth with enzyme inactivation, enzyme rest activity and quality. A user friendly interface was developed and demonstrated to the members of the Industry Advisory Platform.

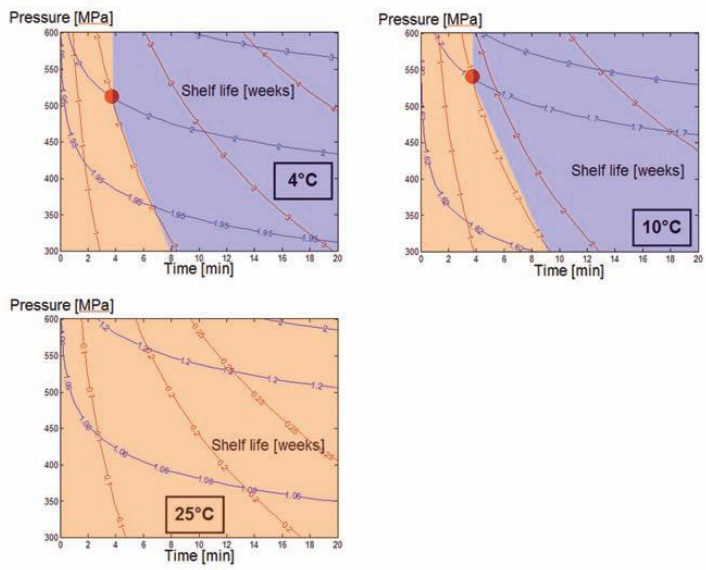

Figure 2.4.3 Shelf life (weeks) of orange juice based on microbial (red) and enzymatic (blue) spoilage as function of pressure (MPa) and process time (minutes).

Decision support system to advice potential users of NP

To enhance the implementation of NP schemes, a decision-support system based on virtual design software was developed. Here, a chain-oriented approach is chosen to investigate the optimal technology and conditions, including cost aspects. The decision support system tool is developed to help potential users of novel processing

technologies to make decisions about the likely benefits for their business. By answering a short list of specific questions, a potential user (e.g. a food manufacturer) can easily evaluate whether a technology is relevant for their products and if implementation is economically feasible. Based on the answers given, a relevant next question is selected. The answers are combined to give an advice on potential interesting novel processing technologies including costs and effects on shelf life and quality (Figure 2.4..4). The tool also includes a menu with extensive information about processing related areas such as packaging, product quality assessment, pre- and post-processing steps and environmental considerations. Newly-marketed product examples have been included in the tool describing the product, its packaging and relevant information such as brand, producer, technology, ingredients, storage conditions, shelf life and market. Possible packaging options are described, in addition to pre- and posttreatment implications of novel processing. The tool was presented to the members of the Industry Advisory Platform and based on their input, adaptations to the system were made. The tool is now available on the NovelQ website for the IAP members.

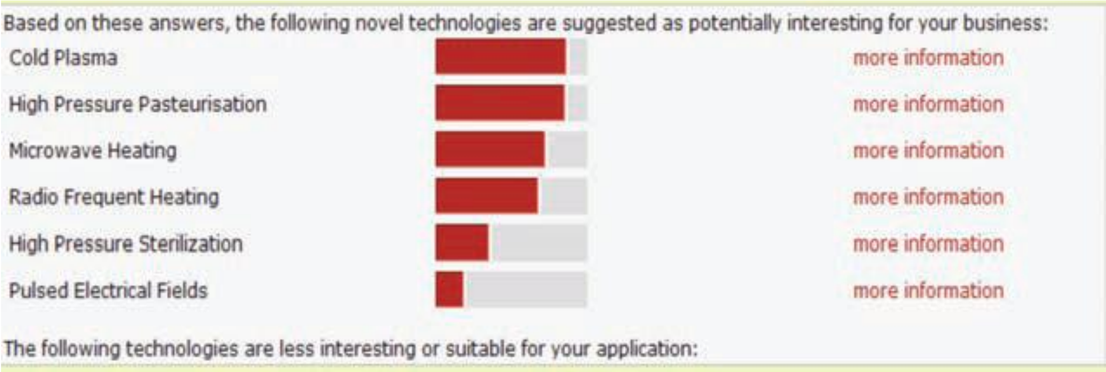

Figure 2.4.4 Example of a ranking of NP in the decision support system

Commercial available NP equipment and rules for scaling up novel processing
For implementation of NP schemes (starting from the end-point of product introduction) it is important that reliable equipment is available on a relevant scale. NovelQ addressed the specific R&D problems that are currently limiting the scaling up of small scale pilot equipment towards production units. Within NovelQ, rules for equipment scale up were given together with solutions of specific scaling up problems. This was done for high pressure pasteurisation and sterilisation, pulsed electric field processing and advanced heating technologies. The outcomes were presented to industry in workshops dedicated to specific technologies, e.g. high pressure processing in Prague and advanced heating in Gothenburg. The results were used as input for the research activities on scaling up novel processing equipment.

Research on specific scaling up problems of HP sterilisation units on industrial scale and problems related to the reliability of these units
High pressure is commercially applied at room temperatures. However, high pressure at elevated temperatures (HPT treatment) will extend the possible application of this technology by giving more possibilities in extension of shelf life combined with high quality and specific product quality improvements that are not possible at room temperature. Research activities focused on all challenges that might be met when up scaling pilot HP equipment to a typical industrial capacity of 1500-2000 l/h. Research was carried out into equipment demands related to HP processing at elevated temperature. Important topics included:

- reliability and safety of equipment: especially leakage of the system, due to sealing of the equipment, occurs frequently at high pressure sterilisation units due to the high temperatures used. Various sealing systems were designed and evaluated (figure 2.4.5).
- maintenance of equipment: for a cost effective high pressure process it is necessary that the time needed for system maintenance is limited. Maintenance protocols were developed to achieve this.
- safety of products processed with HP equipment: inactivation kinetics of micro-organisms when applying high pressure sterilisation conditions were translated in conditions safe in (semi-)production processes and production environment.

- integration of HP equipment in processing: this activity addressed the integration of high pressure in an entire production line, including pre-treatment, packaging and post treatment. Important issues are e.g. temperature control in the entire chain and integration with packaging.

Figure 2.4.5 Part of a high pressure sterilisation unit where sealing is essential at the high pressure vessel and the intensifier used to achieve the high pressure necessary for sterilisation.

Research on cold plasma as disinfection method for surfaces

Cold plasma gas is considered as a disinfection method for food and packaging materials. Before this gas will be used in a food environment several requirements have to be met simultaneously. The plasma gas should be available at sufficient low temperature, on a relevant scale of operation and should fit within a hygienic food production environment. Above all, the gas should be free of toxic compounds. These basic technological requirements were addressed in an early stage of the project. In this way realistic specifications of industrial scale operations were obtained.

Cold plasma treatment was investigated and evaluated on food compatibility, process homogeneity and impact level with respect to microbial efficiency and retention of initial product quality. Based on this findings, together with OMVE The Netherlands, a cold plasma demonstrator was developed that is now commercially available (Figure 2.4.6). The demonstrator is capable to produce a jet of nitrogen plasma without the need of a vacuum at temperatures as low as 40°C and is used in and outside NovelQ to study the effects of cold plasma on micro-organisms and surfaces. Based on the findings of this workpackage and WP 1, the concept of cold plasma as a disinfection tool in a food environment was reviewed and large scale applications that have become feasible from a technical and economical point of view have been identified.

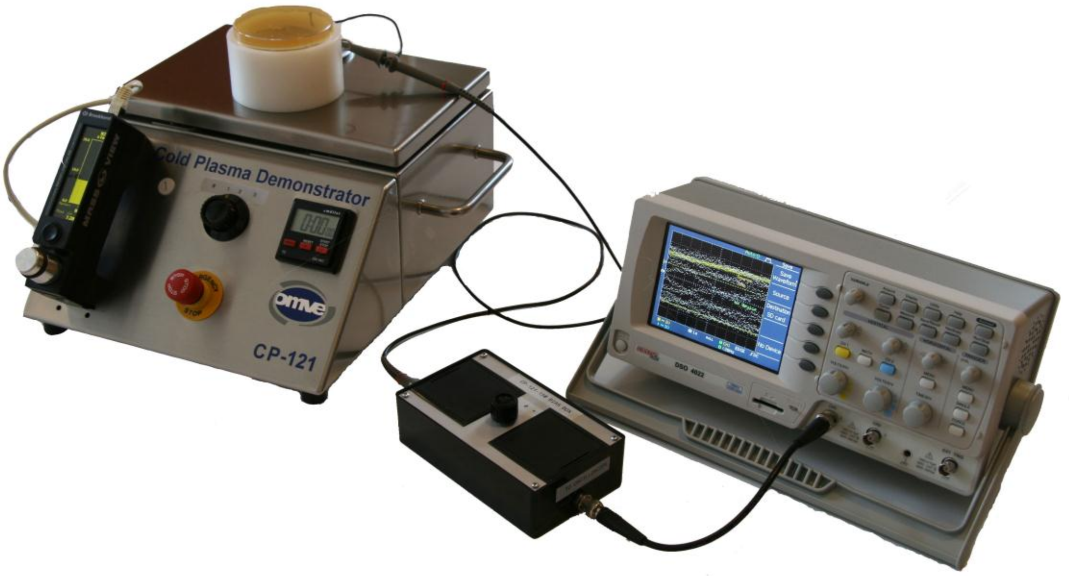

Figure 2.4.6 Cold plasma demonstrator developed in NovelQ with OMVE The Netherlands

Characterisation and specifications of small scale pilot processing units

Within the project, a range of processing units was used to evaluate the possibilities of novel processing schemes. Their specifications were evaluated and described in a database on the project website.

When evaluating the possibilities of novel processing for application in the food industry, companies often perform a feasibility study first on lab or pilot-scale level. It is important that these experiments are performed in a consistent and harmonised manner, e.g. in such a way that the results can be compared and objectively judged. Moreover, it is crucial that results from scientific literature and professional journals are used as reference, allowing to compare pros and cons. The partners in NovelQ developed a procedure assuring that all partners used the same research protocols for similar equipment. The procedure was tested in practice for high pressure equipment – operated at a wide range of processing conditions – that is available in the laboratories of a substantial number of NovelQ partners. Figure 2.4.7 shows the temperature of pressure transmitting media and pressure profiles of four different high pressure units during a standard experiment at 500 MPa and 25°C starting temperature. It can be concluded that it is absolutely necessary to carefully characterise the used equipment and compare the equipment conditions at lab or pilot-scale with industrial scale units.

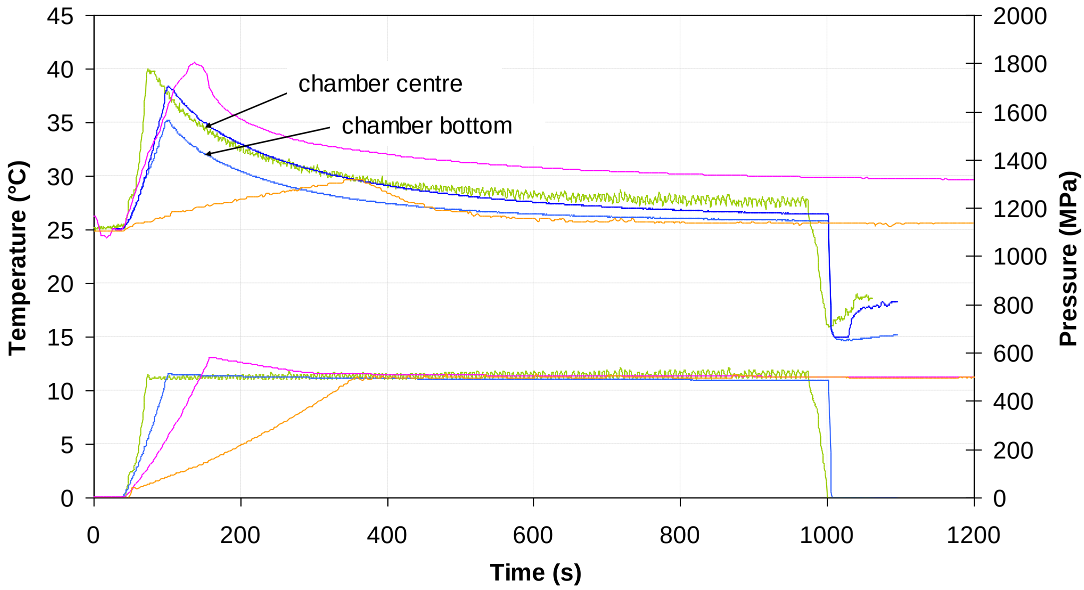

Figure 2.4.7 Example of pressure (lower part of graph) and temperature (upper part) profiles during HP treatment at various research units.

Third approach: demonstration of product improvement using NP technologies

Integral demonstration of product achievement using NP

The aim of the integral demonstration activities was to evaluate the general application and viability of NP schemes by comparison of the effect of NP processing and conventional processing at equivalent processing level and to provide a guiding document for application of NP schemes.

In the first integral demonstration, orange juice was treated with high pressure, pulsed electric field treatment and mild heat pasteurisation at equivalent microbial inactivation level and as reference an untreated juice was used. One batch of orange juice was used for the different treatments. The samples were analysed on microbial, physical, and chemical aspects during shelf life. In addition to this, sensory evaluation and consumer preference was researched. These results are described in subproject 3. In general, this integrated demonstration showed, that both pulsed electric field treatment and high pressure processing can substantially increase the shelf life of fresh orange juice while maintaining its fresh characteristics. The fresh juice spoiled between 9 and 20 days, while the NP treated juices were still unspoiled at up to two months chilled storage (see Figure 2.4.8).

An integral demonstration of non-acid solid food (carrots) was executed to show the effects of NP on solid foods. During this study, mild and severe heat pasteurised and heat sterilised carrot pieces were compared with mild and severe HP pasteurised and HP sterilised carrot pieces respectively. Additionally, for the two sterilisation processes, the effect of Ca2+ addition to the brine and low temperature blanching as pretreatment was studied.

In addition to this, specific comparisons were performed for high pressure sterilisation of high added value products. As this technology will be relatively expensive, it is foreseen that especially complex food products with high added value will profit from this technology. Product developed was done for ready to eat meals and vegetable dips resulting in an evaluation of the effect of high pressure and heat sterilisation on sensorial attributes of these products.

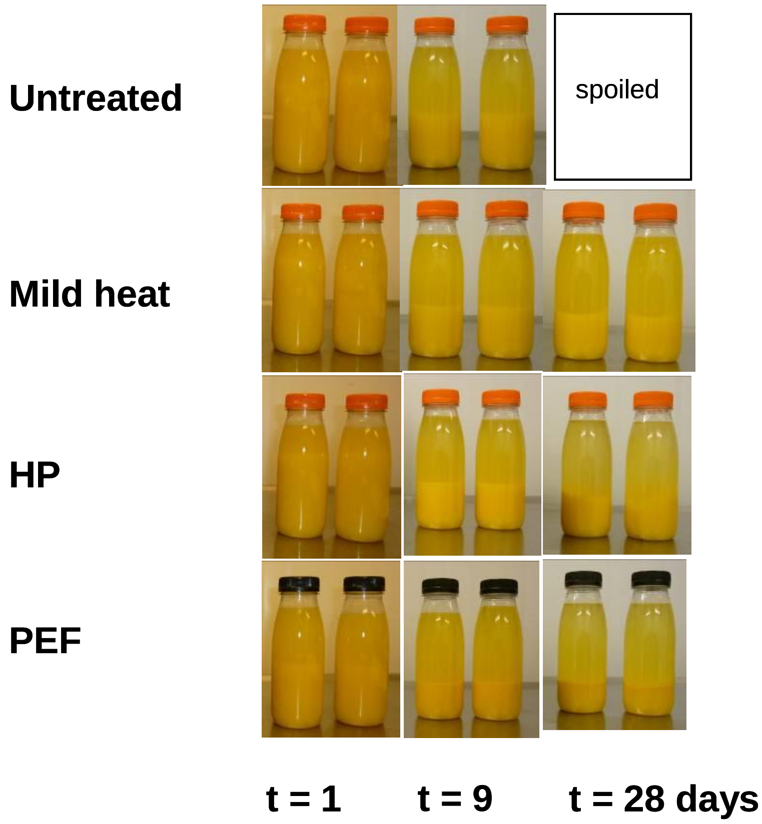

Figure 2.4.8 Photographs of untreated and HP, PEF and heat pasteurised orange juices during shelf life.

Demonstration projects

To enhance the implementation of novel processing, demonstration projects were part of NovelQ. These projects consist of research partners in NovelQ and food industries and equipment manufacturers, including SMEs, coming from the Industrial Platform.

At the start of NovelQ, three demonstration projects were included on novel applications of advanced heating technologies. A competitive call was organised (described in more detail in subproject 5) for these demonstration projects, resulting in three additional workpackages and four new industrial partners on HP and cold plasma demonstration.

Demonstration projects on novel applications of advanced heating technologies

- Minimal pasteurisation/sterilisation technology by application of water immersed radio-frequency heating for food products in consumer packages.
- Design of ready-to-eat meals compositions for uniform microwave heating
- Ohmic heating technology of highly viscous pumpable foods with particles

Demonstration projects on novel technologies

- Cold plasma treatment for inactivation of microorganisms on food surfaces
- Packaging materials for high pressure sterilisation
- High pressure processing of healthy, complex food products

Demonstration trials

In addition to the demonstration projects, where companies became partner of NovelQ, IAP members mentioned that they were interested in short feasibility studies to evaluate if NP could be interesting for a specific product. NovelQ recognised that this could be a good opportunity to enhance the implementation of NP. The NovelQ consortium offered therefore demonstration trials at partner organisations, in different regions in Europe to IAP members. The aim was to demonstrate on pilot scale the possibilities of a specific novel technology (HP pasteurisation, HP sterilisation, PEF, cold plasma, advanced heating technologies) for a specific product – with or without being packed in a novel package material – by performing a trial in 1 or 2 days.

The partner and the IAP member defined the experimental set-up, performed the experiments and reported them. The NovelQ partner enabled access to its NP equipment, operated the equipment and gave input for NP processing. The IAP member provided the materials for the trial (e.g. food products, packaging material, processing tools) and knowledge of the product to be tested.

10 companies together with a NovelQ partner have demonstrated new applications of advanced heating and novel processing. The applications tested include:

- Ohmic heating of fruit preparations
- High pressure processing of cereals products
- Robotic handling of delicate products
- High pressure processing of dairy products
- Continuous microwave heating
- Microwave drying of waste products
- Microwave drying of cereals
- High pressure sterilisation of vegetables

2.4.4 Main dissemination activities

Sub-project 4 and 7	
Scientific publications	10
Book Chapters	6
Technical articles submitted in professional magazines	30
Major international conference papers presented	30
Workshops/meetings organised	6
Other: web based tools developed	2
Thesis	2
TCD contributions (oral, posters)	3
Draft papers, planned papers, planned conferences	10

2.4.5 Interaction with other Sub-projects

Interaction of sub-project 4 with other sub-projects:

- **Sub-project 1**: Sub-project 4 delivered modifications to HP equipment available at the partners of Subproject 1 to make this equipment suitable for high temperature use. The basic research results from Sub-project 1 were used in the R&D activities in Sub-project 4, including models and kinetic data, sensors for characterisation of equipment and process impact and mechanistic insight. Sub-project 1 delivered scientific input for the integral project demonstration and the specific demonstration projects.
- **Subproject 2**: Sub-project 4 researched process homogeneity of cold plasma treatments. This was used to study the effects of cold plasma on packaging materials as studied in Sub-project 2. Insight from Sub-project 2 was used in the decision support system and predictive modelling activity in Sub-project 4. The results of Sub-project 2 were used for integrated product handling and packaging and to develop hygienic materials for NP equipment. Sub-project 2 delivered scientific input for the integral project demonstration and the specific demonstration projects.
- **Sub-project 3**: Sensory data and research results on consumer attitude were included in the decision support system in Sub-project 4. These results were also used in the demonstration projects. Sub-project 4 delivered the samples of the integrated demonstration of orange juice for sensory and consumer evaluation.
- **Sub-project 5**: Sub-project 4 delivered all necessary input for dissemination and training activities in Sub-project 5. The Industry Advisory Platform developed in Sub-project 5 gave advice on specific workpackages in Sub-project 4. The demonstration projects in Sub-project 4 were carried out with companies via an competitive call procedure; they were also member of the Industry Advisory Platform. The demonstration trials were performed with members of the IAP.
- **Sub-project 7**: Sub-project 7 provided input to the hygienic processing with HPP in WP12. Moreover, sub-project 4 treated packaging material with high pressure high temperature processes to evaluate if these packaging materials were suitable for high pressure sterilisation.

Interaction of subproject 7 with other sub-projects:
This sub-project has strong links with the basic research in Sub-projects 1 and 2, the consumer perception of product and process addressed in Sub-project 3 and the dissemination and technology transfer in Sub-project 5. Examples of specific links are:

- The integral demonstration of product improvement using NP technologies (WP 20) combined basic science results (Sub-projects 1 and 2), consumer acceptance results (Sub-project 3) and dissemination and technology transfer (Sub-project 5).
- The demonstration projects (WP21-23) were set up in direct link with Sub-project 5 and used results generated in Sub-projects 1-4.

2.4.6 Conclusion

Activities in Subprojects 4 and 7 had the overall objective to facilitate and speed up the introduction of novel processing in the food industry. 22 partners, including universities, research organisations, equipment suppliers and (food) industry, worked together in 15 workpackages to achieve these objectives.

They successfully worked on hygiene, integrated product handling and environmental impact of novel processing, resulting in:

- insight in the hygienic risks associated with high pressure and pulsed electric field processing and methods to reduce these risks
- guideline for hygienic high pressure processing
- guidelines for solving problems of integration of processing and packaging operations related to ohmic heating treatment
- demonstrator of a flexible, hygienic handling system for fragile food systems including three designs of grippers
- life cycle analyses of novel processing technologies showing opportunities to improve the sustainability of food systems by reducing energy use in processing and waste reduction in the food chain.

Equipment design of novel processing equipment was researched and novel technologies were developed using an applied and market oriented research approach, resulting in:

- predictive model of quality and shelf life of products treated with high pressure and pulsed electric field processing that is available for IAP members at the website of NovelQ
- decision support system to advice potential users of novel processing and to give information to them
- rules for equipment scale up together with solutions to overcome specific scaling up problems
- specific solutions for scaling up of high pressure sterilisation units
- technology requirements of cold plasma processing, resulting in a cold plasma demonstrator that is now commercially available
- database of NP units used in the project and procedures to assure that research results from different units are comparable.

Demonstration of product improvement using novel processing resulted in:

- a comparison of HP, PEF, mild heat treatment at equivalent microbial inactivation level on orange juice
- a comparison of HP and heat treatment at pasteurisation and sterilisation level of carrot pieces
- product development and comparison of HP and heat treatment on high added value products like ready-to-eat meals and spreads/dips.
- Six demonstration projects with industry on novel processing
- Ten short demonstration trials showing new applications of novel processing.

2.4.7 References

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- J. Davis, G. Moates, K. Waldron. PEF and HP: environmentally friendly procesing? A case study of carrot juice. HC Mastwijk, K Knoerzer, C Versteeg. Atmospheric based gas discharges. In: C. Doona, K. Kustin, F. Feherry Case studies in novel food processing technologies. January 2010.
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- Toxicological aspects of preservation of food by pulsed electric fields. A.M. Matser, H.J. Schuten, H.C. Mastwijk. In Food preservation by pulsed electric fields. From research to applications. Eds. H.L.M. Lelieveld, S. Notermans, S.W.H. de Haan, Woodhead Publishing, 2007, p. 201-211.
- Future potential of pulsed electric field treatment: treatment of bacterial spores, emulsions and packed products. H.C. Mastwijk, P.V. Bartels. In Food preservation by pulsed electric fields. From research to applications. Eds. H.L.M. Lelieveld, S. Notermans, S.W.H. de Haan, Woodhead Publ. 2007, p. 307-319.
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- New Food NovelQ issue Hygienic design of novel processing equipment, October 2010.
- Sonesson U., Novel processing and sustainable food production – a perfect match or not?, New Food, (2010), 5, 40-41.
- Publication about first NP shelf life model in Dutch food magazine VMT, September 2008.
- Article in special issue of New Food: Predictive shelf life modelling of orange juice treated by novel processing, October 2010.
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- WUR ontwikkelt hoge druksterilisator. News item website Elsevier Voedingsmiddelenindustrie, July 2007.
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- Duivels houdbaarheidsdilemma, de Grootte, Yves. Voedingsmiddelentechnologie, 2007, 7 September, nr 18/19, p 30-32.
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- Special issue New Food From lab scale to pilot scale, A. Matser, M. Houška, H. Mastwijk. October 2010.
- Technical information entitled “Characterisation of a pilot plant of continuous heating treatment: the ohmic heating” August 2007.
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- Vers onder druk. VMT no 24, frontpage + page 18- 20. Magazine for food processing industry in Benelux, nov-08.
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- Le High pressure food processing, ou la pasteurisation à froid. Alfons Caders in Industrie Technique et Management, June 2009.
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- Report entitled “industrial problems related to the integration of continuous processing and packaging equipment”, August 2007 .
- Research Summary Sheet Novel processing methods for the production and distribution of high-quality and safe foods (NovelQ). Sheet 4. Determination of the degree of survival of microorganisms within High Pressure (HP) processing systems, August 2010.

<u>Selection of workshops organised by NovelQ and presentations given on these workshops</u>

- Hygienic design for novel processing, Dr. John Holah, NovelQ and PathogenCombat Workshop, Ljubjana, Slovenia, nov-08.
- Sensitive, hygienic and flexible grippers for robotic food handling, SIK, invited guests from food industry in Sweden, robot station and gripper demonstration. Färsk Forskning, (member days at SIK), 12-03-2008.
- Sterilisation of foods with high pressure, challenge or reality, Presentation of A. Matser, at the Workshop HP processing application in industry, 30 May 2008, Prague, Czech Republic.
- Experience with production of fruit - vegetable juices treated by HP, presentation of M. Houska at the Workshop HP processing application in industry, 30 May 2008, Prague, Czech Republic.
- AM Matser. Development and demonstration of novel food technologies. Presentation High Q RTE NovelQ workshop on non thermal technologies. Bologna. September 2009.
- Sensitive, hygienic and flexible grippers for robotic food handling. SIK, invited guests from the food industry in Sweden, robot station and gripper video presentation, December 2009.

<u>Selection of posters and presentation on TCD activities</u>

- Optimisation of microwave heating uniformity, Seminar on “Färsk forskning”, SIK, 7 Feb 2007H.J Schuten. Effect of cold nitrogen plasma on whey protein stabilized emulsion. NovelQ Training and Career Development Meeting, Basic insight in novel technologies for food processing and preservation, 10-11 January 2007, Belgium.

- Development of flexible and sensitive end effectors for food products, Berlin, Anders Petterson, September 2008.
- H. Mastwijk. Basic principle, process boundaries and 'state of the art' industrial applications of plasma processing. NovelQ Training and Career Development Meeting, Basic insight in novel technologies for food processing and preservation, 10-11 January 2007, Belgium.

Selection of presentations

- New technologies: ensuring hygiene standards. Dr. John Holah, Trygg mat – Nytt regelverk, Nofima Norconserv, Stavanger, Norway, April 2009 .
- Potential for microbiological spoilage in high pressure processed foods. Edyta Margas and Dr. John Holah, International Association for Food Protection, Grapevine Texas, July 2009.
- Hygienic design issues for emerging preservation technologies, Edyta Margas, Emerging Technologies Panel, May 2010.
- Project presentation at Food Manufacturing Engineering Group (FMEG), "control & automation for sustainability& quality in food manufacturing", 16 May 2007.
- Sensitive, hygienic and flexible grippers for robotic food handling. Control 2008, Manchester,UK, 3 Sept. 2008.
- Sustainability of novel processing technologies, a European perspective, Presentations by Thomas Ohlsson and Ulf Sonesson "LCA: Joining up the food chain"at TOTAL FOOD 2006, The Hague, The Netherlands, 7-9 November 2006.
- Environmental assessment of novel processing technologies in the food industry : oral presentation at TOTAL FOOD 2009, Norwich, UK, 22-24 April 2009.
- Processing developments for liquids, A. Matser, Anuga Food Tech, 3-4 April 2006, Köln, Germany.
- High pressure preservation. A. Matser, Workshop VIGEF, 13 November 2008, Gorinchem, NL.
- AM Matser Milde conservering: hoge drukpasteurisatie. Presentation meeting Meat Industry, Wageningen, March 2009.
- A.M. Matser. Novel Processing. Guest lecture Process and Product Technology, University of Applied Sciences, Van Hall Larenstein, Wageningen, audience: students, 19 mei 2009.
- A.M. Matser. Convenience fresh-like food processed by novel environmental friendly preservation methods. Presentation at Stork Food & Dairy Systems Novel Processing Symposium, 19-20 August 2010, Amsterdam.
- Lecture on conference at CTU "New technologies of food preservation" (in Czech), Milan Houska, September 2007.
- Raaholt, B., Janestad, H., and Vinsmo, L.-G., Demonstration of the usefulness of Electromagnetic Modelling in Product Development Work: Microwave Defrosting, Tempering, and Heating of Ready Meals, oral presentation at 11th Conf. on Microwave and High Frequency Heating, Oradea, Rumania, 4th of September, 2007.
- Gepascaliseerde Vezet Smoothie: NVVL FNLI symposium, Utrecht, November 2009
- Presentation Novel food processing and preservation technologies. PathogenCombat workshop. Ghent January 2010.

Selection of posters

- Survival of microorganisms in HPP systems and the potential for leaker spoilage, July 2010.
- En robot som är lätt på handen (trans eng "A robot with a soft touch". A poster presenting WP13.2 and describing the project in general terms. Presented at the "Färsk forskning" (fresh research) – day at SIK where the latest projects at SIK are presented for industry and researchers. February 2007.
- Thermal diffusivity of mashed potatoes and olive oil at high pressure. Poster presented at EHPRG 2009, M Houska, A Landfeld, J Strohalm.

Thesis

- Thesis "Development and application of an ATP bioluminescence method to assess biofilm survival on materials used in pulsed electric field equipment", at Chalmers Institute of Technology, Gothenburg, Sweden, presented at seminar in Gothenburg, 11 June 2007.
- Thesis Anders Petterson Hygienic design of grippers and automatic handling system.

2.5 Dissemination, Technology Transfer and Training and Career Development Network: description of main results from Sub-project 5

2.5.1 Introduction to Sub-project 5 including main objectives, contractors involved

The overall objective of Sub-project 5 was to maximise acceptance of new technologies by dissemination of information, knowledge-transfer to stakeholders in a targeted manner, and to train young scientists in NovelQ at the beginning of their career to ensure they were positioned best to respond to future opportunities.

The three activities in the Sub-project 5 are grouped together; each was crucial for maximum impact within the consortium and amongst stakeholders:

WP 24 – *Dissemination* and interaction with stakeholders within and beyond the consortium. This WP addressed dissemination amongst project partners and with stakeholders outside NovelQ including consumers, which took into account their needs (link with Sub-project 3).

WP 25 – *Technology transfer* from research to industry. This WP focused on discussions with potential manufacturers and users of novel technologies, making it clear to both the capabilities of novel technologies. To facilitate these discussions and bring together industrial stakeholders, and obtain their feedback on project activities, an Industry Advisory Platform (IAP) was established at the start of the project. This WP also developed documentation (e.g. business cases) describing novel technologies, which explained potential or existing (dis)advantages and cost implications. Discussions between the IAP and NovelQ researchers/management were reported to relevant WP and experts from different WP were invited periodically to present their latest results at IAP meetings.

WP 26 – *Training and Career Development* Network was established for early-career NovelQ researchers and given high priority. The aim of the Training and Career Development Network (TCD) was to create enthusiasm and self-confidence, and to pass on knowledge and experience in areas including science communication, teamwork, project management, and understanding stakeholders' needs. A team of senior experts coached them throughout the project, allowing to get views from experts outside their immediate working environment (e.g. from other universities and research centers).

The contractors involved in Sub-project 5

#	Partner	Expertise	Involvement in SP5	
1	A&F	industry-oriented working approach, organisational expertise relevant for workshops, communication and PR skills	SP5 WP24 WP25	Coordinator WP leader WP leader
2	Campden BRI	membership-based system , experience in training sessions for industry	WP24	
3	SCA	member of BEUC, direct involvement in communication towards consumers	WP24	
4	EFFOST	links to numerous sister organisations in and outside Europe	WP24 WP25	
5	Unilever	an industry partner and member of ETP Food for Life	WP25	
6	IFR	science communication, outreach and public engagement for EU-funded instruments	WP26	WP leader
7	KEKI	consumer science, knowledge on ethical issues and dissemination expertise	WP24 WP26	
8	KULeuven	Chair of Training and Career Development Network (months 1-36)	WP26	

2.5.2 Working approach

The working approach was oriented towards knowledge-transfer, removing barriers and improving the communication internally and externally about novel processing (including training).

Dissemination and interaction with stakeholders within and beyond the consortium as well as training of early-career NovelQ scientists was achieved through the following instruments:

- Publication and dissemination of **written and visual documentation** about novel processing in English as well as local languages

  In parallel with scientific publications (produced by Sub-projects 1, 2 and 3), special emphasis was put on dissemination of NovelQ results for industry, consumer (organisations) and the wider public. Scientific articles arising from NovelQ were converted to more popular publications and submitted to (inter)national food oriented trade magazines with industrial readership. To make writing these articles easier, guidelines on how to write more accessible publications were developed and – on request – sent to NovelQ authors with less experienced/ confidence about writing for a broader audience.

Business cases for industrial stakeholders and students (14-21) on novel processing were disseminated. Other kinds of dissemination material such as videos have also been developed to help spread information about the project.

- Organisation of **meetings** and other **NovelQ (public) events**
  Annual meetings for project partners, tailor-made training events and workshops, targeted meetings with other EU projects, brokerage events and debate sessions were organised for partners and stakeholders as well as dedicated events orientated to the needs of industry and research including international science conferences and (novel processing) exhibitions. Meetings were organised in different European countries to ensure project information was disseminated equally in all regions.

- Communication via the **project website** is one of the most important tools for dissemination. The NovelQ website was developed and divided into public pages, partner section, and sections for industry and early-career NovelQ researchers and monthly updated.

- Establishment of the **Industry Advisory Platform**
  For effective transfer of novel processing technologies to potential users and to ensure NovelQ focused on topics relevant to industrial stakeholders, an Industry Advisory Platform was set up at the start of the project. The Platform has been opened to companies and other (private) organisations interested in novel processing during the lifetime of the project in order to allow new parties to step in once NP were becoming of interest to them.

- The **Training and Career Development Network** was established following the NovelQ kick-off meeting in 2006. TCD organised bespoke scientific and career development training for early-career researchers associated with NovelQ and related projects. This training offered practical and theoretical learning about novel technologies and their exploitation as well as equipping individuals with a wide range of background knowledge and practical (soft)-skills to enhance and promote career development. TCD activities enjoyed a strong support from NovelQ senior scientists, many of whom are still mentors for TCD members.

2.5.3 Main results achieved

Dissemination activities within and beyond NovelQ consortium

a. meetings, workshops and contributions to international conferences
NovelQ dissemination materials, e.g. NovelQ flyer, project poster, standard presentation, NovelQ banners each presenting one of the novel technologies as research in NovelQ, were developed and presented on different occasions.

To present the project findings to a wider audience, NovelQ (jointly) organised 27 meetings of which were 11 public workshops as listed below:

Targeted audience: science community
(organised by NovelQ unless stated otherwise)

- Consumer acceptability of new foods and food technologies: What can be done to prevent problems before they occur? (February 2007, Budapest, HU)
- Existing and forthcoming novel processing methods (November 2007, in parallel with EFFoST 2007, Lisbon, PT)
- Joint workshop with PathogenCombat, Networking in Europe in the area of hygienic design in novel processing (November 2008, in parallel with EFFoST 2008, Ljubljana, SI)
- Joint workshop with DoubleFresh, Ultra fresh and chilled meals (April 2009, Wageningen, NL)
- Joint workshop with HighQ RTE, Non-thermal technologies: impact on food safety and quality (September 2009, Bertinoro, IT)
- Joint workshop with representatives of HighQ, Double Fresh and Healthy Structuring at SIK, Sweden, February 2008.

Targeted audience: industry
(organised by NovelQ unless stated otherwise)

- Novel processing methods for the production and distribution of high quality and safe food (July 2007, Campden, UK)

- HP utilisation in the food industry (May 2008, Prague, CZ)
- High pressure processing for safe high quality seafood (September 2008, Stavanger, NO)
- Success stories in advanced heating technologies (February 2011, Gothenburg, SE)
- Possibilities of HPP in (near) fresh foods (Mini-symposium, May 2010, Monster, NL)

Targeted audience: BEUC food officers, consumer groups, Commission
(organised by NovelQ unless stated otherwise)

- Impact of novel processing nutritional, quality and safety aspects and impact of novel processing on sustainability (BEUC Food Officers meeting, November 2009, Brussels, BE).

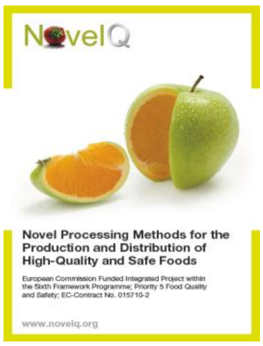
- NovelQ and its progress: SCA reported periodically on relevant NovelQ activities at BEUC Food Officers Meetings (June 2006 Athens GR, November 2006 Brussels B, June 2007 Bled SI, November 2007 Brussels B, June 2008 Parma IT, November 2008 Brussels B, June 2009 Berlin GE, November 2009 Brussels B and October 2010 London UK).
- Presentation on NovelQ activities during the visit of Dr. Janez Potocnik and Dutch Cabinet and the EU Commissioner to Wageningen (19 February 2008, NL).

Targeted audience: NovelQ partners
Six annual project meetings including WP meetings and visits to partner organisations

Subject to the scope of meetings and targeted audiences, workshops were organised as a stand-alone event or in parallel with international conferences and symposia. In addition to these meetings, information about NovelQ has been presented at a variety of scientific conferences including European Federation of Food Science and Technology (EFFoST) Annual Conferences, IFT (Institute of Food Technologists) meetings, IUFoST conferences, IFT Nonthermal processing division meetings, European Hygienic Engineering Design Group (EHEDG) conferences, Food Factory of the Future and EuroFoodChem meetings. NovelQ has also been presented at food (processing) exhibitions and fairs such as ANUGA (Germany) and IPA (France) as well as other regional meetings with national focus. Altogether, more than 100 (oral and poster) presentations were given.

Other forms of communication were used to disseminate information about the NovelQ such as radio interviews, TV/ film via DG Research and creation of a short video on the use of high pressure processing equipment.

b. publications in food magazines
As well as scientific publications (as reported in the NovelQ Scientific Sub-projects), NovelQ contributed to a range of food-oriented magazines in an attempt to reach as wide an audience as possible and, in particular, industrial readers and consumers. Special emphasis was placed on converting scientific publications into more accessible versions for the wider public. More than 60 articles, instead of the 12 originally promised, were published in, for example, Food Safety Magazine, New Food, Food and Beverage International as well as national magazines and newspapers. In order to address consumers' needs, the Slovenian Consumer Organisation (member of BEUC) prepared an e-brochure describing novel technologies and important NovelQ results. This brochure has been disseminated to, among others, BEUC food officers, Consumer International Association and EFFoST.



In the final year, contact was sought with New Food Magazine, which has a readership of 35,000 with a view to producing a Special Issue. Discussions with New Food resulted in the NovelQ Special Issue published in October 2010 featuring the following articles:
- Industrial applications of novel processing technologies
- Decision support tool to select appropriate technologies for specific industries

- Demonstration of novel technologies
- Packaging challenges for novel processed food
- Hygienic design of novel processing equipment
- How to compare novel and conventional processing methods in new product development: case study on orange juice
- Hygienic assembly and transfer of food products: A demonstration system for the automatic processing of vegetables
- Predictive shelf life modelling of orange juice treated by novel processing
- NovelQ processing and sustainable food production: a perfect match or not?
- The NovelQ 10C approach towards SMEs
- Interview with Dr. Jürgen Lucas

This issue has been widely distributed to NovelQ partners, the Industry Advisory Platform members, New Food subscribers, the European Commission, EFFoST 2010 delegates and others. Subsequent feedback suggests it was well received amongst industry readers.

c. Joint actions with other running FP6/7 projects

NovelQ sought contact with other FP6 related projects (i.e. DoubleFresh, HighQ RTE, Healthy Structuring and PathogenCombat) as well as FP7 projects (e.g. AgriFoodResults and High Tech Europe Network of Excellence) in order to identify common opportunities and synergies. This resulted in a number of joint actions such as public workshops (as described above), 3D-animations developed by an FP7 project on disseminating EU project results (AgriFoodResults), nomination of NovelQ for the AgriFoodResults Communication Star award for the best dissemination, and presentation of HighTechEurope (FP7 Network of Excellence) project activities to the Final Industry Advisory Platform Meeting (as described below). In addition, PhD students from other EU projects including Healthy Structure, PathogenCombat, MoniQA, EuroFir, Dream, MycoRed, InsideFood and some small industry projects as well as those from NovelQ attended the NovelQ PhD Symposium, BerlinFOOD (September 2010, Berlin, DE) (see also Chapter Training and Career Development Network).

d. Dissemination *via* NovelQ website and web-based dissemination tool

At the start of the project, NovelQ's website was developed for internal and external dissemination. The website is divided into a *general visitor part* and three login sections: a *partner section* for exchange of project information amongst NovelQ partners, an *IAP section* designed for communication and information exchange with industrial stakeholders (Industry Advisory Platform members) and the *TCD section* for NovelQ early-career scientists. Information in each section has been updated regularly during the lifetime of the project.

In the final year of the project, a web-based tool for dissemination was developed to present NovelQ results via a virtual *factory* for novel processing equipment, *supermarket* stocking NovelQ products, *kiosk* for publications and a *map* of Europe for TCD members.

Each category contains NovelQ information, which can be downloaded. This tool has been made available to NovelQ partners and Industry Advisory Platform members via the website.

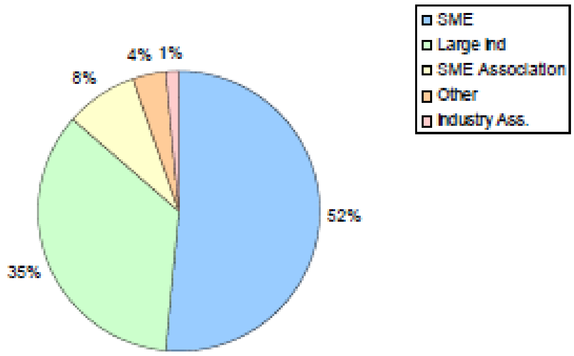
NovelQ was also selected to provide information for an EU website describing successful innovation projects financed by the European Community. The EU website can be accessed via http://bit.ly/hGYTT2.

Technology transfer via Industry Advisory Platform

a. Industry Advisory Platform

To ensure that technologies, once proven to be suitable for application, are indeed used to the benefit of industry, an Industry Advisory Platform was established. Initially, 30 enterprises signed a Letter of Support to indicate their willingness to participate in NovelQ. The numbers of IAP members steadily grew to 88 at the end of the project, of which 52 percent are SMEs (see figure below).

During the lifetime of the project, the IAP was open to private companies (food manufacturers, equipment suppliers or packaging firms) and other (inter)national organisations interested in novel processing technologies.

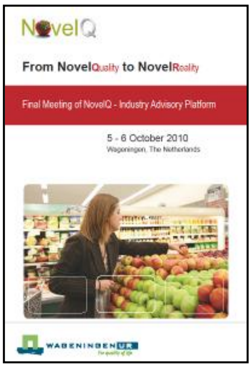


IAP members have been informed regularly about relevant project activities and applicable results emerging from the project via, for example, the NovelQ IAP website, newsletter (twice a year) and presentations at IAP annual meetings. Business cases describing novel technologies – elucidating advantages and disadvantages of novel technologies – were also developed for IAP members. In return, they have been asked to participate actively in IAP annual meetings and give input and feedback on NovelQ project activities.

In total, five IAP meetings were organised at which NovelQ outcomes and progress were discussed. The IAP annual meetings were hosted by members (Stork FDS [NL], NC Hyperbaric [ES]), NovelQ partners (Univ. of Lleida [ES], Univ. Montpellier II [FR], Wageningen [NL]) or held in

parallel with an international exhibition (ANUGA fair, GE). An industrial tour was organised for IAP members to provide an industrial perspective of high pressure processing and pulsed electric field. The tour included visits to three Spanish companies with novel processing equipment.

In October 2011, the final IAP meeting presented results from NovelQ, and included a mini-symposium, a debate on future aspects of European food research, and a technology market with novel processing equipment demonstrations and product tastings. The meeting was attended by almost 60 IAP members.



The IAP has contributed significantly to dissemination of project results for industrial stakeholders and enabled a better understanding of novel processing techniques within the industry as well as understanding of industrial needs amongst researchers. Below are some comments from IAP annual meetings:

- *"Good level of presentations", "Find a way to make IAP more visible in the food industry", "List of product with NovelQ technologies would be appreciated", "More product samples, more tastings!", "Sharing internally is key", "Looking forward to good use of IAP website", "Good networking opportunities", "Good atmosphere, useful informal discussions"*

b. Pulsed electric field to save lives

At the second IAP meeting, discussions between EFFoST and OMVE (IAP member) were initiated regarding a new application for pulsed electric field and safe water. The aim was to produce a small, robust PEF unit capable of generating safe drinking water in third countries, generally, but in particular (natural) disaster areas (e.g. flooding, earthquake). These discussions led to organisation of a safe-water workshop (October 2009, NL) and construction of a small prototype as well as a report on the needs and opportunities for PEF in generating safe drinking water.

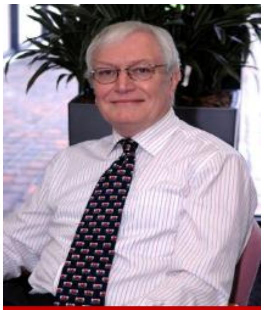
c. Technology transfer via direct industrial involvement

In order to increase technology transfer and enable industries interested in novel processing to join NovelQ, a competitive call for new industrial partners was organised during the second year. This competitive call resulted in three new demonstration work-packages and four new industrial project partners (all SMEs).

During the third and fourth years, IAP members were invited to take part in the proof-of-principle demonstrations organised by the NovelQ project. The aim was to show on pilot-scale the potential of novel technologies for real food products by performing proof-of-principle processing for one-two days. IAP members could participate in these demonstrations and test their products using novel processing pilot-scale facilities located at NovelQ partner sites throughout Europe. In total, 10 proof-of-principle demonstrations were performed (see Sub-project 4).

Training and Career Development Network


Professor Indrawati Oey, University of Otago (New Zealand)


Professor Roger Fenwick (IFR, UK)

Discussions with young persons attending the NovelQ kick-off Meeting held in Wageningen in February 2006 led to the establishment of NovelQ – Training and Career Development Network. The day-to-day activities of TCD Network such as communication and planning across national borderd were carried out by Dr. Indrawati Oey (TCD chair) and Roger Fenwick (IFR, WP 26 leader) who was succeeded by Dr. Sian Astley (IFR) in the 3rd project year.
Thanks to the enourmous effort of Dr. Oey supported by WP 26 leaders as well as Professors, Hendrickx and Knorr and others, in total 10 TCD meetings were organised during the NovelQ project period, including two public symposia: NovelQ-EFFoST 2009 PhD symposium and NovelQ Berlin Food PhD Symposium in 2010.

In parallel with their academic learning, graduate students in NovelQ and related EU-funded instruments, the Training and Career Development Network (TCD) included:

a. Visits to universities (e.g. KULeuven [BE], TUB [DE]) and commercial sites (e.g. Stork pilot plant in Indulleida [ES])
b. Networking with and mentoring by senior researchers (e.g. Huug de Vries, Huub Lelieveld, Professor Antonio Delgado)
c. Opportunities to practice and develop science communication skills (e.g. science communication training workshops, NovelQ-EFFoST 2009 PhD Symposium)
d. Workshop on writing and managing project proposals (RTDS, AT, February 2010)
e. Participation and organisation of scientific meetings (e.g. NovelQ annual meetings, NovelQ-EFFoST 2009 PhD Symposium, BerlinFOOD 2010)

The meetings were tailor-made to the needs of members (40 members, 16 organisations, 11 countries) and included specific issues identified by them. The programme culminated in BerlinFOOD 2010, which was attended by more than 100 PhD Student from EU-funded instruments such as Healthy Structure, MoniQA PathogenCombat, EuroFIR, Dream, MycoRed and InsideFood as well as some small industry projects. Five newsletters, four dedicated to the TCD networks activities and one about BerlinFOOD 2010, were published during the lifetime of the project.

Young Researchers Special Interest Group
The aim of the TCD Network was to create a sustainable programme of training and career development for young researchers in parallel with their academic learning. In part, this was achieved within NovelQ; any EU-funded instrument could adopt the programme developed by NovelQ to enhance early-career researchers' skills. Ensuring others have such opportunities will be addressed by the newly re-established EFFoST Young Researchers Special Interest Group (SIG). Supported by Huub Lelieveld (EFFoST) and Siân Astley (IFR, UK), the SIG executive met in Dublin at EFFoST 2010, and agreed to facilitate opportunities for

researchers to develop transferable and scientific skills such networking, soft-skills (e.g. science communication) and scientific expertise (e.g. proposal writing).

Business cases for schools
Five business cases describing advanced heating, high-pressure processing (HPP), pulsed electric field (PEF), cold plasma technologies and packaging – as used or developed by NovelQ – were adapted for older children and undergraduates. These offer teachers and lecturers a starting point from which to introduce topics across science curricula from heating methods (e.g., convection, conduction and radiation) to food safety and environmental impact. Versions in English can be downloaded from the NovelQ website and used for educational purposes including staff training.

2.5.4 Interaction with other Sub-projects

The nature of Sub-project 5 means interaction with other NovelQ Sub-projects which was very extensive. Members of the TCD Network were drawn from SP1 (largest contributor), SP2, SP3 and SP4. These early-career researchers shared their research at NovelQ annual meetings and external at EFFoST 2009 and BerlinFOOD 2010. Participation at Career Development and NovelQ meetings also provided them with networking opportunities with senior NovelQ researchers and partners' representatives. Senior NovelQ scientists also took part in TCD meetings, providing support and feedback to TCD members as well as updating their own skills (e.g. project management).

Translation of scientific results into popular articles for trade journals was guided by SP5 members, leading to direct interactions with all Sub-projects. Similarly, IAP meetings included representatives from Sub-projects, providing insights into NovelQ outcomes – within the confines of commercial confidentiality – and potential applications; some of partners have hosted the IAP members at their facilities.

2.5.5 Main dissemination activities

The main results achieved are described in the Chapter above. The table below shows lists all the dissemination activities of Sub-project 5.

Dissemination activities in SP 5	number
Referred journal papers published	-
Referred journal papers accepted	-
Referred journal papers submitted	-
Technical articles submitted in magazines, including: ▪ including NovelQ Special Issue (12 publications) ▪ BEUC web brochure ▪ KEKI booklet (in preparation now)	62

Dissemination activities in SP 5	number
Major international conference papers presented	52
Other presentations at other stakeholders; meetings, roundtables, company visits, exhibitions etc.	48
NovelQ Workshops/meetings organised (incl. public events 11, TCD 9, IAP meetings 5, brokerage events 2)	27
Videos, films, radio interview	5
Newsletters (IAP, TCD)	12
Awards	4
Web-based dissemination tool	1
Others	5

2.5.6 Conclusion

NovelQ activities have been disseminated widely across Europe, as depicted in the following figure (see blue dots for meeting locations). IAP and TCD membership has been substantial (89 and 40, respectively), and the average meeting attendance was 25-30 participants per IAP meeting (note: final IAP meeting was attended by almost 70 participants) whilst TCD numbers have varied between nine (Career Development) and 150 (BerlinFOOD 2010). The number of publications, newsletters and questionnaires has been far above those anticipated at the proposal phase and described in the first Description of Work of NovelQ.

2.5.7 References

<u>Examples of some publications in international food oriented magazines:</u>

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- Jennifer Davis, HP processing toward sustainability, Food Safety Magazine, November 2009.
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- Huug de Vries, NovelQ' contribution to a wide application of novel processing technologies, New Food Magazine, June 2010.
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- Isabel Odriozola-Serrano, Pulsed electric field: opportunities for healthier tomato juice, Food & Beveraage Int., December 2010.

Examples of some national publications:

- Huug de Vries. Kick-off meeting NovelQ, Wageningen International, March 2006.
- Krisztina Marton, Elindult a NovelQ project, KEKI Info, June 2006.
- Huug de Vries, NovelQ een bijzonder project, De Wijzer, June 2006.
- Huug de Vries, Innovaties in Food, Link Magazine, June 2006.
- Huug de Vries, Houdbaar vers, Innovaties in Europe, September 2006.
- Huug de Vries, Milde conservering, Elsevier Voedingsmiddelenindustrie, December 2006.
- Huug de Vries, European innvoation approach in novel processing, KEKI info, March 2007.
- Peter v.d. Elzen, Europa mist een zichtbare Food & Drug Administration, Technisch weekblad, March 2007.
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- Ariette Matser, Conserveren onder zevenduizend bar, Technisch Weekblad, July 2007.
- Tim Brocklehurst, Science and Innovation (IFR journal), Novel processing methods for the production and distribution of high quality and safe foods, September 2007.
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- Marjana Peterman, Nove tehnologije, VIP Consumer Magazine, May 2009.
- Huug de Vries, Vers, smakelijk en toch lang houdbaar, Volkrskrant, NRH Handelsblad, August 2009.

Other references

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- www.effost.org
- www.beuc.org
- www.newfoodmagazine.com/?s=novelq
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- www.onderzoekinformatie.nl/nl/oi/nod/onderzoek/OND1314287/
- ec.europa.eu/research/biosociety/food_quality/projects/099_en.html
- www.iapriweb.org/news.php?id=34
- www.foodvalley.nl/Lists/Agenda/DispForm.aspx?ID=175
- www.centrolerici.ceub.it/File/Programma-HighQ.pdf
- ec.europa.eu/research/biosociety/inco/projects/0081_en.html

3 *General conclusions*

3.1 Achievements of the project to the state-of-the art

In chapter 2.2 of the first DoW, the intended enhancements to the state of the art were described for high pressure, pulsed electrical field, cold plasma and new packaging concepts for NP. Knowledge gaps were identified.
In Sub-projects 1 and 2, a set of review paper was written on high pressure and PEF in the first project year. In the final project year, a similar exercise was carried out based on the results coming out of the NovelQ project. The achievements are remarkable.

In general, the approach applied in Sub-project 1 (section 2.1.2) allowed to perform highly controlled kinetic studies to fully quantify and understand the effects of high pressure thermal processing and pulsed electric field processing on quality and safety aspects of foods in the context of processing intensities covering pasteurisation and sterilisation (in case of HP processing) levels. As the same study vehicles were used throughout the sub-project, comparison of (novel) unit operations on a quantitative basis and from a viewpoint of true equivalence became within reach (as for instance undertaken in Sub-project 4). Furthermore, the first sensors and models design, validation and optimisation of novel processing technologies based on high pressure thermal and pulsed electric field processing were developed. Finally, a step forward was made in the understanding and quantification of the effects of cold plasma on microbial food safety aspects.

Major progress was made in the knowledge on the effect of novel processing on packaging materials through an extensive evaluation of the impacts of NPs on the performance of common and novel packaging materials and on their interaction with the packaged food. Particular emphasis was given to HP/T treatments and combination of novel packaging concepts (i.e biodegradable films and edible coatings, nanocomposites, bio-active polymeric systems) with novel processes that permitted to prolong the shelf-life above that accessible with currently available technologies.
Key issues such as the evolution of material properties with process conditions as well as food-packaging interactions associated with NPs were analysed and modelled through the development of integrated theoretical and numerical tools that allowed a) the prediction of functional and structural properties of the packaging materials, b) the prediction of the process/package-product interactions for simulating and controlling migration of unwanted compounds (for regulatory issues on undesirable compounds and quality maintenance by avoiding scalping), c) the assessments of the suitability for use in HP treatments of certain polymers and multilayer structures in view of designing specific package structures.

The results of the work in Sub-project 3 research indicated that consumers perceive PEF and HPP treated juice to be a better choice than pasteurised juice if the price and taste are right. But most of all consumers want freshly produced apple juice with a premium taste at an acceptable price. The finding that HPP juice is easier to accept than PEF juice is also in line with previous studies. The results of the consumer observation study showed, that the

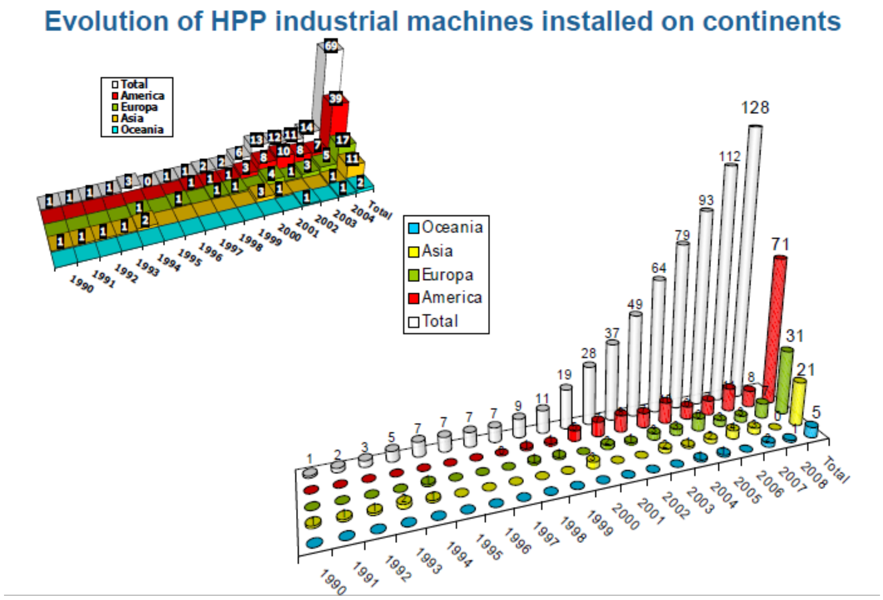
freshly pressed, mildly pasteurised and high pressure processed juices do not differ from each other on the tested attributes, except for sour. The average liking scores for the three juices were comparable. The quantitative consumer acceptance study showed, that the attitude change toward the technologies due to the sensory experience can be explained as an affective conditioning effect. Due to the pairing of the technology name with the sensory experience, the affective reaction elicited by the sensory experience is transferred to the technology name. The focus group interviews with consumers regarding the rename of the PEF technology to ‘micro pulse’ technology discovered, that 'micro pulse' name has better associations (indulgence, short, modern), than pulsed electric field (associated with radiation, unhealthy, unnatural, rough) and 'micropulse' is in no way associated with 'electricity' among then respondents.
It should be noted that these studies were carried out in different regions in Europe, including Central-East Europe and the North of Europe due to the participating partners in NovelQ.

The integrative approach of Sub-projects 4 and 7 led to insights how to overcome barriers in hygiene, environmental impact opportunities, shelf-life, selection in technologies, upscaling, etc. Sub-project 4 was able to bridge the gap between lab-scale experiments and industrial development. Clear guidelines and models are available that can guide industry towards the appropriate technology and show ways of implementation in their processing lines. This has increased awareness and number of successful NP innovations.

Finally, the NovelQ project was able to bridge the gap between food manufacturers and equipment suppliers, by bringing them together in the IAP platform. The discussions between them contributed to better understanding of each other demands and quality offers; and enabled them to jointly step into (short-term) demonstration projects.

3.2 Impact of the project on industry and research

At the start of the project, it has been stated that the science base of NP in Europe is rather strong, while the number of market application (near to) zero as compared to the USA and Japan. Now, Europe is catching up, e.g. as shown for HP in the figure below (with courtesy of NC Hyperbaric).



The growing interest of companies in the IAP platform and short-term demonstrations also revealed the business interest in novel processing. The major strength of IAP is the mix of food manufacturers and equipment suppliers. It is highly recommended to further support R&D activities at the cross-sector border.

NovelQ activities resulted in e.g. the following examples of industrial applications:

- New Mediterranean vegetable dish being marketed in the South of France based on ohmic heating technology
- Cold plasma lab-scale equipment
- Novel packaging materials for high pressure sterilisation
- New range of fruit and vegetable products that are now produced by high pressure processing in the Benelux.

In addition, many IAP members have already used to knowledge generated in NovelQ in their businesses. Due to confidentiality reasons, details cannot be revealed.
The impact of the project on research has been substantial in terms of graduates, PhD defences (17), new professors (3). Thanks to the high number of scientific publications, presentations in conferences and other dissemination activities, NovelQ is very much seen in the scientific community.
The Training and Career Development Network was very much appreciated by the young scientists in the project and had also a large impact outside the project, resulting in a special PhD conference organised by the young scientists of NovelQ and attended by over 200 participants.

Remark on management of Integrated Projects
It has been stated that the management of these large, Integrated Projects has been considered as too bureaucratic and time consuming. It is our experience that this could be avoided in case of:

- Starting with a strong and cooperative core group and extend the consortium via the core group members.
- Sharing responsibilities within the project at SP-level and for key activities such as Industry related issues, training, etc.
- Respecting the partners having long term scientific goals and shorter term more applied research goals.
- Guaranteeing links between SMEs and nearby research institutions working together with them.
- Report according to one-single format, starting with 3-month reporting in year one (one A4 max), half a year (a few pages) and finally yearly. Do not embarrass partners with new formats as management team. This also holds for the emails send around; clear requests, concise and not over demanding (in number and text length).
- Taking care that the management team is built on complementary skills allowing creation of enthusiasm, overall guidance, timely reporting, etc and rely on a European Desk for support.
- Allowing partners to communicate and provide feedback in order to improve the coordination and report back on taken actions.
- Finally and most important: let the partners show what they have achieved individually and collectively at meetings.

These simple messages allow coordinating large projects and really built an integrated project with deliverables.

3.3 References

Project website: www.novelq.org
Appendices:

- List of review publications
- Special issue New Food

4 *Dissemination and Use*

At the end of the project, the publishable results that are ready to be publiced are the scientific results documented in scientific publications. More technology oriented results (e.g. adaptations to equipment and process conditions for safe processing) are at the moment not protected by patents or other measures and are therefore not publishable.

On the following pages, exploitable results from the NovelQ project are listed. They have also been publishend on the Cordis website – Technology market place.

Title

Indicator systems for high pressure process evaluation.

Abstract

One of the targets of NovelQ has been the development of methods to evaluate quantitatively the process impact and uniformity of high pressure (HP) thermal processing of foods. One of the approaches adopted to map temperature uniformity in HP vessels was the use of protein-based, extrinsic, isolated pressure-temperature-time indicators.

Using a step-wise, kinetics-based research strategy consisting of
(i) selecting and evaluation of candidate sensors,
(ii) screening of the p,T sensitivity,
(iii) kinetic calibration under isothermal-isobaric conditions and
(iv) validation of the kinetics under dynamic conditions,
four different protein-based, extrinsic, isolated pTTIs (based on Bacillus amyloliquefaciens amylase, Bacillus subtilis amylase or ovomucoid), spanning the pressure-temperature domain of HP pasteurisation and sterilisation, were developed (Grauwet et al. 2009, 2010a,b,c).
At step 2 and 3, solvent engineering was used as a corrective feedback action. Hereby, the protein solvent condition (e.g. buffer pH, buffer type, protein concentration, addition of sugars, etc.) was purposely modified to obtain the desired indicator characteristics and to reach three objectives:
(i) the read-out windows of the protein systems coincides with the application window;
(ii) the read-out windows of all indicator systems differs;
(iii) the p,T-sensitivity of inactivation is adjusted.
The potential of these 4 systems for use in uniformity mapping was investigated at two levels: pilot (both for pasteurisation and sterilisation conditions) and industrial scale (only available for pasteurisation conditions) and two orientations (horizontal or vertical).

Differences in pTTI read-outs at different locations in the vessel illustrated low and high temperature zones (Grauwet et al. 2009, 2010a,b,c). The former could be attributed to combinations of conduction phenomena and free convection phenomena as evidenced by CFD modelling (Grauwet, Rauh et al. 2011). The zone of lowest temperature needs to be addressed in relation to the food safety objective.

Grauwet, T., Rauh, C., Van der Plancken, I., Vervoort, L., Delgado, A., Van Loey, A., Hendrickx, M.E. (2011) Potential and limitations of methods for temperature uniformity mapping in high pressure thermal processing. Submitted to Trends in Food Science and Technology
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Grauwet, T., Van der Plancken, I., Vervoort, L., Hendrickx, M., Van Loey, A. (2009) Investigating the potential of Bacillus subtilis alpha-amylase as a pressure – temperature – time indicator for high hydrostatic pressure pasteurization processes. Biotechnology Progress 4, 1184-1193.
Grauwet, T., Van der Plancken, I., Vervoort, L., Hendrickx, M., Van Loey, A. (2010a) Mapping temperature uniformity in industrial scale HP equipment using enzymatic pressure-temperature-time indicators. Journal of Food Engineering. 98, 93-102.
Grauwet, T., Van der Plancken, I., Vervoort, L., Hendrickx, M., Van Loey, A. (2010b) Protein-based indicator system for temperature gradient detection in high pressure high temperature processing. Food Research International. 43, 862–871.
Grauwet, T., Van der Plancken, I., Vervoort, L., Hendrickx, M., Van Loey, A. (2010c) Solvent engineering as a tool in enzymatic indicator development for mild high pressure pasteurization processing. Journal of Food Engineering.97, 301–310.

Subject Descriptors

Industrial technologies	- Food science

Current stage of development

Experimental development stage (laboratory prototype)

Further details about the stage of development:

Proof of principle

Sources of support

EU

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NovelQ

Type of IPR

Market application for the Result

Industrial technologies	- Foods, drinks

Collaboration Sought

- Available for consultancy
- Further research or development support

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Title

Formulations and procedures for obtaining novel biodegradable and bioactive films suitable for HP/T treatments

Abstract

Biodegradable films, edible coatings and bio-active packaging materials based on polymers from renewable resources were developed. Both thermoplastic (dry) and solvent (wet) based technologies were employed. Selected packaging systems were used in combination with HP treatments to improve shelf life of selected food systems. A variety of thermoplastic zein (TPZ), wheat gluten (WG) and thermoplastic starch (TPS) materials were prepared and characterised in order to evaluate the correlation between material composition, thermoplasticization conditions and extensional rheology. Multilayer films based on TPZ with tailored barrier to oxygen and water vapour were successfully developed for HP Pasteurisation treatments.
Proteins and polysaccharides have been used in combination with suitable plasticizers to produce coatings for the relevant application together with high pressure/temperature (HP/T) treatment. For example, coatings and films were prepared from avenin, zein and kafirin (sorghum prolamin).
Bio-nanocomposites based on nanoclay and POSS dispersed in several biopolymeric matrices were investigated with the aim of improving barrier, thermal and mechanical properties of packaging films.
New active antimicrobial biopolymer was designed based on PLA as polymer matrix containing volatile active agents for an action by direct or indirect contact with food. This combined action between pressure and antimicrobial agent was used to reduce the intensity of the HP treatment and/or the quantity of antimicrobial compound added in the film and consequently permitted to reduce the impact on food and the cost of the treatment.

Subject Descriptors

Industrial technologies	- Food science - Packaging

Current stage of development

Experimental development stage (laboratory prototype)

Further details about the stage of development:

Sources of support

EU

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NovelQ

Type of IPR

- Partnership/other contractual agreement(s)

Market application for the Result

Industrial technologies	- Foods, drinks - Packaging

Collaboration Sought

- Available for consultancy
- Further research or development support

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Title

Software tools and associated predictive numerical models for the design of packaging structures and for the prediction of structural and barrier properties

Abstract

Mathematical models and their numerical implementation have been developed to predict the evolution of structure/morphology and the barrier properties of polymeric materials employed for the realisation of flexible packaging structures subjected to HP/T treatments. In particular, a number of these numerical tools allow the prediction of several relevant structural properties such as i) the density evolution of the amorphous phase of glassy polymers, ii) the dependence of glass transition temperature on pressure, iii) the dependence of amount of crystallinity as a function of temperature and pressure, iv) the evolution of PVT properties. Other theoretical models and numerical tools use this information to predict sorption isotherms of gases and vapours and their diffusivity in glassy and rubbery polymers employed in food packaging, based on equation of state theories and free volume theories. As a whole, the different numerical tools implemented within the project are able to model and predict functional properties of starting materials and, on the basis of temperature/pressure histories, are also able to model and predict changes of functional properties promoted by HP treatments.
Moreover, analytical and finite element approaches were developed to evaluate the stress state which develops as a consequence of high pressure treatments in multilayer film structures.

Subject Descriptors

Industrial technologies	- Food science - Packaging

Current stage of development

Scientific and/or technical knowledge (basic research)

Sources of support

- EU

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NovelQ

Type of IPR

- Partnership/other contractual agreement(s)

Market application for the Result

Industrial technologies	- Foods, drinks - Food products (animal,human)

Collaboration Sought

- Available for consultancy
- Further research or development support

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Title

Knowledge database on the different research results concerning consumer behaviour

Abstract

Within the framework of NovelQ project an extensive research on scientific literature on consumer acceptance of novel technologies (genetic modification, high pressure treatment, food irradiation, pulsed electric field treatment) was conducted in online databases, in Science Direct, Blackwell-Synergy Publishing, Emerald Publisher, Nature Biotechnology and Agbioforum. The aim of the establishment of the searchable knowledge database is to provide information on results of earlier and recently finished research investigating the attitude and behaviour of the consumers with different socio-demographic background towards NP (novel processing) technologies and NP products and generating conclusions to forecast and handle consumers' reactions to NP products.

118 articles from 57 scientific journals were collected systematically and elaborated electronically. The database contains solely first full publications which appeared in scientific papers. In the database there are 95 articles about consumer perception of genetic modification, 22 articles about irradiation, 4 articles about high pressure treatment and 1 about pulsed electric field treatment derived from 239 authors. The database contains results from the whole word, 47 publications from America, 1 from Africa, 61 from Europe, 8 from Australia, 11 from Asia. There are articles from year 1987 to 2006.
The elaboration of the articles was based on 24 parameters. From every publication, the following information were recorded: Authors, Title, Publication date, Studied technology, Data collection process, Data analysing process, Place/location of the survey, Respondents, Studied products, Data collection process, Dates analysing process/valuation method, Information provided about the technology to the consumers, Results about the acceptance, Results about clusters, Results about conjoint, Results about knowledge, Results in general, Results about socio-demographic factors, Results about labelling, Results about trust and Conclusions.

The searching engine/system of Access database was developed in order to utilize easily and effectively this enormous quantity of data collected and recorded. It is possible to search in the database by several parameters with many key words and to list the whole content in different ways.

Subject Descriptors

Industrial technologies	- Biotechnology - Food science - Distributed databases - Information analysis

Current stage of development

Scientific and/or technical knowledge (basic research)

Sources of support

- EU

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NovelQ

Type of IPR

- Partnership

Market application for the Result

Industrial technologies	- Food products (animal,human)

Collaboration Sought

- Available for consultancy - Further research or development support

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Title

Decision Support System to advise potential users of novel processing technologies

Abstract

Within NovelQ a decision support system was developed to enhance the implementation of novel processing schemes. Here, a chain-oriented approach was chosen to investigate the optimal technology and conditions, including cost aspects. The decision support system tool was developed to help potential users of novel processing
technologies to make decisions about the likely benefits for their business. By answering a short list of specific questions, a potential user (e.g. a food manufacturer) can easily evaluate whether a technology would be relevant for his products and if implementation would be economically feasible. Based on the given answers, a relevant next question is selected. The answers are combined to give an advice on potential interesting novel processing technologies including costs and effects on shelf life and quality. This tool also includes a menu with extensive information about processing related areas such as packaging, product quality assessment, pre and post-processing steps and environmental considerations. Newly-marketed product examples are included in the tool describing the product, its packaging and relevant information such as brand, producer, technology, ingredients, storage conditions, shelf life and market. Possible packaging options are described, in addition to pre and post-treatment implications of novel processing.

Subject Descriptors

Industrial technologies	- Food science - Product development

Current stage of development

Prototype/demonstrator available for testing

Further details about the stage of development:

The decision support system has been developed within the FP6 Integrated Project 'NovelQ'.

Sources of support

- EU
- National

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NovelQ

Type of IPR

- Partnership/other contractual agreement(s)

Market application for the Result

Industrial technologies	- Foods, drinks - Food products (animal,human)

Collaboration Sought

- Marketing agreement
- Private-public partnership
- Available for consultancy

Collaboration Details

Food producers that are interested in using a novel technology (such as high pressure pasteurisation, high pressure sterilisation, cold plasma, microwave heating, radio-frequent heating and pulsed electric fields) are invited to make use of this tool in order to identify opportunities for novel processing application in their businesses.

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Title

User-friendly model for shelf-life prediction of food products treated by novel processing

Abstract

There is a clear need to predict the shelf life of novel processing treated products. Within the NovelQ project, predictive modelling was performed including the entire production chain, e.g. ingredients (initial microbial load), effects of novel processing, packaging and storage. Shelf life was evaluated with respect to microbiology, quality and nutrients. The main factors determining quality and shelf-life were identified: initial quality and contamination, effect of novel processing, packaging and storage conditions. By linking these factors in a model it was possible to predict quality and shelf-life. A shelf life model for pulsed electric field and high pressure pasteurisation treated orange juice was developed using data from the literature and insights from NovelQ This model can be applied to predict shelf life based upon microbial and enzymatic spoilage, and determination of processing conditions to obtain a desired shelf life. The model combines microbial inactivation and growth with enzyme inactivation, enzyme rest activity and quality. A user friendly interface was developed within the NovelQ project.

Subject Descriptors

Industrial technologies	- Food science

Current stage of development

Guidelines, methodologies, technical drawings

Further details about the stage of development:

User-friendly model for shelf-life prediction of food products treated by novel processing was developed and tested by the NovelQ project

Sources of support

- EU
- National

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-2006-15710 NOVELQ

Type of IPR

- Partnership/other contractual agreement(s)

Market application for the Result

Industrial technologies	- Foods, drinks

Collaboration Sought

- Private-public partnership
- Available for consultancy

Collaboration Details

Interested (food companies) are invited to contact us to receive more information about the user-friendly model for shelf-life prediction of food products treated by novel processing and its application for their businesses.

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Title

Computerised optimisation system for designing foods, packaging and equipment resulting in a more uniform microwave heating characteristic

Abstract

A computerised tool for demonstrating the usefulness of numerical modelling to improve microwave heating uniformity was developed and is available for industry now. The tool demonstrates the applicability of numerical modelling tools in product development work, in order to improve the quality related to heating uniformity after microwave heating of ready meals. The simulations are based upon coupled electromagnetic and heat transfer modelling of microwave defrosting, tempering, and heating of ready meals from frozen.
The developed computerised tool is an expert system, which was built to make it possible for the user to interactively select food components, in order to build up a ready made meal. The expert system combines numerical modelling with long experience and knowledge in microwave technology and food science.

Subject Descriptors

Industrial technologies	- Food science - Product design

Current stage of development

Results of demonstration trials available

Further details about the stage of development:

The computerised tool is available via SIK as an expert system to evaluate the potential of improving the reheating of ready to eat meals in microwaves.

Sources of support

- EU

Programme Acronym

NovelQ

Project reference or contract number

FOOD-CT-200615710 NovelQ

Type of IPR

- Partnership/other contractual agreement(s)

Market application for the Result

Industrial technologies	- Foods, drinks - Food products (animal,human)

Collaboration Sought

- Licence agreement

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APPENDIX

List of review publications issued at the end of the project:

- Journal: Trends in Food Science and Technology (article submitted)
  Title: Potential and limitations of methods for temperature uniformity mapping in high pressure thermal processing
  Corresponding Author: prof. dr. Marc E Hendrickx,Katholieke Universiteit Leuven
  First Author: Tara Grauwet, Phd
  Order of Authors: Tara Grauwet, Phd; Cornelia Rauh, PhD; Iesel Van der Plancken, PhD; Liesbeth Vervoort, drs.; Antonio Delgado, PhD; Ann Van Loey, PhD; Marc E Hendrickx, PhD
  Abstract: One of the targets in the European project NovelQ (Framework 6, Priority 5 'Food Quality and Safety', Integrated Project NovelQ FP6-CT-2006-015710) has been the development of methods to evaluate quantitatively the process impact and uniformity of high pressure (HP) thermal processing of foods. Such methods serve as a basis for design, evaluation and optimization of processes. The current review paper describes potential and limitations of two approaches for temperature uniformity mapping in HP reactors: (i) computational thermal fluid dynamics modeling and simulation of temperature fields and (ii) use of protein-based, extrinsic, isolated pressure-temperature-time indicators for experimental temperature uniformity mapping.

- Journal: Trends in Food Science and Technology (article submitted)
  Title: Modeling, Simulation, Optimization and Impact Measurement of Pulsed Electric Field Processing
  Corresponding Author: Mr Nicolas Meneses, Food Engineer,Berlin University of Technology
  First Author: Nicolas Meneses, Food Engineer
  Order of Authors: Nicolas Meneses, Food Engineer; Jens Krauss, Dipl.- Ing.; Henry Jaeger, Dipl.-Ing.; Oezguer Ertunc, Dr.-Ing.; Cornelia Rauh, Dr.-Ing.; Dietrich Knorr, Prof. Dr.-Ing.; Antonio Delgado, Prof. Dr.-Ing.
  Abstract: Pulsed electric field (PEF) processing of liquid foods was evaluated using numerical and experimental methods in order to improve process efficiency in terms of microbial inactivation while keeping heat sensitive compounds. Optimization procedures have been applied to reduce process parameters inhomogeneity, to reduce the thermal load and to ensure a safe and high quality food product. Relevant aspects such as modifications of insulator shape geometry, impact of process parameters, identification of optimal treatment conditions, insertion of static mixing devices, implementation of electrode cooling devices, as well as, numerical simulation of process parameters, enzyme inactivation and pH-shifts during the PEF processing are reviewed.

- Journal: Trends in Food Science and Technology (article submitted)
Title: PEF processing effects on quality and health-related constituents in plant-based foods
Authors: Isabel Odriozola-Serrano, Ingrid Aguiló-Aguayo, Robert Soliva-Fortuny,
Olga Martín-Belloso*,
Department of Food Technology, University of Lleida, Rovira Roure 191, 25198 Lleida, Spain, Phone: +34 973 702593, Fax: + 34 973 702596, e-mail: omartin@tecal.udl.cat
*Author to whom correspondence should be addressed.
Abstract: The deleterious effect of thermal processing on food quality has been extensively reported. Many of the compounds found in plant-based foods that are related to quality also exhibit health-promoting biological functions. Non-thermal processing technologies, such as pulsed electric fields (PEF) have been developed during the last decades as an alternative to thermal pasteurization of liquid foods. Not much information is available, though, regarding the effects of this technology on minor constituents of the treated foods, which are often related to quality and health-promoting benefits. This review summarizes the main results achieved within the framework of the EU FP6 integrated project 'NovelQ' regarding the effects of PEF on the main compounds affecting quality- and health-related properties.

- Journal: Trends in Food Science and Technology (article submitted)
Title: Microbiological aspects related to the feasibility of PEF technology for food pasteurization
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Abstract: Processing unit operations for the purpose of inactivating harmful microorganisms are of primary importance in ascertaining the safety of food. The capability of Pulsed Electric fields (PEF) to inactivate vegetative cells of microorganisms at temperatures below those used in thermal processing makes this technology very attractive for the food industry as a non-thermal pasteurization process. Commercial exploitation of this technology for food pasteurization requires identifying the most PEF-resistant microorganisms of public health concern and defining the treatment conditions that would reduce the population of these microorganisms to a level that guarantees food safety. The objective of this paper is to summarize the research that has been conducted within the framework of the EU FP6 integrated project Novel Q in order to enhance the current state of the art regarding the feasibility of using PEF technology for food pasteurization.

- Journal: Trends in Food Science and Technology (article submitted)
(Bio)chemical reactions during high pressure/high temperature processing affect safety and quality of plant-based foods

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Tel +32 16 32 15 72 18, Fax + 32 16 32 19 60 19
Abstract: In recent years, the range of equipment and applications for high pressure pasteurization has gradually increased on the European market. Sterilization under conditions of elevated pressures is in the pipeline, albeit at the research level. Knowledge on the effect of high pressure/high temperature processing on food safety and quality attributes is still too limited. This review discusses recent progress made in understanding the impact of high pressure/high temperature processing on food safety and quality attributes of fruit and vegetable based products, within the EU FP6 integrated project NovelQ.

- Journal: Trends in Food Science and Technology (article in press)
  Title: Processing and shelf life issues of selected food packaging materials and structures from renewable resources
  Authors:Giuseppe Mensitieri[b], Ernesto Di Maio[b], Giovanna G. Buonocore[a], Irma Nedi[b], Maria Oliviero[a,b], Lucia Sansone[b] and Salvatore Iannace[a,*]
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  Abstract: Use of polymers from renewable sources for food packaging applications is steadily growing. However, as compared to thermoplastic synthetic polymers, they present problems when processed with traditional technologies and show inferior performances in terms of functional and structural properties. This review paper focuses, in its first part, on current issues related to processing, such as thermoplasticization of starch and proteins, extrusion of films and foams. In the second part, the strategies for the technological advancements aimed to improve barrier properties, to promote active antimicrobial functionality and to apply these materials also in demanding high pressure processing of packaged foodstuff are discussed
  * Corresponding author.

- New Food – NovelQ Special Issue, October 2010 (see next page)

RESULTS & OVERVIEW

NovelQ

In collaboration with NovelQ, *New Food* is pleased to present the results of the integrated project. The project objectives were to develop and demonstrate novel processing techniques to improve quality and facilitate innovation for the European food and beverage sector. Project partners discuss the research they've been carrying out over the past five years and examine what it means for the food and beverage industry.

Industrial applications of novel processing technologies

In only five years, novel processing methods have found their way to the European food markets thanks to the spirit of entrepreneurs and a sound scientific base in Europe. The number of high pressure pasteurised products on the market has increased four-fold, the first ohmic-heated products are being sold, 10 or more pulsed electrical field units have been purchased and very recently, the first five cold plasma surface disinfectors were launched.

Trends towards fresher and healthier products (e.g. illustrated by the top five sold products in Dutch retail) have formed the basis of a renewed look at processing. This has also been accelerated by the need for systems with a lower environmental impact that do not compromise production costs.

Centuries of temperature-focused processing are being challenged by new observations about non-thermal processing. Even though a radical shift is not foreseen in the near future, these discussions have at least opened minds to more intelligent approaches for mild processing. Volumetric heating (e.g. using microwaves) instead of surface heating (i.e. boiling) is just one example. However, the wider spectrum of electromagnetic energy (i.e. pulsed electrical field, plasmas, pulsed light, radio frequency, microwaves, etc.) and uses of pressure (i.e. ultra high pressure, ultrasound, etc.) have gained attention from both the scientific and developmental perspectives.

It is an honour to present the latest results from the European Integrated Project 'NovelQ', which we think are relevant to the industry-minded readers of *New Food*. These results have been achieved by a consortium consisting of 36 partners from industry, universities, contract research centres and non-profit organisations. Features of NovelQ include the Training and Career Development Network, coaching the next generation of public and private sector R&D employees, and the NovelQ Industry Advisory Platform; 75 industry representatives have joined to provide feedback and discuss the latest developments. The innovative approach of, and stimulating discussions with, DG Research, and in particular Dr Jürgen Lucas and Dr Jean-Marc Chourot, have been driving factors in the success of this project.

If after reading this special issue, free membership of the NovelQ Industry Advisory Platform is of interest to you, please feel free to contact us (andrea.seleljova@wur.nl).

On behalf of our project partners, I wish you enjoyable reading and new insights for your businesses.

Huug de Vries
Project Co-ordinator NovelQ

Guest Editors

Siân Astley, IFR

Siân has worked extensively with individuals and organisations throughout Europe in a variety of disciplines including research, food and biotech industries and the media. She is the author of more than 300 popular science articles for magazines and trade publications as well as 25 peer-reviewed papers, and she was awarded her Diploma in Science Communication in 2009 (Birkbeck University of London). After 14 years as a bench-scientist, Siân became Communications Manager for NuGO, one of the first FP6 Networks of Excellence. She is currently the European Communications Manager for the Institute of Food Research in Norwich (UK), supporting scientists to communicate their EU-funded research around the world.

Huub Lelieveld

Huub Lelieveld is President of the Global Harmonization Initiative, member of the Governing Council of IUFoST, Member and Past-President of EFFoST (the European Federation of Food Science and Technology) and the same of EHEDG (the European Hygienic Engineering and Design Group). He is a fellow of IAFoST (the International Academy of Food Science and Technology), a fellow of IFT and has been Chair of the Nonthermal Processing and the International divisions of IFT. At Unilever, he was responsible for hygienic processing and plant design and novel processing technologies. He has written chapters for many books and encyclopaedia, over one hundred scientific articles, articles for magazines and presented hundreds of papers, globally.

Ariette Matser

Ariette Matser is currently Senior Scientist – Mild Preservation and Novel Technologies and Programme Coordinator – Mild Preservation within Food & Biobased Research of Wageningen UR. She studied Food Science at Wageningen UR. Her primary research activities include novel technologies and food safety and quality, preservation and processing of food products and effects on food quality, and food structure and the effects of processing on this. Management activities are involvement in (inter) national R&D projects, project acquisition and coordination of activities on novel technologies. She is Project Coordinator of the European project NovelQ.

Lilia Ahrné
Director of Department Process and Technology Development, SIK

Ariette Matser
Senior Scientist Novel Processing, Wageningen UR, Food & Biobased Research

Demonstration of novel technologies and advanced heating has been a key goal for NovelQ

One of the goals of NovelQ is to facilitate and speed up industrial exploitation of novel technologies by carrying out extensive demonstration activities with real food products and industrial equipment in close collaboration with the food industry. A variety of activities have been undertaken during the lifetime of NovelQ demonstrating the advantages of novel processing and advanced heating with respect to product quality and shelf-life (Figure 1).

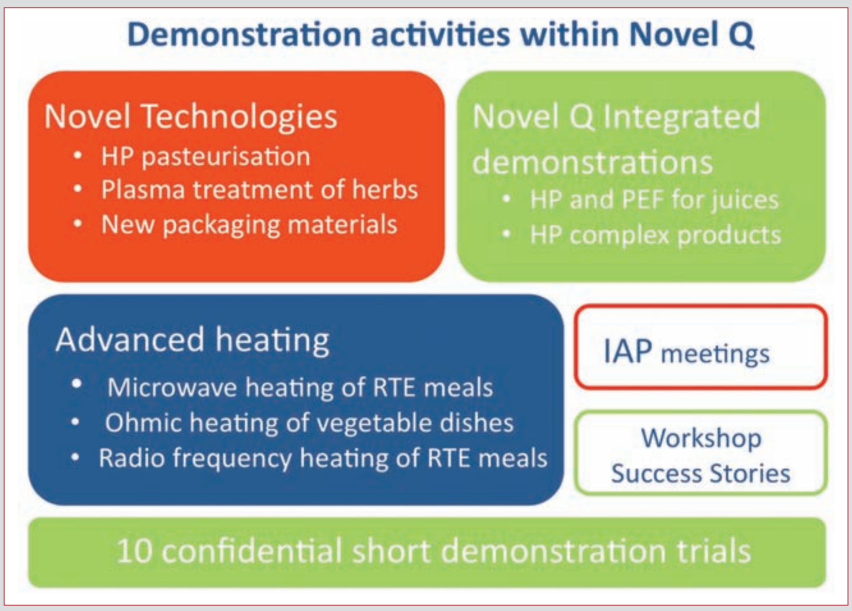
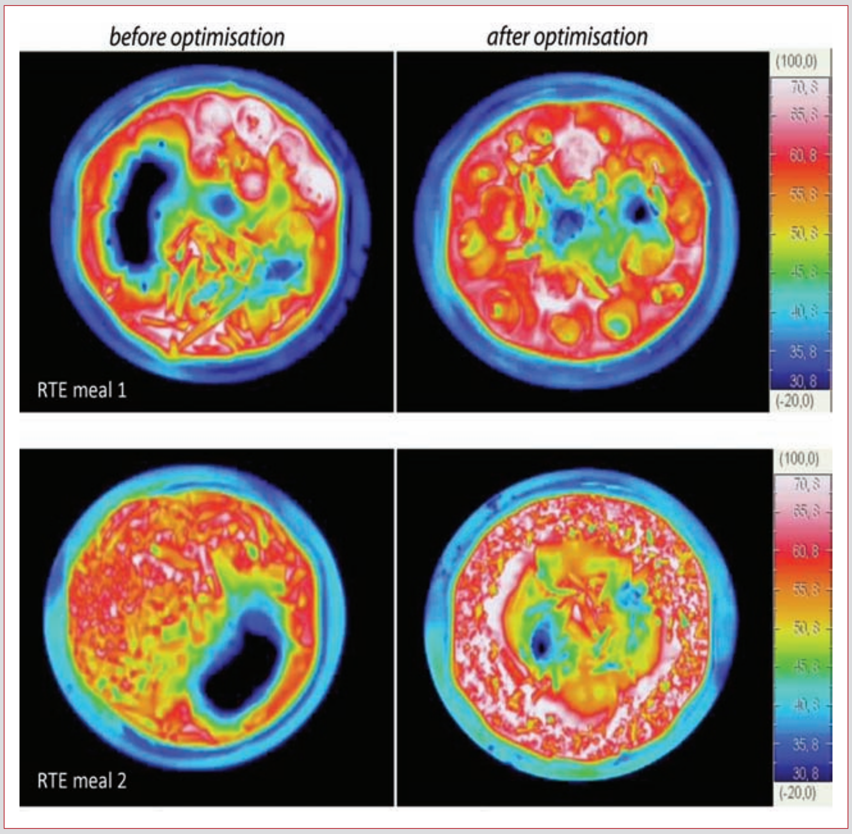


Figure 1 During the lifetime of the NovelQ project, various type of demonstration projects have been done in collaboration with industry. HP = High Pressure; PEF = Pulsed Electric Field; RTE = Ready-to-eat; IAP = Industrial Advisory Platform

During the first 18 months, demonstration activities were focused on more mature advanced heating technologies such as microwaving, radio frequency and ohmic heating. Although these technologies have been studied for quite some time and they have clear advantages for some applications, the number of known applications in the food industry that are commercially successful is still low. Within NovelQ, three 18-month demonstration projects, partially financed by industry, were completed using new applications for advanced heating. To stimulate further the use of advanced heating by the food industry, a workshop – 'Success stories in advanced heating technologies' – was organised by SIK (Swedish Institute for Food and Biotechnology) at which equipment producers and food industry presented success stories and identified bottlenecks for implementation.

During the midterm of NovelQ, a competitive call led to three new demonstration projects, coordinated by industrial partners, focusing on new technologies. These projects included high pressure processing for a variety of innovative and healthy foods, plasma

DEMONSTRATION ACTIVITIES



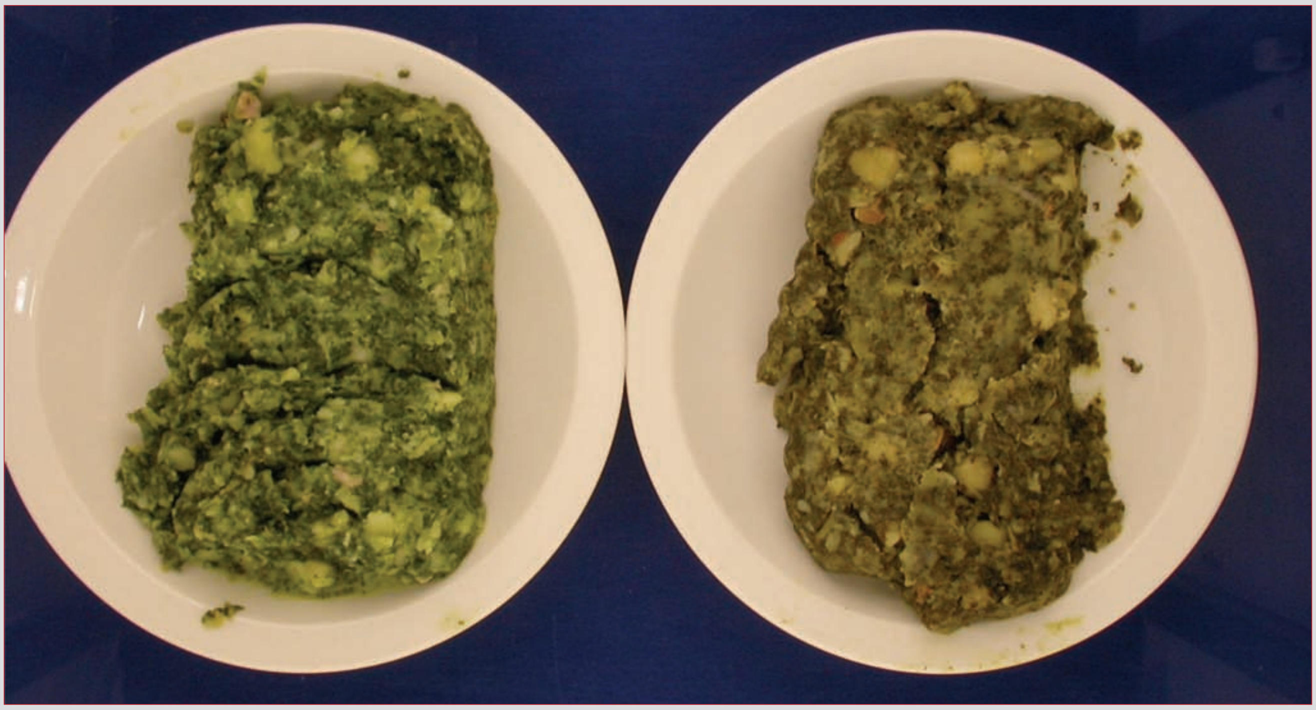
Optimisation of microwave heating uniformity of ready-to-eat meals

treatment of herbs and new packaging material for high pressure processing. Furthermore, 10 short (one / two day) confidential demonstration trials were carried out with IAP members to test new ideas involving novel processing.

Finally, in the last 18 months, two integral demonstration projects which integrated all the scientific results obtained by NovelQ were performed. One of the demonstrations compared thermally processed orange juice with high pressure and pulsed electric fields, based on equivalent microbial inactivation, in terms of general quality attributes such as sensory characteristics, and shelf-life. The other demonstrations consisted of HP sterilisation processes (shelf stable foods) of complex products (meals). Results from these integral demonstrations will be presented at the final NovelQ IAP meeting to be held in Wageningen on 5 – 6 October 2010 (more information at www.novelq.org).

Advanced heating

» A minimal pasteurisation / sterilisation technology by application of water immersed radio-frequency heating for food



Demonstration of radiofrequency as a volumetric heating method for sterilisation of food products (left) compared with conventional sterilisation (right)

products in consumer packages. (A&F, Struik Foods Group, The Netherlands)

» Design of ready-to-eat meals compositions for uniform microwave heating (SIK, Procordia Food, Sweden)
» Ohmic heating technology of highly viscous pumpable foods with particles (CTCPA, OPAL, PENY, France)

Novel technologies

» Cold plasma treatment for inactivation of microorganisms on food surfaces (Koldsteril, Switzerland)
» Packaging materials for high pressure sterilisation (Icimendue, Italy)
» High Pressure processing of healthy, complex food products (TOP, The Netherland, NC Hyperbaric, Spain)

A demonstration of Ohmic heating of vegetable mixture (top) compared with conventional process (bottom)

DEMONSTRATION ACTIVITIES

A demonstration of high pressure processing of dairy products: high pressure treated strawberry yoghurt (left) and reference (right)

Ariette Matser

Ariette Matser is currently Senior Scientist – Mild Preservation and Novel Technologies and Programme Coordinator – Mild Preservation within Food & Biobased Research of Wageningen UR. She studied Food Science at Wageningen UR.

Her primary research activities include novel technologies and food safety and quality, preservation and processing of food products and effects on food quality, and food structure and the effects of processing on this. Management activities are involvement in (inter) national R&D projects, project acquisition and coordination of activities on novel technologies. She is Project Coordinator of the European project NovelQ.

Lilia Ahrné

Dr. Lilia Ahrné is Director of the Department for Process and Technology Development at SIK – The Swedish Institute for Food and Biotechnology and Associated Professor in Food Engineering at Chalmers Technical University. Before joining SIK, she worked for Tetra Pak Processing Systems. Her research interests are to understand the effect of processing on physical, chemical and structural characteristics of foods, and use this knowledge to develop new processes and products taking in account sustainability aspects as energy consumption and costs. Processes under study include both traditional and novel technologies. She has extensive experience in coordination of industrial and European research projects.

Integral demonstration

- Pasteurisation of orange juice (high pressure pasteurisation, PEF and thermally processed). For more details, see 'How to compare novel and conventional processing methods in new product development: a case-study on orange juice' in this issue
- Integral demonstration for complex sterilised ready-to-eat meals (thermal and high pressure pasteurisation)

Short-time demonstration projects

Ten companies together with a NovelQ partner have demonstrated new applications of advanced heating and novel processing. The applications tested include:

- Ohmic heating fruit preparations
- HP cereals products
- Robotic handling of delicate products
- HP dairy products
- Continuous microwave heating
- Microwave drying waste products
- Microwave drying cereals
- HP sterilisation vegetables

Ariette Matser & Hennie Mastwijk
Wageningen UR

Diána Bánáti
Director General, Central Food Research Institute

Liesbeth Vervoort & Marc Hendrickx
Katholieke Universiteit Leuven

How to compare novel and conventional processing methods in new product development: A case-study on orange juice

The overall objective of the EU FP6 NovelQ Integrated Project was to formulate strategic solutions for technical and basic research hurdles to enhance the development and successful demonstration of Novel Processing (NP) schemes. A parallel approach was chosen based on providing a sound scientific base and technology transfer.

The first approach has generated new insights for mechanistic and kinetic aspects on the impact of novel technologies on food safety and quality as a basis for process and product development. The second has led to integrated product and process development, and demonstration trajectories. It has also resulted in enhanced implementation of NP.

Within NovelQ, evaluating the general applicability and validity of several NP schemes was defined as an important task. The effects of NP and conventional processing have been compared using well-defined processing conditions, resulting in guidelines for the application of NP schemes by food manufacturers. These guidelines integrate the results of various activities within NovelQ involving several partner organisations. More specifically, a fruit-based product, orange juice, was selected and processed with conventional heat treatment, high pressure (HP) treatment and pulsed electric field (PEF) treatment. Process impact and homogeneity were monitored, the effects on shelf life and product quality evaluated and sensorial analysis carried out. This article describes the approach chosen and gives an overview of the results. Detailed results will be described elsewhere in scientific publications.

How to compare the effects of novel processing and conventional processing on products?

When industry is interested in evaluating the potential of NP for a specific (or new) product, the first step is often a feasibility study to obtain an impression of the effects of the specific technology on the product characteristics including shelf life and (sensorial) quality. Comparison of the effects of NP technologies with the effects of conventional preservation treatments is crucial, and in some cases, an untreated product will serve as a reference. Selection of specific process conditions used both for the novel process as well as for the

NEW PRODUCT DEVELOPMENT

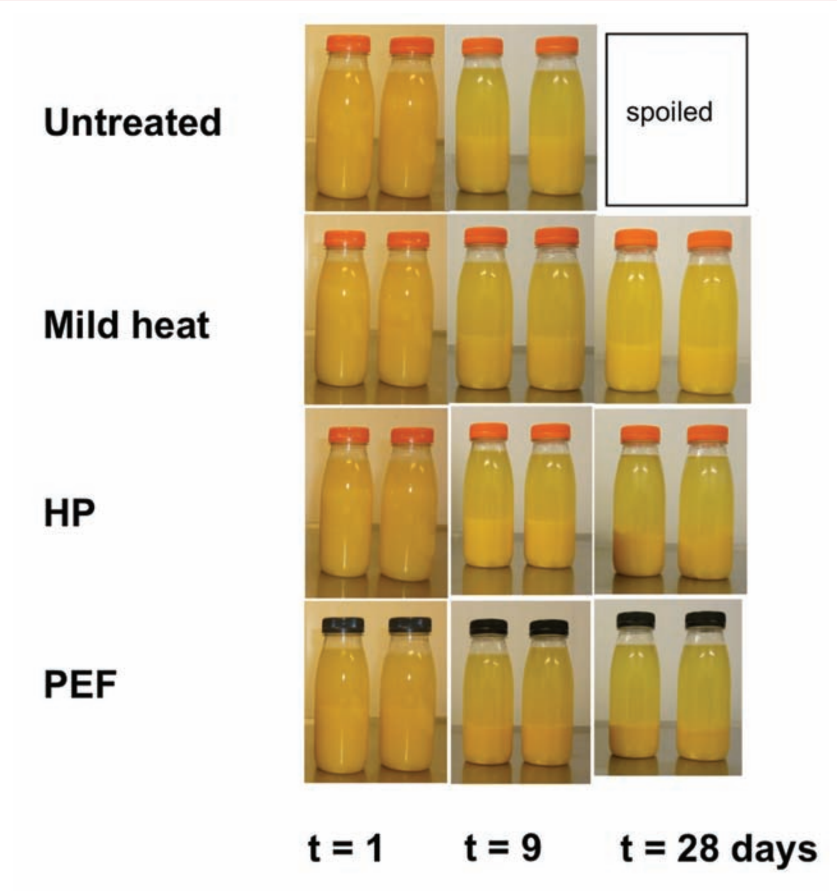


Figure 1 : Photographs of untreated and HP, PEF and heat pasteurised orange juices during shelf life

conventional process is important for a correct and fair comparison. For example, comparison of a very mild novel process with a traditional / conventional process, which causes over-processing, may result in a biased (positive) view of the novel processing. In general, state-of-the-art conventional processing has to be used for proper evaluation. However, selecting the appropriate processes (technologies, sequences and conditions) is complex. The first problem is choosing an equivalent processing level for all the processing technologies. Different targets can be used as a reference point including food safety (pathogens), food spoilage (spoilage micro-organisms, enzymes) and food quality.

The main criterion for choosing process conditions is food safety, according to EC regulation EC 2073/2005 Microbial criteria for Foodstuffs. A more practical recommendation is the FDA guidelines documented in Juice HACCP, which requires a five-log reduction of the pathogen identified as the 'pertinent microorganism', which is the most resistant microorganism of public health significance that is likely to occur in the juice. For orange juice, this is *E. coli* O157:H7. Therefore, the processing conditions should be the minimum required to guarantee a five-log reduction in *E. coli* O157:H7. Table 1 gives an overview of the processing conditions to achieve this equivalence in safety. Furthermore, the conditions should be selected in such a way that the quality aspects of the product (e.g. colour, overall liking) are as high as possible. Equivalent processing levels with respect to inactivation of enzymes or other quality affecting components can result in a different set of process conditions.

The second issue that has to be considered is the safety margin. In industry, a safety margin is applied to avoid the risk of insufficient processing. To determine such a margin, the coldest spot designated equipment is determined and, based on this, the processing conditions selected. However, this will result in considerable over-processing of a major proportion of food in, for example, pasteurisation of packed products. For novel processing, the safety margins are more difficult to identify and often not included in the selection of appropriate conditions. Table 1 gives examples of industrial process conditions for the selected technologies, and shows large differences amongst process conditions compared with the conditions sufficient to achieve equivalent safety levels.

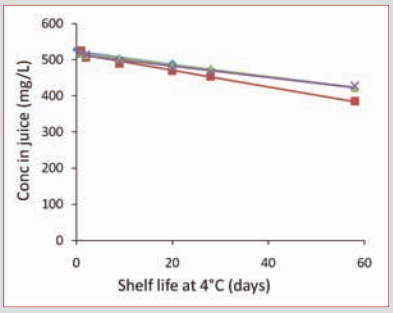


Figure 2 L Ascorbic acid in orange juices directly after processing (untreated (◊), high pressure (Δ), pulsed electric field (X), and heat treatment (□)) and during shelf life

The third issue is scale up of processing. Often, pilot-scale equipment is used to develop NP since industrial-scale equipment is not always available. Process conditions at pilot-scale can differ from industrial-scale equipment, for example, differences in pressure build up rate in high pressure processing, and heat transfer and packaging sizes in conventional heat processes. Attention should be paid to unrealistic comparisons or conditions that cannot be achieved at industrial-scale.

Table 1 Comparison of the processing conditions necessary to achieve a 5 log reduction of *E. coli* O157:H7 in orange juice and industrial conditions for chilled orange juice

Technology	Food safety conditions	Industrial conditions
Fresh juice	Limited shelf life	3-8 days shelf life
Heat pasteurisation	3-6 s treatment at 71.1°C*	10-30 s treatment at 72-87°C
High pressure pasteurisation	1-5 min treatment at 350-500 MPa	1 min treatment at 600 MPa
Pulsed electric field treatment	Unknown**)	40 microsec at 20 kV/cm

**) This is the minimum required temperature-time combination that should be guaranteed in a heat pasteurisation process.*
***) no data available on pathogen studies*

In addition to this, recipes and packaging may be different for each, for example, pre-cooking of a pasta dish may be different for heat processes compared with high pressure processing and the taste balance can be altered by specific processes resulting in the need for different amounts of seasoning (i.e. herbs, spices or salt).

NovelQ approach for comparison of effects of NP on orange juice

As described above, the aim of the integrated demonstrations within NovelQ was to evaluate the general applicability and validity of NP schemes by comparing the effects of NP and conventional processing at equivalent levels. As pulsed electric field treatment was included in the study, a liquid food product was chosen which already exists on the market, preserved using conventional technologies. In this study, orange juice was treated with high pressure, pulsed electric field treatment and heat pasteurisation, and untreated juice was used as a reference. As both HP and PEF result in a product that requires chilled storage, a heat pasteurisation process was selected on the basis of comparable food safety levels. Commercially available oranges, currently used for fresh juice, were selected for this test. Processing conditions were selected as having a similar impact with respect to food safety. Thus, in this study, orange juice processing by HP, PEF and conventional thermal processing were compared under similar conditions of low thermal impact and chilled storage conditions during shelf life. Conditions close to the food safety conditions in Table 1 were used, although these conditions may need to be adjusted scaling up to industrial levels. After processing, the samples were distributed to NovelQ partners KU Leuven (Belgium), KÉKI (Hungary), Life-UC (Denmark) and Wageningen UR (The Netherlands). Logistics were important to assure quality and safety levels were guaranteed and monitored well during transport.

As samples were to be used for sensory evaluation, equivalent processing levels were selected whilst ensuring food safety was guaranteed. The absence of pathogens was explicitly checked. Directly after processing, all samples were within required safety limits according to EC 2073/2005. During shelf life, additional microbial evaluations were carried out in triplicate for each treated orange juice

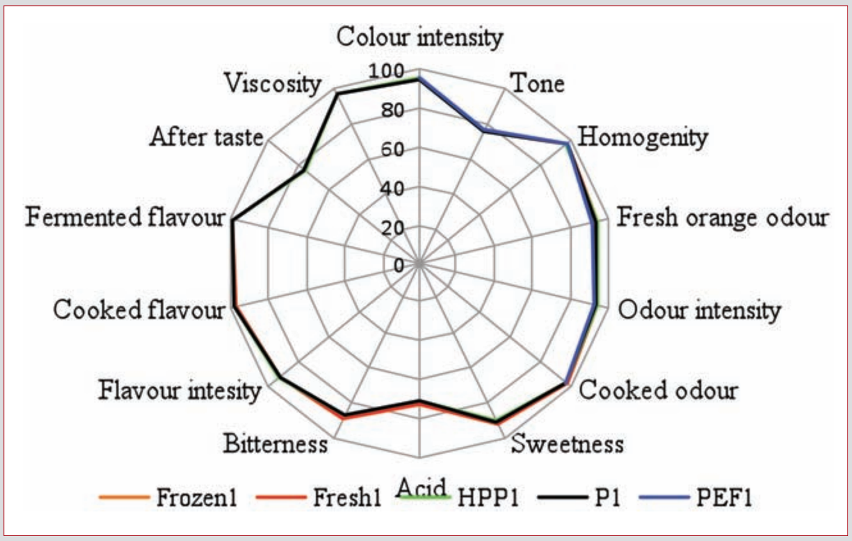


Figure 3 Sensorial evaluation of orange juices directly after processing by trained experts

Figure 4 Restaurant of the Future (Wageningen UR) used for the study of consumer acceptance of orange juice

with respect to aerobic mesofilic plate count, *Enterobacteriaceae*, yeasts and moulds, and lactic acid bacteria. As expected, the untreated juice was spoilt between 9 and 20 days during storage at 4˚C. No spoilage was found after two months storage at 4˚C with HP, PEF and mild heat pasteurisation.

Cloud stability, and in particular cloud separation, is an important quality aspect for orange juice and determining physical stability during shelf life. As this process is caused mainly by residual enzyme activity, enzyme inactivation during processing and temperature during shelf life are the most important factors for shelf life. Figure 1 on page 36 shows pictures taken during the shelf life tests. Cloud stability was highest for heat pasteurised juice and HP, but considerably lower for PEF treated juices. The untreated juice shows the fastest cloud separation and, after nine days, microbial spoilage caused disturbance of the cloud. These results are in line with the activity of the major enzyme involved, pectinmethylesterase.

A wide range of quality attributes were determined directly after processing and during shelf life including pH, colour, total soluble solids, dry matter content and viscosity. Different components were determined including vitamins (ascorbic acid and dehydro-ascorbic acid), sugars, acids and carotenoids; details will be published in peer-review journals later this year. Figure 2 on page 36, however, gives an example of this work and shows the effect of processing and shelf life on ascorbic acid. The results reveal that only minor changes were observed at the process conditions selected.

In addition to the chemical, biochemical and physical analyses, sensory evaluation was carried out by trained experts. These experts evaluated the juices directly after processing and during shelf life. After the second evaluation day (nine days), the untreated juices were no longer evaluated because of safety restrictions. Frozen samples were used as an alternative to represent the fresh sample. Figure 3 on page 37 gives an example of the qualification of samples on the first evaluation day, showing no major differences between the samples. During storage, only minor (non significant) differences in odour were observed.

Acceptance and liking of these juices was also examined by a repeated exposure test. Consumer acceptance was evaluated by observation in the Restaurant of the Future (Figure 4, page 37) at Wageningen UR. This facility allows consumer behaviour to be studied in 'real life' situations. Juices were offered to regular users of this facility and their buying behaviour was monitored. Almost no differences were observed in buying behaviour between the treatments; most people tasted one of the juices once and then returned to their previous habit.

Conclusions

In general, this integrated demonstration showed that both pulsed electric field treatment and high pressure processing can extend the shelf life of fresh orange juice and maintain its fresh characteristics. The fresh juice spoiled between nine and 20 days while the NP-treated juices were unspoiled after two months chilled storage.

For this specific product, both new technologies and mild heat pasteurisation represent alternatives to obtain a mildly processed product with a longer shelf life under refrigerated conditions. It has yet to be shown whether industrial processing conditions after scaling up would lead to the same result.

The thermal pasteurisation conditions chosen in this study are very mild and were carried out as an HTST process followed by aseptic filling resulting in minimal impact on juice quality. Although the shelf life of the heat pasteurised samples was two months, the temperature-time combination selected should be regarded as insufficient since heat penetration is limited in a large-scale heat pasteuriser, especially with more viscous products. These effects do not occur for NP since the critical process parameters are, in principal at least, not based on a temperature-time combination.

The current study proves that the comparison of technologies on specific products needs careful selection of critical processing conditions based on the principle of equivalence. At the same time, the study proves that with such careful selection and improvement in conventional processing, better products can be achieved.

Acknowledgement

As this is an integrated demonstration, many partners and co-workers have contributed to this task. We would like to thank everyone who contributed for their efforts and enthusiasm.

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Novel processing and sustainable food production – a perfect match or not?

Food is indispensible to humans. Aside from the provision of energy and nutrients, it contributes to a range of important aspects of human life such as pleasure, cultural identity and heritage. At the same time, food accounts for a significant global share of total environmental impact and resource use. It is difficult to accurately quantify this impact, but estimates show that food chains globally account for 25 - 30 per cent of greenhouse gas emissions and energy use, and food production occupies most of the available arable land. Agriculture is also the single largest user of water and has a tremendous impact on biodiversity.

Considering the global situation regarding climate change, energy and water usage as well as depletion of ecosystems, all sectors need to decrease their impact and food is no exception. The established method of assessing the environmental impact of products is Life Cycle Assessment (LCA). LCA focuses on the product and should include the whole life cycle 'from-cradle-to-grave'. When performing an LCA, all relevant inflows (energy, material etc.) are quantified and related to the product at a certain stage in the life cycle (e.g. MJ/litre milk at the retail gate). Also included are methods to weigh together the emissions of different single substances contributing to the same environmental impact, such as in climate change where emissions of carbon dioxide, methane and nitrous oxide are transformed into the single unit 'carbon dioxide equivalents'.

As a general rule, products of animal origin such as meat, fish and dairy have greater impact than those of vegetable origin, but there are of course exceptions. Food processing is often a smaller share of a products' life cycle environmental impact; primary production (agriculture and fishery) generally dominates whilst the later portion of the chain (households) dominate for some products. In some cases, packaging and transport can be of importance. However, for highly processed vegetable products, processing can account for the largest share of life cycle impact. Since primary production often accounts for a large share of total impact, reduced waste in later steps is an important potential improvement. Even if food processing has a lower environmental impact for many products, how the food is processed can dramatically affect its performance; what packaging was used, preferred shelf-life and final preparation, the environmental impact of food processing is a combination of direct impact (energy- and water use, direct emissions from factories) and indirect impact (choice of packaging, shelf-life, raw material utilisation). Obviously, processing affects sensory and nutritional qualities, which in turn affect wider sustainability aspects but this is not included here, despite its importance.

Novel processing and sustainability

Novel, mild processing methods and treatments, based on physical measures, are highly promising in terms of:

- less use of energy
- less use of water
- efficient use of raw materials by better yields and less waste
- efficient use of packaging materials and avoidance of re-packing
- shelf life extension and reduction of product losses in the food chain
- less cleaning and disinfectants
- avoidance of chemical preservatives

This list shows good correspondence with important aspects mentioned in the introduction. Thus, novel processing technologies offer alternatives for more sustainable food products. However, it is important to consider the entire life cycle of individual food products rather than product groups because reality is too complex and food is too diverse a product group for generalisations. Moreover, many environmental aspects must be considered; sustainability is more than just energy use. Within NovelQ, LCA studies have been applied to several cases where novel processing technologies have been compared with conventional processing. One of these will be used to demonstrate the life cycle environmental performance of different technologies applied to specific products, and highlight the importance of looking at the entire systems, not just the process in isolation.

Case study example – production of tomato salsa

In this case study, conventional heat treated salsa was compared with fresh salsa and two high-pressure (HP) processed salsas, one pasteurised and one sterilised. An assortment of methods for production brought about a number of differences between the products, which are summarised below (the case study is more thoroughly described in Davis et al, 2009):

» heat treated salsa packaged in glass jars
» fresh, untreated salsa (citric acid is added) packaged in polypropylene tubs
» high pressure treated salsa packaged in polyethylene pouches
» high pressure and temperature treated salsa packaged in polyethylene pouches (sterilised)

The resulting products are slightly different in terms of freshness, storage requirement and shelf life (closed and opened, respectively). The life cycles were followed from production of agricultural inputs (raw ingredients) through processing, transportation and retail, finishing at the point of consumption in the household. The results showed that HP processing gave lower energy use (Figure 1), partly due to more energy efficient processing but more as a result of the potential to use more energy efficient packaging. The energy use by the retailer was higher for HP sterilised and heat-treated products even when they are stored at ambient temperature as compared with fresh and HP pasteurised products, which demand refrigerated storage. This is explained by the much longer storage time for HP sterilised and heat-treated products (12 months). Transportation is a significant contributor to all four product life cycles (transportation includes all transport of packaging materials, raw materials and the product up to retailing), but there are only minor differences between the products. It is also important to note that consumer transport accounts for a large part of the overall energy use; conventional salsa has a slightly higher contribution than the others because the packaging is heavier. Other differences were small and are not explained here. The environmental gains of HP against heat-treatment are reached through the combination of issues where more energy efficient processing is only one aspect.

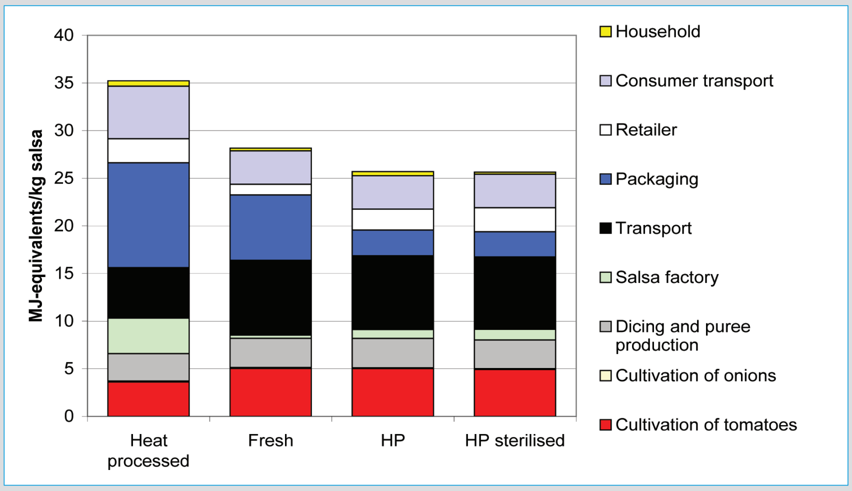

Figure 1 Use of primary energy in the life cycle of tomato salsa products

Discussion

It is not possible to answer the question posed in the title in a single sentence. The changes in environmental impact caused by switching from conventional to novel processing arises from a combination of factors in raw material requirements (quality), utilisation (wastage), processing energy, shelf-life, packaging solutions and so on. Food products are an extremely heterogeneous group with very different 'environmental profiles' from a life cycle perspective, which complicates matters further. Novel processing technologies bring about very different options for processing, packaging and product quality. Hence, the environmental impact of novel processing, as well as any change in the food chain, depends on the context; how the food chain as a whole is designed and managed. Regardless of this discouraging complexity, there are good opportunities to design food chains including novel technologies, as shown in the case study example above. LCA methodology is improving and databases are being developed, making analyses less costly and time consuming. The application of LCA combined with economic assessments has been shown to be an efficient tool for improving food business from both an economic and environmental point of view.

In conclusion, novel processing technologies provide great opportunities to improve the sustainability of food systems by reducing energy use in processing and waste in the food chain. But it is important to consider the entire life cycle of a product when designing the process / system so as to avoid increasing environmental impact from, for example, new packaging, which comes with the technology, or overlooking benefits from options made possible with new technology. Finally, it is important to keep in mind the potential to increase product quality, both sensory and nutritional, which novel processing brings about. This might turn out to be as important more broadly than simply the environmental aspects.

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Packaging challenges for novel processed food

In the last few years, the fast development of novel processing methods for food preservation to improve safety, quality and shelf life of packaged foods gave place to important gaps of knowledge that must be filled in the area of suitable packaging materials. In particular, in the European Project NovelQ (FP6-CT-2006-015710), the effect of novel processing technologies, such High Pressure (HP) as well as microwave (MW) heating on the performances and structural integrity of several types of packaging materials has been investigated along with issues related to food/packaging interactions.

HP treatment is steadily gaining as a food preservation method that maintains the natural sensory and nutritional attributes of food, extending shelf life with minimal quality loss. It consists of applying high pressure (typically in the 300-800 MPa range over a period of several minutes) to packaged foodstuff to greatly reduce the number of microorganisms and also to deactivate enzymes by mechanical action. HP pasteurisation is conducted at 25 – 40°C while HP sterilisation is conducted at 90 – 110°C.

We discuss here some relevant issues addressed in the NovelQ project related to the effect of HP treatments on packaging materials in terms of mechanical resistance of packaging structures, of the possible reduction of their functional properties (e.g. barrier properties) and of possible migration and scalping phenomena of small molecules in conventional plastic, novel biodegradable and nano-composite packaging materials. Moreover, in this contribution we also report on packaging/food interaction during MW heating of packaged foodstuff.

Suitability of commercial packaging materials for HP treatments

Packaging materials for HP treatments have to be flexible enough to withstand the compression forces while maintaining physical integrity without losing the properties which guarantee the adequate protection of packaged food[1,2]. In fact, HP treatment can promote changes in crystallinity, density and orientation of plastic packaging materials that could affect, in turn, mechanical and mass-transfer (vapour and gas barrier, migration/scalping) properties of the package in a significant extent.

Moreover, interfacial stresses arising between the different elements of multilayer structures as a result of the high pressure, could bring about delamination and extensive detachment of the layers.

In the course of the NovelQ project, a systematic analysis has been performed on the behaviour of flexible single materials and multi-layer commercial plastic structures (Table 1, page 45), used to package selected foodstuff (i.e. tap water, carrot juice, carrot puree and solid sliced carrots) to be HP treated.

Tests performed on films of LLDPE and of PP confirmed that these materials are capable of withstanding the HP treatment conditions, both for pasteurisation and sterilisation, without displaying significant changes or deterioration of barrier, mechanical and morphological properties, as also reported in the recent literature[3]. It is worth noting that LLDPE can be submitted to treatments at temperatures as high as 110°C without occurrence of melting, since HP conditions promote an increase of melting temperature.

Referring to laminated structures, the PA cast / PP cast bilayer films were found to be the most suitable for HP pasteurisation and sterilisation up to 700-800 MPa (see Figure 1, right side), although results were to some degree dependent on the adopted lamination adhesive. Slightly worse results were obtained with OPA/PP cast films, while multilayer structures made of PET/PP were found unsuitable for HP sterilisation due to delamination phenomena (Figure 1, left side). However, we cannot exclude that better results could be obtained with PET/PP structures made of films processed in different conditions as compared to the materials we used (e.g. different degree of orientation or different heat setting procedures

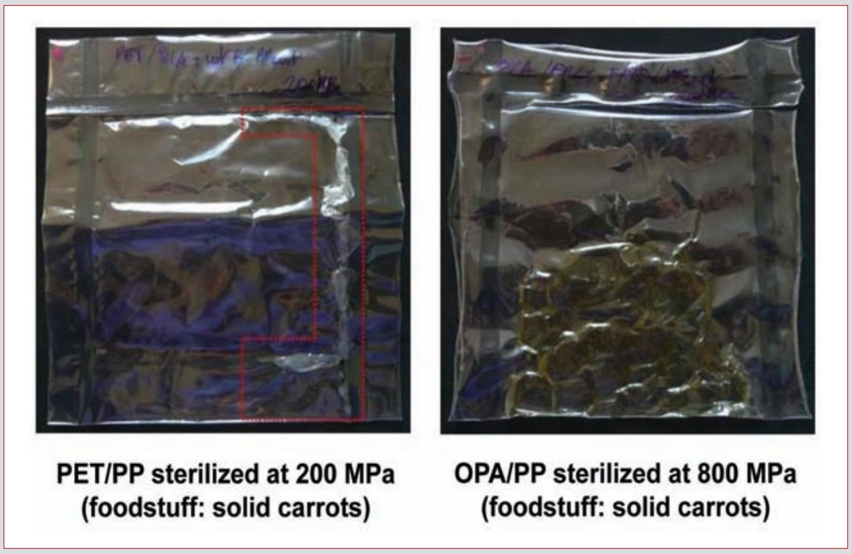

Figure 1 Photographs bilayer structures used to package solid carrots, after HP sterilisation. The delaminations areas in the case of PET/PP cast films (left side) highlighted with dashed red line

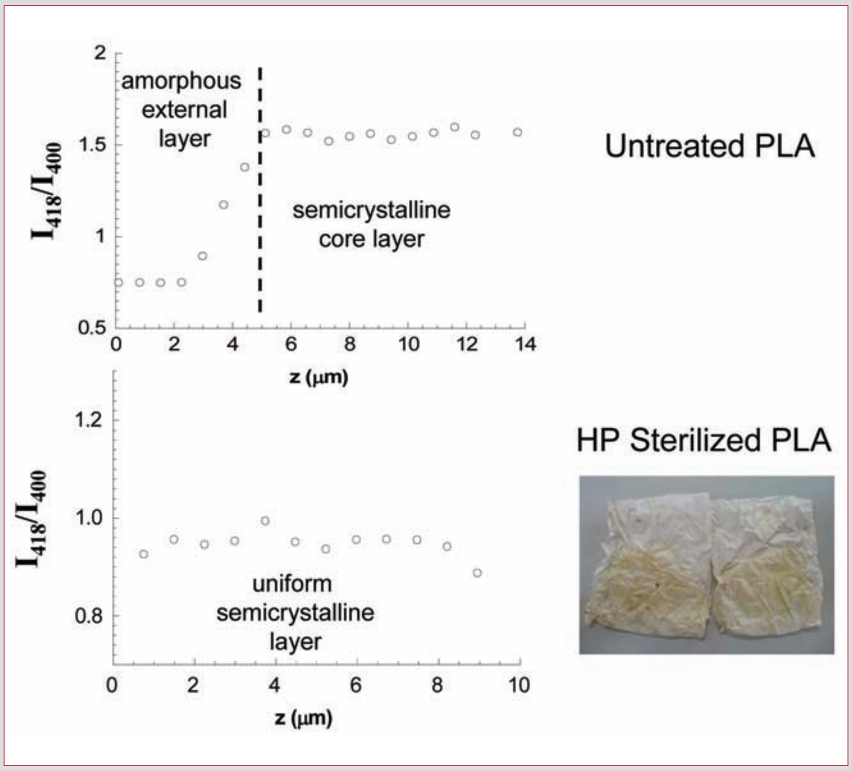

Figure 2 Micro-Raman depth profile of the untreated PLA (upper) and of HP sterilised PLA at 700 MPa (lower). The ratio reported in the ordinate is related to crystallinity. PLA pouches were transparent before HP sterilisation and whitens as a consequence of crystallisation (see photo)

of PET films). In general, the multilayer structures withstanding processing without delaminating did not display significant changes of mechanical and functional properties as a consequence of treatment. Moreover, our results confirmed that films including aluminium foil or metallised layers are unsuitable for HP sterilisation, as already indicated in some literature reports[1,2,4] due to extensive delamination phenomena.

Finally, tested coextruded structures did not perform as well as best performing laminated structures at the highest pressure / temperature conditions.

The results reported above are in agreement with recent results reported in the literature[5].

Experimental results on delamination of multilayer films have been rationalised in terms of a finite element (FEM) analysis of the process of HP treatment of pouches made by using multilayer films containing tap water. The delamination occurrence was attributed to the development of interlaminar normal and shear stresses. To summarise the findings of FEM simulations for the case of bi-layer films, it can be stated that an 'heuristic' measure of the goodness of the coupling between layers is the percentage difference between the

» Contrary to microwave heating, substantial knowledge was still required about the specific effect of pressure on food/packaging interactions at the beginning of the NovelQ project «

Young modulus of one of the films and the overall modulus of the bi-layer structure: the lower this difference, the lower the likelihood of interfacial failure. In practical terms, in the case of examined bilayer structures including PP cast film (i.e. PA cast/PP cast; OPA/PP cast and PET/PP cast) this rough measure would predict the 'best coupling' in the case of PA cast/PP cast bi-layer films. This is exactly what emerges from the experimental evidences.

Biodegradable packaging materials for high pressure treatments

Suitability of two classes of biodegradable polymers for HP treatments were investigated analysing: i) commercial coextruded multilayer PLA structures and ii) novel laminates based on thermoplasticised zein.

PLA oriented multilayer films, made of two top sealable amorphous PLA layers and of a core of partially crystalline PLA (Treofan 121 by Biophan, 44 μm thick), has been used to prepare pouches containing tap water or solid carrots. The pouches have been treated to HP pasteurisation and to sterilisation. While pasteurisation did not promote relevant variations of the barrier properties of PLA, HP sterilisation treatments promoted relevant changes in crystallinity which was accompanied by brittlening of the material. Figure 2 shows the micro-Raman profiles of the PLA films and a picture of the PLA pouches after the HP sterilisation. The profile analysis in Figure 2 shows that the crystalline amount after the HP treatment (circles) is rather uniform along the thickness, indicating that the crystallinity in the external layers increased as a consequence of the HP treatments.

Lamination of thermoplastic zein proteins (TPZ) with hydrophobic layers of poly-ε-caprolactone (PCL) were also developed to prepare biodegradable flexible packaging materials with controlled barrier and mechanical properties suitable for high pressure

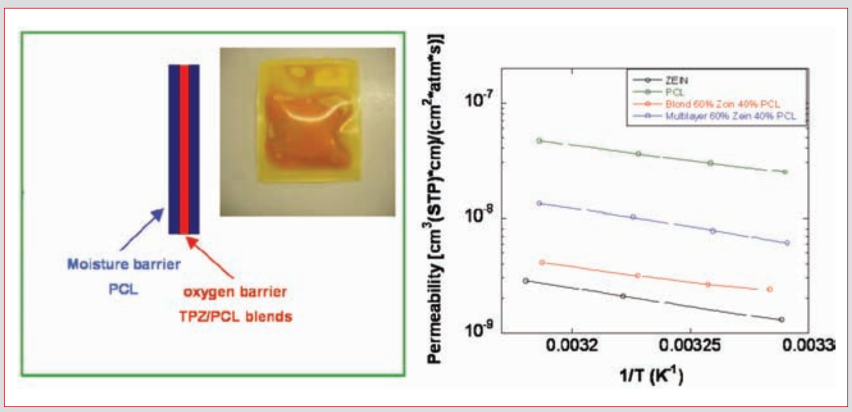

Figure 3 Left: schematic view of the multilayer novel structures based on PCL and a blend of thermoplastic zein with PCL. The photograph shows a pouch containing carrot puree after HP pasteurisation at 700 MPa. Right: oxygen permeabilities of PCL, zein and PCL/zein multilayer and blend films

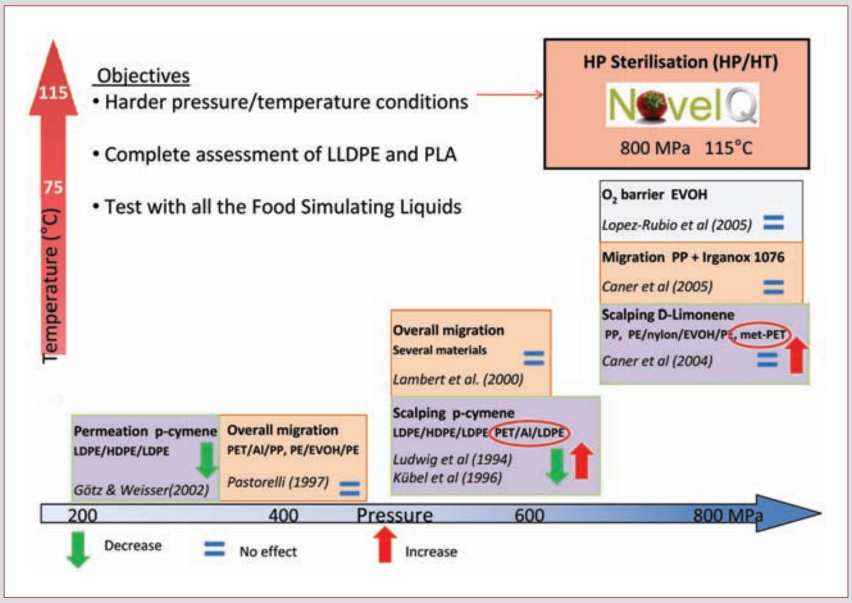

Figure 4 Overview at the starting up of NovelQ project of the available existing studies concerning impact of high pressure processing on food packaging system and synthetic presentation of the objectives of the project to go beyond the state-of-the-art (from Guillard V, Mauricio-Iglesias M, Gontard N. (in press) Crit Rev Food Sci Nutr)

pasteurisation treatments. Zein, the prolamine of corn, is of industrial interest mainly for its unique hydrophobicity and barrier to oxygen. When denaturated by applying a suitable plasticiser in combination with heat and shear, zein can be thermoplasticised[6], in a way similar to thermoplastic starch[7], and processed by using extrusion blowing technologies[8] to prepare single layer or multilayer films. Figure 3, page 44 (right hand side) compares oxygen permeabilities of pure zein, pure PCL, multilayer PCL/zein structures and TPZ/PCL (40:60) blend: a tailoring of oxygen permeability can be obtained by a proper selection of PCL and zein structures. HP pasteurisation performed on carrot juice and solid carrots packaged with multilayer TPZ-PCL structures revealed the compatibility of such structures with HP treatments at low temperatures (Figure 3, left). In particular, HP treatment up to 700 MPa did not promote detectable changes of mechanical properties as well as oxygen and water vapour barrier properties.

These laminated TPZ/PCL structures were unsuitable for HP sterilisation due to the low glass transition temperatures of the TPZ phase (~50°C) and the low melting temperature of the PCL phase (~60°C). However, we have developed TPZ that incorporates nanolayers of silicates (nanoclay) that results in bio-nanocomposite materials with improved thermo-mechanical properties (increase of glass transition temperature by ~20°C), paving the way to a possible use for HP treatments at temperatures higher than those employed for HP pasteurisation.

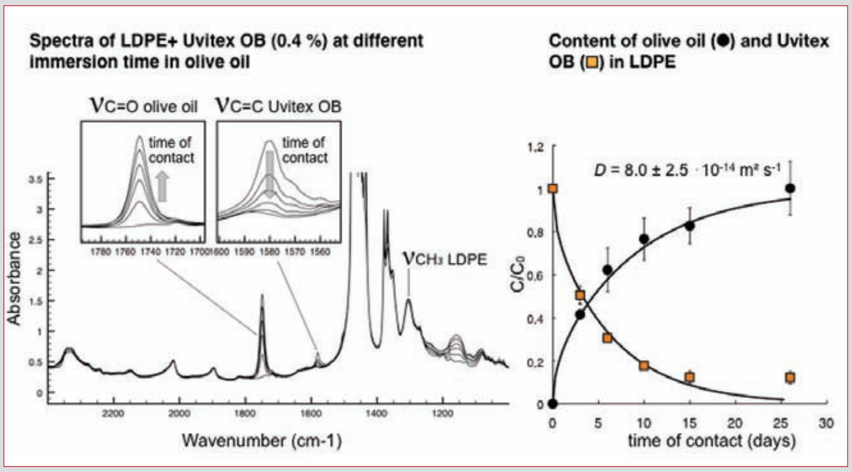

Figure 5 Example of the use of non-destructive FT-IR based methodology to study simultaneous olive oil and Uvitex OB (additive) migration in LDPE (adapted from Mauricio-Iglesias *et al*[40]

Table 1 List of commercial single and multilayer films used for HP Pasteurisation and sterilisation treatments

Material	Abbreviated identification
Single material films	
Linear Low Density Polyethylene	LLDPE
Cast Polypropylene	PP cast
Multilayer laminated films	
Bioriented Polyetheyleneterephthalate/Linear Low Density Polyethylene	PET-LLDPE
Bioriented Polyetheylenterephthalate/cast polypropylene	PET-PPcast
Metallized Bioriented PET/ Linear Low Density Polyethylene	PETmet-LLDPE
Bioriented Polyetheylenterephthalate/Polyamide/Aluminum foil/ Linear Low Density Polyethylene	PET/PA/Al/LLDPE
Cast Polypropylene/Bioriented Polyethyleneterephthalate/Polyvinylidene chloride-coated	PP cast/PET/PVDC coated
Cast Polyamide/Cast Polypropylene	PA cast/PP cast
Cast Polyamide/ink/Cast Polypropylene	PA cast/Ink/PP cast
Multilayer coextruded films	
Bioriented Polyamide/Cast Polypropylene	OPA/PP cast
Polypropylene/ Polyethylenevinylalcohol/Polypropylene	PP/EVOH/PP
Polypropylene/Polyamide/Polypropylene	PP/PA/PP

Migration and scalping phenomena in light of food safety

Novel food processing methods, such as high pressure or microwaves, imply that both packaging and foodstuff undergo the stabilisation treatment. During such treatment, the packaging material is involved and exposed to different processing conditions which may alter its structure and consequently its mechanical and mass transfer (barrier and migration) properties. For instance, processing conditions, such as time/temperature couple undergone during conventional or microwave heating, are known to accelerate mass transfer from packaging materials into food. Numerous publications could be thus found on the effect

PACKAGING

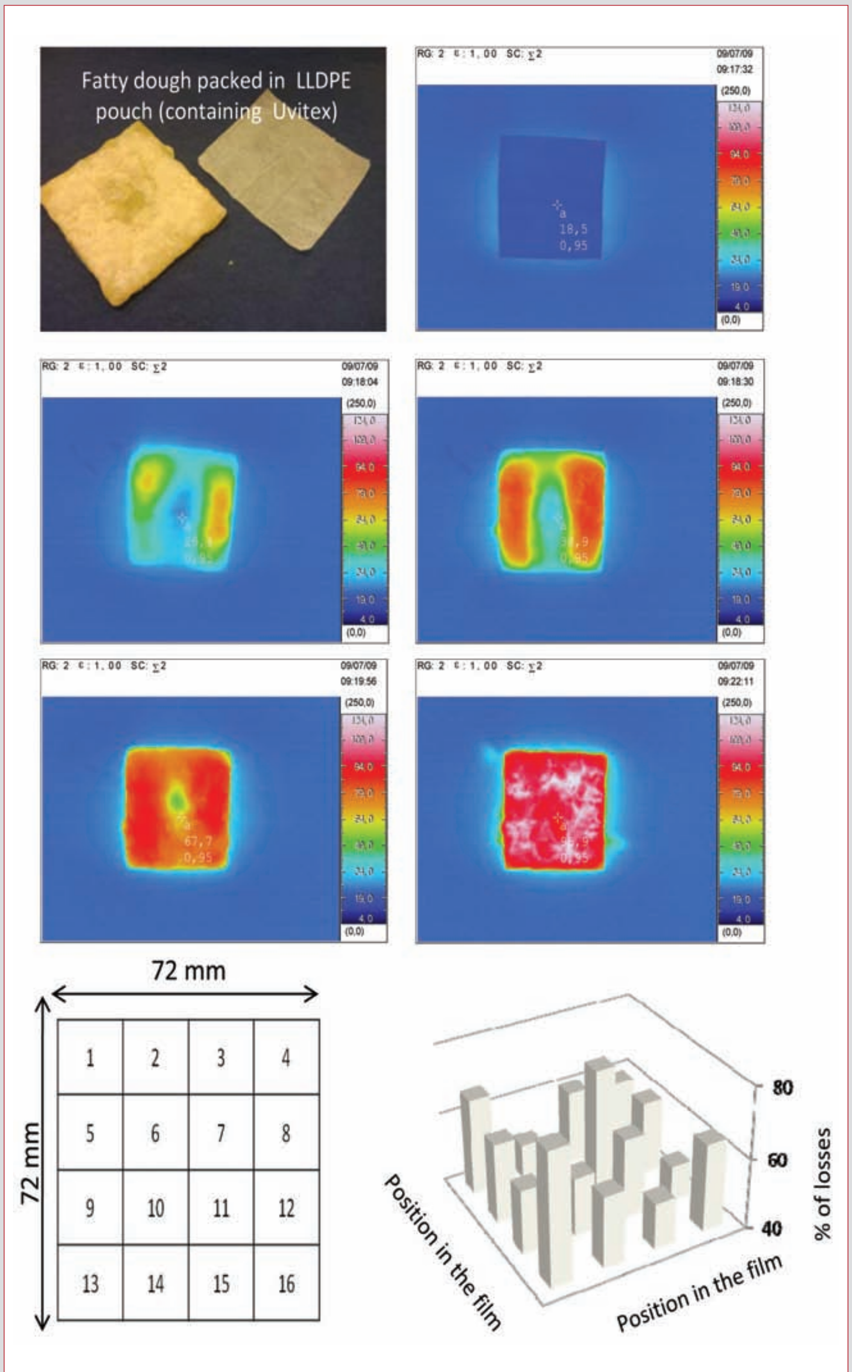

Figure 6 Mapping of the surface temperature of LDPE film used to pack fatty dough during a four minute microwave heating and subsequent predicted migration into food of Uvitex OB initially present in the packaging

of temperature on overall and specific migration from plastics materials into food during microwave heating[9-33]. Most of the authors conclude the importance of the high level of temperature that could be reached (specially in the case of susceptor technology) and its heterogeneity in the material[13,30,31]. Contrary to microwave heating, substantial knowledge was still required about the specific effect of pressure on food/packaging interactions at the beginning of the NovelQ project. As shown in Figure 4 on page 45, only four studies dealing with this subject were found in literature: two dealing with the global migration[34,35] and two others with the specific migration of one antioxidant, Irganox 1076[36], and a pressure-transmitting fluid, 1,2 propanediol[36,37]. All these studies were performed on synthetic plastic materials and nothing was known about the expected behaviour of biodegradable materials and 'active' biodegradable materials during and after HPT.

It appeared thus crucial at the beginning of the NovelQ project to (1) understand and clarify the effect of high pressure treatment (especially harder pressure and temperature condition) on the food/packaging interactions of conventional synthetic material but also of biodegradable materials (Figure 4) and (2) to assess the effect of temperature heterogeneities during microwave treatment of a packed fatty food on the migration of an plastic additive.

Effect of high pressure treatment on food packaging interactions

Three materials were studied, namely linear low density polyethylene (LLDPE), polylactide (PLA) and a wheat gluten/montmorillonite (WG/MMT) nanocomposite. Food/packaging interactions were studied after two HP/T treatments intended to perform a pasteurisation (800 MPa, five minutes, 40°C)

> *» HP treatment is steadily gaining as a food preservation method that maintains the natural sensory and nutritional attributes of food, extending shelf life with minimal quality loss «*

and a sterilisation (800 MPa, five minutes, 115°C) treatment, as well as subsequent storage for 10 days. Specific migration of an additive (Uvitex OB) was assessed for LLDPE and PLA, whereas other adapted tests were carried out for WG/MMT, i.e. overall migration, protein migration and nanoparticles migration. HP/T treatments did not significantly modify the migration or scalping in the conditions studied but for the release of nanoparticles from WG[38,39]. Furthermore, the increase in the melting point of LLDPE allowed the sterilisation of LLDPE whereas it melted when submitted to a conventional thermal sterilisation.

To date the most frequently used methods in migration assessment are based in expensive and time consuming methods based on destruction and quantification. To make easier packaging testing, modelling has recently been approved as a method for migration assessment (directive 2002/72/CE). However, the parameters needed, i.e. diffusivity (D) and the partition coefficient (K) are seldom available. The use of FTIR and Raman spectroscopy to assess migration behaviour and, more importantly, to determine the diffusivity of an additive in LDPE was successfully carried out allowing a complete characterisation of mass transfer[40] (Figure 5, page 45).

In the framework of the NovelQ EU project, the French JRU IATE demonstrated that antimicrobial bio-sourced packaging materials may contribute to combine environmental protection and food quality improvement. PLA-based materials containing AITC previously encapsulated in cyclodextrins was demonstrated to be an efficient optimised antimicrobial system for inhibiting *B. cinerea* growth during at least 10 days at 22°C. Moreover, combining mild HP treatment (around 300 MPa) and use of active film proved to be more efficient for inhibiting *B. cinerea* growth than either a HP pasteurisation-like treatment (800 MPa) or antimicrobial packaging used alone, even though the quantity of active compound released from the film was lower than the minimal quantity required to obtain inhibition at atmospheric pressure. This combined effect between pressure and antimicrobial agent can be used to reduce the quantity of active agent used in antimicrobial film and/or to reduce the intensity of the HP treatment (Table 2[41]).

Table 2 Combined effect of high pressure processing and antimicrobial activity of allyl isothiocyanate (AITC) and of active PLA-based film containing cyclodextrins encapsulated on the growth of Botrytis cinerea during storage (10 days) at 22°C (from Raouche et al. submitted)

	0.1 MPA	300 MPA	600 MPA	800 MPA
CONTROL	+	+	+	+
AITC	+	+	-	-
PLA/CD$_{AITC}$	+	-	-	-

+ growth of Botrytis cinerea; - no growth after 10 days of storage

Effect of temperature heterogeneities during microwave heating on the food / packaging interactions

The use of IR probe allows the mapping of temperature on food surface during microwave heating (methodology of SIK). This showed the local, surface temperature reached in each point of packed fatty dough (worse case for migration of hydrophobic substance such as common additives of LDPE) during the MW heating (Figure 6, page 46). From this mapping, several areas of homogeneous temperature have been selected and the potential migration of Uvitex OB added in the material in contact with food was predicted for each pre-selected area using the mathematical model developed in JRU IATE during the NovelQ project and the diffusivity of Uvitex OB determined using the non destructive FT-IR based method presented above (Mauricio-Iglesias, Guillard et al., 2009). The resulting predicted migration rate show that a large quantity of Uvitex OB could be potentially released in fatty food during less than four minutes of MW heating. It is important to point out that heterogeneities in surface temperature lead to huge differences in level of migration (from less than 50 per cent to more than 70 per cent depending of the temperature). These high levels of migration underlined the roles of both the temperature and the nature of the food in contact (fatty versus aqueous medium) in migration phenomena. Moreover, this experiment illustrated the importance of temperature heterogeneities during MO heating and their impact on migration. These preliminary results need to be experimentally validated and it is worth looking more in-depth in further studies.

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Valérie Guillard

Dr. Valérie Guillard is a specialist of mass transfer modelling of food/packaging interactions, working at the University of Montpellier II for 10 years. She is the designer of a mathematical model permitting to predict in advance the mass transfer of gas or vapour in a food / packaging system and between the different phases of a food product (e.g. water migration in composite food). This tool requires an accurate knowledge of the parameters describing mass transfer. Dr. Valérie Guillard is thus working on the determination of diffusivity and solubility parameters in food and packaging materials.

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Giuseppe Mensitieri

Giuseppe Mensitieri graduated in Chemical Engineering on 1985 at the University of Naples Federico II where he is full professor of Materials Science and Technology and of Macromolecular Materials. He is currently Director of the Bachelor Program in 'Materials Science and Engineering'.

His main field of research is that of polymeric materials with focus on structure – properties relationships. In particular, his research activities concern transport through polymers of low molecular weight molecules, thermodynamics of solute-polymer mixtures, polymer – penetrant chemical-physical interactions, technological applications related to mass transport phenomena.

Giuseppe Mensitieri has been visiting researcher at the Department of Chemical Engineering of the University of Toronto and the Department of Chemical Engineering of the North Carolina State University. He is author of 85 scientific publications on international refereed journals, eight book chapters and of four patents.

Nathalie Gontard

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Hygienic design of novel processing equipment

The hygienic design of food processing equipment is a critical factor in determining the quality and safety of foods produced. It involves the selection of suitable materials of construction, their fabrication into a functional piece of equipment, the ability of constructed equipment to produce food hygienically and the maintenance of hygienic conditions throughout the equipment's working life. There is a significant amount of guidance and information available on the principles of hygienic design for traditional food processing equipment (from the European Hygienic Engineering Design Group; www.EHEDG.org), but the nature of NP techniques such as High Pressure Processing (HPP) and Pulsed Electric Field (PEF) may impose other additional stresses on the equipment surfaces, their construction materials and their fabrication.

Figure 1 High Pressure commercial Unit (Wave 6000_300 HC Hyperbaric) showing packaging carriers Copyright: NC Hyperbaric

Hygienic design is very important for food safety because of its role in ensuring that the equipment does not harbour hazards, e.g. microorganisms, and can be effectively cleaned of material generated during production. For equipment that produces pasteurised/sterilised products, however, the most important function of the hygienic design is providing a barrier to outside microbial re-contamination.

There are three major vectors of microbial contamination: surfaces, liquids and air. Contamination from equipment surfaces can be exacerbated by its process performance e.g. ageing of selected materials during the process

» The hygienic design of food processing equipment is a critical factor in determining the quality and safety of foods produced «

and its influence on both organic and microbial cleanability; also temperature, pressure and volume differentials during processing etc. These factors are summarised in Table 1 on page 52 for HPP and PEF.

HPP

In a typical HP process, the food product is packaged and sealed prior to processing; therefore, the risks of post process contamination are minimal. However, even a packed

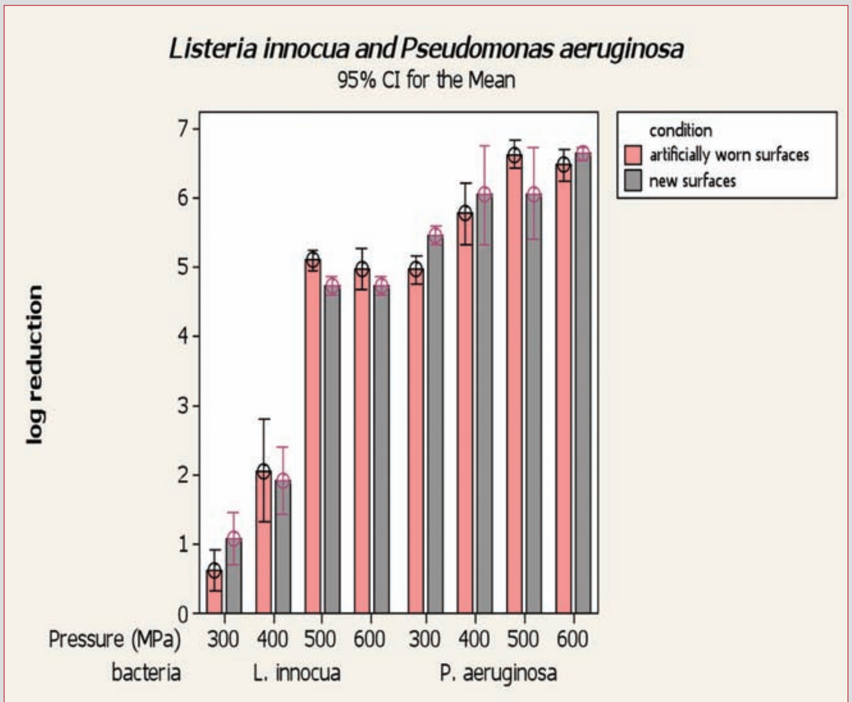


Figure 2 Effect of high hydrostatic pressure on *P. aeruginosa* and *L. innocua* in new and artificially worn surface adhered niches

» Contamination from equipment surfaces can be exacerbated by its process performance «

product may be subjected to microbial spoilage when surrounded by a high level of micro-organisms and if processing affects the integrity of the package. It is important, therefore, to identify and control all the routes of microbial contamination during the HP process and investigate the influence of the process on any microorganism migration through the packaging material.

Air

The water pressure transmitting system is not a closed system but is open to the atmosphere and there is a risk of microbial contamination of the water. The significance of the general risk imposed by air depends on the air handling system design, process, cleaning operations and people. The best way of controlling contamination by airborne micro-organisms in HP processes is to close the system by placing covers on the water tanks.

Water

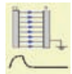
Commercially available High Pressure equipment uses drinking water as a pressure transmitting fluid. Most of the water used during the process is re-circulated and any deficit is made up with fresh water. To avoid build up of microorganisms in the water tank, there is a need for regular cleaning and disinfection. To ensure that all fluids are drained from the tank, a minimum radius of three millimetres on the tank side to bottom junction and 3° slope on the tank bottom has to be present.

Surfaces

Microbiological sampling of High Pressure equipment, undertaken within the NovelQ project, has shown a high level of microbial contamination. Highest counts are usually associated with the closure sealing arrangement (Table 2, page 52).

The major construction material of high pressure processing equipment is stainless steel which, under pressure, is subjected to stresses and deflections and ultimately, material failure due to fatigue and corrosion. The construction of vessels protected by shrink fit layers, autofrettage or wire or strap bindings has been well established to ensure that material changes are controlled and vessels are safe.

Table 1 Potential sources of microbial contamination during processing

VECTORS	HPP 	PEF 
Air	Water transmitting system	-
Liquids	Pressure transmitting fluid	-
Surfaces	Chamber Closure Carriers Lubricants External packaging	Chamber Electrodes Insulators Seals and joints
Process	Pressure changes Material changes	Material changes

Other materials of construction are used in pressure vessels, either as seals or as food packaging containers (Figure 1, page 50). Seals usually use a metal-to-metal contact surface arrangement alone, acting as both an initial and a final seal, or in combination with softer deformable elastomeric materials. Any elastomeric material in sealing arrangements will be subjected to material changes due to pressure cycling and will have a limited life prior to replacement during routine maintenance. The impact of such material pressure changes on microbial retention is not known, though high levels of microorganisms can be associated with the seal arrangements. This may, of course, be due to poor cleaning. Carriers which are constructed of materials such as polypropylene are also subjected to pressure changes.

Table 2 Microbial loading of High Pressure equipment

Sample	Pilot plant (Maximum values) 5 rigs	Commercial plant (Maximum values) 5 units
Pressure transmitting fluid	5.0×10^5 cfu/ml	3.0×10^3 cfu/ml
Vessel surface	5.6×10^2 cfu/cm^2	3.4×10^2 cfu/cm^2
Packaging carrier	8.0×10^1 cfu/cm^2	2.1×10^0 cfu/cm^2
Closure	2.2×10^5 cfu/cm^2	2.4×10^5 cfu/cm^2
Closure seals	5.1×10^3 cfu/cm^2	8.0×10^5 cfu/cm^2

» Standard hygienic design rules which may be applied to typical food processing equipment very often cannot be applied to High Pressure equipment «

Lubricants are often used around the closures to prolong seal efficacy. A high number of microorganisms may be found in lubricants and on the machine parts covered by them. Lubricants do not come into direct contact with product; however, they do come into contact with packaging materials. Use of lubricants should be restricted within the High Pressure equipment or antimicrobial lubricants should be used.

Process

Surface imperfections, crevices and micro cracking may arise through the introduction of continued high pressures. Microorganisms trapped in such crevices and protected with soil may be very difficult to remove. Studies conducted by Campden BRI have shown that microorganisms attached to smooth surfaces, and surfaces with crevices, have a similar resistance to High Pressure (Figure 2, page 51). Therefore, there is minimal risk that ageing of the materials can enhance surface contamination levels due to better survival of microorganisms.

Pressure and temperature differentials may favour microbial migration through the packaging, especially during the de-pressurisation process. However, initial studies conducted by Campden BRI with polyethylene pouches do not indicate increased migration caused by HP processing, although further work with different packaging materials must be carried out.

Generally, the microorganism level on food processing equipment can be controlled by better hygienic design, appropriate cleaning and disinfection systems and personnel hygiene. Unfortunately, standard hygienic design rules which may be applied to typical food processing equipment very often cannot be applied to High Pressure equipment. The main challenge of HP equipment is to withstand the applied pressure. Even if the chamber's closure had more hygienically designed seals with no crevices present, the high pressure transmitting fluid would be forced into them. The only way to minimise HP equipment contamination of those areas is to have dismountable parts which can be cleaned manually.

To establish and harmonise best hygiene practice for High Pressure Processing, Campden BRI in conjunction with other NovelQ partners is planning to produce a guidance document on Good Manufacturing Practice (GMP) for High Pressure Processed (HPP) Foods. This will be published in 2011 and will include sections on packaging handling before and after the process, suitable packaging materials, QC checks, cleaning and disinfection of HP equipment, personnel hygiene etc.

Table 3 The major construction materials for PEF equipment

Surfaces	Material
Electrodes	Boron carbide (B4C) Stainless steel Titanium
Insulators	Epoxy resins Ceramics PEEK (Polyetheretherketone) PTFE or PTFE enclosed in a hard PVDF body Delrin (POM) Polypropylene Ultem
Seals and joints	Silicon rubber Silicon glue

PEF

Surfaces

A possible application of Pulsed Electric Field is to preserve liquid foods. The food product comes into direct contact with the surfaces of PEF equipment and there are many established materials (Table 3, page 52) which have been chosen by PEF equipment manufacturers primarily based on their ease of manufacturing.

Process

The ageing of polymer insulators, such as Epoxy resin and PEEK, usually occurs and can be accelerated by different types of environmental stress factors. The factors that are most likely to cause stress in insulators used in the food industry are humidity, temperature variation and mechanical stress. Electrical degradation which causes ageing often involves mechanisms such as treeing, partial discharges and dielectric heating.

Treeing can occur in the form of water treeing and electrical treeing. Water treeing arises when a material absorbs moisture under the influence of an asymmetric alternating electric field. This causes the formation of water-filled tubules that grow in a tree-like way. In electrical treeing, a similar tree-like structure is formed, but in this case, it is of gas-filled tubules. Electrical treeing is caused by localised partial discharges.

A partial discharge can be described as a localised dielectric breakdown of the insulation material which happens when the material is under high voltage stress.

Electrical currents may cause internal heating (dielectric heating) of the insulator material when discharges occur in voids in the material, this may in time cause a thermal breakdown.

SIK studied biofilms of Pseudomonas fluorescens on new and aged surfaces subjected to PEF treatment. The results indicated that there was better survival of microorganisms attached to the surfaces with crevices after PEF treatment. It can be concluded from these initial studies that there is a concern that microorganisms can survive PEF treatments, when adhered to surfaces or when in cracks, which could then re-contaminate the treated product. This work therefore needs to continue to establish appropriate controls.

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Edyta Margas is a Research Officer in the Food Hygiene Department at Campden BRI. Edyta has an engineering degree in Food Quality and Management and a Masters degree in Food Technology and Nutrition from the Wroclaw University of Environmental and Life Science in Poland. After graduating, she started work at Campden BRI and has worked there for over four years. Edyta has just started a PhD course in Food Microbiology at the University of Nottingham. Edyta is responsible for managing the day to day activities of a number of projects, which has involved both laboratory based research work, factory studies in a number of countries in Europe and the USA, and presentations at internal Campden and international meetings. She is responsible for contamination control in dry food processing environments and her PhD project is focused on Salmonella management in low aw food products and their environments.

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Dr. Lilia Ahrné is director of the department for Process and Technology Development at SIK – The Swedish Institute for Food and Biotechnology and Associated Professor in food engineering at Chalmers Technical University. Before joining SIK she worked for Tetra Pak Processing Systems. Her research interests are to understand the effect of processing on physical, chemical and structural characteristics of foods, and use this knowledge to develop new processes and products taking in account sustainability aspects as energy consumption and costs. Processes under study include both traditional and novel technologies. She has extensive experience in coordination of industrial and European research projects.

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From laboratory-scale to pilot-scale

The implementation of a novel processing technology needs a science-based approach where product benefits initially demonstrated in a laboratory environment and the associated risks are used to predict enhanced quality when the technology is used in large-scale industrial operation. We discuss four novel technologies business cases developed for food application moving from laboratory to industrial-scale application.

For the successful implementation of novel processing schemes – working back from product launch – it is important for reliable equipment to be available at laboratory and pilot-scales. Validation of products and processes on an industrial scale is less thorough than pilot-scale testing: smaller batch sizes allow more critical parameters to be assessed, resulting in a better understanding of the process. In many cases, large-scale industrial equipment cannot be used; for example, laboratory-scale equipment is indispensible for checking critical parameters related to microbial inactivation kinetics of targeted pathogens.

The availability of product specific data for novel processing is a significant problem for risk assessment, which nevertheless has to be achieved prior to the introduction of new products in the European food and beverage markets. Within the 6th Framework of the European Commission, the Integrated Project NovelQ has examined specific research and development issues that create problems in scaling up laboratory equipment to pilot and full-scale industrial units. Topics covered include both generic issues such as the effects on homogeneity when volume-to-surface ratios are changed, as well as practical solutions for de-mixing phenomena. Usually, the development of large, industrial-scale novel technologies is triggered by feasibility studies using small, laboratory-scale equipment where small sample numbers and volumes can be evaluated. When supporting evidence indicates the process can enhance quality and / or shelf life of products, processes are scaled-up to evaluate small numbers of realistic food products (pilot-scale) and industrial-scale equipment developed where these studies are positive. At each stage, specific problems encountered have to be evaluated and resolved before moving to larger-scale production.

From our analysis, we surmise that prior to large-scale utilisation of a technology, it is important that:

- Laboratory-scale equipment should be available for trials with model systems and to build a sound scientific base describing physical-chemical reactions, inactivation kinetics of pathogens, spoilage micro-organisms and enzymes

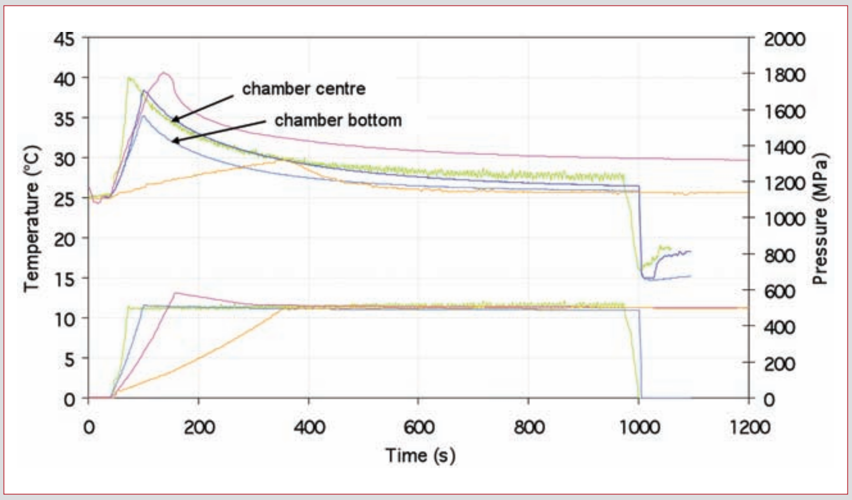

Figure 1 Example of pressure (lower part of graph) and temperature (upper part) profiles during HP treatment at various research units

UP-SCALING

Figure 2 Characteristic lab-scale HP equipment for inactivation kinetics (multi-vessel system, Wageningen UR)

- Small-scale equipment should be located in microbiological and chemical laboratories for experiments with specific components (e.g. pathogens)
- Pilot-scale equipment should be accessible to perform small trials with real food matrices (products) in likely final packaging to study the effect of processing conditions on shelf life and quality, and establish any implications, seen and unforeseen. Typically, pilot-scale systems are used for feasibility and demonstration activities
- Industrial-scale testing equipment, including pre- and post-processing facilities as required, is essential for proper implementation of the process in the industry

It is fundamental that equipment is fully characterised to ensure control over the results and allow proper comparison with products from other systems. Only under such conditions

» The principles for scaling-up have to be determined for each technology separately «

can the small and pilot-scale results translate into specifications for industrial units. Within NovelQ, research and development and scaling-up activities were focused on equipment for high pressure pasteurisation and sterilisation, pulsed electric field processing, cold plasma treatment and advanced heating.

Up-scaling principles

The principles for scaling-up have to be determined for each technology separately. For high-pressure pasteurisation treatment,

Table 1 Pilot equipment at NovelQ partners

NovelQ partner	Characteristics			Location
High pressure processing	**Volume [l]**	**Pressure [MPa]**	**T [°C]**	**Location**
Wageningen UR, Food & Biobased Research	4	800	125	Wageningen, The Netherlands
TU Berlin, Department of Food Biotechnology and Food Process Engineering	0.75	800	80	Berlin, Germany
KU Leuven, Laboratory of Food Technology	0.6	690	100	Leuven, Belgium
SIK	1.4	900	80	Gothenburg, Sweden
TNO Quality of Life	2	900	60	Zeist, The Netherlands
Food Research Institute Prague	2	550	60	Prague, Czech Republic
Beskyd Frycovice a.s. via Food Research Institute Prague	125	450	ambient	Frycovice, Czech Republic
Friedrich Alexander Universität Erlangen Nürnberg	2	700	80	Erlangen, Germany
NC Hyperbaric	55	600	30	Burgos, Spain
Pulsed electric field processing	**Capacitiy [l/h]**			
Wageningen UR, Food & Biobased Research	200			Wageningen, The Netherlands
TU Berlin, Department of Food Biotechnology and Food Engineering	600			Berlin, Germany
University of Lleida	28			Lleida, Spain
University of Zaragoza	20			Zaragoza, Spain
Keki	7.2			Budapest, Hungary
Advanced heating	**Technology**	**Power [kW]**		
Wageningen UR, Food & Biobased Research	Microwave	6		Wageningen, The Netherlands
Wageningen UR, Food & Biobased Research	Radio frequency	7		Wageningen, The Netherlands
TU Berlin, Department of Food Biotechnology and Food Process Engineering	Ohmic	11.5		Berlin, Germany
CTCPA	Ohmic			Avignon, France
Opal	Ohmic	10-50		France

equipment is available at all relevant scales within the NovelQ consortium. The activities of equipment suppliers, universities and research organisations have led to reliable industrial units for food manufacturers. Because high-pressure pasteurisation is widely used, experience is available concerning maintenance and operational efficiency, and insights have been shared with (potential) users.

For thermally-assisted high-pressure sterilisation treatment, reliability of equipment at larger scales is a serious problem. Due to the high temperatures used in combination with high pressures – allowing inactivation of spores (sterilisation regime) – current designs of high-pressure pasteurisation units cannot be used. Laboratory and pilot-scale units are available, but not industrial units. More in-depth research and development is needed for vessel design, sealing and homogeneity at high pressure and high temperature. Research in NovelQ has shown that design and selection of materials is crucial for achieving proper sealing at, for example, 700 MPa and 115°C. Although high-pressure sterilisation is a combination of high-pressure and high-temperature processes, homogeneity of temperature distribution in the vessel during the process is just as important as it is with other thermal processes.

Figure 3 Pilot-scale pulsed electric field equipment including pre and post handling for trials with pumpable food products (pilot PEF unit Wageningen UR)

At the start of NovelQ, pulsed electric field equipment was available for pasteurisation of pumpable fluids on a scale of several hundred

UP-SCALING

litres per hour. This flow-through capacity is sufficient for performing pilot studies with real food products. The most important scaling issue, however, relates to chamber design to ensure the treatment of fluids in a homogeneous manner without generating excess heat; fluids may contain small-sized particles up to one centimetre in diameter. Integration of PEF into production lines is also of concern with respect to pre and post-processing aseptic packaging, as is hygiene and contamination of the entire production line, which is essential to guarantee safe production at reduced temperatures. These issues are not normally considered with pilot-scale equipment. Periodic in-line cleaning and pre-sterilisation of PEF units were found to have a significant impact on the process and chamber design. However, expertise gained in NovelQ means many of these hurdles have now been overcome.

Figure 4 Industrial microwave tunnel (Uvox Microwaves AB)

Scaling-up of advanced heating technologies was only investigated in part by NovelQ. Special focus was placed on the interaction between the impact of volume on quality and new menu designs. In general, industrial-scale equipment is available for technologies such as ohmic heating, microwave and radio frequency heating, defrosting and drying.

Characterisation of equipment

When evaluating the potential for novel processing in the food industry, companies often perform feasibility studies at laboratory- and pilot-scales. It is important for these experiments to be performed in a consistent and harmonised manner to ensure the results can be compared and judged objectively. It is crucial that results from scientific literature and professional journals are considered, allowing the pros and cons to be evaluated fully, and science-based information presented to consumers and legislators. The global harmonisation initiative (www.globalharmonization.org; supported by NovelQ's partners EFFoST) is striving for validated and reliable sources, based on scientific consensus and reproducible experiments.

NovelQ developed standard operating procedures to ensure partners used the same research protocols for test equipment. These have been thoroughly tested in practice for high-pressure equipment – operated over a wide range of processing conditions – and are available in the laboratories of many NovelQ partners.

Figure 1 on page 55 shows the temperature of pressure transmitting media and pressure profiles of four different high pressure units during a standard experiment at 500 MPa and 25°C starting temperature. The graphs reveal the wide range of conditions arising with real products. The main differences observed include the pressure-building time and the impact of vessel dimensions, especially the ratio between vessel height and diameter, pressure fluids and design of the units (e.g. use of internal or external intensifier for pressure). Thus, characterising the equipment used and comparing equipment conditions at laboratory and pilot-scales with industrial-scale units is imperative.

» Periodic in-line cleaning and pre-sterilisation of PEF units were found to have a significant impact on the process and chamber design «

Development of specific research units

Easy access to hands-on support and the opinions of independent experts substantially

Figure 5 A laboratory scale cold plasma unit including diagnostics that was developed by Wageningen UR Food & Biobased Research developed in collaboration with the Dutch SME OMVE BV

increases the success of novel technologies in industry. Sharing experiences in a research network such as the NovelQ Industry Advisory Platform (IAP) yields convincing arguments for investment strategies uninhibited by issues such as confidentiality. Small-scale units for high-pressure, pulsed electric field and advanced heating technologies are already available. Cold plasma, however, is a more recent innovation for non-chemical surface decontamination. Within NovelQ, this potential was recognised at an early stage and, consequently, the need for standardised laboratory-scale units generating food-grade cold plasmas. With such a unit, research organisations and universities can perform relevant studies on, for example, inactivation kinetics of micro-organisms. A well-characterised small-scale unit was developed for the production of nitrogen-based plasma gas (see Figure 2 on page 56). Initial decontamination tests successfully carried out by Wageningen UR Food & Biobased Research (NL) and the Institute of Food Research (UK) produced identical results. These units are currently being used for pathogen studies, related to food safety issues, as well as studies on food quality. Such developments will improve knowledge of cold plasma applications and support implementation of this technology by the food industry.

Availability and accessibility of pilot-scale equipment for HPP, PEF and advanced heating with detailed characteristics

Pilot-scale equipment, available at some NovelQ partners, has enhanced implementation of novel technologies, (see Table 1 on page 56). One and two-day trials were organised during the project, allowing food manufacturers to test their products using pilot facilities whilst evaluation of the processing conditions on quality and shelf life were carried out jointly. If *New Food* readers are interested in evaluating the effects of a specific novel process on their products, they are welcome to contact the relevant NovelQ partner.

Ariette Matser

Ariette Matser is currently Senior Scientist – Mild Preservation and Novel Technologies and Programme Coordinator – Mild Preservation within Food & Biobased Research of Wageningen UR. She studied Food Science at Wageningen UR.

Her primary research activities include novel technologies and food safety and quality, preservation and processing of food products and effects on food quality, and food structure and the effects of processing on this. Management activities are involvement in (inter) national R&D projects, project acquisition and coordination of activities on novel technologies. She is Project Coordinator of the European project NovelQ.

Hennie Mastwijk

Hennie Mastwijk is a senior scientist at Wageningen UR Food & Biobased Research, The Netherlands (www.wur.nl). He is involved in the development of equipment and food products through electronic based mild preservation processes.

Milan Houška

Milan Houška is the head of the department of food engineering at the Food Research Institute Prague. He is dealing with physical properties of foods and heat and novel processes including their mathematical modelling. He is the author of many scientific papers, patents and innovations already marketed. He coordinated the project that finalised with high pressure pasteurised juices on the Czech food market.

Anders Pettersson
SIK

John O. Gray
IIT

Hygienic assembly and transfer of food products: A demonstration system for the automatic processing of vegetables

Food production constitutes the largest European manufacturing sector, employing some four million people and generating an annual turnover of approximately EUR 850 billion of which EUR 50 billion products are exported. The sector is unusual in that a large percentage of its output still depends on manual operations; a situation that is probably due to the way the industry has evolved over previous decades and the fact that a vast number of companies in the sector are SMEs where the take up of automation has been relatively slow throughout the European arena.

However, in the last five years, there has been a trend within the sector to adopt modern manufacturing techniques with the introduction of robotic and automatic procedures. Drivers include the requirements for product consistency and traceability, hygiene, waste and water minimisation, food chain security, employment legislation and, of course, 'bottom line' (fiscal) improvement. Europe has a vibrant automation industry but there are barriers to transferring solutions from, for example, the automobile industry to food manufacturing. Food products are generally irregular in shape, are often soft and fragile and produced in variable orientation. There is a requirement for hygienic system design (not just wash-down capability) and production runs can be quite short, requiring flexibility in automatic procedures. In this paper, we focus on the design of a production line for the automatic sorting of fruit and vegetables, and highlight how some of the challenges outlined can be addressed, with particular focus on novel gripper design and innovative visual robotic addressing orientation problems. The conclusions drawn that can benefit the design of large production facilities can be linked to novel food processing procedures.

Automatic product assembly and transfer

Once raw materials for manufacture have been hygienically processed, final products often require some form of assembly such as 'ready meals' and insertion in primary packaging. These procedures are traditionally accomplished manually as it is often claimed that the dexterity and flexibility of human operation is essential. Programmable robotic and automatic systems can clearly provide a high degree of functionality and flexibility, but traditional robotic grippers are generally inappropriate for the acquisition and transfer of food products, making it necessary to develop a novel set of grippers for the food sector. Ideally, such grippers should not only be designed on sound hygienic principles but also able to deal with multiple products on the same line without time consuming and complex tool changing operations.

To address this issue, novel grippers have been developed, the first prototype[1] is based on the so-called Bernoulli effect. These lift objects without contact, making them particularly interesting for food products. However, the inherent drawback of this type of gripper is that it is only able to handle flat or planar products. To overcome this limitation, a deformable surface was developed. A matrix of metal pins covered with a thin rubber sheet creates a surface that can be deformed and locked (Figure 1). By gently pressing the gripper over the product (planar or 3D) and activating a set of locking bars, the gripper surface is locked into the shape of the product's top surface. This forming enables generation of a necessary narrow space between the product and the gripper, and thus a lift force can be generated. The prototype has been shown to be able to handle a range of product shapes and variations. However, the lift force generated was limited and the grip technique is mainly suitable for smaller products with a mass of less than 70 grams.

A combination of the Bernoulli gripper and another novel processing technique has been investigated within NovelQ. Cold plasma is a relatively new decontamination process with promising features. By replacing the air flow used in a Bernoulli gripper with cold plasma, decontamination and handling could be achieved in a single step. Furthermore, as the Bernoulli gripper does not make contact during the lifting, the entire product can be treated with cold plasma, avoiding shadowed spots. Initial results using this combination have been negative, but an explanation and solution may be possible[1].

A second prototype[2] was developed that utilises phase-shifting properties of a Magneto rheological (MR) fluid. On each arm of the parallel arm gripper, an electromagnet was attached and a pouch of MR-fluid bonded to the surface (Figure 2). In ambient conditions, an MR fluid behaves akin to motor oil with low viscous flow. However, a magnetic field induces a phase-shift; the fluid becomes a semi-solid with a pronounced yield stress and a consistency likened to peanut butter or toothpaste. During gripping, the pouches of MR-fluid are pressed against the sides of the product and softly deforms around its contours, exerting very little force. As the gripper arms reach a standstill, the electromagnets are activated and the MR-fluid solidifies, geometrically locking the product into a perfect mould. This gripper has shown promising results: it is able to handle a range of products including apples, tomatoes, strawberries, broccoli and grapes, and exerts extremely low forces during handling.

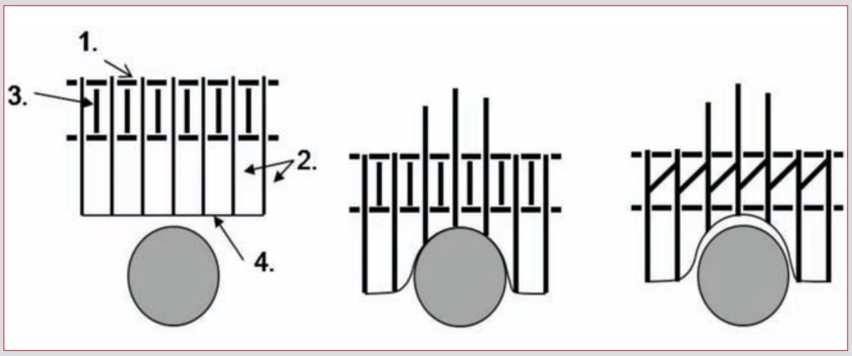

Figure 1 Schematic description of the 3D Bernoulli gripper during a shaping sequence. 1: support plates; 2: matrice pins; 3: vertical locking bars; 4: gripper surface

One difficulty encountered with the MR-fluid gripper is making a design suitable for washing down with a hose. The linear motion of the gripper arms is difficult to seal against ingress of microorganisms and / or moisture into the mechanism. A third prototype has been

Figure 2 MR-fluid gripper arms holding a wooden model of a strawberry

Figure 3 Enclosed parallel arm gripper actuator with force sensor and magnetic coupling. The base of the moving arm (left) contains the set of magnets

developed to address this problem, and to demonstrate an alternative approach for delicate gripping. This gripper uses a parallel arm actuator but it is equipped with a force sensor, enabling slim gripper arms and delicate grip forming, and a magnetic coupling. The magnetic coupling is used to enable encapsulation of the complete drive unit in a box (Figure 3). With a magnetic coupling, the force moving the gripper arm can be transferred through the box wall. A set of magnets is fastened on the linear mechanism inside the box and a corresponding set of magnets on the gripper arm. This concept allows for a completely hygienic, washable gripper to be designed.

This prototype has demonstrated the concept is valid: with the force gripper and the data extracted from the vision system, each product type can be gripped with a specific set grip force (Figure 4). Although the design allows for hygienic handling, additional decontamination during handling may be beneficial, and a potential automated decontamination process has been tested with promising results. Products with a grip width of 5 – 65 millimetres and a weight of approximately 0 – 500 grams can be handled including apples, tomatoes, strawberries, carrots, grapes and broccoli[3]. Further development will include stainless steel casing, which can be hosed down, increased grip force and reduced grip time.

» To make full use of the flexibility provided by a robot, it is very important to be able to re-program it «

A demonstration system for the handling of vegetables

A complete demonstrator has been developed to better understand and demonstrate the potential offered by a flexible, hygienic handling system for fragile food products (Figure 5, page 63). In a cleanroom facility at SIK (SE), a robot equipped with the new flexible force gripper has been installed to demonstrate flexible handling and production with fragile food products prior to primary packing.

An IP68 encapsulated vision system has been programmed to distinguish between apples, tomatoes, carrots, small carrots, strawberries, broccoli and grapes. This enables individual grip forces, and thus a strawberry can be handled using as little force between the gripper arms as 50 grams whilst higher forces are used for harder products such as carrots.

To make full use of the flexibility provided by a robot, it is very important to be able to re-program it. As this traditionally requires specialist skills, not always available in a food plant, steps towards more intuitive re-programming have been investigated. Instead of traditional robot programming, a

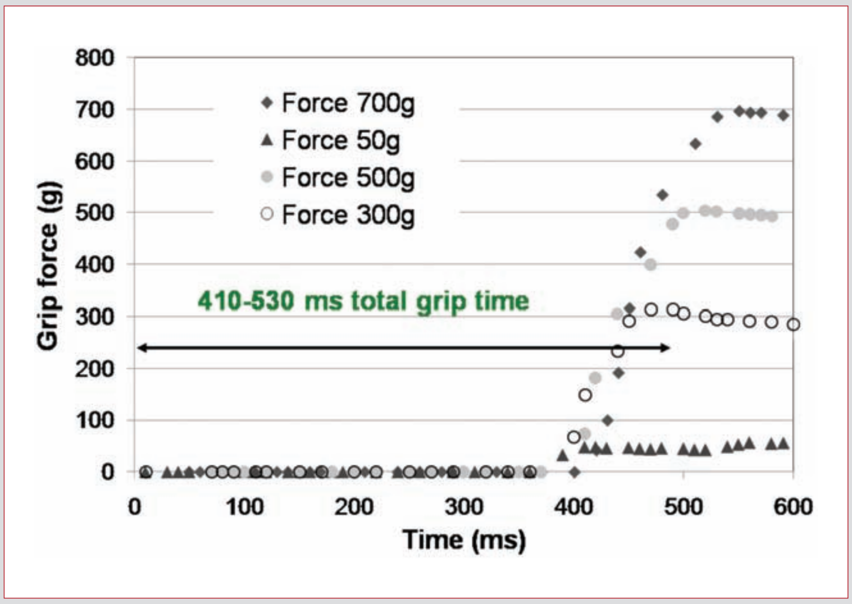

Figure 4 Presentation of grip force and grip time graphs for various grip force settings

Figure 5 Robot station during flexible production. Variable and fragile products arrive mixed to the robot and are individually handled and placed according to the layout designed in the GUI

graphical user interface (GUI) approach was tested (Figure 6). Products can be selected by a button click. An image of the product appears that can be dragged, dropped and rotated freely by the operator using a PC mouse. Multiple products can be selected to form the desired product layout. When a satisfactory layout has been designed, production is started by pressing a button.

The products are identified and parameters extracted by the vision system as they arrive to the robot. Each product is matched against the product layout, as defined in the GUI. Product matches are sent to the robot and queued until the product is within reach of the robot. For each product, grip force and gripper separation is set from vision data as the gripper is moved into position by the robot (Figure 5). A grip command is initiated by the robot and the gripper grips the product to a specified individual grip force suitable for that product type. The product is placed at the coordinates corresponding to the layout in the GUI (Figure 7, page 64).

The demonstrator shows the concept of a flexible robotic production unit for fragile and variable food products, and a new product layout can easily be redesigned using the GUI. If the right products are supplied, the changeover time is zero. No aligners are needed as the robot and vision system can cope with random placement and orientation. A continuous and mixed inflow of products can be processed by one single robot station with each product transferred individually to avoid bruising or denting.

Conclusions and future work

Hygienic manufacturing encompasses the entire operation from the input of raw

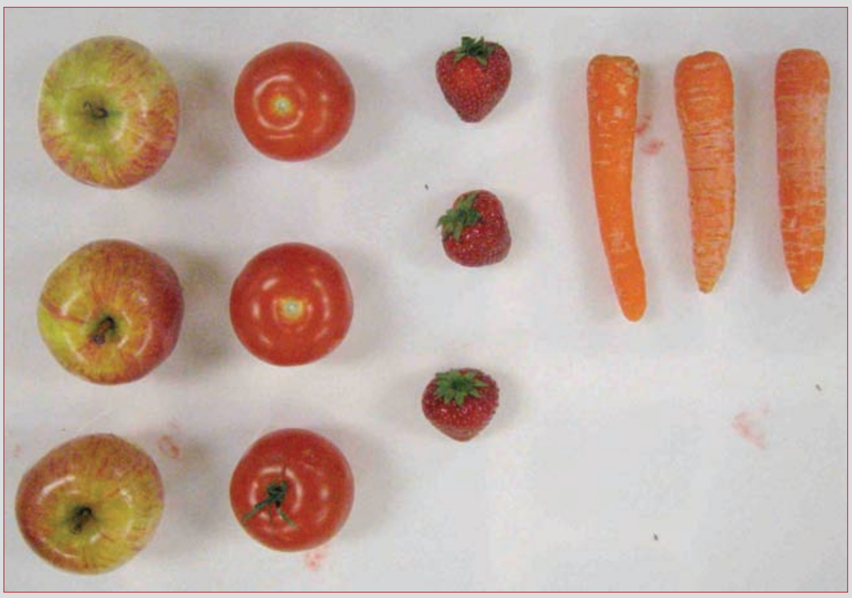

Figure 6 Resulting production after completely automated robot handling with a flexible gripper

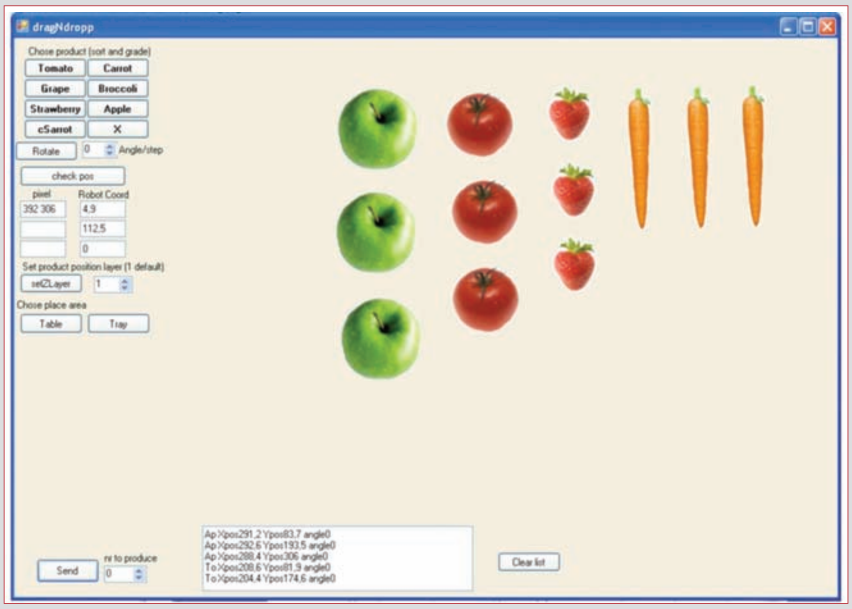

Figure 7 Graphical User Interface (GUI) for product placement planning using drag and drop

ingredients to the processing and packaging of the final product. A significant improvement in hygiene can be accomplished by removing, as far as possible, human operators from physical contact with food products and replacing their function with fully automated procedures. Such procedures can be designed to be inherently hygienic in all operational, procedural and maintenance matters, and can be further exploited by use of containment concepts, which enable manufacturing in – for example – inert or UV-radiated environments. Recent advances in robotic technology and non-contact sensing has made ideal manufacturing scenarios possible, although there is still significant work to be undertaken to develop 'off-the-shelf' solutions tailored to food industry needs. From a fairly slow start in 2000, recently there has been rapid uptake of automation technology within the sector and it is one of the fastest growing markets for robotic application in the UK, for example. The driver is not just hygienic operation although this is vital but other strong economic factors that impact directly on the sustainability, efficiency and profitability of the industry.

Figure 8 Additional layout example

Acknowledgement

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Anders Pettersson

With a background as a food material scientist at SIK and with a recent MSc degree in mechatronics, Anders has tried to approach this project from both a food science and from an engineering point of view. The project has furthermore formed the core of Anders' doctoral studies which has been performed in connection to the University of Sheffield.

Ariette Matser, Miriam Quataert, Remco Hamoen and Huug de Vries
Wageningen UR, Food & Biobased Research

The decision support tool to select appropriate technologies for specific industries

In past years, it has become clear that the variety and complexity of novel processing methods is a major bottleneck for companies in deciding where to invest. Even though the pros and cons of technologies have been highlighted in various books (HPP, PEF-books, EME etc.), the most appropriate technologies for specific applications often have not been compared directly. Thus, NovelQ has created a decision support tool for companies.

By answering a short list of specific questions, a potential user (e.g. a food manufacturer) can easily evaluate whether a technology is relevant for their products and if implementation is economically feasible. The tool includes a menu with extensive information about processing-related areas such as packaging, product quality assessment, pre- and post-processing steps and environmental considerations.

State-of-the-art in novel processing – such as high pressure, pulsed electric fields, cold plasma, ohmic heating, microwave, radio frequency and pulsed lights – has been described in a variety of review journals and books. NovelQ has written business cases for these technologies including new scientific insights specifically for industry and made them available to members of the Industry Advisory Platform (IAP). However, it is still difficult for the industry to evaluate novel processes (NP) and this can be a limiting factor for further development and implementation.

To promote implementation, it is necessary to provide an approach for selecting an appropriate novel scheme on the basis of

DECISION SUPPORT SYSTEM

desired quality and shelf life for a specific food product. NovelQ has developed a decision support system based on a chain-oriented approach to investigate the optimal technology and conditions, including cost aspects. The purpose of the decision support system is to assist food manufacturers and their equipment suppliers in the assessment and screening of novel preservation technologies. This (decision support system) tool can be used to evaluate whether novel technologies are relevant and offer significant benefit, which can be translated into an economical relevance.

The tool can be used in two ways: applications for which no conventional alternative is available (e.g. due to the effects of heat on specific properties of the product) and those applications for which industry is seeking new applications (e.g. premium soups and sauces).

» The aim of the decision support system tool is to help potential users of novel processing technologies to make decisions about the likely benefits for their business «

The NovelQ business cases formed the basis of the decision support system. This version was discussed with industry, both those with novel technology experts and potential users. Based on feedback, an upgraded and user-friendly version has been launched with the layout, technical specification and visual information restructured for users.

Presentation of the design of the DSS software tool

The aim of the decision support system tool is to help potential users of novel processing technologies to make decisions about the likely benefits for their business. The tool needed to be widely accessible and intuitive to use. It was decided, therefore, to create an internet-based system rather than distributed stand-alone software. Access is via the NovelQ IAP home page (see Figure 1).

At the core of the tool is a list of questions about the novel processing technologies. Users responses about treatment and products generate the most relevant follow-on questions automatically. The technologies available are ranked based on the user's answers, which are summarised on the results page (see Figure 2). Answers can be easily changed and the updated ranking shown without changing the question and the order in which they are presented. Users can also find more detailed information giving a general description of the technology, potential applications, placement in the production process, status of the technology and commercial availability and existing applications as well as an explanation as to why a technology is less relevant for a given application or product (see Figure 3).

» Product quality is the most important deciding factor in the application of new technologies «

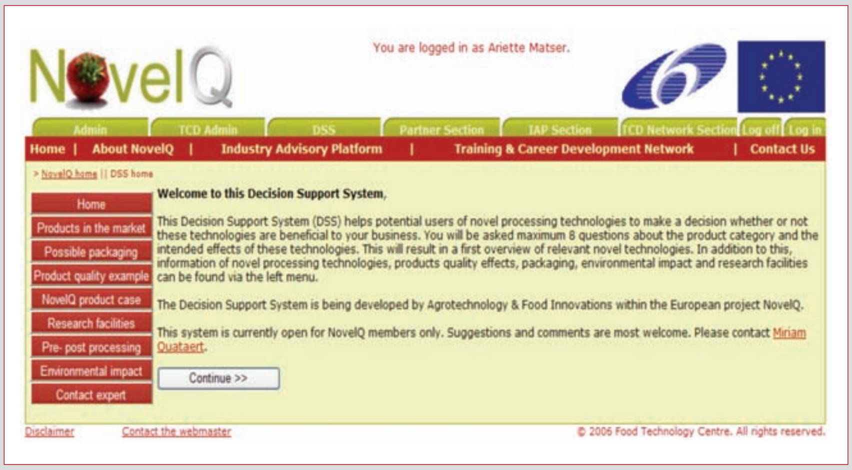

Figure 1 Homepage of decision support system providing information on novel processing (left) and entrance to the questions to select potentially interesting technologies

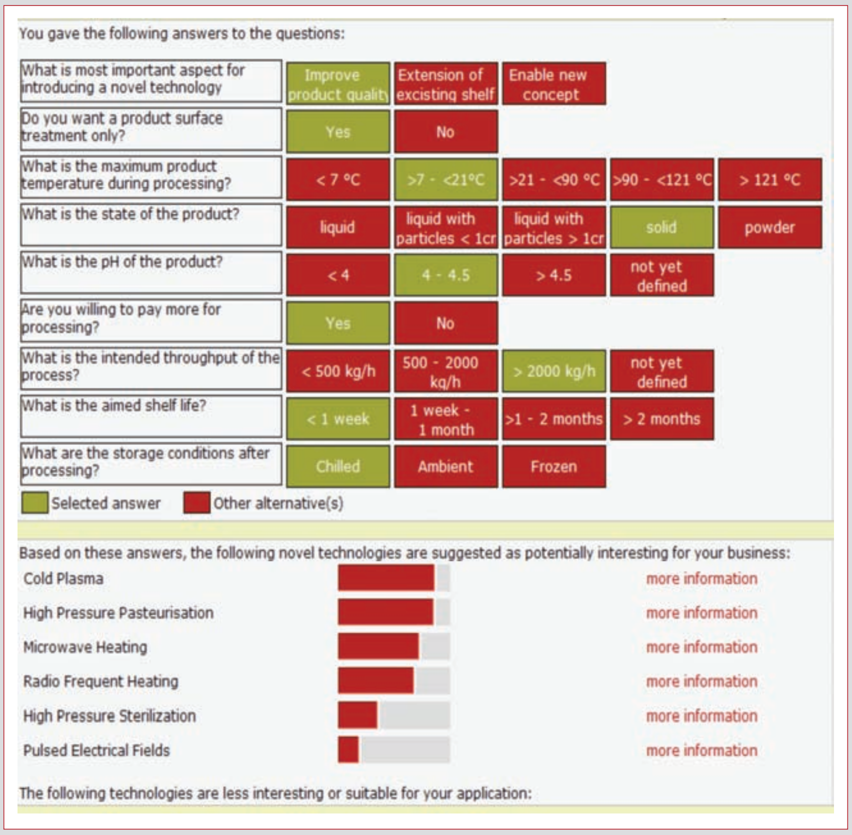

Figure 2 Example of questions and ranking of technologies for a specific application

The outcomes of using the DSS tool

In addition to the advice on potential interesting novel processing technologies for a specific application, users suggested a menu for information about products in the market, packaging options and research facilities (see Figure 1). Newly-marketed product examples have been included in the tool describing the product, its packaging and relevant information such as brand, producer, technology, ingredients, storage conditions, shelf life and market.

Possible packaging schemes include information about different kinds of packaging materials that can be used for novel processes including photographs and descriptions of the materials. Information about the properties of materials in relation to processing conditions is also provided. Examples of appropriate materials that cannot withstand specific conditions (e.g. in case of high pressure, high temperature profiles) are demonstrated with pictures of treated packaging samples.

Product quality is the most important deciding factor in the application of new technologies. However, providing convincing and reliable quality samples is not straight-forward. For example, a colour scale index programme had to be developed to distinguish between processed products; the tool shows

Explanation of the ranking of **Pulsed Electrical Fields.**

You gave the following answers to the questions:

Question:	Answer:	Reason:	Score:
What is the maximum product temperature during processing?	>7 - <21°C	Optimal temperature for PEF processing is between 30 and 50°C	0.5
Are you willing to pay more for processing?	Yes		1
What are the storage conditions after processing?	Chilled		1
What is the pH of the product?	4 - 4.5		0.9
What is the intended throughput of the process?	> 2000 kg/h		1
What is the aimed shelf life?	< 1 week		1
Do you want a product surface treatment only?	Yes	PEF processing is a volumetric treatment	0
What is the state of the product?	solid	PEF can be used for liquids and liquids with small particles	-5
What is most important aspect for introducing a novel technology	Improve product quality		1

Figure 3 Explanation of ranking of pulsed electric field for solid product

> *» Environmental impact of new technologies is becoming increasingly vital for decision makers «*

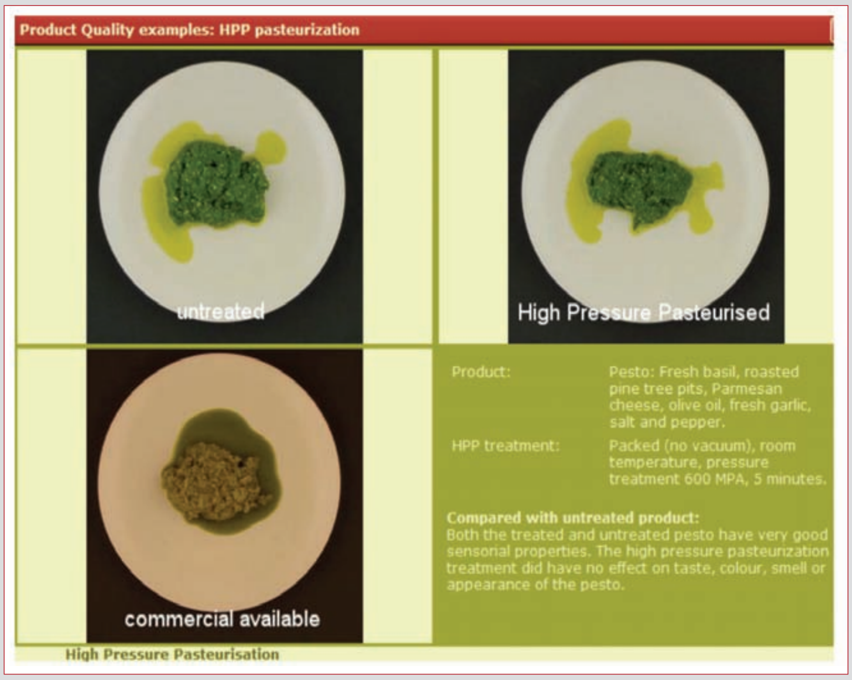

Figure 4 Example of product quality information in the decision support system

State-of-the-art in novel processing

Examples include:

- Pulsed electric fields technology for the food industry; Springer (Germany), 2006
- NovelQ special issue of Trends in Food Science and Technology (June 2008)
- Ultra High Pressure treatment of foods (Aspen publishers, September 2002)
- Minimal Processing Technologies in the Food Industry (Woodhead publishing, August 2002)
- Food Preservation by Pulsed Electric Fields:From Research to Application- edited by H.L.M. Lelieveld, S. Notermans and S.W.D. de Haan. Woodhead Publishing Ltd.,
- October 2007, ISBN 1 84569 058 3, 384 pages

several images of treated products (see Figure 4) for comparison. Direct comparison is facilitated by images of products (orange juice) processed using conventional heat pasteurisation, pulsed electrical fields (pasteurisation) and high pressure (pasteurisation). The final outcomes are presented in the product quality case menu-option.

Product samples are of major importance to industry. Thus, a feature for research facilities has been added accessing an extensive list of potential research pilot facilities including

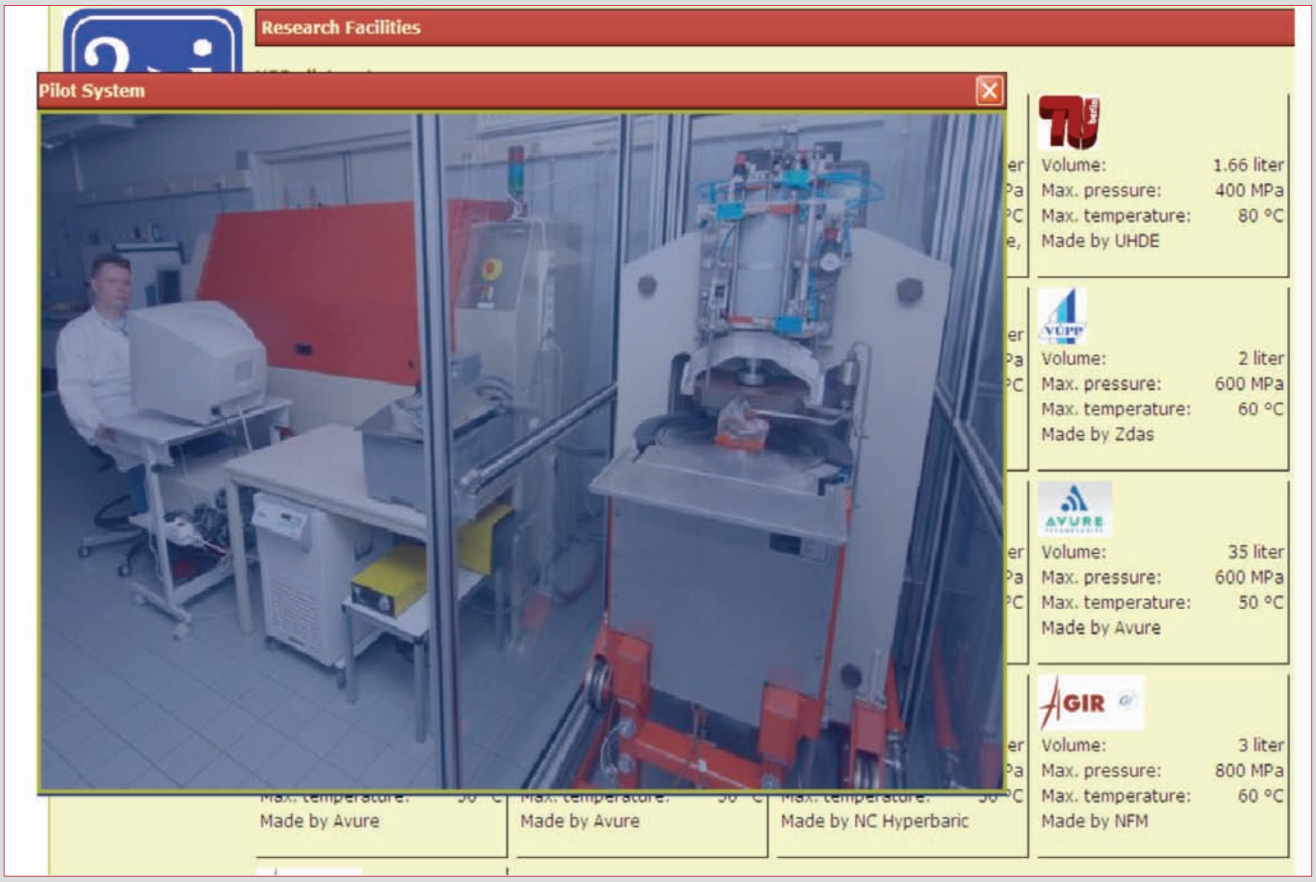

Figure 5 Picture pop-up of possible research facilities

technical specifications and contact details of the providers (see Figure 5).

The tool also includes a comparison of estimated costs of the technologies. Real costs of a technology are subject to the specific application (e.g. throughput, number of working hours, depreciation period and interest) but estimated costs allow users to consider costs associated with the technologies and processing costs a company will also incur such as pre-processing, packaging and logistics. Estimated costs include processing, without pre-treatment and packaging costs, but include equipment, energy and maintenance.

Implementation of novel technologies in existing processing facilities may cause severe problems. Assistance to adapt pre- and post-processing systems is imperative. The tool provides information about different processing lines, and required adjustments, by means of pictograms.

Finally, environmental impact of new technologies is becoming increasingly vital for decision makers. Life-cycle-assessment data is embedded in the tool where available.

Conclusion

A second version of the NovelQ decision support system tool is available for NovelQ IAP members. *New Food* readers are invited to join the NovelQ IAP and test the tool. Feedback is welcomed and will be used to develop the tool further.

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Her primary research activities include novel technologies and food safety and quality, preservation and processing of food products and effects on food quality, and food structure and the effects of processing on this. Management activities are involvement in (inter) national R&D projects, project acquisition and coordination of activities on novel technologies. She is Project Coordinator of the European project NovelQ.

Miriam Quataert

Miriam Quataert is Senior Scientist, Product Development and Application and Programme Coordinator Food Design and Structuring within Food & Biobased Research of Wageningen UR. She studied Food Science at Wageningen UR.

Miriam has a background in product development within research and industry. Her primary research and project activities are in the area of new product development, food reformulation, effect of novel processing on food quality and texture. Management activities are involvement in (inter) national R&D projects, project acquisition and coordination of activities on food design and structuring.

Huug de Vries

Within Wageningen UR, Huug de Vries has been responsible for the Food Technology Centre (FTC) since April, 2006. FTC focuses on initiation, research and development of novel processing technologies in the food and life science sectors.

Huug de Vries is also the Project Coordinator of the European Integrated Project 'Novel Processing Methods for the Production and Distribution of High-Quality and Safe Foods (NovelQ)'.

Previously, Huug de Vries was the Director of Strategy and Commercial Affairs at A&F B.V. and project manager for the development of a sustainable maritime reefer container for transport of perishables. He has participated in projects covering the entire chain from sustainable food production, processing and distribution up to consumption. His PhD research – at the edge of physics and biology – was carried out at the department of Molecule and Laser Physics at the Radboud University of Nijmegen, The Netherlands.

Huug de Vries
Project Coordinator, NovelQ

Huub Lelieveld
Executive Committee, Global Harmonisation Initiative

The NovelQ 10C approach towards SMEs

On 18 February 2010, Máire Geoghegan-Quinn – the new Commissioner for Research, Innovation and Science – gave a speech at the American Chamber of Commerce to the European Union. Mrs Geoghegan-Quinn made two striking remarks:

"My job title covers research, innovation and science. I am glad that President Barroso decided to connect up these different areas. While science and research creates a pool of ideas, innovation policy must bring these ideas to the market. So, it makes sense to link them. In fact, I am the first ever European Commissioner for Innovation – a clear sign of its growing importance for our jobs and growth and our society."

"…and in collaborative research projects involving public and private sector partners, I want 15 per cent of the funding to go to small and medium-sized businesses… **[note: most recent analysis shows the level of SME participation to be 7.5 per cent]…"**

These comments are further emphasised by the European Technology Platform (ETP) Food for Life implementation plan, which states:

The structure of the food industry in Europe is unique amongst the manufacturing sector with the overwhelming proportion of the sector (96 per cent) having less than 50 employees (SMEs and micro enterprises) [note: and being the largest manufacturing sector in Europe].

Few such companies have the resources to undertake anything other than quality control and assurance work, and they cannot be expected to participate in research where the payback is frequently long-term in nature.

The needs of such companies must be met through larger conglomerations of research-based and industry-wide associations working closely with them. However, the sector does include a small number of very large, research-minded companies that can be expected to support joint public-private research projects or programmes in specific areas.

NovelQ '10C' strategy for involving SMEs

In 2005, it became clear that SME participation in projects funded by the European Commission (EC) was poor. The EC introduced the concept of 'incremental innovations' – small improvements that add value to products or services to generate customer benefits – in one of their calls on food processing. Based on this mind-set, the strategy for SME and industry participation in NovelQ is defined by '10C Actions', namely:

Action 1: Combined science and applied research approach

The NovelQ consortium decided to follow a strict parallel research-applied science approach from the start of the project in 2005. A basic science approach was followed for immature food technologies – high pressure, high temperature sterilisation, pulsed electrical fields and cold plasma – where payback on any investment is anticipated to be long-term. These types of activities can easily be shared with stakeholders, including the public; a requirement for publicly-funded research. More mature technologies including high pressure pasteurisation (as compared with sterilisation) and advanced heating technologies (e.g. microwave, ohmic heating and radio frequency) followed an applied research approach involving SMEs directly.

Action 2: Construction of the NovelQ Industry Advisory Platform

An Industry Advisory Platform (IAP) was created to facilitate effective transfer of novel processing technologies to potential users, and to ensure NovelQ focused on topics important to the food industry, large and small. The IAP members have promoted and exploited our results as well as identifying bottlenecks for us and our spin-off projects to examine more closely. Best practice is disseminated via established networks including the European Federation for Food Science and Technology (EFFoST), and industry and non-profit organisations. Currently, the IAP has 75 members from SMEs, multi-nationals, industrial networks and other international organisations that are interested in novel processing and packaging.

Action 3: Cross-sector involvement of SMEs

The NovelQ consortium has actively sought out food manufacturers, food machinery and equipment suppliers and packaging companies to join the Industry Advisory Platform (IAP). Some members are able to offer something novel whilst others are interested in new research acquisitions. The resulting cross-sector platform stimulates more discussion, ultimately benefiting all participants. As stated by one of the members, "SME suppliers attract SME buyers and vice versa." Thus, the IAP has been kept open to new parties willing to participate under the agreed terms of reference throughout the lifetime of the project, yielding a dynamic discussion platform continuously refreshed by new members.

Action 4: Combined workshops with related European projects with SMEs as target audience

Thematic workshops have been organised for

SMEs with other European projects. This action has brought together knowledge transfer experts and SMEs involved in EU-funded projects, and provided opportunities to share best practice and add value. Representatives from SMEs are full participants; encouraged to present and engage with the discussions. Significant examples include joint workshops with PathogenCombat (www.pathogencombat.com) on hygiene, DoubleFresh (www.doublefresh.eu) on shelf life of convenience foods and HighQ RTE (www.highqrte.eu) on safety of ready-to-eat meals.

Action 5: Communication with SMEs

In addition to workshops, planned and executed in collaboration with other EU-funded projects, NovelQ outcomes have been disseminated in partnership with 16 other EU-funded agri-food projects via AgriFoodResults. The EU-funded AgriFoodResults network (www.agrifoodresults.eu) has three main objectives:

» Offer innovative and sustainable services for dissemination
» Raise skills of European food scientists on dissemination practices
» Successfully disseminate recent results from agrifood research projects

AgriFoodResults specifically targets SMEs and has helped steer the NovelQ dissemination strategy and define the outputs required by SMEs.

Action 6: Competitive calls for SMEs

The NovelQ consortium opened up to SME members at the project half-way point. Working closely with the European Commission, an action plan for competitive calls was set up including tender description, wide-scale dissemination, short-format proposals, evaluation criteria and independent evaluators. These allow SMEs to become involved as and when previously immature technologies warrant application. Four new SME partners joined the NovelQ consortium under these terms and progress was reported to IAP members using business cases, leaflets, news-letters, PowerPoint presentations, roundtable discussion and website updates.

Action 7: Compact proofs-of-principle

IAP members were also invited to participate in short-term, proof-of-principle testing at NovelQ partner organisations across Europe for one to two days. Novel processing equipment was provided by the NovelQ partner and made available to IAP members who supplied their own food and packaging materials. The results were reported in a short, publicly-available leaflet.

Action 8: Company visits to SME

In-house demonstrations of novel processing technologies have proven to be very effective at enticing companies to join the IAP. In Spain, the technology provider, NC Hyperbaric, offered deeper insight into high pressure pasteurisation by showing IAP members their production facilities. Campofrio – a customer of NC Hyperbaric – hosted IAP members for a live demonstration of high pressure processing technologies for meat products. Similarly, Stork BV exhibited pulsed electrical field equipment including the latest aseptic filling lines at their facilities in Amsterdam, and performed a live demonstration at a fruit juice producer, Indulleida S.A. in Spain. The NovelQ Training and Career Development Network – providing training and career-relevant learning opportunities for NovelQ young scientists – also visited these companies to become acquainted with research, development and production processes, particularly in European SMEs. For the companies involved, these visits are for developing strategies for attracting future, highly-educated employees.

Action 9: Continuity for SMEs in a dynamic platform organisation

A sustainable action plan for SMEs, beyond the lifetime of the project, is essential to attract and retain their participation. NovelQ has explored how the IAP activities can continue to provide relevant information, stimulate active participation in roundtable discussion and workshops and facilitate interactive meetings between SMEs and potential (multinational) customers. SME-oriented research organisations within NovelQ have initiated the discussions with EFFoST and with the ETP Food for Life to explore how a Europe-wide industry platform might be implemented.

Action 10: Co-ordinated feedback

As one of the final actions of NovelQ, the consortium will provide the European Commission with the '10C strategy' for best practice involving SMEs in EU-funded projects as well as suggesting improvements and new topics which have been proposed by SMEs as topics for new funding calls. The enthusiasm and entrepreneurship of European SMEs is feeding back to the EC, and NovelQ partners believe a sound strategy – such as the 10C approach – will yield positive results for research organisations and SMEs involved in future EU-funded projects.

The involvement of SMEs in NovelQ

Company representatives have given their input for this Special Issue of New Food. It should be noted, however, that the involvement of SMEs, and the cooperation between SMEs and large companies, has led to numerous demonstrations of applied research results during the lifetime of the project.

Huug de Vries

Within Wageningen UR, Huug de Vries has been responsible for the Food Technology Centre (FTC) since April, 2006. FTC focuses on initiation, research and development of novel processing technologies in the food and life science sectors.

Huug de Vries is also the Project Coordinator of the European Integrated Project 'Novel Processing Methods for the Production and Distribution of High-Quality and Safe Foods (NovelQ)'.

Previously, Huug de Vries was the Director of Strategy and Commercial Affairs at A&F B.V. and project manager for the development of a sustainable maritime reefer container for transport of perishables. He has participated in projects covering the entire chain from sustainable food production, processing and distribution up to consumption. His PhD research – at the edge of physics and biology – was carried out at the department of Molecule and Laser Physics at the Radboud University of Nijmegen, The Netherlands.

Huub Lelieveld

Huub Lelieveld is President of the Global Harmonization Initiative, member of the Governing Council of IUFoST, Member and Past-President of EFFoST (the European Federation of Food Science and Technology) and the same of EHEDG (the European Hygienic Engineering and Design Group). He is a fellow of IAFoST (the International Academy of Food Science and Technology), a fellow of IFT and has been Chair of the Nonthermal Processing and the International divisions of IFT. At Unilever, he was responsible for hygienic processing and plant design and novel processing technologies. He is the lead editor of 'Hygiene in food processing', the 'Handbook of hygiene control in the food industry', and 'Food preservation by pulsed electric fields: From research to application'. He is co-editor of several other books, including the recently published 'Ensuring Global Food Safety: Exploring Global Harmonization'. He has written chapters for many books and encyclopaedia, over one hundred scientific articles, articles for magazines and presented hundreds of papers, globally.

An interview with Dr Jürgen Lucas

In May 2010, we interviewed the European Commission Project Officer for NovelQ, Dr Jürgen Lucas. Dr Jürgen Lucas works at Directorate-General Research, Directorate E – Biotechnologies, Agriculture and Food, Unit E.3 – Food, Health and Well-being in Brussels. We asked about European Commission activities, project opportunities in the food processing area and about the added-value for an industry partner in participation in a European project. The interviewers underline the new approach of the EC towards industry, in particular SMEs.

Could you give a short summary of the activities of your unit in DG Research as well as your role in European R&D?

"The role of our unit is to ensure that sound EU research with high European added-value is funded and managed, which will address the challenge of securing the availability of safe, nutritious and affordable food.

Our activities are embedded within the theme 'Food, Agriculture and Fisheries, Biotechnology', which supports further consolidation and development of a sustainable European Knowledge Based Bio-Economy (KBBE). All aspects covering the food chain are approached within our part of the theme, thereby responding to the vision of EU2020 (http://ec.europa.eu/eu2020/index_en.htm) by building links with other important policy areas such as competitiveness and innovation, greening of the EU economy, public health, environment, food and energy security and raw material supply.

As a unit, we cover the whole project cycle of multinational European research projects in the food area. When we start writing a new work programme (where all research topics are included foreseen to be funded), we collect all possible input about the new research topics. The draft work programme is discussed with the Advisory Group and the Programme Committee. Whereas the Advisory Group consists of independent scientific and industrial experts, the Programme Committee is exclusively composed of representatives of the 27 Member States and the 13 Associated Countries. The role of both groups is to advise on future strategic lines, propose new research topics and give feedback on the draft version(s) of the new work programme.

When the work programme has been cleared by the Programme Committee, and approved by the Commission, a call for new project proposals is published on Cordis (http://cordis.europa.eu).

The European Commission tries to explain in the call text the main scope of the work programme topics, requirements, funding conditions, etc. However, the Commission is not involved in building up consortia.

During the submission stage, we prepare for the proposal evaluation. We consult the EMM (Expert Management Module, https://cordis.europa.eu/emmfp7) database – published at the Cordis website – to find independent evaluators. We check their availability and possible conflicts-of-interest with the submitted proposals.

The evaluation is carried out in two steps; firstly, a remote evaluation via a web-based tool and, subsequently, the same experts meet in Brussels for consensus discussions on each proposal.

When the project proposal has passed the evaluation stage successfully, the main submitting organisation (the project co-ordinator) receives an invitation to contract negotiations, which is about the scientific, legal and financial aspects of the project. After signing the EU grant agreement, the project receives a first payment and can start its activities.

It takes about two to two-and-half years from the first draft of a work programme to the start of project activities."

How can industrial organisations get involved in this whole process?

"As mentioned, a number of individual industrial (and academic) experts are already involved in the work programme writing phase via the Advisory Group. In addition, the European Technology Platform 'Food for Life' is one of the important discussion partners for the Commission. The Platform unites various stakeholders from agriculture, food processing, supply and ingredient industries, retail, catering, consumers and academia (http://etp.ciaa.eu). SMEs as well as large enterprises are welcome to become partners in the project consortia. To encourage a number of participating (small) companies in the EU projects, participation of SMEs is made a requirement in some topics."

What is the importance of European research, innovation and science in the AgriFood sector compared to other sectors?

"According to CIAA figures, R&D investment in research and development represented 0.37 per cent of turnover of the food and drink industry in 2009, which is low compared to other sectors (e.g. pharmaceutics, or ICT) and other developed countries. The European Commission helps by paving the way to foster higher private research investment, also involving SMEs."

In one of the 6th Framework Programme calls, the EC published a topic on incremental innovations in novel processing. NovelQ was funded through this call. Could you explain what the term 'incremental innovation' means?

"We should not expect any 'big bangs' or radical innovations in the area of food science via one project alone, comparable to the development of an 800 seat aircraft. For incremental innovations, we should strive to consolidate product development processes, make processes more cost-effective and sustainable and improve the organisation of the food chain. However, food science does lead to some radical innovations; think about spray dried coffee, which was really a huge change for the consumers. Another example is the general introduction of the household refrigerator."

How far can you go in innovation with public money? Did NovelQ do the right thing?

"I would say that NovelQ has delivered what was within its objectives. Innovation can be achieved through adaptation of technology or, for example, food composition. We have included a topic in the FP7 Work Programme 2011, which was published in July 2010, on the reduction of salt, sugar and fat in foods. The topic is supported by policy and industry; it is of societal relevance and will lead to innovation. I see this as a very suitable research topic with high European added-value, and surely justified for spending public funds on."

What is your opinion about industry participation in EU Food research in general, and specifically within NovelQ?

"Industry participation is not an objective in its own right, but should always be seen as a means leading to more innovation, which is crucial for Europe. To attract a higher number of SMEs to our projects, we have put figures against the financial contribution — and hence participation in research — going to SMEs

INDUSTRY INSIGHT: NOVELQ

in the work programme. This has already been applied in other themes of the Seventh Framework Programmes – for example within Health. In addition, some topics have been written in such a way as to avoid limiting the research subject, so the consortia, both academia and companies, can bring their own ideas to the project."

What we have learned from NovelQ is that for the successful participation of SMEs in EU-funded projects, a strong link is needed between SME and (research) organisations with experience in European R&D programmes. Do you agree?

"It is difficult for SMEs to do the job by themselves. And when negotiating projects with SMEs, I recommend that each SME has a strong link with a research organisation, preferably one speaking the same language, to help and support them with both the scientific and the administrative part of the project."

What highlights and research examples within NovelQ are – in your opinion – worth mentioning and further exploring?

"Let me mention the multidisciplinary approach of NovelQ. Links between food technology and nutrition, or food technology and packaging, have been set up in order to reach common objectives in the field of novel processing.

When we mention the need for a multi-disciplinary approach in our call topics, we often hear that it is difficult to create this link with other R&D areas. However, we are convinced that by linking different disciplines within a research consortium, the chances for success and innovation increase considerably. In fact, since the 6th Framework Programme, we insist on having consumer research in projects on food development because developing a new food without knowing what the consumers think of it does not make sense."

Other Directorate-Generals (DGs) in the European Commission also contribute to research programmes. Do you provide them with the information coming out of your projects?

"It is our task to inform our colleagues from other DGs about our projects. For example, there is an expert committee on agricultural and process contaminants in DG Health and Consumers. The former project HEATOX, which dealt with the formation of acrylamide during food processing, was of major importance to them. Representatives from HEATOX have been invited to committee meetings several times; we also sent them the final publishable report of HEATOX.

Another example is the platform on physical activity and health from DG Health and Consumers, which also looks very carefully at the results from our projects. DG Enterprise and Industry receives information about our projects about chemicals and nanotechnology, which they need to do, for example, nano-technology risk assessments."

Is the food industry – and related industries (e.g. technology providers) – sufficiently involved in providing relevant topics for the European R&D agenda?

"This is one example of tasks for the European Technology Platforms (ETPs) such as 'Food for Life'. We also rely on, among others, the CIAA (Confederation of Food and Drink Industries, http://www.ciaa.be/asp/index.asp); they are comprised of the big players as well as associations of small companies. However, only looking at food manufacturers would give us a limited view. It is the task of all of the Scientific Officers at DG Research to constantly keep in contact with all stakeholders such as universities, research organisations, the industry and consumers by, for example, attending congresses and reading relevant journals or assessing the progress of the ongoing research projects."

What kind of recommendation would you give to readers of *New Food* regarding research, innovation and science in Europe?

"Be full actors in pushing new research ideas and projects at a high scientific level for more innovation in Europe. Information is a key aspect for this, and consequently check websites such as the one of the KBBE (http://cordis.europa.eu/fp7/kbbe/home_en.html).

Also, please check the Cordis website, in particular the Cordis newswire, because everything that is new and relevant in DG Research including information from the projects is published there. This is the best way to stay informed and learn who to contact."

If *New Food* readers are interested in applying for an EU grant, what would be your practical tips about how to begin?

"I understand it is difficult for an interested person or organisation, be it from academia or the industry, to begin without having support from someone who is experienced, who knows how a proposal should be written, how the evaluation is carried out, how a project is coordinated.

Anybody who is interested in applying for a grant should also consider working as an evaluator at least once. This is a valuable experience and it gives you an opportunity to learn more about proposal writing. Naturally, it is a paid job; if you want to consider acting as an evaluator, please enter your data into the expert database.

Any interested organisation should also contact their national contact point (NCP). The NCPs have regular contact with the Commission, they are well informed about the new calls and project opportunities; they know about different programmes, and can help you finding project partners, etc.

In conclusion, all academic and industrial organisations are most welcome to become project partners. This holds for SMEs and large enterprises as well as for associations. Stepping into a European project enables all project partners – thanks to the financial support from the European Commission – to share and transfer knowledge Europe-wide as well as receiving the latest insights in R&D. The experience of a multinational European research project has always been considered a benefit by the participants, both academia and enterprises."

Floor Boon
TNO

Nicolas Meneses & Dietrich Knorr
Technische Universität Berlin

Predictive shelf life modelling of orange juice treated by novel processing

Shelf life is defined as the period during which a product is acceptable for human consumption. Products are spoiled by microbial, chemical and physical processes. Shelf life is determined by the raw material quality, product formulation, processing, packaging and storage conditions. Processes that determine shelf life can be described using mathematical models, which can be used to predict shelf life or determine preservation conditions to achieve a desired shelf life. In this article, a predictive shelf life model for orange juice treated by high pressure (HP) and pulsed electric field (PEF) processing is described. Shelf life is based on microbial and enzymatic spoilage.

Orange juice is an acidic product with a pH of approximately 3.5 at which spore-forming bacteria cannot grow and pasteurisation is sufficient to obtain a microbially-stable product. The initial microbial population of orange juice ranges from 4 to 8 log cfu/ml. In the model, 5 log cfu/mL was assumed and the juice accepted for human consumption up to 6 log cfu/mL[1]. For microbial growth, a doubling time of 24 hours at 4°C was assumed, resulting in a shelf life of four days for fresh juice. An activation energy of 120 kJ/mol[2] was used to describe the yeast growth at various storage temperatures.

Besides spoilage, it is important to guarantee a microbially-safe food product. *Listeria monocytogenes* is considered to be the most important target micro-organism. There is no agreement concerning a mathematical model that accurately describes the inactivation kinetics of micro-organisms using the combined effects of temperature and pressure. The main problem is a lack of understanding of the basic underlying physical mechanism of inactivation. The first-order model of Dogan and Erkmen[3], describing

SHELF LIFE MODELLING

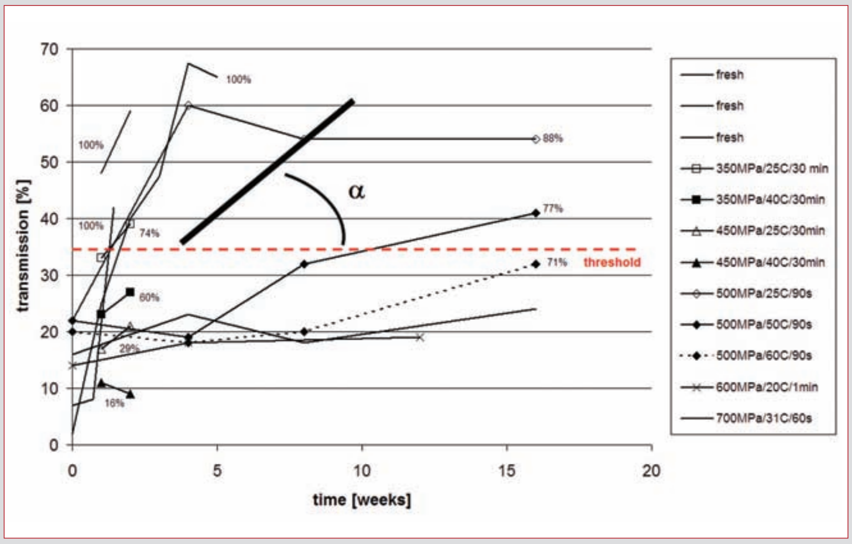

Figure 1 Cloud loss in orange juice during storage at 4°C [6,9-12]

inactivation of *Listeria monocytogenes* in orange juice as a consequence of high pressure (300-600 MPa) at 25°C, was used to predict the microbial spoilage in orange juice.

It is generally accepted that the main inactivation mechanism of micro-organisms with PEF treatment is electroporation of the cell membrane. This is dependent on product conductivity and pH[4]. There is no model describing the combined effect of PEF and temperature. The three models most commonly used to describe inactivation kinetics as a

» It is generally accepted that the main inactivation mechanism of micro-organisms with PEF treatment is electroporation of the cell membrane «

function of the electric field strength and treatment time are the Hülsheger model, the Peleg model and Weibull distribution. These models are empirical since theoretical models for the PEF inactivation mechanism have not yet been coupled to inactivation kinetics. The Weibull model from Gomez *et al.*[4], describing

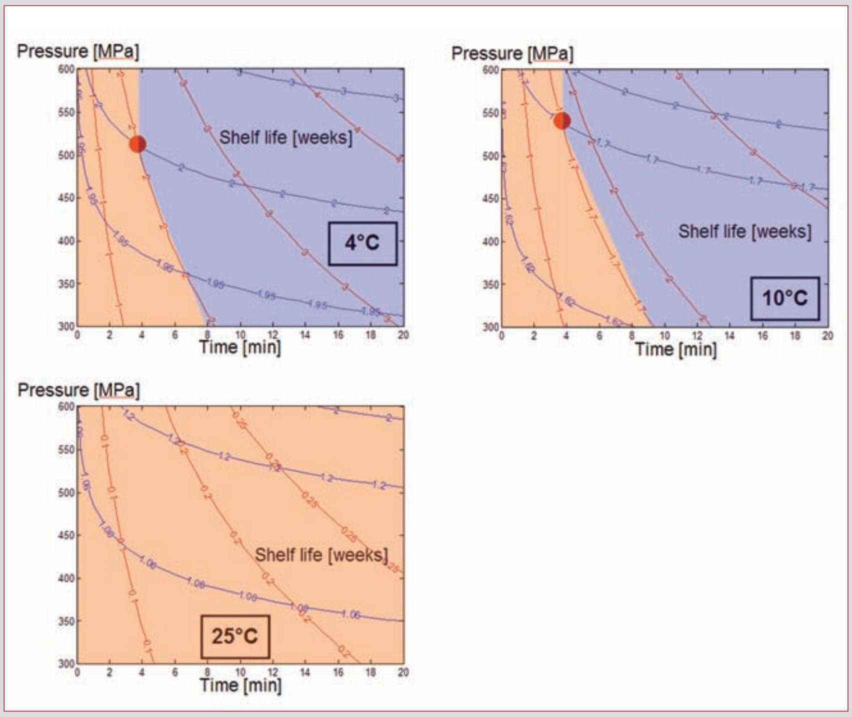

Figure 2 Shelf life (weeks) of orange juice based on microbial (red) and enzymatic (blue) spoilage as function of pressure (MPa) and process time (minutes)

Listeria monocytoges inactivation in a buffer (pH 3.5 – 7.0) with a conductivity of 2 mS/cm at electric field strengths between 15 and 29 kV/cm, and treatment times between 100 and 1500µs was used in the shelf life model (pH 3.5); checked against the predictive capability of the model with measurements in apple juice, the results were in close agreement.

Predicting enzymatic shelf life

Enzyme activity in food may result in a change in the chemical composition of the product, altering flavour, odour, colour and texture. Reactions where enzymes have a role in food are oxidation, browning, texture loss and ripening. The enzyme pectinmethylesterase (PME) was chosen as the target enzyme in orange juice because its affect on quality aspects such as cloud stability is well known.

In the literature, models were found describing the inactivation of PME in orange juice by the combined effects of temperature and pressure[5,6]. Enzyme activity depends strongly on the matrix, and therefore models based on data from purified enzymes in buffers cannot be used for shelf life. The models described by Polydera *et al.*[5] and Nienaber and Shellhammer[6] were based on first-order fractional conversion and the Arrhenius and Eyring equation. The model of Polydera *et al.*[5] was selected to predict shelf life because it describes the combined affects of temperature (40 – 60°C) and pressure (400 – 800 MPa) on PME inactivation for any arbitrary combination.

Many publications were found describing the impact of PEF treatment on PME inactivation in orange juice. Only Elez-Martinez *et al.*[7], however, developed a kinetic inactivation model for PME and a model based on Fermi's model was used for shelf life. Yeom *et al.*[8] confirmed the combined effects of temperature and PEF. However, in this model, the effect of temperature on PME inactivation was not taken into account.

Processing inactivates enzymes to a certain degree; product formulation and storage condition determine the activity of the enzyme and as a result, the rate of degradation during further storage. Initial enzyme activities in fruit juices are difficult to compare because the enzyme activity is proportional to the pulp content of the juice (often not mentioned) and because different measuring methods result in different magnitudes of activity. For the shelf life model, PME rest activity was related to cloud-loss during storage (see box). Transmission above 36 per cent was defined as cloud-loss and 'off-spec'[6,9,10].

» Enzyme activity in food may result in a change in the chemical composition of the product, altering flavour, odour, colour and texture «

Predicting the shelf life of orange juice

Shelf life models for microbial and enzymatic spoilage were combined in such a way that, for each process setting (within the boundaries of the model), the shelf life of orange juice could be predicted. For some process settings, microbial deterioration was dominant; for others it was enzymatic deterioration. The results are given in Figure 2 on page 76 for HP treatment and in Figure 3 for PEF treatment.

For HP treated orange juice, it was shown that at low storage temperatures (4 – 10°C) and longer processing times (for 300 – 500 MPa, longer than eight minutes and for 500 MPa, longer than five minutes), enzymatic spoilage determined shelf life. For short processing times and storage at elevated temperatures (25°C), microbial spoilage became more dominant. For PEF treated orange juice, microbial spoilage always determined the shelf life (in a range between 19 – 28 kV/cm and 10 – 1000 µs); similar values for shelf life based on yeast (four weeks) were found by Elez-Martínez *et al.*[13].

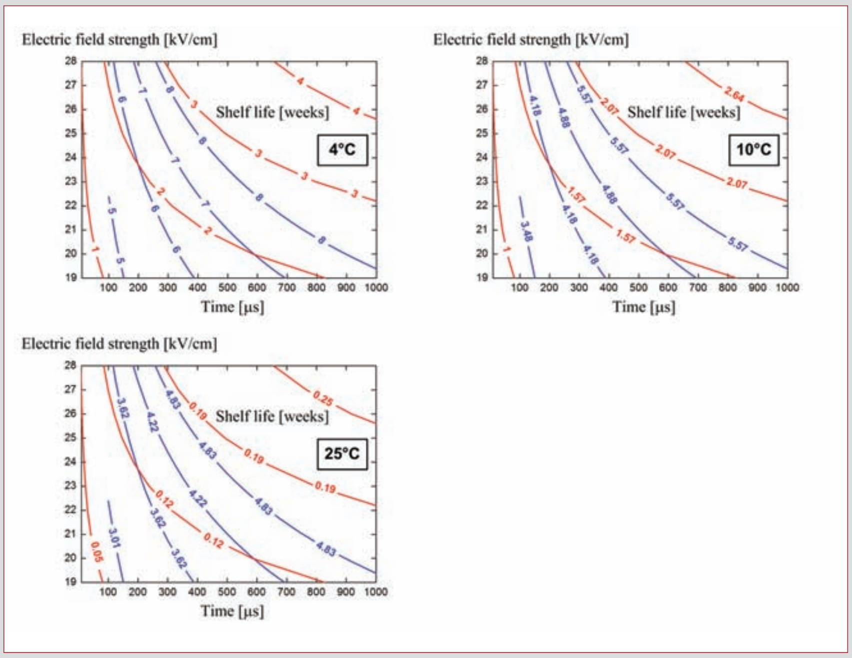

Figure 3 Shelf life (weeks) of orange juice based on microbial (red) and enzymatic (blue) spoilage as a function of electric field strength (kV/cm) and process time (µs)

Modelling cloud stability during storage

Cloud is established by measuring the transmission of the supernatant at 650 nanometres. The initial cloud for fresh orange juice was five per cent and after HP treatment, it increased to 20 per cent[6,9-12]. For PEF, no literature data was available, but based upon colour measurements directly after PEF treatment[8], the cloud was estimated to be slightly greater than fresh juice at 7.5 per cent.

The relation between enzyme activity and rate of cloud-loss was based on data taken from the literature. For example, the data for 4°C are shown in Figure 1 on page 76 for HP treated orange juice. The rest activity was correlated to the slope of cloud-loss. It should be noted that the absolute PME activity is related to slope of the cloud-loss, but this was not possible because this data could not be compared directly.

The relationship found between the slope of cloud-loss as a function of the storage temperature and the rest activity after treatment (for fresh orange juice RA = 100 per cent) was:

$$slope(4°C) = 0.318e^{0.0307RA}$$

$$slope(T_{storage}) = slope(4°C)e^{-\frac{E_A}{R}\left(\frac{1}{T_{storage}}-\frac{1}{277}\right)}$$

Based on the limited data available on cloud stability at higher storage temperatures[6,9,11], an estimation of the activation energy (EA) of 20 kJ/mol was made. The cloud loss was described by:

$$transmission(t) = transmisson(0) + slope(T_{storage}) \cdot t$$

The relative PME activity for fresh orange juice is 100 per cent and shelf life was reached after 10 days (i.e. time to obtain a transmission above 36 per cent). The high rate of cloud change (steepness of the slope) is due to the high rest activity. Shelf life of HP and PEF treated orange juice was dependent on the intensity of the processing.

Conclusions

A shelf life model for PEF and HP treated orange juice was developed using data from the literature and insights from NovelQ. The model can be applied to predict shelf life based upon microbial and enzymatic spoilage, and determination of processing conditions to obtain a desired shelf life. The model combines microbial inactivation and growth with enzyme inactivation, enzyme rest activity and quality.

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Nicolas Meneses

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NovelQ Annual Meeting, 2009

NovelQ

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Disclaimer

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Novel Processing Methods for the Production and Distribution of High-Quality and Safe Foods

Introduction

NovelQ brings together European expertise in science and technology and a substantial Industry Platform to address incremental innovations in novel processing and packaging. Europe already has a competitive position based on patents, expertise and pilot-scale facilities in this area. NovelQ aims to extend and strengthen this competitive advantage.

Project Activities

Main Objectives

To formulate strategic solutions for technical and basic research hurdles in order to develop and successfully demonstrate novel processing in EU, through:

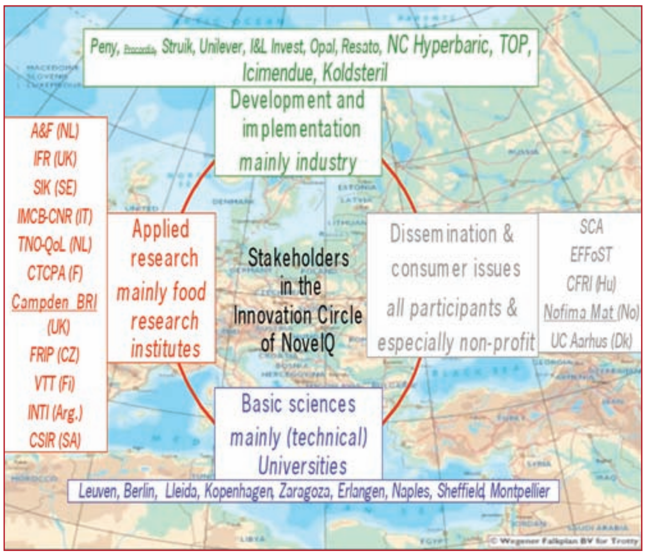
- substantially extending shelf-life of food products;
- responding to the demands of consumers for food with fresh characteristics that contribute to health, convenience, well-being;
- enhancing eco-friendly innovative processing (reduction of water, energy, chemicals, and of fresh produce loss), and solving migration problems.

Processes and Products

High pressure, pulsed electrical field, cold plasma, advanced heating technologies, new packaging concepts are included that are sustainable and eco-friendly.

Key emphasis is put on plant-based products, both solid and liquids, including carrot, tomato, strawberry, apple and broccoli. In addition, whole meals are taken into account in the project.

Project Partners & Industry Advisory Platform



Food manufacturers, equipment suppliers and knowledge centres jointly optimise cross-sectorial innovations. All together, 35 partners have joined forces. Over 70 industries have become member of the Industry Advisory Platform. The Industry Advisory Platform helps exploiting and promoting results as well as identifying bottlenecks to be examined in the project. Best practices are disseminated in (new) member states countries via established networks such as EFFoST.

Further Information

Execution phase: 1-3-2006 - 28-2-2011
EC contribution: 11.3 M€
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