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# SUNNIVA

## Final report

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# Report

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*Summary/recommendation:*

The project "Sustainable food production through quality optimized raw-material production and processing technologies for premium quality vegetable products and generated by-products" [SUNNIVA] aimed at the development of a sustainable food system from production to consumption, addressing the entire food supply chain for the vegetables tomato and *Brassicae*. The goal was better utilisation of the vegetable raw materials, reduced energy and water consumption, higher profitability and healthier food. This was achieved by providing various valorisation strategies to reduce waste and limiting environmental impact. Preservation of the intrinsic health-beneficial phytochemicals present in the raw material in order to improve the nutritional properties of vegetable food products was central in the project. The project contained optimization of harvest time and pre-processing storage conditions, development of novel mild processing design based on modelling, and a two-track valorisation strategy. SUNNIVA has demonstrated how the various residual raw materials can be exploited to the full: Either directly for sustainable production of healthy food (as a refined product or an ingredient), or indirectly by bringing it back into the food chain (as organic fertilizers and soil amendment products) in order to generate renewed primary production with minimal environmental impact.

*Summary/recommendation in Norwegian:*

SUNNIVA har demonstrert hvordan ulike restråstoff fra grønnsaker kan utnyttes; enten direkte - som et raffinert produkt eller en ingrediens - for bærekraftig produksjon av sunn mat, eller indirekte ved å bringe den tilbake i næringskjeden som organisk gjødsel og jordforbedringsprodukter for å generere fornyet primærproduksjon med minimal miljøpåvirkning. Ulike valoriseringsstrategier ble utviklet for å redusere avfall og begrense miljøpåvirkning. Bevaring av næringsstoffene som finnes naturlig i vegetabilske råvarer har vært sentralt i prosjektet. Prosjektet inneholdt optimalisering av innhøstingstid og lagringsforhold, utvikling av nye, milde prosesserings-teknologier basert på modellering for å redusere bruk av vann og energi under prosessering.

# Preface

Project acronym: SUNNIVA

Project title: Sustainable food production through quality optimized raw-material production and processing technologies for premium quality vegetable products and generated by-products

Project website: http://sunnivaproject.eu/

SUSFOOD COORDINATOR INRA

AN FP7 ERA-NET ON SUSTAINABLE FOOD PRODUCTION AND CONSUMPTION

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# 1 Final project summary suitable for web publication

The project “Sustainable food production through quality optimized raw-material production and processing technologies for premium quality vegetable products and generated by-products” [SUNNIVA] was funded under the framework of the Era-Net SusFood Call (2014-2017). SUNNIVA aimed at the development of a sustainable food system from production to consumption, addressing the entire food supply chain for the vegetables tomato and *Brassica*. The goal was better utilisation of the vegetable raw materials, reduced energy and water consumption, higher profitability and healthier food. This was achieved by providing various valorisation strategies to reduce waste and limiting environmental impact. Preservation of the intrinsic health-beneficial phytochemicals (HBPC) present in the raw material in order to improve the nutritional properties of vegetable food products was central in the project. The project contained optimization of harvest time and pre-processing storage conditions, development of novel mild processing design based on modelling, and a two-track valorisation strategy.

Non-destructive optical tools to estimate *in situ* flavonols and chlorophyll of *Brassica*, and lycopene content of tomatoes were developed in the present project. These tools enable a large amount of samplings in a very short time compared to conventional wet chemistry and allows for rapid and inexpensive monitoring of HBPC content in the vegetables. The spectrometers can be used when the fruit is still attached to the plant, either in the field or in the greenhouse, for a fast selection of products before harvesting, or during storage for selection before processing. Elicitor treatment of cabbage and tomato to improve storability of the raw material prior to processing and at the same time preserve HBPC was investigated aided by the optical tools developed.

Energy efficient processing designs for novel food products based on fresh and pre-processed tomato and *Brassica* raw material were developed. This resulted in prototype sausage and meatloaf comminute products with 18% (w/w) cabbage. These novel products have a high nutritional value relative to the conventional meat products and comparable sensory quality.

Microwave flow pasteurization was demonstrated a feasible processing strategy for the prefabrication of cabbage, and also in combination with the oxygen-free spiral filter press for the processing of tomato and apple juices. Moreover, numerical models for heath-transfer and heat distribution in agitated retort systems (shaka autoclaves) and industrial type over-pressure microwave ovens were derived. Compared to the traditional industrial static autoclaves, the novel technologies demonstrated a large potential in energy- and water saving. Reduced thermal processing times enabled by in-pack microwave cooking significantly improved sensory properties (especially texture and colour) of cauliflower and broccoli.

Research has been performed to develop valorisation strategies for underutilized vegetable biomass and processing side-streams. This was pursued through two tracks; first the recycling of these fractions back into the food chain. Second, the fractions not suitable for recycling into the food chain were assessed for their potential as raw material for organic fertilizer or soil amendment products. By the use of mild, cost- and energy efficient processing technologies, several different high-quality vegetable side-stream fractions could be processed into juices, smoothies and purees, or otherwise be applied as functional ingredients in food products. It was thus demonstrated that vegetable by-products and side streams could be successfully transformed into tasteful and healthy food products by the use of energy- and cost efficient technologies. Biomass left over from this production, like press cakes, peel,

and scales, was finally incorporated as raw material for organic fertilizer products and the effect on plant growth promotion was investigated. A test batch of a solid soil improver formulation was produced for bean, cauliflower, celery and apple peel. Bioassays validated their potential agricultural value, and further research is instigated to follow up the most promising side streams and the potential of implementing them in commercial organic fertilizer and soil amendment formulation production.

In conclusion, SUNNIVA has undertaken a life-cycle approach by analysing the vegetable food supply *loop* rather than the *chain*, in terms of sustainability. By doing so, the various residual raw materials can be exploited to the full: Either directly for sustainable production of healthy food (as a refined product or an ingredient), or indirectly by bringing it back into the food chain (as organic fertilizers and soil amendment products) in order to generate renewed primary production with minimal environmental impact.

*Figure 1 Vegetable waste at a food processing plant*

# 2 Full proposal summary

We aim at the development of a sustainable food system from production to consumption, addressing the entire food supply chain for the vegetables tomato and *Brassica* (white cabbage, cauliflower and broccoli), and their derived products. The project will increase consumers' access to safe, healthy and convenient food through novel processing techniques, and improve utilization of raw material, by-products and waste, for which valorization strategies will be developed.

*Brassica* and tomatoes represent a major part of the human diet. They are consumed world-wide and are renowned for their health beneficial effects. In Europe, tomatoes and *Brassica* are among the most important vegetables cultivated; the areas for *Brassica* and tomato production cover 400 000 and 250 000 hectares, respectively, yielding 6 and 15 million tons/year.

Preservation of health-beneficial phytochemicals (HBPC) is central in the vegetable processing part of the project. It is technologically challenging to preserve the nutritional and sensory quality of vegetables in processed foods, e.g. provide for acceptable texture, color and health-promoting compounds. Process optimization by modelling, via knowing the temperature distribution of the products during processing, will contribute to preserve HBPC and thus food quality. Tomato and *Brassica* have a high intrinsic health-promoting value and technologies will be developed to preserve the high HBPC level in the derived food products while also developing novel products with beneficial nutritional and sensory attributes. The initial properties of the vegetable raw material before processing is a limiting factor for the quality of the food products derived thereof.

Optimal harvest time and post-harvest elicitor treatments will further increase HBPC in the raw material. We will also explore the use of well-balanced organic N-fertilizer, based on unused vegetable biomass, and enhanced with bio-control microorganisms. Promoting plant health and growth will result in benefits for the consumer, and for the plant (higher phytochemical content is associated with higher disease resistance). This convergence of benefits includes lower cost and reduced environmental pollution. Non-destructive, high throughput optical indices will be used to monitor phytochemicals, reducing the use of toxic chemicals for wet chemistry analysis.

The global volume of vegetable food wastage, not including agricultural waste, is estimated to 400 million tons/year. Valorisation of unused biomass after processing thus enhances food production sustainability and contributes to a lower ecological impact. We will reduce waste in the food supply chain using two strategies. First, processing and stabilization for recycling into the food chain will be investigated through the use of the novel technologies spiral press filtering and refractance window drying. Second, the value of unused vegetable biomass as component in the production of organic fertilizer will be evaluated.

The development of innovative processing technologies is essential for improving competitiveness and economic growth for the European food industry. The novel food processing technologies microwave heating and agitated retorting will be utilized to demonstrate the potential for combining savings in energy and water consumption. The project aims for 25% savings in energy expenses, and 40-60% reduction in water consumption, compared to conventional processing.

# 3 Main results, conclusions and fulfillment of objectives

## 3.1 Summary of main results and conclusions

**WP1:** Initial properties of cabbage and tomato and their waste fractions were determined, to form a basis for further activities. A range of elicitor treatments were tested in post-harvest trials to identify efficient elicitor treatments as tools to influence the content of HBPC in tomatoes and cabbage raw material and their waste fractions. Products both for industry use and fresh market use were targeted. Results showed that the waste fractions of tomato and cabbage could be utilized as valuable sources of HBPC, and also provide better raw material utilization when subjected to efficient post-harvest elicitor treatments. Among the most promising elicitor treatments were ethylene treatments for pink and waste fraction tomatoes, and light/UV-B and ultrasound treatments for cabbage waste fractions. An important point of attention to maximize health benefits of industrial tomato products as well as tomatoes for fresh consumption is that different types or cultivars of tomatoes reach their maximum level of the HBPC lycopene at different maturity stages.

An important part of WP1 was to optimize non-destructive optical tools to facilitate more frequent and inexpensive monitoring of HBPC content of vegetable raw material. A LED reflectance sensor was optimized for in situ measurements on tomato fruits and subsequent estimation of lycopene content. This tool can be used to predict the best harvest time to obtain the highest level of lycopene in tomatoes. For cabbage, fluorescence-based sensors were proved to be able to detect flavonols and chlorophyll in leaves and cabbage heads directly in the field, as well as after harvest. This could be a useful tool to predict cabbage storability. The optical tools were actively used throughout the project, providing additional validation of HBPC monitoring, and allowing more frequent HBPC assessments. The optical tools were also used in WP5 activities.

As a result of realization of **WP2,** three types of health oriented food products were designed, prepared and evaluated. All of them were based on tomatoes and cabbage cultivated in the framework of WP1. Two types of foods were studied only at laboratory scale: fresh tomato based sauce to be served with fish and lyophilisate based vegetable instant smoothie-like drink combining tomatoes, cabbage and herbs. In the case of these products, the attempts were undertaken to increase the proportion of cis-lycopene by microwave induced isomerisation, but this approach turned out not effective. The third type of food products, namely meat sausage and pate enriched with cabbage prefabrication was realized in cooperation with two industrial partners. The first stage dedicated to the preparation of cabbage prefabrication was carried out with the aid of microwave flow sterilisator Enbiojet at Enbio Technology. The cabbage prefabrication technology was designed so as to maximize the content of isothiocyanate and indoles, the health beneficial degradation products of glucosinolates present in this vegetable. The cabbage prefabrication was then used at Meat Company Nowak to prepare meat products. A number of parameters related to healthiness were compared between cabbage containing and regular meat products that showed benefits of cabbage prefabrication addition without major impact on sensory properties of obtained food items.

The results of **WP3** suggested an optimal reciprocal agitation rate for low-viscosity Newtonian liquids at 80 rpm with respect to the average temperature increase and temperature distribution uniformity. For the non-Newtonian case, a certain inertial force was demonstrated to be imposed (over 80 rpm) to start gaining an effect for high viscosity which might even have possible negative effects on the temperature evolution during agitation. Average temperature increase due to the effect of 20 and 80

rpm agitation was very similar due to high viscosity and resulting viscous forces. Negative effect of increased viscous forces in agitated (axial rotation) processes, where the temperature increase as affected negatively with the increasing rotation rate, was also encountered in the literature. It was pointed out that the increasing rotational forces in a high viscous range lead to higher centrifugal forces overcoming the gravitational forces. This prevents the natural convection, and heat transfer tends to be conduction-like with well-formed kernel-like temperature contours by slowing down the temperature increase. A further study to demonstrate the effect of headspace volume to increase the agitation rates for liquid and particulate food products is planned based on the conclusions of the WP3. The only minor change in this WP was about the use of the suggested software (SC Tetra Cradle). Considering the requirement of the solution of temperature and velocity changes along the liquid – gas interface during thermal processing under strong agitated process, the Drs. Ferruh Erdogdu and Mustafa Tutar decided on the use of Ansys Fluent (Ansys Inc. Canosburg, PE, USA) based on the results of the initial test runs. Eventually, Ansys Fluent worked rather well under the given conditions leading to an experimentally validated model developed first time in the literature for oscillated agitation process.

**WP4:** At the start of the project, a data collection, among the partners and their extensive networks, focusing on the availability (in time and space) of vegetable by-products throughout the agrifood chain was initiated. From this exercise it became clear that these biomass fractions truly represent a valuable feedstock for improved valorization strategies toward food, feed, fertilizer, soil improvement etc. Specific by-products are present in significant volumes (e.g. >1000 tonnes/year) in a single location, relatively pure and of good quality (either raw or processed). The most relevant vegetable by-products were characterized for the nutritionally relevant parameters.

In the next step, a biorefinery process scheme was developed centered around the use of the low-oxygen spiral-filter press as fractionation technology. This technology allows to fractionate the wet vegetable by-products into a liquid fraction and a press cake, without the need to add antioxidants. The liquid fraction can be directly valorized as a juice, smoothie or puree after a conservation treatment (pasteurization) or as an ingredient in such preparations. In the project, spiral-filter processing and the subsequent pasteurization was optimized for tomatoes, cauliflower, carrots, peas, beans, red beetroot, celeriac, stalk celery and black salsify. A pilot line was built up in an industrial context and process and product development resulted in 4 selected recipes that were subjected to taste-trials.

In addition, the spiral-filter press technology was combined with the microwave-based pasteurization technology of Enbiojet. As was done for the other products developed, chemical and microbial safety was checked, together with a shelf-life study of the end-products. From this work it became clear that the technologies used have the potential to turn vegetable by-products into tasteful products, appreciated by consumers, that can be marketed as clean label, natural and healthy products.

Follow-up research will focus on the use of the press cakes in food applications (a.o. in the SUSFOOD2 granted projects InProVe and Improve).

**WP5:**

Twenty vegetable waste streams, mainly generated by the Belgian partners of the Sunniva project, were analysed to evaluate their potential as input source for DCM in products such as organic fertilisers, soil amendments, or biostimulants. All streams were characterized for nutrient content, dry

matter content, percentage organic material, lignin, hemicellulose, cellulose and soluble fraction. The main secondary metabolites such as flavonoids and alkaloids and their relative concentration were also determined. These analyses resulted in a complete overview of the characteristics of each stream and indicated a selection of streams with further valorisation potential.
A series of plant bioassays was optimized in WP5 to characterize the effect of the materials on seed germination, plant shoot growth, plant root growth and root phenotype. The bio-assays span a scale from in vitro tests up to greenhouse tests, so the most suitable test could be selected in each situation. These bioassays form a valuable portfolio for future testing.
The use of the vegetable waste streams resulted in a multitude of plant effects, ranging from growth suppression to growth promotion, either above- or belowground, or effects on root architecture. Especially bean, cauliflower, celery, apple peel and salsify waste streams showed significant (positive or negative) plant effects.
A test batch of a solid soil improver formulation was produced for bean, cauliflower, celery and apple peel. Bioassays validated their potential agricultural value.
A cost-effective industrial drying method is crucial for valorisation of the waste streams as raw material in soil improvers or fertilisers. A first large batch was dried at industrial scale, the plant bioassays with this product are still ongoing.
A test batch to investigate the potential as biostimulant in solid formulation was also produced. Promising trends of plant growth promotion were observed with specific vegetable streams.
The biostimulant effect of watery extracts of the materials was also evaluated in different bioassays. A strong effect on root phenotype was observed for specific streams, but additional characterisation is still needed.

The original industrial partner HEVAD (Belgium) left the consortium in November 2014 and was replaced by Greenyard Prepared which was accepted as a partner by IWT in January 2015 and formally joined the consortium in April 2015. Because of this, the Flemish partners in the project were granted an extension in the project period until January 31$^{st}$, 2018, and French partners until December 31$^{st}$, 2017. Polish partners where granted an extension until September 30$^{th}$, 2017, from their funders NCBiR. However, apart for this unforeseen event that led to an extended project period, the project was co-ordinated (**WP6**) according to plan and resulted in significant dissemination and communication (**WP7**) with diverse target groups as illustrated by the publication of 10 scientific papers in international peer-reviewed journals, and several popular science publications and presentations.

## 3.2 Fulfillment of objectives

**WP1**: All major goal, milestones and deliverables were achieved. The calibration of sensors for non-destructive HBPC monitoring was one of the objectives, but also provided a very useful tool in the execution of several other WP objectives. We were able to assess the effects of a whole range of different elicitor treatments on raw material as well as waste fractions of tomato and cabbage. Application of this knowledge by the food industry could provide increased raw material utilization as well as improved HBPC levels and product quality.

**WP2:** All major goals proposed in the project were realized. Most importantly, we demonstrated that current trend of combining meat and plant in one final food item is a feasible technology that does not require any special investment from meat manufacturers if the vegetable is offered in an appropriate form. Moreover, we demonstrated that vegetable prefabrication could be prepared in a way that

enhances the content of health promoting phytochemicals. It is essential to point out that in order to better assess the health quality of meat/cabbage products, we have developed new methods of isothiocyanate determination, of monitoring of lipid oxidation and evaluation of nucleic acid content and size. These methods were not originally taken into account, but were found to be a worthwhile as suggested by observation of food trends.

**WP3:** Based on the objective to develop a computational thermal model and determination of the optimum conditions for oscillated retorts systems, the objective of WP3 were fulfilled with the manuscripts published and presentations delivered in various scientific conferences (see below - Section 4). Regarding the PC breakdown kinetics, the basic kinetic data on PC breakdown showed not to be well described in literature. The data from different studies are not obtained by the same methodology. Kinetic data for modelling PC breakdown should be collected in a following project as more resources will be needed to do so. However, the present models have paved the way for incorporation of kinetic models and modelling of their retention during processing. A general indication on nutrient retention is color changes and a study of changes in color of broccoli under heat treatment was published by Pero et al. (2018 - see below; Section 4).

**WP4** was executed as planned and the formulated objectives were achieved. For the conservation technologies most worked focused on the stabilization of wet products (UHT, pasteurization, microwave pasteurization) and less on drying technologies. This was driven from a sustainability point of view: the production of dry products/ingredients from the vegetable by-products is more energy consuming. In addition there are sufficient market opportunities for the wet products (juices, smoothies, purees).

**WP5:** An important objective of WP5 was to produce test batches of organic fertilisers or soil improvers using the vegetable waste streams as raw materials. These test batches were indeed produced. In the original plan it was foreseen to mix micro-organisms with these raw materials to validate their value as substrate or carrier material. However, with the addition of BND Noliko (Greenyard Prepared) as partner in the project, the number of available vegetable side streams increased tremendously. It was thus decided to focus on the evaluation of all these materials, not only as nutrient source or filling material but also - and mainly - as bioactive compounds with biostimulant activity.

**WP6** and **WP7:** The project was managed, and dissemination executed, according to plan.

# 4 Milestones and deliverables status

## 4.1 Milestones

| No[1] | Milestone name | Planned delivery month[2] | Actual delivery month[2] |
|---|---|---|---|
| M 1.1 | Initial properties of different fractions of tomato and cabbage and their waste fractions identified | 12 | 20 |
| M 1.2 | Successful elicitor applications for tomato and Brassica identified | 24 | 35 |
| M 1.3 | Non-destructive tools for HBPC developed | 15 | 18, 30 |
| M 1.4 | Determined and compared optimum harvest time for tomatoes based on current practice and on maximum content of HBPC | 24 | 32 |
| M 2.1 | Selection of raw materials from field experiments and WP4 valorisation activities for the design of food items | 24 | 24 |
| M 2.2 | Design of food items for preparation of laboratory and industry prototype products based on fresh and pre-processed plant material | 24 | 24 |
| M 2.3 | Preparation of laboratory test products and verification of their health properties with the use of selected chemical and biological markers | 24 | 24 |
| M 2.4 | Preparation of test products at large scale in cooperation with industrial partners and verification of their health properties with the use of selected chemical and biological markers | 36 | 36 |
| M 3.1 | Numerical model on (thermal) PC breakdown ready | 24 | 20 |
| M 3.2 | Numerical thermal model derived | 24 | 20 |
| M 4.1 | Characterized vegetable vaste | 20 | 20 |
| M 4.2 | Valuable fractions derived from vegetables waste/by-products | 24 | 24 |
| M 4.3 | Stabilized fractions on the processed vegetables waste/by-products | 30 | 30 |
| M 4.4 | Potential of selected vegetable-derived fractions | 30 | 45 |
| M 5.1 | Selection of relevant waste/side flows for potential use as raw material in organic fertilizers or soil amendments | 12 | 24 |
| M 5.2 | Stabilized, dry fractions originating from vegetable waste/side-flows available for use as raw material in organic fertilizers or soil amendments | 20 | 30 |
| M 5.3 | Selection of suitable combination of rest fractions obtained from the above with BM to enhance growth or plant disease resistance | 24 | 45 |
| M 5.4 | Evaluation of a new organic fertilizer or soil amendment test batch (produced by DCM) in greenhouse and/or field trials with tomato and Brassica | 36 | 45 |
| M 5.5 | Determination of PC content of plants treated with the organic fertilzers/soil amendments test batch | 36 | 45 |
| M 6.1 | Start-up of project | 3 | 1 |
| M 6.2 | End of project | 36 | 45 |
| M 7.1 | Dissemination plan and exploitation plan ready | 4 | 4 |
| M 7.2 | Final summary | 36 | 48 |

[1] Please indicate the according WP number. For example, deliverable 4.2 would be the second deliverable from work package 4

[2] Measured in months from the project start date (month 1)

## 4.2 Deliverables

| No1 | Deliverable name and language | Nature3 | Dissemination level4 and link to the document | Planned delivery month2 | Actual delivery month2 |
|---|---|---|---|---|---|
| D 1.1 | Non-destructive optical indices | Papers | PU<br>https://pubs.acs.org/doi/abs/10.1021/acs.jafc.5b04962<br>https://doi.org/10.1016/j.jfca.2018.01.023 | 24 | 21, 47 |
| D 1.2 | Guidelines for elicitor treatment of tomato and Brassica | Posters | PU | 36 | 30 |
| D 1.3 | Guidelines for post-harvest elicitor treatment of Brassica waste (Broccoli, cabbage) | Paper (in preparation) | PU | 30 | pending |
| D 1.4 | Guidelines for improving critical points from harvest to retailing (tomatoes for the fresh market) or start of processing of tomatoes | Posters | PU | 36 | 30 |
| D 2.1 | Compiled information on types of raw materials available from field experiments and WP4 that can be used for preparation of food products | Report | INT | 30 | 30 |
| D 2.2 | Consecutive reports containing results of chemical and biological characterization of raw materials selected for further experiments with a set of chemical and biological markers | Posters | PU | 30 | 30 |
| D 2.3 | Description of design of consecutive food items based on different raw materials derived from tomatoes and Brassica vegetables prepared at laboratory scale | Posters | PU | 24 | 24 |
| D 2.4 | Report describing results of chemical and biological characterization of prepared in laboratory prototype food items using a set of chemical and biological martkers | Posters | PU | 24 | 30 |
| D 2.5 | Prepared at an industrial scale these food items that occured most promising according to the results of laboratory tests | MSc Thesis | PU | 36 | 36 |
| D. 2.6 | Report describing results of chemical and biological characterization of prepared in cooperation with industrial partners prototype food items using a set of markers | MSc Thesis | PU | 36 | 36 |
| D 2.7 | Report summarizing the proposed food items along with the suggested technology of their production, and evaluation of markers relevant for their health-quality | Posters | PU | 36 | 36 |

[3] Please indicate the nature of the deliverable. For example Report, Paper, Book, Protocol, Prototype, Website, Database, Demonstrator, Meeting, Workshop

[4] Please indicate the dissemination level using one of the following codes: PU = Public; INT= Internal (Restricted to other project participants); RE = Restricted to a group specified by the consortium; CO = Confidential, only for members of the consortium

| No1 | Deliverable name and language | Nature3 | Dissemination level4 and link to the document | Planned delivery month2 | Actual delivery month2 |
|---|---|---|---|---|---|
| D 3.1 | Report (or review article) on breakdown and inactivation kinetics for selected PC | - | - | 12 | See explanation about the minor deviation from the original proposal |
| D 3.2 | Optimized processes based on measured time/temperature history | Paper, Conference proceeding | PU – https://www.sciencedirect.com/science/article/pii/S0960308516300840 | 27 | 20 |
| D 3.3 | Validation report on thermal model | Paper | PU | 27 | 24 |
| D 3.4 | Article on optimization of PC breakdown by numeric modeling | Paper, Conference proceeding | PU – https://www.sciencedirect.com/science/article/pii/S0960308516300840 https://www.sciencedirect.com/science/article/pii/S026087741730242X | 36 | See explanation about the minor deviation from the original proposal. Optimization study was carried out based on the average temperature change! |
| D 4.1 | Report on the characterization of unused vegetable biomass streams | Report | CO | 20 | 20 |
| D 4.2 | Report on optimized pre-treatment & oxygen-free pressing conditions | Report, Paper | RE (confidential), PU: https://doi.org/10.1016/j.jfoodeng.2017.06.010 | 24 | 24 |
| D 4.3 | Report on the potential of the stabilization techniques evaluated | Report | CO | 32 | 32 |
| D 4.4 | Report on potential of stabilized fractions as food ingredient/component of organic fertilizer | Report | RE (confidential) | 36 | 36 |
| D 5.1 | Overview of the characteristics of the available side-flows according to the relevant criteria for use as raw material in organic fertilizers or soil amendments, and selection of at least one and preferably two side-flows to process further in task 2 | Report | CO | 12 | 24 |
| D 5.2 | Brief SWOT analysis of the different methods tested for drying or stabilizing side-flows for use as raw materials in organic fertilizers or soil amendments. | Report | CO | 20 | 45 |
| D 5.3 | Test batch produced by DCM, using raw materials derived from task 1 and 2 | Prototype | CO | 24 | 32 |
| D 5.4 | Evaluation report of plant response to newly developed test product, in terms of plant growth and disease resistance, from greenhouse and field trials | Report | CO | 36 | 45 |

| No1 | Deliverable name and language | Nature3 | Dissemination level4 and link to the document | Planned delivery month2 | Actual delivery month2 |
|---|---|---|---|---|---|
| D 5.5 | Definite answer on a putative beneficial effect of the newly designed test product on tomato and Brassica PC content, and preparation of at least one peer-reviewed publication related to this | Report | CO | 36 | 36 |
| D 6.1 | Project tools | Document exchange platform, Website, meeting. | CO | 4 | 3 |
| D 6.2 | Yearly reports | Reports | PU | 12, 24, 36 | 18, 37, 48 |
| D 7.1 | Dissemination plan and exploitation plans | Project description, Meeting | PU, INT | 4 | 3 |
| D 7.2 | Website ready and followed up by continuous updates | Website | PU | 6 | 3 |

**Additional comments (in case of major changes or deviation from the original work plan)**

The original industrial partner HEVAD (Belgium) left the consortium in November 2014 and was replaced by Greenyard Prepared which was accepted as a partner by IWT in January 2015 and formally joined the consortium in April 2015. Because of this, the Flemish partners in the project were granted an extension in the project period until January 31st, 2018, and French partners until December 31st, 2017. Polish partners where granted an extension until September 30th, 2017, from their funders NCBiR.

# 5 Work package description and results

## 5.1 WP 1

**Post harvest treatments and applications; optimizing harvest time and improving quality of processing raw material and waste fractions for side streams in Brassica and tomatoes**

Responsible partner: Partner no 2, NIBIO, Ingunn Vågen

### 5.1.1 Original description of work

In WP1, we will reduce tomato and *Brassica* waste and loss from the time of harvest throughoptimizing harvest time aided by high-throughput innovative multi-parametric fluorescence-baseddevices. The same methodology will be used to determine effects of elicitors. Non-destructiveoptical tools are particularly useful for this because they enable a large number of parallelmeasurements in a very short time compared to conventional wet chemistry. The novelty will bethe optimization of non-destructive tools to make them more efficient and user-friendly tovegetable producers and food industry operators.

### 5.1.2 Aim of the Work Package

Investigate and develop methods to induce added value to vegetable raw material postharvest through selection of raw material and improving concentration and composition of HBPC in *Brassica* and tomatoes;

1. Inducing added health value of vegetable raw material for food and by-products

    1.1. Identify initial properties of different fractions of raw materials and their waste fractions.
    1.2. Determination and comparison of optimum harvest time for tomatoes based on i) current practices for industry- and fresh consumption purposes, and ii) on maximum content of HBPC
    1.3. Improving concentration and composition of PC in vegetable raw material and side stream fractions by post-harvest elicitor applications.

Raw materials: Tomatoes produced both for fresh consumption and for processing. Cabbage leaves left in the field after harvesting and cabbage residual biomass after industrial use.

2. Develop non-destructive optical tools to estimate in situ flavonols and chlorophyll of *Brassica* and lycopene content of tomatoes to facilitate more frequent and inexpensive monitoring of PC content of vegetable raw material. These tools will be used in objectives 1.2 and 1.3. The tools will also be valuable for sorting raw material into quality classes for specific purposes or as guidance in elicitor treatments.

### 5.1.3 Report on results obtained and changes to the original work plan/WP aims

**A- results obtained**

All activities in WP1 were successfully performed according to the project plan, with some adjustments to the timing of some activities and deliverables.

Initial properties (HBPC) of cabbage and tomato and their waste fractions were determined, to form a basis for further activities. Products aimed at both industry use and fresh market use were targeted, and the initial studies covered products from different plant nutrition regimes as well as different cultivars. For tomatoes, the waste fraction considered was the so-called “breaker tomatoes” that are discarded after harvest. For cabbage, the waste fractions considered were cabbage leaves left in the field and still attached to the plant, cabbage leaves discarded in connection with harvest/storage, and cabbage biomass discarded by food industry in connection with their handling and processing. As an example, the assessments of initial properties showed that waste fractions of cabbage contain much higher flavonol and ascorbic acid values than the utilized part of the cabbage, illustrating the great potential in utilizing cabbage waste biomass as a source for health beneficial phytochemicals.

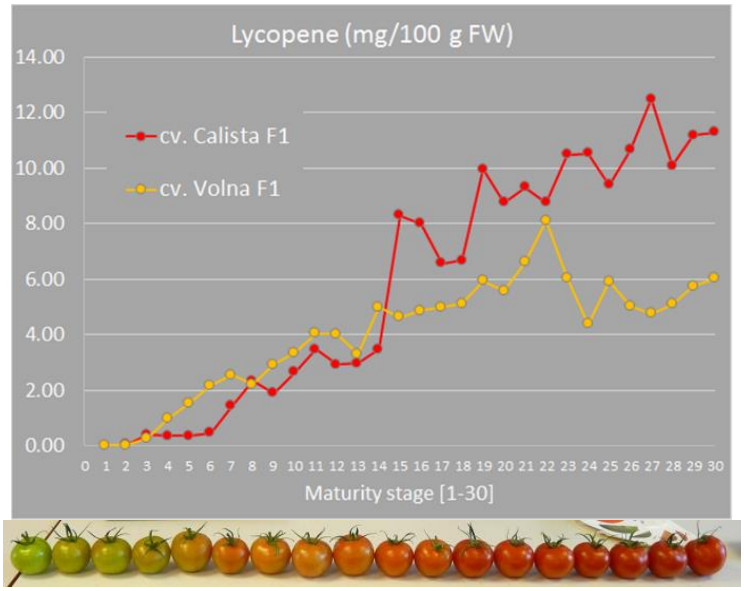


*Figure 2 Lycopene content in relation to maturity stage for tomato fruits for industry (cv. Calista) and fresh market (cv. Volna).*

For tomatoes, lycopene levels were determined related to maturity stage, as illustrated in Figure 1. The studies showed that different types or cultivars of tomatoes reach their maximum level of the HBPC lycopene at different maturity stages, identifying this as an important point of attention to maximize health benefits of industrial tomato products as well as tomatoes for fresh consumption.

A large part of the effort in WP1 was dedicated to identifying efficient elicitor treatments as tools to influence the content of HBPC in tomatoes and cabbage raw material, and their waste fractions. A range of treatments were tested in post-harvest trials, as summarized in the table below.

*Table 1 Elicitor treatments tested in post-harvest trials in the present project*

| Crop | Tomato | | Cabbage | |
|---|---|---|---|---|
| Product fraction | Red fruits | Pink fruits, waste fraction | Cabbage heads | Waste fraction |
| Elicitor treatments | Temperature, 1-MCP, ethylene, time (storage), plant nutrition status (N) | Temperature, 1-MCP, ethylene | DCA (dynamic control atmosphere), natural light, temperature, time (storage), plant nutrition status (N) | Temperature, natural light, UV-B light, ultrasound, UV-B x ultrasound, vacuum, CO2, ethylene |

The most promising results were found with ethylene treatments for pink and waste fraction tomatoes, and with light/UV-B and ultrasound treatments for cabbage waste fractions.

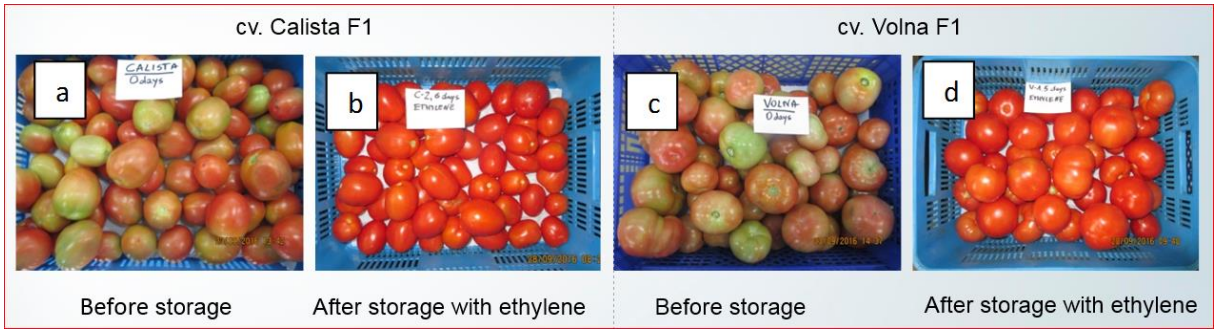


*Figure 3 Example of elicitor treatment: Waste fraction of tomatoes treated with ethylene*

A LED reflectance sensor was optimized for in situ measurements on tomato fruits and subsequent estimation of lycopene content. We found that the lycopene Partial Least Squares prediction models were significantly dependent on the cultivar and the season. This non-destructive method was applied in the field to estimate the crop average tomato lycopene level just before harvest. It showed a significant difference in the crop lycopene content between two harvest dates at a 3-weeks distance due to change in the meteorological conditions. This tool can be used to predict the best harvest time to obtain the highest level of lycopene in tomatoes.

Non-destructive control of lycopene in tomatoes during storage showed that red processing and fresh-market tomatoes under 12 °C retained 90% of the harvest lycopene up to three and two weeks, respectively.

Fluorescence-based sensors were proved to be able to detect flavonols and chlorophyll in white cabbage leaves and heads directly into the field. Measurements on the cabbage heads are useful to predict cabbage storability. The flavonols index was used to monitor the effect of postharvest irradiation of cabbage waste leaves by sunlight or UVB lamps. After few days of irradiation, the flavonols content in the basal part of waste cabbage leaves significantly increased. This approach can stimulate waste leaves reutilization for the recovery of bioactive phytochemicals.

*Figure 4 In-field tomato lycopene monitoring by use of a LED fluorescence sensor*

**B- comments on deviations from the original plan:**

Delivery of the fully optimized optical tool for the lycopene prediction on tomatoes was delayed due to the time required for a proper quantitative determination by means of the destructive extraction and HPLC analysis, which required more time than planned.

## 5.2 WP 2

**Rational design of tomato and/or brassica vegetables containing foodsaccording to food synergy concept**

Responsible partner: Partner no 3, GUT, Agnieszka Bartoszek

### 5.2.1 Original description of work

An example of innovative products based on comminuted meat with vegetables is the Brassica®" products, developed in cooperation with Polish food industry and GUT, and produced so that glucosinolates degrades to chemo-preventive derivatives. The PC present in the vegetables were shown to prevent meat oxidation, a feature that contributes to prolonged shelf life and reduced loss. In **WP2**, this line of products will be expanded to new products with other types of meat, an extended range of Brassica species, and tomato. Novel processing technologies (MW and agitated retorting) will be explored, and the health-beneficial effects of the novel technologies and products will be determined according to food synergy concepts; i.e. the concept that food in its natural form is a nonrandom mixture of nutrients and other bioactive substances tailored to play a concerted role in maintaining life of the organism consuming the food. The rational design of food items proposed in WP2 refers to this concept taking advantage of current knowledge on biological activity of HBPC, and modern technologies that can preserve them.

### 5.2.2 Aim of the Work Package

1. To select and characterize raw materials for further use in the workpackage
2. To design food items and prepare laboratory prototypes based on different raw materials derived from tomatoes and/or brassica vegetables
3. To design prefabrication products and prepare laboratory prototypes that can be conveniently incorporated into meat, fish or ready dishes without altering current production lines
4. To prepare the most promising food items at a larger scale in cooperation with industrial partners
5. To verify the health-quality of laboratory prototypes and prepared in cooperation with industrial partners food items with the set of chemical and biological markers

### 5.2.3 Report on results obtained and changes to the original work plan/WP aims:

**A- results obtained**

Plant material used for the preparation of all food items included tomatoes and cabbage cultivated by InHort. In the first stage, the vegetables derived from different cultivations were characterized by the content and composition of bioactive phytochemicals (mainly glucosinolates and their degradation products, lycopene and other carotenoids, phenolic components), total antioxidant activity, chromatographic profiles of antioxidants. In the second stage, the chosen cabbage variety and cultivation conditions were used to produce enough vegetables for technological trials. The next stage was production of cabbage prefabrication for meat industry. It involved the following stages: mincing cabbage, passing through flow microwave device at Enbio Technology to increase formation of beneficial glucosinolate derivatives, sterilization of cabbage pulp in flow microwave sterilizator, collection of sterile pulp into containers, storage of cabbage prefabrication at -20°C. Upon agreement

with Meat Company Nowak two types of meat products were prepared: white sausage with/without cabbage and baked pate with/without cabbage. Two rounds of technological trials were conducted, where meat products were prepared using actual production line. The products enriched in vegetables were obtained by adding still slightly frozen cabbage prefabrication (about 15%) to meat instead of water. The cabbage prefabrication and meat products were evaluated as regards their healthiness and consumer acceptance. Biomarkers studied included, determinations of bioactive phytochemicals, mutagenic activity in microplate Ames test MPF, cytotoxic activity towards human colon cancer HT29 cells serving as a model of alimentary tract, oxidation of fats, content of nucleic acids and sensory analysis. It has been determined that cabbage prefabrication did not contain glucosinolates which, as expected, in a reaction catalysed by myrosinase degraded to derivatives such as indoles and probably some other compounds that could not be determined because being volatile they were lost during sample preparation. Meat products containing cabbage exhibited higher antioxidant activity. The isolated fraction of potential mutagens arising in meat upon heating from cabbage containing meat products displayed lower mutagenicity in Ames test than that from corresponding regular products. Also the oxidation of fat fraction occurred to lower extent in meat products containing cabbage. At the level of nucleic acids, pairs of products seemed very similar. Sensory analysis revealed that cabbage containing products did not differ substantially from their regular counterparts, however the probants, who were not informed about the composition of the products, suggested the presence of other smells and other tastes in cabbage containing products, they also found the former more piquant. None of probants could recognize what was added to meat, which shows that the meat and vegetable tastes melted into new composition acceptable for consumers.

In the case of tomato products, a number of food items were proposed, of which finally two were chosen for more detailed assessment. All tested products were prepared in a laboratory scale using tomatoes from Inhort. The first product accepted as promising was a sauce based on chopped tomatoes with red beetroot addition, which resulted in a very appetizing red colour and increased antioxidant activity. The sauce was sterilized in a flow microwave sterilizator in cooperation with Enbio Technology and packed sterile in plastic containers. This tomato product was suitable to be served with fish dishes or pasta. Another promising products were lyophilisates of tomato pulp, also in some cases containing powdered seeds, combined with spices or cabbage lyophilisate, meant as instant veggie shake. It was confirmed that such powdered lyophilisates easily combine with water forming stable suspensions that tasted like a cloudy juice from fresh vegetables. We tried also to increase the proportion of cis-lycopen by microwave treatment, but these attempts were not successful. The antioxidant activity of tomato products prepared was strictly related to other additives, spices known to be a rich source of antioxidants increased this activity.

In summary, the study demonstrated that vegetable prefabrication is a good solution for meat industry and could be exploited to enhance healthiness of meat products. Firstly, the technology of vegetable prefabrication production may be optimized to increase the content of beneficial phytochemicals in vegetable pulp and its safe storage. Secondly, a convenient form of such prefabrication causes that in meat company its application on the production line does not require any special or difficult additional operations, thus does not increase production costs. Our studies also demonstrated that lyophilized powdered tomatoes can be used for a production of convenient healthy instant drinks with a nice appearance and a taste of freshly prepared cloudy juices.

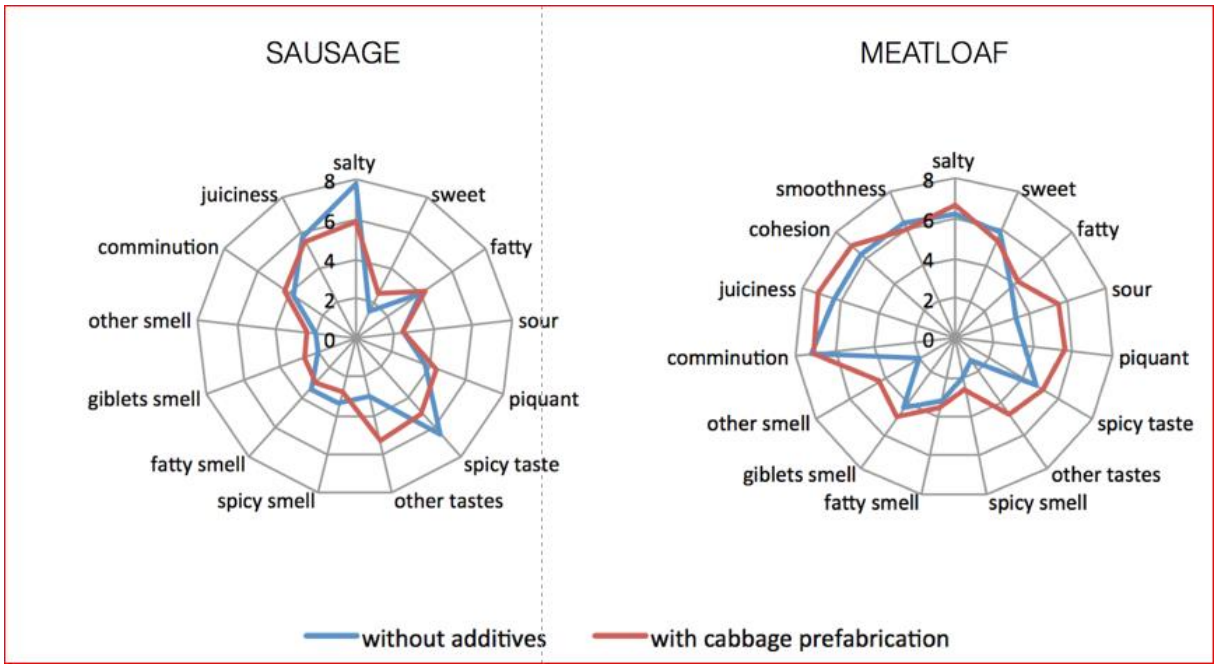


*Figure 5 Sensory analysis of sausage and cabbage with and without prefabricated cabbage*

**B- comments on deviations from the original plan**

The realisation of the project was prolonged till the end of September 2017. This was dictated by the schedule of academic year. Two students were involved in realisation of the project in the framework of their MSc project and they could work on it full time only in the semester beginning from March 2017. Polish Ministry of Science and Higher Education agreed for this extension, especially that also another SUNNIVA partner extended their period of realization of the project.

## 5.3 WP 3

**Modeling thermal effects on vegetable quality parameters**

Responsible partner: Partner no 6, AU, Ferruh Erdogdu

### 5.3.1 Original description of work

For optimal process design, the temperature distribution inside the product must be known.

Therefore, heat transfer modeling for the tomato and *Brassica* based products will be carried out in the first stage of **WP3** to determine temperature distribution during a novel agitated retort processing as a volumetric heating process. This was specifically chosen for processing due to its ability to impose forces up to 3-4 g to enhance the convective mixing within the product. The enhanced mixing via the longitudinal agitation leads to a significant reduction in processing time, and ensures the same microbial decimation with less energy use, and thus increased production efficiency. Reduced (thermal) processing time will also improve nutritional and sensory quality

of products. In the second phase, changes in the quality factors will be determined to optimize the process. This will lead to a modeling tool to optimize the agitated retort processing and minimize product development costs via reduced processing costs and energy, while improving the quality. Preservation/breakdown of PC will form the objective function while the agitation rates (strokes/min) and process temperature will base for decision and explicit/implicit variables. The results will be compared with the results of conventional processing techniques, e.g. still retorting. Even if traditional canning is convenient, and provides a universal and economic method for processing and preservation, there is a need to reduce energy costs, improve nutritional quality and enhance sensory attributes. While new packaging formats have emerged, the latest agitation process, where reciprocating agitation is carried out in horizontally oriented containers, reduces processing times ≈90% and enables energy savings without compromising quality. To accomplish these objectives, multi-phase model simulations will be performed using a finite volume method based on discretization of governing flow equations for each phase in a non-inertial reference frame of moving mesh, where the grid moves with the computational geometry using the CRADLE SC/Tetra CFD program.

### 5.3.2 Aim of the Work Package

Preservation/breakdown mechanisms of PCs in tomato and *Brassica* based products are to be reviewed from literature and experiments of the other WP's. Changes in the quality factors will be modeled based on the time/temperature history during processing. Heat transfer modeling of tomato and *Brassica* products will be carried out to determine temperature distribution of the products during agitated retort processing to optimize the process. The results will be compared with the results of conventional processing techniques, e.g. still retorting.

### 5.3.3 Report on results obtained and changes to the original work plan/WP aims:

**A- results obtained**

For optimal process design of a shaking – reciprocally agitated system, a computational mathematical model was first developed. For this purpose, the studies were carried out in two parts: experiments (where the experimental data was used for model validation purpose) and the numerical modelling studies. After developing and validating the model with the experimental data, it was used to determine the optimum shaking – reciprocal agitation rate. The results of suggested an optimal reciprocal agitation rate for low-viscosity Newtonian liquids at 80 rpm with respect to the average temperature increase and temperature distribution uniformity. The further increase of the agitation rate did not contribute to any increase of the temperature or the uniformity of the temperature distribution inside the cans. In the second stage of the numerical modeling studies, a high viscous – non-Newtonian (2% CMC solution) was used to demonstrate the effect of reciprocal agitation on the high viscous liquids, compared to the previous case of water as a low viscosity Newtonian liquid. For non-Newtonian case, a certain inertial force was determined to impose (over 80 rpm) to start gaining an effect with respect to temperature change.

Evolution of flow field and temperature during agitation involves interactions between agitation (inertial), gravitation and viscous forces. Therefore, a force analysis by introducing Froude (Fr) and Taylor (Ta) numbers was performed to compare the effects of the reciprocal agitation on temperature evolution. The Fr and Ta numbers are defined to be the ratio of reciprocal agitation – inertial force to gravitational and inertial to viscous forces, respectively. Based on this concept, these two modified dimensionless numbers were defined:

$$\text{Fr}=\frac{f_{reciprocal-inertial}}{f_{gbf}}=\frac{\omega^2 R}{g} \qquad (13)$$

$$\text{Ta}=\frac{f_{reciprocal-inertial}}{f_{viscous}}=\frac{\omega^2 R^4}{\nu^2} \qquad (14)$$

where $f_{rbf}$ is the reciprocal buoyancy, $f_{gbf}$ is the gravitational buoyancy, $f_{reciprocal}$ is the reciprocal and $f_{viscous}$ is the viscous forces, $\left(\omega=\frac{2\pi f}{60}\right)$ with $f$ is the reciprocal agitation rate (rpm) and R was the crank radius (0.075 m) of the reciprocal agitation system**,** g is the gravitational acceleration (9.81 m/s²), and $\nu$ is the volume averaged kinematic apparent viscosity of the fluid in the domain (m²/s). The higher agitation rates, based on the changes in Ta number, were even reported to have possible negative effects on the temperature evolution during agitation. Average temperature increase due to the effect of 20 and 80 rpm agitation was very similar due to high viscosity and resulting viscous forces. . A further study to demonstrate the effect of headspace volume to increase the agitation rates for liquid and particulate food products is planned based on the conclusions of the WP3.

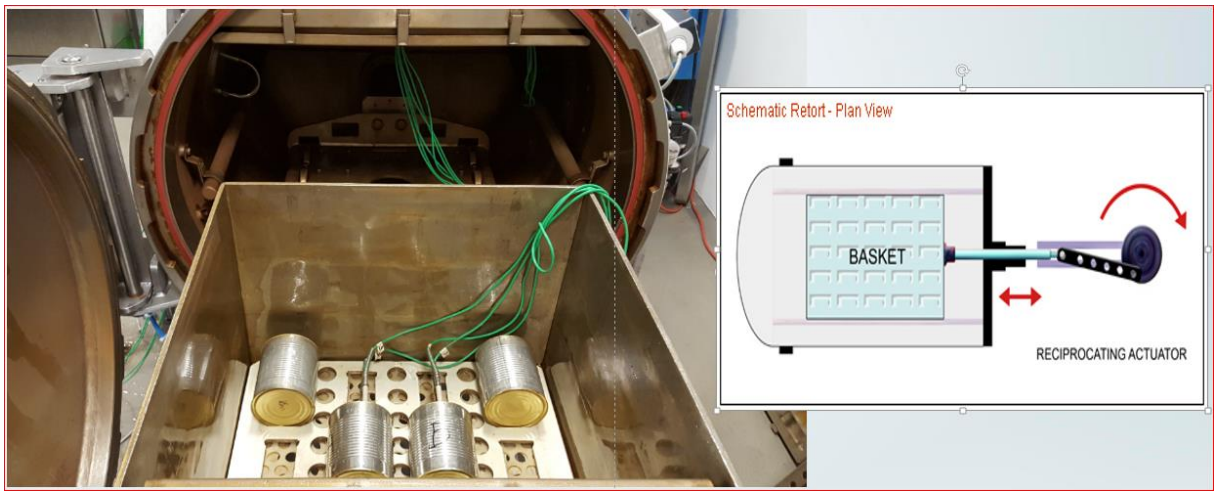


*Figure 6 Shaking autoclove (Shaka) and principle of a shaking retort systems*

**B- comments on deviations from the original plan**

The only minor change in this WP was about the use of the suggested software (SC Tetra Cradle). In the original proposal, it was suggested that the SC Tetra Cradle was going to be used to solve the two – phase problem in the reciprocally agitated cans, but based on the initial 2-dimensional mathematical model studies, Drs. Ferruh Erdogdu and Mustafa Tutar decided on the use of Ansys Fluent (Ansys Inc. Canosburg, PE, USA). Another minor deviation from the original plan was about the optimization of the process. Based on the initial proposal, the preservation/breakdown of PC were to be the objective function while the agitation rates (strokes/min) and process temperature will base for decision and explicit/implicit variables. Regarding the PC breakdown kinetics, the basic kinetic data on PC breakdown showed not to be well described in literature. Therefore, the WP partners decided to use the temperature increase and temperature uniformity as a function of reciprocal agitation rate to determine the optimum process condition. About the kinetic data for modelling PC breakdown, it was planned to carry out this task in a following project as more resources will be needed to do so. However, the present models have paved the way for incorporation of kinetic models and modelling of their retention during processing. A general indication on nutrient retention is color changes and a study of changes in color of broccoli under heat treatment was also published.

## 5.4 WP 4

**Vegetable by-product processing for recycling into the food chain**

Responsible partner: Partner no 5, ILVO, Bart van Droogenbroeck

### 5.4.1 Original description of work

Vegetable biomass is highly perishable because of its high moisture content. Mechanical pressing of the underutilized vegetable biomass results in a 'liquid' and 'solid' fraction. This process is used e.g. to make vegetable and fruit juices and blends thereof. However, the use of many conventional pressing processes results in significant loss of HBPC. For example, losses of 50% - 90% of the phenolic compounds during apple juice production are reported. A novel oxygen-free pressing system was introduced recently, enabling a phase separation of the raw material, dissolved oxygen removal, and filtering in one movement: a **spiral-filter press**. This technology will be used in **WP4**. This equipment is very useful to process high-moisture vegetable and fruit biomass as it allows to produce a natural cloudy but smooth juice (the liquid fraction), which is low in dissolved oxygen and rich in HBPC and dietary fibers and results in a press cake rich in functional PC, with increased potential for valorization. Drying of vegetables and fruits is one of the most efficient ways to preserve foods. Drying reduces the products $a_W$, thus inhibiting microbial growth and decreasing degradation, resulting in enhanced stability. Freeze-dried products are known to have high quality, since the technique preserves bioactive compounds, colour, texture and flavor. However, due to the use of vacuum, sub-zero temperatures, and long drying time, it is one of the most expensive drying technologies. From an economical point of view, it is thus very difficult to use freeze-drying as a stabilization technology in the valorisation of vegetable by-products and waste. However, during the last decade, novel drying technologies were developed such as **Refractance Window drying** (RWD). RWD is a novel thin-film drying method featured by short processing time, low energy cost, and excellent product quality. The slow level of heat transfer in the final stage of the drying helps to prevent quality degradation of the product, resulting in dried products of the same quality as freeze-dried products. At the end of the process, the belt carrying the dried product then moves over a cold water bath before the product is being scraped off the belt. Since the RWD is a relatively new technology, there are only a limited number of publications on the use of RWD as a stabilization technology for vegetable biomass and its effect on the quality characteristics of dried products. RWD is one of the innovative technologies that will be evaluated in **WP4** for the development of a cost-effective stabilization and valorisation route for the unused vegetable waste and by-products, with maximal preservation of the nutritional and functional content.

### 5.4.2 Aim of the Work Package

The aim is to increase overall sustainability of the vegetable production by investigating the potential of underutilized vegetable biomass for recycling into the food chain as technical, nutritional, functional ingredients/additives. The objectives are:

1. Estimate the potential of *Brassica*, tomato and other vegetable biomass for recycling into food chain based on: volumes; availability; important chemical-nutritional-phytochemical parameters

2. Evaluate the potential of innovative stabilization and processing techniques maximally preserving the quality of the raw material
3. Study the potential of most promising (stabilized) vegetable fractions as food ingredient/ additive.

WP2 will evaluate WP4's best fractions as food ingredients/additives. WP1 elicitor and non-destructive measurements and WP3 modelling work is relevant for WP4 process also. Fractions not suitable for the food chain will be delivered to WP5 to evaluate their potential as component in organic fertilizer or soil amendment.

### 5.4.3 Report on results obtained and changes to the original work plan/WP aims

**A- results obtained**

At the start of the project a questionnaire was sent out to the partners and their network collecting data on availability, economic importance, moisture content and nutritional and phytochemical content of vegetable by-products throughout the agrifood chain. From this exercise it became clear that several vegetable biomass fractions truly represent a valuable feedstock for improved valorisation strategies toward food, feed, fertilizer, soil improvement etc. Selected vegetable by-products were characterized for the nutritionally relevant parameters (protein, fat, dietary fibre, minerals, vitamins, pesticides, heavy metals, mycotoxins & microbiology).

In the next step, a biorefinery process scheme was developed centered around the use of the low-oxygen spiral-filter press as fractionation technology. This technology allows to fractionate the wet vegetable by-products into a liquid fraction and a press cake, without the need to add antioxidants, as the vacuum applied in the system reduces the presence of oxygen. The spiral-filter processing was optimized for tomatoes, carrots, peas, beans, red beetroot, celeriac, stalk celery and black salsify. In the next step pasteurization was applied to carrot, red beetroot, celeriac, tomato, celeriac, and black salsify. The impact of the applied processing on the end-products was studied and the shelf-life was studied at 4° & 21°C, up to 6 months. The study on tomato processing was performed in more detailed and resulted in three published papers.

A spiral-filter press pilot line was built up in an industrial context at Greenyard Prepared. Process and product development using this processing line resulted in 4 selected recipes that were also subjected to taste-trials.

In addition, the spiral-filter press technology was combined with the microwave-based pasteurization technology of Enbiojet (tomato, carrot and apple juice). Also a demo for the project partners was organized around this topic. As was done for the other products developed process impact, chemical and microbial safety was checked, together with a shelf-life study of the end-products.

The potential of the RWD drying technology (DOW, Dry-On-Water®) was evaluated to stabilize cauliflower puree, in comparison with freeze drying. From this study it became clear that DOW drying is less energy-consuming than freeze drying. Further research is needed to identify the qualitative differences of both stabilized products obtained (solubility, taste, nutritional value, stability, colour etc.).

From this work it became clear that the technologies used have the potential to turn vegetable by-products into tasteful products, appreciated by consumers, that can be marketed as clean label, natural and healthy products.

Follow-up research will focus on the use of the press cakes in food applications (a.o. in the SUSFOOD2 granted projects InProVe and Improve).

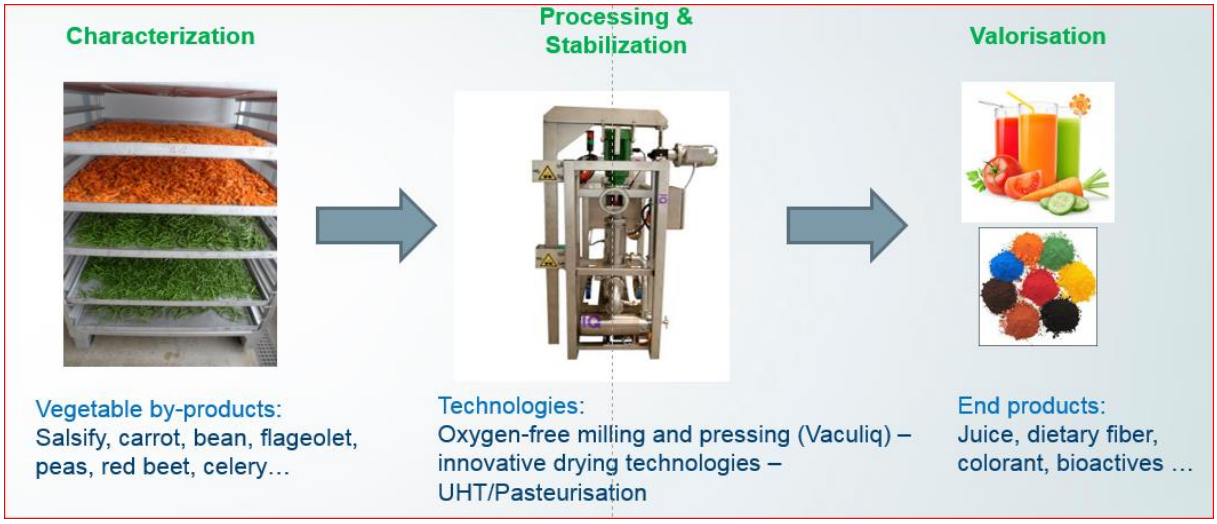


*Figure 7 Simple schematic overview of the steps in vegetable by-product valorisation through recycling back into the food chain*

**B- comments on deviations from the original plan:**

In the evaluation of the conservation technologies, most worked focused on the stabilization of wet products and less on the production of dry products using drying technologies. For the wet products (juices, smoothies, purees) both conventional heat treatments (pasteurization via UHT Pilot installation) and innovative microwave pasteurization was studied. This choice was driven from a sustainability point of view: the production of dry products/ingredients from the vegetable by-products is more energy consuming. In addition there are sufficient market opportunities for the wet products (juices, smoothies, purees).

## 5.5 WP 5

**Side flow valorization of vegetable by-products through incorporation into organic fertilizers and soil amendments**

Responsible partner: Partners no 7, DCM, Inge Hanssen, and 10 KU Leuven, Christine Vos (transferred to Scientia Terrae, DCM in 2016)

### 5.5.1 Original description of work

Side-flows and waste from vegetable processing can also be recycled as raw material for the production of organic fertilizers or soil amendments, the aim of **WP5**. The suitability of such biomass for this production depends on its water content, nutritional value, organic material content and type, and content of putative bio-active components (PC), absence of heavy metals and other chemical and microbial contaminants. The innovative processing techniques applied in WP4 will also be used for this purpose.

Besides the development of a test product (organic fertilizer or soil amendment) based on the vegetable left-over biomass by DCM in WP5, the amendment with beneficial micro-organisms (BM) will also be evaluated to increase the valorisation potential. BM can promote plant growth and disease resistance and increase the HBPC content of plants. In WP5 the effect of the test product on the HBPC content will be evaluated, thus indirectly offering a both health-promoting and sustainable food option to consumers.

### 5.5.2 Aim of the Work Package

1. Study the potential of vegetable waste or side-flows as raw materials for organic fertilizer or soil amendment. Relevant parameters are plant nutritional value, organic material, bio-active components, and substrates for micro-organisms.
2. Processing (drying and stabilizing) such waste/side flows to improve their valorisation potential as raw material for organic fertilizer or soil amendment according to the criteria listed in (1).
3. Study the suitability of the processed raw materials as carriers for beneficial micro-organisms (BM) and study the tomato response (growth and disease resistance) to the processed raw materials and BM, for design of a true test product.
4. Study the plant response to the test product in greenhouse and/or field tests with tomato and *Brassica* to assess biomass production, plant disease resistance as well as plant secondary metabolites and HBPC content in response to the test product.

### 5.5.3 Report on results obtained and changes to the original work plan/WP aims

**A- results obtained**

In the course of the project, 20 different side streams were analysed to evaluate their potential as input source for DCM products. A first set of parameters was related to their potential use in organic fertilisers or soil amendments, including nutrient content, dry matter content, percentage organic material as well as lignin, hemicellulose, cellulose and soluble fraction. The 'phytochemical' content of the streams was determined by INRA Nancy, focusing on secondary metabolites such as flavonoids and

alkaloids. Streams with a high level of such specific metabolites might have a biostimulant effect on plant growth. These analyses resulted in a clear overview of the initial potential of each side flow for DCM.

In addition to the analysis of the above (bio)chemical properties, the effect of the streams on plant growth was determined in a greenhouse bioassay optimized by KUL. The use of several streams resulted in plant growth promotion, with three streams being selected particularly as being promising. Repetition of the bioassays with streams from a different batch confirmed their growth promoting potential. One waste stream was also seen to result in growth suppression. This can be a desirable trait for certain applications and hence was also further investigated. Apart from shoot growth, KUL also examined root growth. A tomato rhizotron set-up was optimized to visualize the root phenotype in a soil substrate. A digital image analysis workflow was developed to allow quantification of the results. Plant disease resistance was studied for some of the materials, but did not give positive results.

Based on the above analyses, the four most promising streams were selected for the production of industrial test batches. A first series of test batches focused on a solid formulation to study their potential as filling material in organic fertilisers. In a tomato growth bioassay, plant levels of chlorophyll, flavonoids and anthocyanins were followed non-destructively, using the Dualex sensor that was developed within the Sunniva consortium. In addition root and shoot weight were measured. Comparison of the results with the profile of a standard DCM filling material confirmed the potential of these waste flows as filling material for organic fertilisers.

Out of these four selected streams, one was particularly interesting as a filling/carrier material. The stream was amended with a beneficial microbial *Trichoderma* isolate and the survival of the micro-organism was monitored. Remarkably, results showed that this material was not suitable as a microbial carrier since the survival of the isolate was negatively affected. Therefore no further tests were performed on this topic.

The effect of organic fertilisers with addition of the selected streams was evaluated on the secondary metabolite level in tomato and parsley, both destructively (HPLC) and non-destructively (sensor). No clear trends could be observed in the results.

A cost-effective industrial drying method is paramount to use the streams in an economically feasible way. The streams should reach a dry matter content of at least 90%. DCM and BND Noliko (Greenyard Prepared) therefore studied the feasibility of different market-available drying possibilities. A batch of 7,6 tonnes of the wet stream was recently dried on industrial scale. Tests with this batch are ongoing to verify its properties and potential.

A second series of test batches was produced by DCM to investigate the potential as biostimulants in a solid formulation. Plant tests in tomato and lettuce gave possibly interesting trends but variation was too high to draw any firm conclusions at this point. Further investigation is needed here.

In addition to the solid biostimulant formulations, watery extracts were prepared for the different streams, and their effect on plant growth was characterized. Bioassays included an Arabidopsis agar test to visualise root phenotype; a mungbean assay to check for root formation and a cress germination assay. Certain extracts demonstrated a strong effect on root phenotype. Those streams were additionally examined in a tomato hydroponics test in a greenhouse. Final tests are still ongoing.

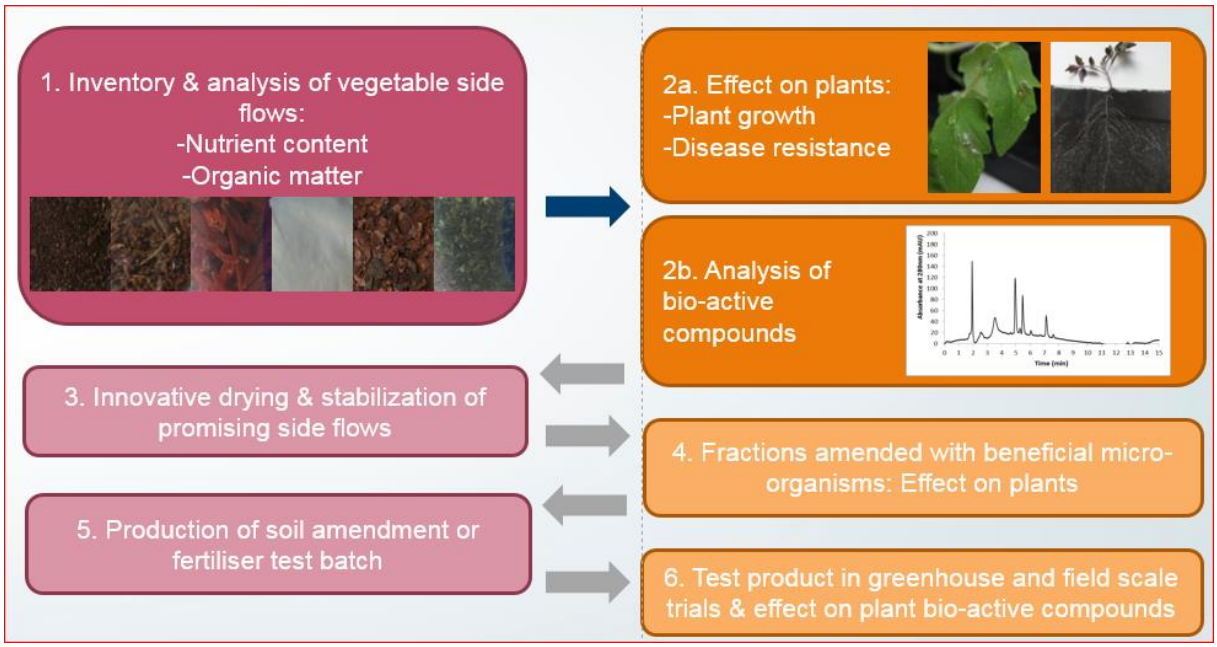


*Figure 8* *Simple schematic overview of the steps in vegetable side-flow valorisation through incorporation into organic fertilizers and soil amendments*

**B- comments on deviations from the original plan**

Large-scale field or greenhouse tests with fertiliser or soil improver test batches could not be performed by the Norwegian and Polish project partners because of the different timelines of the Belgian project partners compared to the other partners. However, two small-scale greenhouse tests were performed by DCM, in collaboration with INRA (exp 1) and with KULeuven (exp 2).

## 5.6 WP 6

**Management**

Responsible partner: Partner no 1, Nofima, Trond Løvdal

### 5.6.1 Original description of work

### 5.6.2 Aim of the Work Package

The main objective of this work package is to coordinate and monitor the project to ensure the proper development of all activities: on time, in budget and with maximum quality:

1. to coordinate and supervise research activities according to the work plan
2. to monitor quality and timing of project results and to resolve conflicts
3. to carry out the overall administrative and financial management of the project
4. to manage the partners relationship in the project and with the authorities
5. to manage the foreground generated by the project
6. to coordinate the project communication

### 5.6.3 Report on results obtained and changes to the original work plan/WP aims:

**A- results obtained**

The CA was signed by all partners by 14th of April 2014, and supplemented by a revised version June 5th 2015. Annual general meetings were conducted according to plan and concluded by a final meeting in April 2017. WP-meetings were held as appropriate and organized by WP-leaders. Other meetings were performed by Skype when necessary. All milestones were achieved and followed by deliverables exceeding the total numbers planned. The interactions between partners and WP's have been excellent. The national funding bodies were reported according to national regulations independently by respective partners. A mid-term report was submitted to the SusFood administration in August 2015, and a joint report in the form of a project factsheet was submitted to the Daniel and Nina Carasso Foundation in May 2017. The progress of the project were reported as oral presentations by the coordinator at SusFood status seminars held in 2014, 2015, and 2017.

**B- comments on deviations from the original plan:**

The Sunniva Project was originally scheduled to end by April 14th, 2017. However, as mentioned in Section 1.2 and Section 2 (Additional comments), some partners were granted extensions for up to January 31st, 2018. This led to few challenges, especially regards the monitoring and coordination of research activities, as already mentioned above.

## 5.7 WP 7

**Dissemination**

Responsible partner: Partner no 1, Nofima, Trond Løvdal

### 5.7.1 Original description of work

### 5.7.2 Aim of the Work Package

The main goal of WP7 is to disseminate the project results to the food processing industry as well as a broader audience through multiple dissemination platforms such that they can effectively access and apply outputs from the project; and to ensure the exploitation of the foreground generated in SUNNIVA in the food industrial sector, and mainly in the Vegetable Supply Chain.

### 5.7.3 Report on results obtained and changes to the original work plan/WP aims:

**A- results obtained**

The goal of publishing 8 papers in international peer-review journals was achieved with two more than targeted (Section 4.1), and there are at least three papers *in prep.* that are likely to be submitted for publication within 2018. The project resulted in several oral and poster presentations at international conferences and seminars targeting a broad audience (Section 4.2). A project web site (www.sunnivaproject.eu) was launched soon after project start. Sunniva has contributed significantly to training and education of students and young scientists by co-funding two PhD's, five MSc,'s and five Engineering Diplomas. During the last stage of the project, several articles in trade magazines were published (Section 4.2).

# 6 Publications and dissemination activities

## 6.1 List publications in peer reviewed journals


Agati, G., Tuccio, L., Kusznierewicz, B., Chmiel, T., Bartoszek, A., Kowalski, A., Grzegorzewska, M., Kosson, R., Kaniszewski, S. (2016). Non-destructive optical sensing of flavonols and chlorophyll in white cabbage (*Brassica oleracea* L. var *capitata*) grown under different nitrogen regimes. Journal of Agricultural and Food Chemistry, 64: 85-94, DOI: 10.1021/acs.jafc.5b04962. https://pubs.acs.org/doi/abs/10.1021/acs.jafc.5b04962

Erdogdu, F., M. Tutar, Øines, S., Barreno, I., Skipnes, D. (2016) Determining the Optimal Shaking Rate of a Reciprocal Agitation Sterilization System for Liquid Foods: A Computational Approach with Experimental Validation. Food and Bioproducts Processing. doi:10.1016/j.fbp.2016.07.012. https://www.sciencedirect.com/science/article/pii/S0960308516300840

Parchem, K., Bartoszek, A. (2016). Phospholipids and products of their hydrolysis as dietary preventive factors for civilization diseases. (in polish). Postepy Hig Med Dosw (online), 2016; 70. http://www.phmd.pl/fulltxt.php?ICID=1227640

Pilipczuk, T., Kusznierewicz, B., Chmiel, T., Przychodzén, W., Bartoszek, A. (2017). Simultaneous determination of individual isothiocyanates in plant samples by HPLC-DAD-MS following SPE and derivatization with N-acetyl-L-cysteine. Food Chemistry, 214: 587-596. https://www.sciencedirect.com/science/article/pii/S030881461631158X?via%3Dihub

Kosson, R., Felczynski, K., Szwedja-Grzybowska, J., Grzegorzewska, M., Tuccio, L., Agati, G., Kaniszewski, S. (2017). Nutritive value of marketable heads and outer leaves of white head cabbage cultivated at different nitrogen rates. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science. http://dx.doi.org/10.1080/09064710.2017.1308006

Erdogdu, F., Tutar, M., Sarghini, F., Skipnes, D. (2017). Effects of viscosity and agitation rate on temperature and flow field in cans during reciprocal agitation. Journal of Food Engineering, 213: 76-88. https://doi.org/10.1016/j.jfoodeng.2017.05.030

Kips, L., De Paepe, D., Van Meulebroek, Van Poucke, C., Larbat, R., Bernaert, N., Van Pamel, E., De Loose, M., Raes, K., Van Droogenbroeck, B. (2017). A novel spiral-filter press for tomato processing: process impact on phenolic compounds, carotenoids and ascorbic acid content. Journal of Food Engineering, 213: 27-37. https://doi.org/10.1016/j.jfoodeng.2017.06.010

Ciaccheri, L., Tuccio, L., Mencaglia, A. A., Mignani, A. G., Hallmann, E., Sikorska-Zimny, K., Kaniszewski, S., Verheul, M. J., Agati, G. (2018). Directional *versus* total reflectance spectroscopy for the *in situ* determination of lycopene in tomato fruits. Journal of Food Composition and Analysis. https://doi.org/10.1016/j.jfca.2018.01.023.

Pero, M., Askari, G., Skåra, T., Skipnes, D., Kiani, H. (2018). The change in the color of heat treated vacuum packed broccoli stem and floret during storage: effects of process conditions and modeling by ANN. Journal of the Science of Food and Agriculture. In press doi: 10.1002/jsfa.8936 http://onlinelibrary.wiley.com/doi/10.1002/jsfa.8936/epdf

Ciaccheri, L., Tuccio, L., Mencaglia, A. A., Sikorska-Zimny, K. M., Hallmann, E., Kowalski, A., Mignani, A. G., Kaniszewski, S., Agati, G. (2018). Predicition models for assessing lycopene in open-field cultivated tomatoes by means of a portable reflectance sensor: cultivar and growing season effects. Journal of Agricultural and Food Chemistry. In press https://pubs.acs.org/doi/10.1021/acs.jafc.8b01570

Kaniszewski, S., Kosson,R., Grzegorzewska, M., Kowalski, A., Bagełek, E., Szwejda – Grzybowska, J., Tuccio, L., Agati, G. (2019) Yield and Quality Traits of Field Grown Tomato as Affected by

Cultivar and Nitrogen Application Rate. Journal of Agricultural Science and Technology. Vol. 21, Issue 4. In press

## 6.2 List additional dissemination activities that are not listed above

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Kick-off meeting, Leuven, Belgium | Meeting | Consortium | Hosted by KU Leuven, 18.-19. February, 2014 |
| Kołodziejski, D., Cyprys, J., Groszewska, M., Piekarska, A., Pilipczuk, T., Bartoszek, A. (2014). The influence of pre- and postharvest treatments on selected biological and epigenetic activities of brassica species. | Poster | Scientific community. | 23rd Biennial Congress of the European Association for Cancer Research, Munich, Germany, July 5-8, 2014 |
| Annual meeting, Gdansk, Poland, | Meeting | Consortium | Hosted by GUT, 22.-23. September, 2014 |
| Stankevic, M., Chmiel, T., Klimaszewska, K., Kusznierewicz, B., Lewandowska, A., Tynek, M., Bartoszek, A. (2014). Rational design of tomato and/or brassica vegetables containing foods according to food synergy concept; presentation of SUNNIVA project. | Poster | Scientific community, Trade and Industry. | NutriOx 2014 Nutrition and Ageing, Metz Technopôle, France, October 1-3, 2014 |
| Løvdal, T. (2014). Progress Report | Electronic Report | Funding body | Submitted to RCN, October 2nd, 2014 |
| Bartoszek, A., Kusznierewicz, B., Piekarska, A., Szczygłowska, M., Łuczak, J., Bączek-Kwintra, R., Antonkiewicz, J., Poleska-Muchiado, Z., Pilipczuk, T., Malinowska-Pańczyk, E., Grzywa-Niksińska, I., Namiesnik, J., Klimaszewska, K., Konieczka, P. (2014). The exploitation of white cabbage for the soil phytoremediation and biofumigation – overwiev of the results of the project AGROBIOKAP | Proceedings paper | Scientific community. | 3rd International Glucosinolate Conference, Wageningen, October 12-15, 2014 |
| Løvdal, T. (2014). The SUNNIVA project. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | SUSFOOD Conference, Paris, France, October 21, 2014 |
| Kusznierewicz, B., Piekarska, A., Kołodziejski, D., Pilipczuk, T., Koss-Mikołajczyk, I., Namieśnik, J., Bartoszek, A., (2015). Determination of individual isothiocyanates/indoles occurring as a result of glucosinolate degradation and their relation to biological potential of different Brassica plants. | Poster | Scientific community, Trade and Industry. | Annual meeting AACR, 18-22 April, 2015, Philadelphia, USA. |
| Mignani, A. G., Ciaccheri, L., Mencaglia, A. A., Tuccio, L., Agati, G. (2015). Application of a LED-based reflectance sensor for assessing in situ the lycopene content of tomatoes (Lycopersicon esculentum Mill.). | Proceedings paper | Scientific community | The SPIE DSS - Defence, Security, Sensing Technologies and Appliactions, Baltimore MD, USA, 20-24 April 2015. |
| Annual meeting, Merelbeke, Belgium, | Meeting | Consortium | Hosted by ILVO, 27.-28. April, 2015 |

[5] Please indicate the nature of the deliverable. For example Report, Paper, Book, Protocol, Prototype, Website, Database, Demonstrator, Meeting, Workshop

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Ludynia, M. (2015). The comparison of antioxidant activity of solvent extracts from different morphological parts of three cultivars of tomato. | Engineer Diploma | Scientific community | GUT |
| Romanowska, P. (2015). The influence of processing on the content of selected bioactive substances in brassica vegetables; The comparison of antioxidant activity of different morphological parts of cabbage. | Engineer Diploma | Scientific community | GUT |
| Stankiewicz, U. (2015). The possibility of using waste products of cauliflower. The comparison of the antioxidant activity of the different morphological parts of two varieties of cauliflower. | Engineer Diploma | Scientific community | GUT |
| Tuccio, L., Agati, G. (2015). Sunniva project 1st year (April 2014 - April 2015) report – CNR-IFAC. | Report | Funding body | Submitted to DNCF and MIPAAF |
| Van Droogenbroeck, B. (2015). Innovation in process- and product development to valorize plant-derived by-products. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | Hightech Meets Agro Event, Venlo, The Netherlands, June 11th, 2015 |
| Løvdal, T., Vågen, I., Agati, G., Tuccio, L., Kaniewski, S., Gregorowska, M., Kosson, R., Verheul, M., Bartoszek, A., Erdogdu, F., Tutar, M., van Droogenbroeck, B., Vos, C., Hanssen, I., Larbat, R., Robin, C., Skipnes, D. (2015). 1st year report; the Sunniva project. | Report | Coordinators, Funding bodies | Submitted to SusFood coordinators and RCN |
| Hansen, I. (2015). Voortgangsverslag project SUNNIVA. | Report | Funding body | Submitted to IWT |
| Parchem, K., Rekawiecka, A., Pilipczuk, T., Kusznierewicz, B., Ahuja, I., Bones, A. M., Bartoszek, A. (2015). The composition of glucosinolates, their degradation products and the oil content in the myrosinase-deificient MINELESS rape seeds. | Poster | Scientific community, Trade and Industry. | Scientific congress of Polish Chemical Society. 21-25 September, 2015. |
| Van Droogenbroeck, B. (2015). Sunniva overview. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | EU-Noshan, EU-Tradeit, EU-Fusions, EU-Refresh, EU-Healthy Minor Cereals, and EU-Sunniva joint seminar in the frame of EuroFoodChem, Madrid, Spain, October 13th, 2015 |
| Løvdal, T. (2015). Report from SusFood Research Project SUNNIVA. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | SusFood Status Seminar, Brussels, Belgium, October 13th, 2015 |
| Koss-Mikolajczyk, I., Pilipczuk, T., Kusznierewicz, B., Hanschen, F., Dawidowska, N., Osowicka, M., Zielinski, D., Bartoszek, A. (2015). Correlation of the phytome composition of three cauliflower varieties with their biological activity. | Poster | Scientific community, Trade and Industry. | XVIII EuroFoodChem, Madrid, Spain, 13 – 16 October 2015. |

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Parchem, K., Rembacz, P., Tynek, M., Karlovic, G., Bartoszek, A. (2015). Enzymatic interesterification of palm oil in a laboratory-scale kit using continuous method compared to the chemical interesterification. | Poster | Scientific community, Trade and Industry. | XVIII EuroFoodChem, Madrid, Spain, 13 – 16 October 2015. |
| Niklas, A. (2015). The comparison of antioxidant activity of aqueous extracts from different morphological parts of three cultivars of tomato. | Engineer Diploma | Scientific community, Trade and Industry. | GUT |
| Løvdal, T. (2015). Progress Report | Electronic Report | Funding body | Submitted to RCN, November 5th, 2015 |
| Erdogdu, F., Tutar, M., Skipnes, D., Øines, S., Løvdal, T. (2015). Computational modelling of reciprocal-agitation retort process for canned liquid foods. | Oral presentation | Scientific community, Trade and Industry. | 29th EFFoST International Conference – Food Science Research and Innovation, Athens, Greece, 10-12 November 2015. |
| Tutar, M. (2015). Proyecto SUNNIVA. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | Horizon 2020 Infoday, Vitoria-Gasteiz, Spain, 9 December 2015. |
| Hansen, I. (2016a). Voortgangsverslag project SUNNIVA. | Report | Funding body | Submitted to IWT |
| Hansen, I. (2016b). Voortgangsverslag project SUNNIVA. | Report | Funding body | Submitted to IWT |
| Skipnes, D., Erdogdu, F., Tutar, M., Øines, S., Barreno, I., Løvdal, T. (2016) Optimization of a thermal process with reciprocal agitation by computational modelling. | Oral presentation | Scientific community, Trade and Industry. | FOODSIM'2016, April 3-7, 2016, Katholieke Universiteit Leuven, Ghent, Belgium. Presented by T. Skåra, Nofima. |
| Løvdal, T. (2016). SUNNIVA; a Bioeconomic Era-net project. | Oral presentation | Trade and Industry, Scientific community, Policy makers | Seminar and workshop on the possibilities in Bioeconomics. Næringsforeningen, Stavanger, April 25., 2016. |
| Annual meeting, Sesto Fiorentino (Firenze), Italy | Meeting | Consortium | Hosted by CNR-IFAC, 28.-29. April, 2016 |
| Post, L. (2016). The influence of cultivar conditions on antioxidant activity of white cabbage (Brassica oleracea var. capitate f. alba). | Engineer Diploma | Scientific community | GUT |
| Romanowska, P. (2016). The influence of microwaves on activity of myrosinase and degradation of glucosinolates in white cabbage and comparison of health benefits of meat products of functional food character. | MSc thesis | Scientific community | GUT |
| Głazowska, J., Stankiewicz, U., Bartoszek, A. (2016). The application of capillary electrophoresis for profiling DNA degradation in meat submitted to thermal processing. | Poster | Scientific community | Proceedings of the 10th International Symposium on Chromathography of Natural Products. Lublin, Poland, 2016 |
| Parchem, K., Poleska-Muchlado, Z., Kusznierewicz, B., Chmiel, T., Stankewic, M., Kaniszewski, S., Kosson, R., Bartoszek, A. (2016). HPLC analysis of bioactive compounds in white cabbage cultivated under different conditions. | Poster | Scientific community | Proceedings of the 10th International Symposium on Chromathography of Natural Products. Lublin, Poland, 2016 |

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Parchem K., Romanowska P., Bartoszek A. (2016). Influence of cabbage phytochemicals on the formation of oxidized phospholipids in meat products | Poster | Scientific Community | 2nd European Summer School on Nutrigenomics, Camerino, Italy, J. Nutrigenet. Nutrigenomics, 9: 136, 2016 |
| Parchem K., Bartoszek A. (2016). The development of a convenient toolbox to characterize bioactive phospholipids present in foodstuffs. | Poster | Scientific Community | Programme and Abstracts of 1st International Conference on Food Bioactives and Health, Norwich, UK, 2016 |
| Głazowska J., Stankiewicz U., Bartoszek A. (2016). Qualitative and quantitative analysis of nucleic acids in processed pork meat: content, degradation and fragmentation profile. | Poster | Scientific Community | Programme and Abstracts of 1st International Conference on Food Bioactives and Health, Norwich, UK, 2016 |
| Głazowska J., Bartoszek A. (2016). Nucleic acids. A neglected nutrient? | Poster | Scientific Community | Programme and Abstracts of 1st International Conference on Food Bioactives and Health, Norwich, UK, 2016 |
| Koss-Mikołajczyk I., Kusznierewicz B., Bartoszek A (2016). Composition of phenolic compounds and antioxidant activity of different varieties of mirabelle plum (P. domestica L. ssc Syrica var cerea). | Poster | Scientific Community | 10th World Congress on Polyphenols Applications, Porto Portugal, 2016, J. ISANH, 3: 111, 2016 |
| Bartoszek A. (2016). A healthy diet; preventing lifestyle diseases | Invited lecture | Members of Parliaments of Southern Baltic states | 14th Southern Baltic Sea Parliamentary Forum, Kiel, Germany, 2016 |
| Mencaglia, A. A., Ciaccheri, L., Mignani, A. G., Tuccio, L., Hallmann, L., Kaniszewski, S., Løvdal, T., Agati, G. (2016). In field non-destructive monitoring of lycopene content in tomatoes. | Poster | Scientific community | COST FA1106 QualityFruit Conference. University of Porto, Portugal, 6th-8th of October, 2016. |
| Agati, G. (2016). Sunniva project 2nd year (April 2015 - April 2016) report – CNR-IFAC. | Report | Funding body | Submitted to DNCF and MIPAAF |
| Bernaert, N., Coudijzer, K., Van Droogenbroeck, B., Verstraete, K. (2016) Onderzoek naar optimale verwerking van groenten en hun reststromen | Article | Trade and Industry, Scientific community | Proeftuinnieuws,13 May 2016. |
| Erdogdu, F.,Tutar, M., Øines, S., Barreno, I., Skipnes, D. and Løvdal, T. (2016). Computational determination of viscosity and agitation rate effects during reciprocal-agitated retort processing. | Oral presentation. | Scientific community, Trade and Industry, Funding bodies | 4th International ISEKI_Food Conference, Vienna, Austria, 6th – 8th of July, 2016. |
| Løvdal, T. (2016). Progress Report | Electronic Report | Funding body | Submitted to RCN, September 12th, 2016 |
| Hansen, I. (2017a). Voortgangsverslag project SUNNIVA. | Report | Funding body | Submitted to IWT |
| Hansen, I. (2017b). Voortgangsverslag project SUNNIVA. | Report | Funding body | Submitted to IWT |
| Van Droogenbroeck B. (2017). Upcycling of underutilized biomass fractions from the agri-food chain | Oral Presentation | Scientific community | 11th International Conference on Agrophysics Soil, Plant & Climate, Lublin, Poland, 26th – 28th of September, 2016 |
| Kaniszewski, S., Kosson, R., Kowalski, A., Grzegorzewska, M., Szwedja-Grzybowska, J. (2016). Effect of nitrogen fertilization on lycopene content and quality traits of tomato (Lycopersicon esculentum L.) fruits for fresh market and processing. | Poster | Scientific community | 3rd International Symposium on Horticulture in Europe SHE2016, Chania, Crete, Greece, 17th – 21th of October, 2016. |

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Grzegorzewska, M., Kaniszewski, S., Kosson, R., Badelek, E., Sikorska-Zimny, K. (2016). The effect of nitrogen fertilization and postharvest treatment with 1-MCP and ethylene on durability of tomato fruits. | Poster | Scientific community | 3rd International Symposium on Horticulture in Europe SHE2016, Chania, Crete, Greece, 17th – 21th of October, 2016. |
| Kosson, R., Kaniszewski, S., Grzegorzewska, M., Kowalski, A., Tuszynska, M. (2016). Nutritive value of marketable head cabbage and waste outer leaves of Brassica oleracea L. var. capitata subvar. alba as affected by nitrogen fertilization. | Poster | Scientific community | 3rd International Symposium on Horticulture in Europe SHE2016, Chania, Crete, Greece, 17th – 21th of October, 2016. |
| Bernaert, N., Van Droogenbroeck, B., Verstraete, K. (2016) Valorisatie van reststromen | Article | Trade and Industry, Scientific community | VMT FOOD, 7 dec 2016. |
| Van Droogenbroeck B. (2016) In elke reststroom zit nog wat bruikbaars. | Article | Trade and Industry, Scientific community | Management & Techniek, 10 dec 2016. |
| Van Mierlo K. (2016) Exploring the potential of Dry-On-Water technology to stabilize agrifood by-products and analyzing its environmental impact. | MSc Thesis – Report | Trade and Industry, Scientific community | Internship WUR student at ILVO |
| Van Droogenbroeck, B. & Hansen, I. (2017) - The Sunniva Project | Oral Presentation | Trade and Industry, Scientific community | VLAIO INFOSESSIE EU-COFUNDS: FACCE Surplus & SUSFOOD2 |
| Innovative processing of vegetables & fruits | Workshop | Trade and Industry, Scientific community | ILVO – Food Pilot, 21th – 22nd of February, 2017 |
| UHT vs MW processing of tomatoes | Demonstrator Film | Trade and Industry, Scientific community | http://sunnivaproject.eu/uht-vs-mw-processing-of-tomatoes/ |
| In-field Analysis of Cabbage | Demonstrator Film | Trade and Industry, Scientific community, Farmers | http://sunnivaproject.eu/in-field-analyzis-of-cabbage/ |
| Final meeting, Stavanger, Norway | Meeting | Consortium | Hosted by Nofima, 6.-7. April, 2017 |
| Løvdal T., Robin, C., Larbat, R., Agati, G., Tutar, M. (2017). Report to Daniel and Nina Carasso Foundation. International Research Program – Project Factsheet. | Report | Funding body | Submitted to DNCF, June 2nd, 2017 |
| Løvdal, T. (2017). Final Report | Electronic Report | Funding body | Submitted to RCN, June 2nd, 2017 |
| Parchem K., Maciołek P., Bartoszek A. (2017). Impact of dietary oxidized phospholipids on human health and methods of their qualitative assessment in foods. | Oral presentation | Scientific community | IUBMB Advanced School on "A molecular view of the food-health relationship", Spetses, Greece, 2017 |
| Kusznierewicz B., Chmiel T., Parchem K., De Paepe D., Van Droogenbroeck B., Krajczyński M., Bartoszek A. (2017). Porównanie wpływu dwóch technologii pasteryzacji w przepływie (UHT, mikrofalowej) na zawartość przeciwutleniających fitozwiązków w sokach jabłkowych i pomidorowych. | Oral presentation | Scientific community | X Ogólnopolskiej Konferencji Naukowej Technologów Przetwórstwa Owoców i Warzyw, Nieborów, Poland, 2017 |
| Głazowska J., Bartoszek A. (2017). Kwasy nukleinowe - nieznany składnik żywności. | Oral presentation | Scientific community | XLIII Sesja Naukowa Komitetu Nauk o Żywności i Żywieniu PAN nt. Żywność dla Przyszłości, Wrocław, Poland, 2017 |

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Kusznierewicz B., Chmiel T., Parchem K., De Paepe D., Van Droogenbroeck B., Bartoszek A. (2017). Wpływ pasteryzacji oraz przechowywania na jakość prozdrowotną jabłek i pomodorów. | Oral presentation | Scientific community | XLIII Sesja Naukowa Komitetu Nauk o Żywności i Żywieniu PAN nt. Żywność dla Przyszłości, Wrocław, Poland, 2017 |
| Parchem K., Maciołek P., Bartoszek A. (2017). Charakterystyka produktów termicznego i enzymatycznego utlenienia fosfolipidów żółtka jaja kurzego.. | Oral presentation | Scientific community | XLIII Sesja Naukowa Komitetu Nauk o Żywności i Żywieniu PAN nt. Żywność dla Przyszłości, Wrocław, Poland, 2017 |
| Kusznierewicz B., Koss-Mikołajczyk I., Głazowska J., Parchem K., Kowalski A., Grzegorzewska M., Kosson R., Bartoszek A. (2017). The influence of post-harvest irradiation on glucosinolates-myrosinase system in external leaves of white cabbage | Poster | Scientific community | 4th International Glucosinolate Conference, Berlin, Germany, 2017 |
| Kusznierewicz B., Piekarska A., Pilipczuk T., Chmiel T., Iori R., Bartoszek A. (2017). The updated toolbox of analytical methods for characterization of Brassica plants and foods based on them. | Poster | Scientific community | 4th International Glucosinolate Conference, Berlin, Germany, 2017 |
| Niklas A., Cieślak W. (2017). Development of functional food products based on cabbage and tomato. | MSc thesis | Scientific community | GUT |
| Agati, G. (2017). Sunniva project 3rd year (April 2016 – April 2017) report – CNR/IFAC. | Report | Funding body | Submitted to DNCF and MIPAAF |
| Van Droogenbroeck, B. & Bernaert N. (2017) Groenteafval verdient beter dan valorisatie als voeder | Article in e-newsletter | Scientific community, Trade and Industry, Policy makers, Funding bodies | http://www.vilt.be/groenteafval-verdient-beter-dan-valorisatie-als-voeder |
| M. Grzegorzewska, E. Badełek, K. Sikorska-Zimny, S. Kaniszewski, R. Kosson<br>The effect of 1-MCP treatment on storage ability of tomato fruits | Poster | Scientific community | XII International Controlled & Modified Atmosphere Research Conference, Warsaw, Poland, 18th – 20th of June, 2017 |
| M. Grzegorzewska, E. Badełek, K. Sikorska-Zimny, S. Kaniszewski, R. Kosson<br>Determination of the effect of ethylene treatment on storage ability of tomatoes | Poster | Scientific community | XII International Controlled & Modified Atmosphere Research Conference, Warsaw, Poland, 18th – 20th of June, 2017 |
| Agati, G., Kusznierewicz, B., Bartoszek, A., Grzegorzewska, M., Kosson, R., Kowalski, A., Seljåsen, R., Tuccio, L., Vågen, I. M., Kaniszewski, S. (2017). Valorization of waste cabbage leaves by UV postharvest treatments. | Oral presentation | Scientific community | The 17th Congress of the European Society for Photobiology, Pisa, Italy, 4th – 8th of September 2017. |
| Løvdal, T., Erdogdu, F., Van Droogenbroeck, B., Vågen, I., Bartoszek, A., Vos, C., Hanssen, I., Agati, G., Kaniszewski, S., Skipnes, D., Tutar, M., Larbat, R., Robin, C. (2017). Sustainability in the vegetable food supply chain - overview of the results of the project SUNNIVA. | Oral presentation | Scientific community, Trade and Industry, Policy makers, Funding bodies | 31st EFFoST International Conference 2017 and joint SusFood seminar, Melia Sitges, Sitges, Spain, 13th-16th of November 2017. |
| Den sunne “søpla” | Website popular article | Consumers, Scientific community, Trade and Industry, Policy makers, Funding bodies | https://nofima.no/nyhet/2017/12/den-sunne-sopla/ |

| Dissemination activity | Nature[5] | Target group/ stakeholders reached | Comment |
|---|---|---|---|
| Healthy Waste, Creating Value 2017, p 24 | Magazine article | Consumers, Scientific community, Trade and Industry, Policy makers, Funding bodies | https://nofima-326d.kxcdn.com/wp-content/uploads/2018/02/Creating_value_2017.pdf |
| Van Droogenbroeck B., (2017) Valorisatie van witloofwortelen en andere plantaardige reststromen. | Oral presentation | Consumers, Scientific community, Trade and Industry, Policy makers, Funding bodies | Presentation given during the Potato, Vegetable and Fruit contact day at ILVO |
| "Søppel" gir nye matprodukter | Magazine article | Trade and Industry, Consumers, | https://smakmagasinet.no/artikler/2018/03/kalprodukter/ |
| Innovasjon gir bedre mat og reduserer matsvinn | Magazine article | Trade and Industry, Consumers, | https://smakmagasinet.no/artikler/2018/02/nofima-innovasjon/ |
| Sikorska, J. & Kwaterska, K. (2018). The influence of chosen elicitors on the content of bioactive compounds in waste cabbage leaves | MSc thesis | Scientific community | GUT |

## 6.3 Further possible actions for dissemination

- InProVe – application submitted for the SusFood2 co-founded call, Topic 1, March 13, 2017; recommended for funding
- SuperVeg - application submitted for the SusFood2 co-founded call, Topic 2, March 13, 2017; not recommended for funding
- Improve - application submitted for the SusFood2 co-founded call, Topic 2, March 13, 2017 - recommended for funding
- Paper in revision; Pero, M., Kiani, H., Skåra, T., Skipnes, D., Askari, G. Optimizing thermal processing of broccoli: model development, numerical simulation, experimental validation
- Paper under preparation about modification of bioactive compounds profile of cabbage waste from food processing industry by means of postharvest UV radiation and ultrasound treatments. Seljåsen, R., Bartoszek, A., Vågen, I.M.
- Paper *in prep*.: Review on Lycopene content in tomato and tomato processing / preservation of bioavailable lycopene
- Paper for Innovative Food Processing on the technological trial of production of cabbage/meat products and their assessment *in prep.*
- COST action proposal was submitted April 27th, 2018

## 6.4 List possibly generated IPR/patents

DCM is still evaluating whether IP protection on certain results of the project is relevant.

# *7* Impact and added value of the project

## 7.1 What is the added value of the transnational cooperation compared to a national research approach in regard to the subject of the project

The Research institutions involved in SUNNIVA has benefitted from the knowledge transferred between leading food technology institutes, and European food industry. SUNNIVA has contributed to the training of researchers on cutting-edge methodology, and mobility of students through internships between partners. The access to facilities for processing and field trials, and new methods has facilitated research of a high standard throughout Europe. The project has contributed to reinforced cooperation in research, development and innovation between European countries in order to maximize the contribution of research to the development of more sustainable food systems from production to consumption, and the creation of a European network on sustainability in the vegetable food supply chain.

- Norwegian (Fjordland, Fjordkjøkken), Polish (Meat Company Nowak), and Belgian (Greenyard Prepared) food companies were involved in the project. They have all been involved and benefitted from the project through research on the innovative technologies and product development. To some extent, novel technology were implemented, at least on a pilot scale.
- A Polish equipment supplier (EnBio Technology) was involved in the project. They were given the opportunity to display their innovative microwave technology to a broad audience of European Industry and Research institutions. The technology was used for production of new cabbage/meat food products, and combined with oxygen-free juice pressing for the production of tomato and apple juice. The Enbio Technology was demonstrated on a workshop at ILVO's Food Pilot Plant initiated through the SUNNIVA project.
- The Belgian company De Ceuster Meststoffen was involved in the project. They are one of Europes largest producer of organic fertilizers and biocontrol companies. They have been, in close collaboration with INRA and KU Leuven, performing research on the use of novel raw material based on side-streams in their production.

## 7.2 How would you judge the impact of your project with regard to the main challenges addressed and the SUSFOOD objectives?

Together, the optimization of vegetable harvesting time and pre-processing storage conditions, sustainable food processing and valorisation of by-products and side-streams significantly contributes to valorisation of side streams and waste reduction and less input of water and energy in vegetable food processing.

SUNNIVA has contributed to:

- Added knowledge on Processing design for reduced energy use (i.e. microwave technology, agitated retorting, oxygen free juice pressing).
- Inventory/characterization of alternative vegetable processing side streams.
  - For use in the food chain
  - For use as organic fertilizer and soil amendments
- Non-destructive optical sensors that can be used:

- By farmers for determining the optimal harvesting time with regards the phytochemical status of crops, and to monitor the phytochemical status during post-harvest ripening and storage.
- As a tool to optimize N-fertilization. It is an environmental problem that too much N-fertilization is used in intensive modern agriculture. The sensor thus offers a double benefit: Representing an economic advantage for the producers and reducing environmental contamination by nitrate leaching.
- For research purposes, and the technology can be transferred to other fields (calibrated for use on other plants/crops).

- Recommendations for use of by-products from vegetables as biofertilizers and/or biostimulants and assessment of their effects on plant composition and growth.
- A computational model for reciprocal agitation retort processes were optimum reciprocal agitation rate was reported for low viscosity Newtonian liquid. This supports the reduction of processing time by up to 90% when using agitated retorting as compared to traditional static thermal treatment. This will significantly reduce the input of energy in food processing.

## 7.3 Did you achieve capacity building and to which extent (training activities, workshops, PhD students etc.)

An internal workshop with attendance from Belgian, Polish and Norwegian partners was held on ILVO Food Pilot 21st – 22nd of February 2017. This workshop included demonstration of the Oxygen-free spiral filter pressing technology and comparison of MW and UHT pasteurization of apple and tomato juice. Two PhD students were *in part* funded and supported by Sunniva. Lies Kips, affiliated at ILVO and supervised by Dr. Bart van Droogenbroeck, credited one paper included in her PhD-thesis to the project. Lies Kips worked mainly on optimization and application of the Oxygen-free spiral filter press technology. Milad Pero (University of Teheran), co-supervised by Dr. Dagbjørn Skipnes, enjoyed an internship at Nofima and credited an accepted paper to Sunniva, and have a second Sunniva-paper in revision. Milad Pero's work concentrated on quality aspects of vegetables as an effect of MW-processing. Ozan Althin (University of Ankara) was supervised by Prof. Ferruh Erdogdu and Dr. Dagbjørn Skipnes. He performed most of his MSc work while on an internship in Nofima in the frame of Sunniva. His work was on modelling heath distribution and transfer in the pilot-scale batch MW oven installed at Nofima. Five students at GUT supervised by Prof. Agnieszka Bartoszek achieved their Engineer diplomas (1st stage of studies) in frame of the Sunniva project. These were: Urszula Stankiewicz, Lena Post, Paulina Romanowska, Agnieszka Niklas, Madalena Ludynia. Their work was dedicated to the review of bioactive phytochemicals in tomato and brassica vegetables and the determination of antioxidant activity of representative vegetables. Five students at GUT realized their MSc projects in the framework on Sunniva project under Prof. Agnieszka Bartoszek's supervision and received their MSc degree. These were: Paulina Romanowska, Wiktoria Cieślak, Agnieszka Niklas, Joanna Sikorska and Klaudia Kwaterska. The diploma projects were strictly related to the WP2-related research on cabbage-meat products (P. Romanowska), tomato based food products (W. Cieślak & A. Niklas) and cabbage based food products (J. Sikorska & K. Kwaterska).





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