Project Report

Development of smart, low energy input heat pump drying for increased sustainability in organic food chains

Results report

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SUMMARY

Results report SusOrgPlus

The quality of a product and sustainability of production depend on the cumulative impacts of each processing step in the food chain and their interplay. The future generation of organic food products will depend on both. The Norwegian part of the Era-Net Cofounded project SusOrgPlus has focused on the design, construction and testing of a heat pump dryer running on natural refrigerants and the development of smart drying concept for high quality organic products. This report is summing up the main results from this project.

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APPENDICES

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1 Background and Objectives

The primary objective of the Norwegian part of the SusOrgPlus project has been the development of a demonstration unit on CO_2 neutral drying system, utilising waste heat recovery and a HP application which are economically viable, even on a low scale, thus phasing out fossil fuels, enabling efficient production and implementation of smart processing systems.

The secondary objectives are:

- Implementation of a low cost, smart processing system on a high technological readiness level
- Development, testing and evaluation for sustainable organic food preservation in cooperation with SusOrgPlus partners
- Stakeholder engagement, student involvement and dissemination in order to bring the novel technology to the market
- Fulfil consumer expectation, organic food standards and industry requirements
- Reduce environmental impact and costs for organic food sector
- Establish a demonstration unit for heat pump drying (SINTEF main activity)
- Contribute and cooperate with the SusOrgPlus core team

The primary driver for the project has been a significant need for development of a Code of Practice (CoP) to produce sustainable, high quality organic food products. The quality of a product and sustainability of production depend on the cumulative impacts of each processing step in the food chain and their interplay. The future generation of organic food products will depend on both.

Earlier projects have delivered evidence that many drying systems run very inefficiently in terms of drying time, energy demand (mainly fossil fuels), raw material utilisation and resulting product quality. In addition, not all conventional drying processes are allowed in production and labelling of organic products. The use of non-invasive monitoring and control systems have shown a great potential for improvement of the quality of the resulting products. Simple solutions can readily be implemented into existing processes (e.g., dynamic control of product temperature), while integration of advanced solutions is not possible and/or financially viable in practice. The potential for integration of renewable energy sources (RES) is limited due to the seasonality of many products and a resulting high energy demand over very short time periods. Thus, only biomass boilers and the integration of heat pumps (HP) are feasible in most cases. HP supported dryers are not available on the market which are designed to use climate neutral working fluids or accommodated by sophisticated dynamic control systems that simultaneously cater for smart control systems, optimum product quality, low GWP (Global Warming Potential) and ODP (Ozone Depletion Potential). This has been demonstrated during the lifetime of this project.

2 Project achievements

The project has achieved most of the goals set at the start of the project period; (a) *A heat pump drying system with natural refrigerants and energy storage for utilising waste heat recovery has been developed and demonstrated* (b) *Organic apples and seaweed has been processed and dried in the new demonstration unit,* (c) *Organising a Norwegian stakeholder event for dissemination of the results* (d) *active participation at SusOrgPlus workshops throughout the project lifetime (4 in numbers) and, (e) development of surface temperature controlled drying process.*

The project has established a very skilled and recognised consortium of researchers within the topics heat pump drying, natural refrigerants, organic food products, biotechnology, processing of foods, smart process control systems, LCA, LCC and value chain management, together with technology providers and suppliers.

Objective of SusOrgPlus, specifically for SINTEF	***Result achieved***
The development of a novel heat pump assisted air dryer for the organic sector on TRL6 (Main objective)	*The heat pump drier was designed, projected and a pilot installation was built during the first part of the project; the system was tested, and results published; the heat pump drier is available post-project as lab installation; we consider this objective fully achieved*
Quality analysis for the assessment of the HP dryer performance	*Quality and performance analyses for the apple products and seaweed were done during the project in cooperation with SusOrgPlus partners; the heat pump drying concept did not reduce the product quality*
SINTEF will support the development of products	*SINTEF provided and processed seaweed for further development of organic products. UniTeramo developed crackers and pasta products based on novel raw materials (like nettles);* *SINTEF also developed the concept surface temperature-controlled drying, which is now a commercial option by Innotech GmbH*
SINTEF deliver information for the environmental impact analysis, LCA and LCCA	*SINTEF analysed the impact of heat pump drying in the LCA, and provided the required background data for these investigations; heat pump drying reduced the carbon emissions in the organic value chain*
Smart measurement and control system to further develop and optimise the control algorithms	*SINTEF developed and tested the surface temperature controlled drying concept; SINTEF also established a data acquisition system for optical analyse during drying process; data from the DAQ can be uploaded to the SusOrgPlus database*
Lectures HPD will be given for the course "Food Technology"	*SINTEF did not give lectures in this course due to organisational issues; heat pump drying is already a topic in the course; it was not possible to perform lab-work with the students (partly related to Covid-19).*

Overall objectives of the ERA-NET SusOrgPlus	***SINTEF contribution***
Develop smart processing technologies	*Different smart control strategies were developed and tested; the surface temperature controlled drying concept has high potential for the industry already today; the potential of optical DAQ and AI is not fully utilized yet*
Develop value-added products (natural additives and colourants).	*SINTEF provided some raw material to these investigations*
Increased process efficiency, reduction of specific resource demands and phasing out of fossil through use of renewable energy sources (RES)	*Main activity of SINTEF; a fully electrified drying system and the concept of heat pump drying was established at TRL6. The HPD will enable a fully decarbonized and electrified production in the future*
Reduction of direct waste and increase of livelihoods by utilising and upgrading produce rejected by the fresh produce market	*SINTEF contributed only to a minor extend to this objective. The drying concepts developed can be used for fresh as well as rejected product to produce e.g., dried powder; no investigations with "near-waste" products were done*
Establish sound data base	*Uploading of data sets to the database of UniTuscia for further development of AI controlled systems*
Holistic management and evaluation of value chains, environmental impact (LCA) and economic (LCCA) analyses for selected products	*SINTEF provided the required background data for the LCA analyses regarding the impact of heat pump drying on the organic value chain.*

3 Results

- **Development og a novel heat pump assisted air dryer for the organic sector**

The objective of this work was to install a demonstration unit which enables to evaluate the concept of heat pump drying in an industrially relevant environment (TRL6). Together with the SusOrgPlus partner Innotech GmbH (a supplier of novel drying systems) and a Norwegian supplier of heat pumps, a demonstration unit was designed for validation of an energy efficient drying system suitable for producing high quality organic products. The demonstration unit, including the dryer, a heat pump with R744 as working fluid including two thermal storage tanks, was installed in the HighEFFLab at SINTEF in 2019. The design and construction of the installation has resulted in a heat pump dryer which can be operated in conventional mode as well as heat pump mode. The determined Key Performance Indicators allow a direct comparison of the two modes. Also, the repeatability of the tests was documented.

The installation was financed by the infrastructure project HighEFFLab. The demonstration unit is of a relevant size for smaller producers of dried organic foods, and the concept was validated through drying of organic apples and seaweed. Quality measures of the end products were performed by the Romanian partner UASVM (University of Agronomic Science and Veterinary Medicine of Bucharest), and will be published in a journal paper after the end of the project.

The demonstration unit is available for future research and demonstration project.

- **Quality analysis for the assessment og the HP dryer performance**

A Modelica based dynamic heat pump-assisted dryer model was developed with respect to heat transfer, pressure loss and flow requirements. The simulation results show that a closed loop heat pump assisted drying process reduces the energy demand by up to 84% compared to open loop drying processes with fossil resources as the energy source. This input was used for dimensioning the dryer and the heat pump system for the demonstration unit.

A number of drying experiments were performed to analyse the assessment and the heat pump dryer performance, using apples as the main food product. The main results showed a uniform drying on each tray, both horizontal and vertical and it is possible to dry approx. 100 Kg of apples in one batch, taking 5-6 hours. Since the drying chamber is rather short (short tunnel) only a small temperature glide over the trays was observed, and the increase in relative humidity of the drying air was smaller than expected. This was not considered in the design phase, unfortunately. By running the drying system in bypass control, it was expected a decrease in drying time compared to normal drying. Compared to normal mode, the drying process was the same for the heat pump drying but compared to conventional drying, the decrease in drying time was approx. 15% due to the heat pump.

The use of CO_2 as a refrigerant has shown to be not the most efficient solution for energy recovery from drying air with low relative humidity. Using another natural refrigerant may affect the efficiency of the system positively.

- **Performance of the smart measurement and control system**

A novel control method for the convective drying was developed. In conventional drying the air temperature is controlled by setting a constant value for the air temperature, which is in most cases is the maximum allowed temperature of the product. However, the product temperature is often lower than the setpoint or maximum allowed temperature, especially in the first drying period when the surface of the product is still wet. The new control strategy is based on a constant measurement of the surface temperature of the product by an infrared camera. The measured product temperature is used as a control parameter for the air temperature. This concept allows for a significant reduction in drying time (up to 50%) while maintaining or even improving the product quality. The concept of surface temperature-controlled drying is now integrated by the SusOrgPlus partner Innotech as an option in their commercial drying system.

A Data Acquisition System (DAQ) was developed and tested through SusOrgPlus in which the drying progress is documented by optical analyse. For this concept pictures of the drying product are taken at certain time steps and analysed with respect to colour change and shrinkage already during the drying process. The weight reduction is also analysed continuously during the drying process. This data could also be used as control parameter of the drying process. However, the control algorithm is not finalized, and it is not clear which drying parameter (mainly temperature, humidity or velocity) must be altered when the shrinkage or the colour change too high.

- **Dissemination action**

The dissemination activities where to a certain extend influenced by the Covid-19 pandemic. Instead of a physical workshop with Norwegian stakeholders an online seminar with focus on heat pump drying was performed. The seminar had around 50 participant and the records are available post-project. SINTEF also contributed to the online seminars of USAMV (Romania), UniTeramo (Italy) and UniKassel (Germany).
The DEC activities were led by UniTeramo and SINTEF contributed to several newsletters and information materials.

4 Research tasks and partners involved

The Norwegian part of the SusOrgPlus project has been performed by researchers at SINTEF Energi, and a Norwegian technology supplier, in cooperation with the SusOrgPlus partners, consisting of partners from industry, R&D and universities.

University Kassel has been coordinating the SusOrgPlus project. Their competence within organic agriculture and long-standing experience in post-harvest food handling, processing and drying technologies make them well suited for following up the project and they have been a good discussion partner throughout the project.

SINTEF have been in close cooperation with the industry partner Innotech GmbH from Germany for the development of the heat pump drying and the smart control of the drying system. The intention is to continue both developments in the future.

The University of Agronomic Science and Veterinary Medicine of Bucharest (USAMV) in Romania was involved in the quality analyses of the product from the heat pump drying, as well as the smart drying systems. Dried product from the SINTEF Lab was sent for analysis, and the results were discussed and published jointly.

The University of Tuscia/Italy was responsible for the development of the smart drying system. Among others a system was developed in which the product was identified by artificial intelligence (AI). Part of this system development was included in the SINTEF lab system, and a similar controller was installed. The possibility to upload the data from the SINTEF DAQ (pictures, etc.) to the database of UniTuscia was established, and data can be used to optimize the drying process by AI, also post project.

With the University of Teramo a joint investigation with seaweed was done. SINTEF was processing the raw material by different methods (Microwave Vacuum Freeze Drying and Heat Pump Drying) and UniTeramo as well as USAMV will analyse and document the product quality. A joint publication is planned post-project on the outcome of this investigation.

SINTEF also contributed to the LCA of Swedish University of Agricultural Science (SLU) by providing and testing data for processing and drying of different products. Special focus has been the specific energy consumption of heat pump drying (benchmarked again conventional drying) which has a significant impact on the LCA.

5 Impact on research area, competence development, business and society

The main impact of the Norwegian contribution to the SusOrgPlus must be seen in the development and demonstration of the heat pump drier. To our knowledge this is the first fully electrified R744 heat pump drier demonstrated (see onepager_heat-pump-drying.pdf (sintef.no)). The concept of heat pump drying allows to process and dry all kinds of products with a significant reduce climate impact. The energy consumption can be reduced by 50-70%. This potential is especially important for a de-carbonized industry and in the electrification of drying processes.

6 Dissemination plan and utilisation of the results

The demonstration unit will be available for other project and a description of the main functions and possibilities are available at the HighEFFLab website (www.highefflab.no). A short description of the SusOrgProject and the main experimental results will be posted at the same website.

7 Results which arise post project

Joint publication with USAMV and UniTeramo on the investigation and quality analyse of seaweed.