**Innovative Technologies and Processes for Sustainable Frozen Foods**

Bilge Ece OZEL ([beozel@unite.it](mailto:beozel@unite.it))

Dept. of Bioscience and Technology for Food Agriculture and Environment, University of Teramo, Via Renato Balzarini 1, 64100, Teramo, Italy

Tutors: Prof. Paola Pittia, Prof. Lillia Neri, Danilo Di Florio

This Ph.D. thesis aims to investigate how the quality of food products is influenced by innovative freezing technologies, eco-friendly processes, and storage systems and compare them with conventional methods.

**Tecnologie e Processi innovativi per surgelati sostenibili**

Questa tesi di dottorato di ricerca si propone di indagare come la qualità dei prodotti alimentari sia influenzata da tecnologie di congelamento innovative, processi ecologici e sistemi di conservazione e confrontarli con metodi convenzionali.

1. **State-of-art**

In recent years, there has been a growing demand for frozen foods due to their convenience, extended shelf life, and ease of transportation. However, the frozen food industry has been criticized for its high energy consumption, carbon footprint, and usage of non-renewable resources. The development of sustainable frozen food production is a complex and challenging task that requires innovative technologies optimized for the reduction of the environmental impact of this process while keeping the quality of frozen foods high.

Besides its convenience, freezing and frozen storage can cause irreversible physical changes that the quality characteristics of the product such as flavor, texture, etc. may compromise thus reducing the market potential. however appropriate process conditions and pre-treatments can help prevent negative impacts (Neri et al., 2014).

Studies are shown that, freezing pre-treatments, like blanching inactivates endogenous enzymes, and the use of cryoprotectants able to limit physical and structural damage the food products (Neri et al., 2020, Santerelli et al., 2019)

One of the key areas of sustainable frozen food production is the reduction of energy consumption during the freezing process. Various technologies such as high-pressure, pulsed electric field- (PEF), and ultrasound-assisted freezing have been developed and combined with conventional technologies to achieve more energy-efficient and/or faster freezing. High-pressure shift freezing utilizes elevated pressures to rapidly freeze food while preserving the product’s texture and minimizing ice crystal formation (Benet et al., 2004); PEF-assisted freezing applies short-duration, high-voltage electrical pulses to induce rapid freezing by forming ice crystals within the food (Mok et al., 2015); ultrasound-assisted freezing, utilizes high-frequency sound waves to accelerate freezing rates by creating localized agitation, resulting in faster and more efficient freezing while maintaining the quality of the frozen food. Vacuum cooling, microwave-assisted freezing, and cryogenic freezing can also be used for fast and efficient freezing.

Another innovative approach towards sustainability is the use of renewable energy sources, such as solar and wind energy, to power the freezing equipment. In particular, solar energy has emerged as a promising renewable energy source for food freezing, especially in regions with abundant sunlight (Strielkowski et al., 2021). Solar-powered refrigeration systems offer several advantages over conventional refrigeration systems, such as reducing energy costs and carbon emissions and increasing the reliability and independence of the energy supply (Lehtola & Zahedi, 2019). Solar-powered freezers (SPF) use solar panels to convert sunlight into electricity by using photovoltaic (PV) technology. The panels made up of solar cells, capture sunlight and generate an electric current. This current, regulated by a charge controller, is stored in a battery bank as direct current (DC) electricity for later use. When the freezer needs power, an inverter converts the stored electricity (DC) from the batteries into the alternating current (AC) needed to run the freezer (Ahmed et al. 2019). The freezer's refrigeration system, including compressors and evaporators, keeps the set low temperatures in the freezer chamber. To maximize the self-consumption of PV energy, the energy requirement is adjusted to be aligned with the production of PV energy i.e., PV energy is exploited for cooling the glycol water, which assures the maintenance of cold temperatures in low-voltage cold rooms. Finally, monitoring and control systems provide real-time information on PV energy availability, enabling self-consumption and optimizing renewable energy usage. The energy efficiency of SPF is also due to the cold room configuration, specifically designed to maximize thermal insulation. However, photovoltaic generators produce energy not constantly and temperature fluctuation over time due to the nature of their power source and energy availability may occur (Ahmed et al. 2019; Lehtola & Zahedi, 2019).

So far studies on the temperature fluctuation in solar-powered systems have been carried out engineering level in terms of energy consumption and cost efficiency, while no information is reported in the scientific literature on its impact on products’ quality and safety at the industrial scale. This knowledge gap needs to be fulfilled by research activities aimed to evaluate the effect of solar-powered freezers and fluctuating temperatures on the quality of frozen food products, and to the comparison with conventional processes.

Limited are also the studies aimed to evaluate the effects of freezing when coupled with innovative technologies aimed to enhance the sustainability of this process and/or the effects of freezing and frozen state of unconventional/alternative food sources (e.g., plant-based products, insects) whose consumption globally is increasing as meat-alternatives and/or the reduction of the environmental impact of food production.

# **Ph.D. Thesis Objectives and Milestones**

Within the overall objective mentioned above this PhD thesis project can be subdivided into the following activities according to the Gantt diagram given in Table 1:

**A.1. Evaluation and optimization of the freezing process and frozen storage systems** powered by photovoltaic technology for high-quality food products.

A1.1. Monitoring of temperature fluctuations in SPF chambers as a function of environmental and processing conditions will be carried out.

**A.2.** **Evaluation of the effect of SPF freezing on selected foods.** In collaboration with the company, products of different types (e.g. dairy and meats) will be selected and their main products’ quality parameters defined. Instrumental and analytical methods (e.g. moisture, texture, color… water loss at thawing, sensory properties) will be optimized for the evaluation of the products’ quality parameters of the products in a frozen state and their corresponding stability.

A.2.1. **Products’ quality evaluation during storage in a frozen** state as a function of the process conditions will be carried out. The effect of SPF will be assessed by comparison with results obtained from samples stored in conventional freezers under similar temperature conditions.

**A.3**. **Application of innovative technologies on unconventional/novel food products** (e.g., plant-based products, edible insects) (secondment in NTUA, Athens, Greece).

A3.1. Innovative technologies approaches will be applied and/or combined to enhance the sustainability of the freezing process and the quality and stability of frozen food.

**A.4.** Writing and editing of the Ph.D. thesis, scientific papers, and oral and/or poster communications.

**Table 1** *Gantt diagram for this Ph.D. thesis project.*

1. **Selected References**

Ahmed, R., Sreeram, V., Mishra, Y., & Arif, M. D. (2020). A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization. Renewable and Sustainable Energy Reviews, 124, 109792.

Lehtola, T., & Zahedi, A. (2019). Solar energy and wind power supply supported by storage technology: A review. Sustainable Energy Technologies and Assessments, 35, 25-31.

Mok, J. H., Choi, W., Park, S. H., Lee, S. H., & Jun, S. (2015). Emerging pulsed electric field (PEF) and static magnetic field (SMF) combination technology for food freezing. International Journal of Refrigeration, 50, 137-145.

Strielkowski, W., Civín, L., Tarkhanova, E., Tvaronavičienė, M., & Petrenko, Y. (2021). Renewable energy in the sustainable development of electrical power sector: A review. Energies, 14(24), 8240.

Benet, G. U., Schlüter, O., & Knorr, D. (2004). High pressure–low temperature processing. Suggested definitions and terminology. Innovative Food Science & Emerging Technologies, 5(4), 413-427.

Neri, L., Faieta, M., Di Mattia, C., Sacchetti, G., Mastrocola, D., & Pittia, P. (2020). Antioxidant activity in frozen plant foods: Effect of cryoprotectants, freezing process and frozen storage. Foods, 9(12), 1886.

Neri, L., Hernando, I., Pérez-Munuera, I., Sacchetti, G., Mastrocola, D., & Pittia, P. (2014). Mechanical properties and microstructure of frozen carrots during storage as affected by blanching in water and sugar solutions. Food chemistry, 144, 65-73.

Santarelli, V., Neri, L., Sacchetti, G., Di Mattia, C. D., Mastrocola, D., & Pittia, P. (2020). Response of organic and conventional apples to freezing and freezing pre-treatments: Focus on polyphenols content and antioxidant activity. *Food chemistry*, *308*, 125570.