VII МІЖНАРОДНА
НАУКОВО-ПРАКТИЧНА КОНФЕРЕНЦІЯ
VII INTERNATIONAL SCIENTIFIC CONFERENCE

ЯКІСТЬ І БЕЗПЕКА ХАРЧОВИХ ПРОДУКТІВ

FOOD QUALITY AND SAFETY

13 листопада
November 13

2025

ЗБІРНИК ТЕЗ
BOOK OF ABSTRACTS

Національний університет харчових технологій – Київ, Україна
National University of Food Technologies – Kyiv, Ukraine

JEL: 664.8:621.577

T.M. Levkivska, PhD (Tech.), Associate Professor
A.V. Marchenko, PhD student

National University of Food Technologies (NUFT), Kyiv, Ukraine

3. REFRIGERANTS FOR FRUIT FREEZING IN THE EU: REGULATORY FRAMEWORK, TECHNICAL REQUIREMENTS, AND SUSTAINABILITY TRENDS

Introduction. In the European Union, the use of refrigerants in fruit freezing is governed by a complex and evolving set of regulations aimed at protecting the environment, ensuring food safety, and promoting energy efficiency. As the demand for frozen fruit products grows across Europe and globally, producers must navigate strict legal frameworks and technological standards to remain compliant and competitive. This article explores the key EU requirements for refrigerants used in fruit freezing, their advantages and limitations, and the broader sustainability context shaping industry practices.

Materials and Methods. This section describes the sources of data, analytical methods, regulatory documents reviewed (e.g., EU Regulations 517/2014, 178/2002), and the criteria used to evaluate refrigerants. It includes comparative analysis of GWP values, thermodynamic properties, and safety classifications. The cornerstone of EU regulation on refrigerants is Regulation (EU) No 517/2014 on fluorinated greenhouse gases (F-gases). This law sets out a phasedown schedule for high-GWP hydrofluorocarbons (HFCs), which were widely used in refrigeration systems for decades. The regulation mandates a gradual reduction in the quantity of HFCs placed on the EU market, aiming for a 79% cut by 2030 compared to 2015 levels. It also restricts the use of certain refrigerants in new equipment, especially those with a GWP above 150, and requires leak detection, recovery, and proper disposal procedures [1, 2].

Results and Discussion. In parallel, Regulation (EU) No 2021/1119 (European Climate Law) and the European Green Deal reinforce the commitment to climate neutrality by 2050. These policies encourage the adoption of natural refrigerants such as carbon dioxide (CO_2), ammonia (NH_3), and hydrocarbons (e.g., propane R290, isobutane R600a), which have low or zero GWP and minimal environmental impact [3].

Refrigerants used in fruit freezing must meet stringent technical and safety criteria, especially when applied in food-grade environments. Systems must be hermetically sealed to prevent leakage, and refrigerants must not come into direct contact with the fruit or packaging. This is particularly important for toxic agents like ammonia, which, despite its excellent thermodynamic properties, requires indirect cooling systems and double containment to ensure safety.

Carbon dioxide (CO_2) is increasingly favored for low-temperature applications due to its non-toxicity, non-flammability, and excellent heat transfer properties. However, CO_2 systems operate under high pressure (up to 90 bar), necessitating robust equipment and specialized maintenance. In transcritical systems, efficiency can be lower in warmer climates, but this is mitigated by heat recovery and ejector technologies.

Hydrocarbons such as propane and isobutane offer high energy efficiency and low GWP, but their flammability poses risks. EU standards such as EN 378 and ATEX directives regulate the safe use of flammable refrigerants, requiring explosion-proof components, ventilation systems, and strict installation protocols [4].

Liquid nitrogen (LN_2) is used in cryogenic freezing, especially for delicate fruits like berries. It enables ultra-fast freezing at –196 °C, preserving cellular structure and minimizing ice crystal formation. While LN_2 is inert and leaves no residue, its use is limited by high operational costs, infrastructure demands, and safety protocols related to extreme cold.

Under Regulation (EU) No 178/2002, all stages of food production, including freezing, must ensure consumer safety. Refrigerants must be chemically stable, non-reactive, and free from residues that could contaminate food. Equipment used in freezing must comply with HACCP principles, and materials must be food-grade certified [2].

The General Food Law also requires traceability of all substances used in food processing. Producers must document the type and quantity of refrigerant, maintenance records, and disposal methods. Certification under the F-Gas Regulation is mandatory for technicians handling refrigerants, ensuring proper training and accountability.

Energy efficiency is a key consideration in refrigerant selection. The EU's EcoDesign Directive (2009/125/EC) sets minimum efficiency standards for refrigeration equipment. Natural refrigerants often outperform HFCs in terms of energy use, especially in optimized systems with heat recovery and variable-speed compressors [5].

Lifecycle analysis (LCA) is increasingly used to assess the environmental footprint of refrigeration systems. This includes not only direct emissions from refrigerants but also indirect emissions from electricity consumption. CO_2 and ammonia systems typically have lower total climate impact over their operational lifespan compared to HFC-based systems.

Another important aspect influencing refrigerant selection in the EU is the availability of infrastructure and technical expertise. While natural refrigerants offer clear environmental advantages, their implementation often requires significant investment in specialized equipment, staff training, and system redesign. For example, ammonia-based systems demand corrosion-resistant materials and strict safety protocols, while transcritical CO_2 systems require advanced control algorithms and high-pressure components. As a result, small and medium-sized enterprises (SMEs) may face financial and logistical barriers when transitioning to compliant technologies, prompting the need for EU-level incentives and technical support programs.

In addition to environmental and safety considerations, product quality preservation remains a central concern in fruit freezing. The choice of refrigerant and freezing method directly affects the texture, color, flavor, and nutritional value of the final product. Cryogenic freezing with liquid nitrogen is particularly effective for preserving delicate fruits such as raspberries and blackberries, as it minimizes ice crystal formation and cellular damage. However, conventional mechanical systems using CO_2

or hydrocarbons can also achieve high-quality results when optimized for rapid freezing and uniform temperature distribution. Research continues to explore hybrid systems that combine mechanical and cryogenic technologies to balance cost, efficiency, and product integrity.

Finally, the EU's emphasis on circular economy principles is reshaping how refrigerants are managed throughout their lifecycle. Beyond initial selection and operational efficiency, producers are now expected to consider end-of-life recovery, recycling, and safe disposal of refrigerants. The F-Gas Regulation requires certified technicians to handle refrigerant recovery and mandates reporting of quantities used and reclaimed. Emerging technologies such as refrigerant reclamation units and closed-loop systems are being piloted to reduce emissions and resource loss. These developments reflect a broader shift toward holistic sustainability, where environmental responsibility extends across the entire value chain of fruit freezing operations.

Conclusion. The use of refrigerants for fruit freezing in the EU is shaped by a robust regulatory framework that prioritizes environmental protection, food safety, and energy efficiency. Producers must carefully evaluate the thermodynamic, safety, and legal aspects of each refrigerant option, balancing performance with compliance. As the industry moves toward climate neutrality, natural refrigerants and advanced freezing technologies will play a central role in ensuring that frozen fruit products meet the highest standards of quality and sustainability.

References

1. Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 [Electronic resource]. — Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0517
2. Regulation (EU) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety [Electronic resource]. — Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002R0178
3. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality (European Climate Law) [Electronic resource]. — Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119
4. EN 378:2016. Refrigerating systems and heat pumps – Safety and environmental requirements. – Brussels: European Committee for Standardization (CEN), 2016.
5. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [Electronic resource]. — Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0125