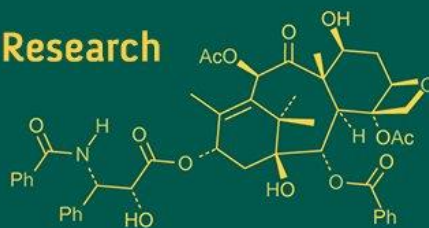
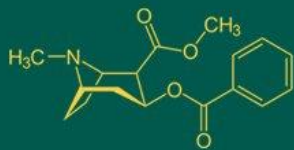


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Development and quality evaluation of beetroot-based functional ice cream

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Abstract

Beetroot (*Beta vulgaris*) has emerged as a potent functional food ingredient due to its high content of betalains, dietary fiber, nitrates, and phenolic compounds. This review explores the incorporation of beetroot into ice cream systems to develop nutritionally enriched functional frozen desserts. Beetroot enhances antioxidant capacity, improves color naturally, and contributes to cardiovascular and metabolic health benefits. Its incorporation significantly influences physicochemical properties such as viscosity, overrun, melting behavior, and sensory characteristics. Processing conditions, including thermal treatment and freezing, affect the stability of betalains and other bioactives. Advanced formulation strategies, including microencapsulation and hydrocolloid stabilization, are essential to maintain product quality. Despite promising applications, challenges such as color stability, earthy flavor, and textural modifications persist. This review highlights recent developments, formulation approaches, and future research directions for beetroot-based functional ice cream systems.

Keywords: Beetroot, betalains, functional ice cream, antioxidants, frozen desserts

Introduction

The global food industry has undergone a significant transformation in recent years, shifting from conventional calorie-dense products to functional foods that offer additional health benefits beyond basic nutrition. This paradigm shift is largely driven by increasing consumer awareness regarding diet-related chronic diseases, including cardiovascular disorders, diabetes, obesity, and certain cancers. As a result, there is growing demand for foods enriched with bioactive compounds such as antioxidants, dietary fiber, vitamins, and phytochemicals. Among these, functional dairy products, particularly ice cream, have emerged as promising carriers for delivering health-promoting ingredients due to their widespread acceptability across different age groups.

Traditionally, ice cream is considered an indulgent frozen dessert characterized by high fat and sugar content. However, modern advancements in food science and technology have facilitated its transformation into a functional multiphase delivery system, capable of incorporating nutritionally valuable ingredients without compromising sensory appeal. The integration of plant-based bioactive components into ice cream formulations has gained considerable attention, as it not only enhances nutritional value but also aligns with the growing preference for clean-label and natural food products.

In this context, beetroot (*Beta vulgaris*) has attracted significant interest as a functional ingredient due to its exceptional nutritional and therapeutic properties. Beetroot is a root vegetable belonging to the Amaranthaceae family and is widely cultivated across temperate regions. It is rich in unique bioactive compounds, particularly betalains, which are nitrogen-containing pigments responsible for its characteristic red-purple color. Betalains are classified into betacyanins (red pigments) and betaxanthins (yellow pigments), both of which exhibit strong antioxidant activity. These compounds have been extensively studied for their potential role in reducing oxidative stress, inflammation, and the risk of chronic diseases (Clifford *et al.*, 2015; Sadowska-Bartosz & Bartosz, 2021)^[2, 13].

In addition to betalains, beetroot is an excellent source of dietary nitrates, which play a crucial role in cardiovascular health by improving endothelial function and enhancing nitric oxide bioavailability. Regular consumption of beetroot has been associated with reduced Blood pressure, improved exercise performance, and enhanced metabolic efficiency.

Furthermore, beetroot contains significant amounts of phenolic compounds, vitamins (such as vitamin C and folate), minerals (including potassium and iron), and dietary fiber, all of which contribute to its functional potential.

Recent trends in food product development emphasize the use of natural colorants as alternatives to synthetic additives, which have been associated with potential health risks. In this regard, beetroot serves as an excellent natural coloring agent, providing an attractive red hue while simultaneously enhancing the nutritional profile of food products. This dual functionality makes beetroot particularly suitable for incorporation into frozen desserts like ice cream, where visual appeal plays a critical role in consumer acceptance.

Despite its numerous advantages, the incorporation of beetroot into ice cream systems presents several technological challenges. The stability of betalains is highly sensitive to environmental factors such as temperature, pH, oxygen, and light exposure. Processing conditions, including pasteurization, homogenization, and freezing, can significantly influence the retention of these bioactive compounds. Additionally, the presence of dietary fiber and plant solids can alter the physicochemical properties of ice cream, affecting parameters such as viscosity, overrun, texture, and melting behavior.

Another important consideration is the sensory impact of beetroot incorporation. While it enhances color and nutritional value, beetroot may impart a characteristic earthy flavor that can influence consumer acceptability. Therefore, optimizing formulation parameters, including the level of beetroot incorporation and the use of flavor-masking agents, is essential to achieve a balance between functionality and sensory quality.

The development of beetroot-based functional ice cream also aligns with the broader objectives of sustainable food systems and waste valorization. Beetroot processing generates by-products such as peels and pulp residues, which are rich in bioactive compounds and can be effectively utilized in food formulations. This approach not only enhances the economic value of agricultural produce but also contributes to reducing food waste and promoting environmental sustainability.

In recent years, advancements in microstructure engineering and food processing technologies have opened new avenues for improving the stability and functionality of bioactive compounds in frozen desserts. Techniques such as microencapsulation, high-pressure homogenization, and controlled freezing have been explored to enhance the retention of sensitive compounds like betalains and to improve the overall quality of functional ice cream.

Therefore, the development and quality evaluation of beetroot-based functional ice cream represent a promising area of research that integrates nutritional science, food technology, and consumer-oriented product development. This review aims to provide a comprehensive overview of the role of beetroot as a functional ingredient in ice cream, focusing on its nutritional significance, effects on physicochemical and sensory properties, processing challenges, and future research prospects.

2. Ice cream as a functional multiphase system

Ice cream is a complex multiphase system consisting of ice crystals, air cells, fat globules, and an unfrozen serum phase. The quality of ice cream depends on the interaction among these phases.

Incorporation of beetroot modifies this structure by:

- Increasing total solids and dietary fiber
- Enhancing viscosity and water-binding capacity
- Reducing overrun due to restricted air incorporation

Studies indicate that vegetable-based additives reduce overrun but improve melting resistance and structural stability (Muse & Hartel, 2004) ^[7].

Beetroot fiber and pectin contribute to improved rheological properties, making it a natural stabilizer in ice cream formulations.

3. Nutritional and functional potential of beetroot

Beetroot is a rich source of bioactive compounds:

- Betalains (betanin, vulgaxanthin): Strong antioxidants
- Dietary nitrates: Improve cardiovascular health and blood flow
- Phenolic compounds: Provide anti-inflammatory benefits
- Dietary fiber: Supports gut health

Research shows that beetroot supplementation significantly increases total antioxidant capacity in dairy products (Georgiev *et al.*, 2010) ^[4].

Additionally, beetroot contributes:

- Natural red-purple color (clean-label advantage)
- Reduced need for artificial additives
- Improved nutritional density

4. Impact of Processing on Beetroot Bioactives

Processing conditions play a critical role in maintaining beetroot quality:

Thermal Processing

- Moderate heating enhances extractability of betalains
- Excess heat causes degradation and color loss

Freezing and Storage

- Freezing preserves nutrients but may disrupt cell structure
- Betalains degrade over time due to oxidation and light exposure

Studies report a significant reduction in betalain content during prolonged storage, highlighting the need for protective strategies such as encapsulation (Azeredo, 2009) ^[1].

5. Formulation Challenges in Beetroot Ice Cream

Developing beetroot-based ice cream requires balancing nutrition and sensory quality:

Challenges

- Earthy flavor affecting acceptability
- Color instability at varying pH and temperatures
- Reduced overrun and increased density
- Texture modifications due to fiber content

Optimal Inclusion Levels

- 5-15% beetroot pulp: best sensory acceptance
- 20%: negatively affects texture and flavor

Moderate incorporation ensures a balance between functional benefits and consumer preference.

6. Microstructure Engineering Approaches

Microstructure engineering is essential for improving product stability and quality:

Hydrocolloids and Stabilizers

- Control ice crystal growth
- Improve texture and mouthfeel

Encapsulation Techniques

- Protect betalains from degradation
- Enhance bioavailability

Advanced Processing Techniques

- High-pressure homogenization improves dispersion
- Controlled freezing enhances microstructure uniformity

These approaches help achieve optimal texture, stability, and nutritional retention.

7. Sensory and Quality evaluation

Physicochemical Properties

- Increased viscosity with beetroot addition
- Improved melting resistance
- Slight reduction in overrun

Sensory Attributes

- Attractive natural color enhances appeal
- Mild earthy flavor may require flavor masking
- Acceptability highest at moderate incorporation levels

Functional Properties

- Increased antioxidant activity
- Improved nutritional profile
- Potential cardiovascular benefits

8. Conclusion and Future perspectives

Beetroot-based ice cream represents a promising innovation in the field of functional foods. It enhances nutritional value, antioxidant capacity, and visual appeal, making it suitable for health-conscious consumers.

However, challenges related to color stability, flavor optimization, and texture modification need to be addressed. Future research should focus on:

- Advanced encapsulation techniques for betalain stability
- AI-based formulation optimization
- Development of plant-based beetroot ice cream
- Clinical validation of health benefits

With continued research and technological advancements, beetroot ice cream has strong potential to become a next-generation functional frozen dessert.

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