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Nano-Bubbles: Tiny Technology, Big Impact on the Food Industry

*V. Boomika¹, B. Thippeswamy² and S. Teja³

¹Horticultural College and Research Institute, TNAU, Coimbatore, India

²Indian Institute of Horticultural Research, Bengaluru, India

³Navsari Agricultural University, Gujarat, India

*Corresponding Author's email: boomika1727@gmail.com

Nano-bubbles, gas filled cavities smaller than 200 nanometers, are an emerging innovation in the food industry. With properties such as high stability, neutral buoyancy, and the ability to penetrate microscopic surfaces, nano-bubbles are transforming traditional food processing and preservation techniques. Their applications include surface sanitation, shelf-life extension, enhanced fermentation, aquaculture efficiency, and water purification. As non-toxic, eco-friendly, and energy-efficient alternatives, nano-bubbles align with the growing global demand for sustainable and safe food technologies. With advancing research and commercialization, nano-bubbles are poised to become a cornerstone of modern food manufacturing and safety protocols.

Keywords: Eco-friendly, Fermentation, Nano-bubbles, Ozone disinfection

Introduction

In the rapidly evolving food industry, innovations that improve efficiency, safety, and sustainability are essential. One such innovation is the nano-bubble—a gas-filled bubble with a diameter less than 200 nanometers. Though microscopic, these bubbles are revolutionizing food handling, sanitation, processing, and storage. Thanks to their long-term stability in liquids, ability to carry gases like oxygen and ozone, and their capacity to reach even the tiniest surfaces, nano-bubbles are being increasingly adopted in food and beverage industries around the world.

What are Nano-Bubbles?

Nano-bubbles, also known as ultrafine bubbles, are gas-filled cavities with a diameter of less than 200 nanometers, approximately 500 times smaller than the width of a human hair. These microscopic bubbles exhibit unique physical and chemical properties that distinguish them from conventional microbubbles or larger gas bubbles commonly found in liquids.

Key characteristics of nano-bubbles

- **Ultra-small size:** Their sub-microscopic size allows them to remain suspended in liquids without rapidly rising to the surface or bursting, as larger bubbles do.
- **Neutral buoyancy:** Nano-bubbles exhibit a near-zero buoyant force, enabling them to stay uniformly dispersed in a liquid for extended durations, even for weeks or months.
- **Gas-carrying capacity:** They can be infused with gases such as oxygen, ozone, carbon dioxide, or nitrogen, tailored to the intended application (e.g., sanitation, oxidation, or preservation).
- **High surface reactivity:** The large surface area-to-volume ratio enhances interactions with microbial cells, chemical compounds, and food particles.
- **Energetic collapse:** When nano-bubbles eventually implode (typically under pressure or agitation), they generate localized hotspots of high temperature and pressure, facilitating physical disruption of microbes and aiding in cleaning or sanitation.

These features enable nano-bubbles to perform a variety of roles in food processing and safety, ranging from surface sterilization to enhancing fermentation and water purification.

Key Applications in the Food Industry

1. Food Cleaning and Surface Sanitation

- Ozone nano-bubbles are highly effective antimicrobial agents, used to disinfect food contact surfaces, fruits, vegetables, and even packaging materials.
- They eliminate bacteria, fungi, and viruses like *E. coli*, *Salmonella*, and *Listeria* without leaving harmful residues.
- Suitable for organic food cleaning, as they eliminate the need for synthetic chemicals.

2. Shelf-Life Extension and Quality Preservation

- Oxygen nano-bubbles enhance storage water quality and reduce oxidation.
- Produce like lettuce, strawberries, and meat retain freshness and color longer.
- Lower microbial load and improved hygiene reduce spoilage and waste.

3. Food Processing Enhancement

- Nano-bubbles improve mixing, emulsification, and ingredient dispersion in products like sauces, dairy beverages, and processed meats.
- Enhance flavor extraction from spices or herbs during cooking or soaking.
- Improve the rheological properties (viscosity, texture) of food products.

4. Fermentation and Brewing

- In brewing industries, nano-bubbles aid in gas transfer and fermentation efficiency.
- Improve production of beer, wine, yogurt, vinegar, and enzymes by regulating dissolved oxygen or CO₂ levels.
- Optimize yeast and microbial activity for better yield and flavor.

5. Water Purification and Recycling

- Nano-bubbles help break down organic matter, reduce chemical oxygen demand (COD), and oxidize pollutants.
- Used for recycling water in food processing plants, reducing environmental impact.
- Promote decontamination in wastewater, aiding circular water use.

6. Aquaculture and Hydroponics

- In fish farming, nano-bubbles increase dissolved oxygen and enhance water quality.
- Improve growth rates, immune response, and survival of aquatic animals.
- In hydroponics, boost plant growth by improving root oxygenation.

7. Oil Removal and Defoaming

- Nano-bubbles aid in removing fats, oils, and grease (FOG) from industrial tanks and pipelines.
- Defoaming capabilities are valuable in beverage production, reducing excess foam without surfactants.

8. Cold Chain and Packaging Integration

- Incorporating nano-bubble-infused water in cold storage environments can reduce bacterial growth during transportation.
- Future applications may include active packaging, using nano-bubble technology to maintain hygiene and freshness inside food containers.

Advantages Over Traditional Technologies

Feature	Nano-Bubbles	Traditional Methods
Eco-friendly	Yes (no harmful residues)	Often chemical-based
Energy-efficient	Lower heat & chemical use	High-temperature sanitation
Safe for direct food contact	Yes	Often not
Cost-effective	Reduced chemical and water use	Higher maintenance cost
Improved food quality	Preserves taste, color, and texture	May cause degradation

Challenges and Future Prospects

- Technology costs: Initial installation and nano-bubble generators may be expensive for small-scale producers.
- Regulatory clarity: Guidelines for nano-bubble use in food industries are still evolving in many countries.
- Research gaps: Long-term effects, especially on product quality, need further study.

However, continuous advancements in nanotechnology, automation, and clean energy are expected to reduce costs and improve scalability.

Conclusion

From disinfecting produce to enhancing fermentation tanks and improving aquaculture, nano-bubbles offer a promising tool for transforming the food industry. Their versatility, safety, and sustainability make them ideal for addressing modern challenges in food processing, hygiene, and environmental conservation. With ongoing research, policy support, and industry collaboration, nano-bubbles can help build a safer, greener, and more efficient food system for the future.

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