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# Infrared Heating in Food Processing: Advancements and Applications

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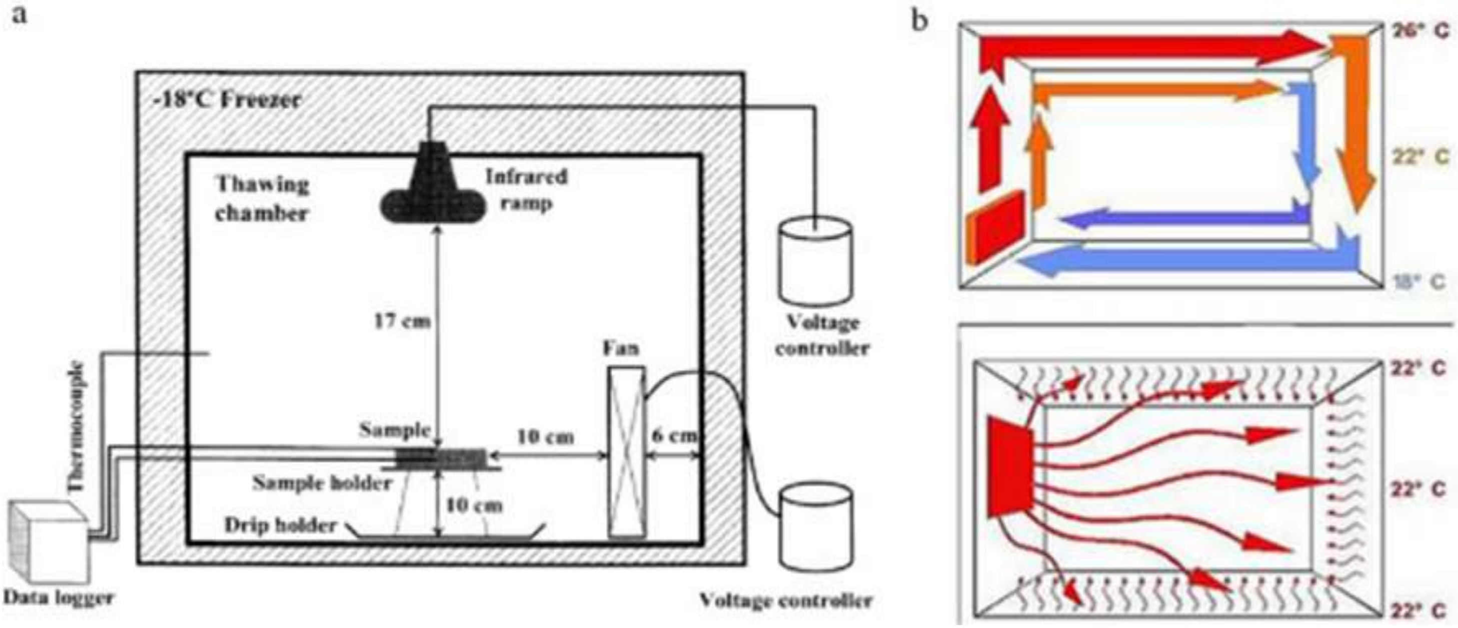
**SUMMARY**

Infrared (IR) heating is an emerging food processing technique known for its energy efficiency, fast heating capabilities, and enhanced product quality. This technology relies on energy transfer through radiation within a wavelength range of 0.7–1000 µm. Unlike conventional methods, IR heating allows direct energy delivery to food surfaces without an intermediary medium, minimizing energy wastage. IR radiation is categorized into near, mid, and far IR, each impacting the heating depth and surface control. The efficiency of IR heating depends on factors like food dimensions and absorption properties, with far IR being ideal for surface treatments and near IR suitable for deeper penetration. IR heating has diverse applications in food processing, including blanching, baking, cooking, roasting, and drying. For instance, IR blanching preserves nutrients and prevents oxidation, while IR cooking reduces fat content and enhances sensory appeal. IR roasting optimizes flavor and texture, and hybrid techniques—such as combining IR with hot air or microwave drying—improve product quality while cutting down on energy use and processing time. Furthermore, IR heating is effective in deactivating microorganisms and spores, making it a viable option for pasteurization. However, the technology faces challenges, including limited penetration depth, the risk of surface overheating, and high initial costs of equipment. These limitations can be addressed by integrating IR heating with complementary methods, expanding its industrial applications and enhancing its flexibility.

## INTRODUCTION

Heating is a fundamental process in food preservation, essential for extending shelf life (Joardder et al., 2021; Joardder and Masud, 2019). Food processing employs several heating techniques, but traditional methods often have drawbacks, such as uneven temperature distribution, excessive energy usage, and inconsistent heating conditions, which can depend heavily on environmental factors (Joardder and Masud, 2019; Sakare et al., 2020). These challenges have driven the development of advanced technologies like microwave heating and infrared (IR) heating. IR heating functions through heat transfer by radiation. The majority of the radiated energy emitted at normal room temperatures falls within the IR range of the electromagnetic spectrum (0.78–1000 µm) (Ramaswamy et al., 2012).

**Fig.1 Infrared Heating in Food Processing**




(**Source:** https://images.app.goo.gl/N93yfrF3tJmWwtS39)

This characteristic makes IR heating highly efficient and well-suited for food processing applications. Its primary benefits include reduced processing times, improved energy efficiency, uniform heat distribution, flexible control over processing parameters, and high-quality end products. Additionally, IR heating is effective in microbial decontamination (Sakare et al., 2020; Riadh et al., 2015). IR heating is divided into three categories based on wavelength: near IR, mid-IR, and far IR. Adjusting the type of IR radiation allows precise control over heating depth (Rastogi, 2015). Another advantage is that IR heating does not require a medium to transmit energy, ensuring that surrounding air remains unaffected during controlled processes (Sakare et al., 2020). However, a notable limitation of IR heating, particularly in drying applications, is its relatively shallow penetration depth (Riadh et al., 2015).

**Principle of Infrared (IR) Heating in Food Processing**

Infrared (IR) heating utilizes energy transfer via radiation, with wavelengths between 0.7 and 1000 µm, positioned in the electromagnetic spectrum between visible light and microwaves. When IR radiation contacts food, the surface absorbs the energy, converting it to heat, which penetrates internally through conduction, enabling rapid and uniform heating. Unlike conventional methods, IR heating directly targets the food surface without requiring a medium, minimizing energy loss.

**Fundamentals of IR Heating in Foods**

1. **Classification of IR Radiation**:

Thermal radiation, covering wavelengths from 0.1 to 100 µm, generates heat in food materials (Rastogi, 2015). While wavelengths of 0.2–0.7 µm (visible and ultraviolet light) affect electronic states and those beyond 1000 µm (microwaves) influence rotational states, IR radiation primarily alters the vibrational states of food molecules. The vibrational effect, with frequencies of 60,000–150,000 MHz, enables efficient internal heating (Fasina et al., 2001; Sakare et al., 2020). IR radiation spans the spectrum between visible light and microwaves, making it effective for food processing applications.

**2. IR Absorption Characteristics of Foods**

Food materials comprise biological polymers, macromolecules, inorganic salts, and moisture, each with distinct absorption wavelengths. Understanding these absorption bands is crucial for optimizing IR heating. Water, with its broad absorption across relevant wavelengths, significantly influences the process, making selective IR heating dependent on both wavelength selection and minimizing water absorption (Pan et al., 2016; Jun et al., 2010). Other critical factors include the food's dimensions and the required penetration depth. For surface treatments, low penetration depth is sufficient, whereas deeper penetration is necessary for processes like dehydration. Since penetration depth decreases with shorter wavelengths, far IR is ideal for surface treatments (Sakare et al., 2020).

**3. Common IR Sources in Food Processing**

IR energy for heating food is supplied through either gas-fired or electrical heaters. Gas-fired heaters emit IR radiation by heating perforated metal, refractory plates, or ceramic surfaces using gas flames. Common types include direct flame radiators, ceramic gas burners, catalytic emitters, and high-intensity porous burners. In contrast, electrical heaters produce IR radiation by passing electricity through an emitter, avoiding combustion by-products and eliminating the need for venting (Rastogi, 2019). Common types include ceramic emitters, radiant panels, quartz tube emitters, and reflector-style IR lamps (Sakare et al., 2020; Pan and Atungulu, 2010). Electrical heaters are more energy-efficient (78%–85%) compared to gas-fired heaters (40%–46%) (Clark et al., 2014).

**Infrared Heating in Food Processing**

**1.Infrared Blanching**

Infrared (IR) blanching offers an energy-efficient alternative to conventional hot air blanching, with superior quality and shelf-life retention. Smith et al. (2018) found that IR-blanched peanuts showed no oxidation even after 18 weeks of storage, unlike conventionally blanched peanuts. Additionally, IR blanching reduced peanut splitting. Chen et al. (2018) reported that IR-blanched carrot slices retained higher vitamin C levels, reduced carotenoid loss, and minimized residual peroxide activity, along with shorter drying times. Sequential IR blanching and hot air drying demonstrated effective processing, with optimal conditions of 110 seconds of IR heating at 552 W, followed by drying at 80°C for 45 minutes. IR-blanched potato chips exhibited 13.79% less oil content and received better sensory evaluation compared to conventionally processed chips.

**2.Infrared Cooking**

IR cooking provides faster cooking times, improved color and texture, and healthier products due to lower fat content. Rahimi et al. (2018) observed that IR-cooked and pre-fried chicken nuggets had significantly less fat than deep-fried nuggets while maintaining similar sensory appeal. Similarly, IR heating enhanced the cooking efficiency of Bambara groundnut seeds by causing cell separation, increasing water absorption rates. Ogundele and Emmambux (2018) noted that dehulling influenced the cooking characteristics of these seeds, showcasing the versatility of IR cooking.

**3. Infrared Baking**

Conventional microwave-baked products often suffer from poor quality, including hard textures, low volume, and uneven crust formation. Combining infrared (IR) with other methods has proven effective for improving baking outcomes, particularly for products with thick crusts. Sumnu et al. (2005a, b) and Sumnu (2001) found that cakes baked using a combined IR-microwave method exhibited reduced weight loss, softer texture, and higher volume compared to other methods. Shyu et al. (2008) reported that pound cakes baked with IR required less time than those baked in electric ovens, while sponge cakes baked with IR remained softer after 7 days of storage.

**4. Infrared Roasting**

IR roasting is widely used to enhance the flavor, texture, color, and overall quality of food products. Pulsed IR roasting, as demonstrated by Kumar et al. (2009), improved the quality of roasted groundnuts while reducing drying time compared to drum and sand roasting. Optimal results were achieved at temperatures of 178–188°C for 6.8–9.2 minutes. Combining IR roasting with microwaves further improved quality and reduced drying time to levels comparable with conventional methods. Uysal et al. (2009) demonstrated the effectiveness of IR-microwave roasting for hazelnuts, suggesting its applicability for other nuts. They also highlighted the significant influence of microwave and halogen lamp power on roasting outcomes.

## Application of Infrared Heating in Drying

**Overview of IR Drying**

Drying aims to remove moisture from food to inhibit microbial growth and spoilage. While conventional hot air drying is energy-intensive, time-consuming, and diminishes food quality, infrared (IR) drying overcomes these limitations. IR heating is efficient, preserving food color and nutrients like ascorbic acid while minimizing browning and enhancing lycopene content. Chen et al. (2015) demonstrated that short- and medium-wave IR radiation were superior to conventional methods for drying jujube, offering improved efficiency and control. Adjusting air velocity and emitter distance can further enhance drying precision (Nowak et al., 2004). Despite some drawbacks, IR drying's potential increases when combined with other drying techniques, such as freeze or hot-air drying, improving quality while reducing costs and drying time.

**Infrared and Hot-Air Drying**

Integrating IR heating with hot-air drying reduces drying time, energy consumption, and enhances product quality. Adak et al. (2017) found that increasing IR power, air temperature, and velocity expedited strawberry drying but noted that excessive IR intensity could impact color quality. Zare et al. (2015) highlighted that moderate IR intensity is optimal for achieving high-quality results.

**Infrared and Freeze-Drying**

IR-assisted freeze drying combines the energy efficiency of IR with the sublimation process of freeze drying, offering superior product quality and lower energy costs. Khampakool et al. (2019) emphasized the importance of dynamic control in IR-assisted freeze drying, which enhances process efficiency over traditional freeze drying.

**Infrared Vacuum Drying**

Vacuum drying paired with IR heating accelerates drying at low temperatures by leveraging reduced pressure for faster moisture removal. Alaei and Chayjan (2015) found that higher temperatures and lower pressures reduced drying time and improved moisture diffusivity, although lower conditions were better for preserving color and minimizing shrinkage. Salehi et al. (2017) demonstrated that pulsed IR vacuum drying improved color preservation in berries compared to hot air drying.

**Infrared and Microwave Drying**

IR-microwave drying effectively addresses challenges like uneven heating and cell damage associated with standalone microwave drying. Sumnu et al. (2005a, b) found that combined IR-microwave drying of carrots yielded higher quality, reduced drying time, and better color properties compared to hot-air or microwave-only methods. This combination is particularly beneficial for achieving low moisture content in dried products.

**Infrared Heating for Microorganism Inactivation**

Food materials are prone to microbial contamination due to exposure to contaminants like soil, impure water, insects, and waste (Eliasson et al., 2014). Infrared (IR) heating, beyond its use in drying, effectively inactivates microorganisms, extending food shelf life.

**Inactivation of Pathogenic Microorganisms**

Conventional dehydration may fail to inhibit certain pathogens capable of thriving in low-water activity conditions (Eliasson et al., 2014). IR heating, with its adjustable wavelength, targets microorganisms at varying depths. Far IR, with shallow penetration, is ideal for surface treatment, while near IR, with deeper penetration, addresses microorganisms throughout the food sample (Ramaswamy et al., 2012).

**Inactivation of Spores**

IR heating efficiently inactivates spores by controlling water activity. For example, during IR decontamination of oregano, increasing drying temperatures from 90°C to 100°C resulted in reduced log reduction (from 5.6 to 4.7), attributed to decreased water activity at higher temperatures (Eliasson et al., 2014).

**Infrared Pasteurization**

IR heating serves as a nonchemical pasteurization method. Bingol et al. (2011) demonstrated successful pasteurization of raw almonds, achieving over 5.5 log reductions in *Pediococcus* populations without affecting the almonds' appearance, flavor, or texture.

Surface pasteurization with IR requires shallow penetration, adjustable via wavelength. The heat generated during surface pasteurization can be retained to further inhibit microbial contamination, enhancing efficiency for industrial applications. IR pasteurization has shown efficacy in inactivating pathogens like *S. typhimurium* and *A. flavus* while maintaining low moisture, faster processing, and better food quality (Huang and Sites, 2008; Alkaya et al., 2016; Gande and Muriana, 2003). Combining IR with other methods can improve results.

**Advantages of Infrared Heating in Food Processing**

- **Energy Efficiency**: Direct energy transfer minimizes waste and enhances efficiency.
- **Rapid Heating**: Accelerates processing time, boosting productivity.
- **Improved Quality**: Ensures uniform heating, preserving nutritional and sensory attributes.
- **Precision Control**: Enables accurate regulation of temperature and intensity.
- **Versatility**: Applicable to various operations such as baking, drying, grilling, and blanching.
- **Hygienic Process**: Non-contact heating reduces contamination risks.
- **Water Conservation**: Particularly beneficial for drying, significantly reducing water usage.

**Disadvantages of Infrared Heating in Food Processing**

- **Surface Heating**: Primarily heats the surface; deeper layers rely on slower conduction, particularly for dense products.
- **High Initial Cost**: Installation and equipment costs are higher than conventional systems.
- **Risk of Overheating**: Improper control may cause surface burning or overheating.
- **Limited Depth Penetration**: Less effective for thick or irregularly shaped items.
- **Material Dependency**: Performance varies based on material absorption properties, requiring adjustments for reflective surfaces.
- **Maintenance Needs**: Regular upkeep and specialized expertise are required to maintain efficiency.

## CONCLUSION

Infrared (IR) heating is a valuable technology in food processing, offering benefits such as high energy efficiency, rapid processing, consistent heating, and enhanced product quality. Its versatility makes it ideal for various processes, including drying, blanching, cooking, baking, roasting, and microbial inactivation. Precise control over heating parameters ensures flexibility while minimizing contamination risks and conserving water. However, challenges like limited penetration depth, surface heating limitations, high upfront costs, and reliance on material properties persist. Integrating IR heating with complementary techniques can help overcome these challenges, delivering optimized results in efficiency, quality, and cost-effectiveness.

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