Exploring the Application of Radio Frequency (RF) Heating in Food Commodities: Eco-Friendly Disinfestation

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India, a significant global food producer, is actively addressing the challenge of minimizing food waste at different stages, including production, processing, retail, and consumption. This involves investing in local initiatives and partnering with international investors to adopt best practices and advanced technology. The production of sustenance, approximately 10% of it is being lost amid postharvest operations between the field and the consumers. This results in about 15 million tons of wasted food grains annually, valued at approximately 2400 million Indian rupees. Insects significantly contribute to post-harvest losses in legumes and grains, occurring during the storage phase before reaching the end user in the market. Infestations in stored grains can lead to weight loss, reduced viability, loss of nutritional quality and financial losses, making the grains unsuitable for consumption.

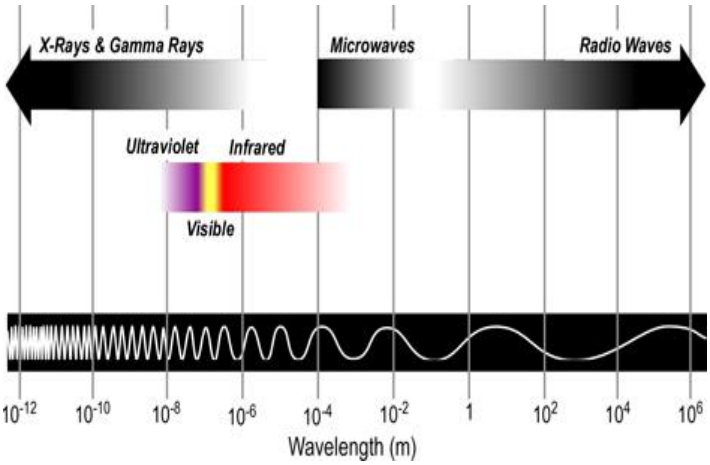
Disinfestation of insects in warehouses during storage is a critical unit operation for extending the shelf life of agricultural commodities. Traditional thermal methods are slow and may harm food quality through prolonged heating. Chemical treatments, while effective, are discouraged due to environmental concerns, residual effects and studies have shown increasing insect tolerance to pesticides in recent years. Hence, it is imperative to adopt eco-friendly disinfestation methods to safeguard the safety and quality of food products. In this context, the introduction of radio-frequency heating technology emerges as a viable alternative to the current chemical practices employed in warehouses and industries.

RF Heating Technology

Radiofrequency waves

Radiofrequency waves are a type of electromagnetic radiation that constitutes distinct frequencies and wavelengths as shown in Fig.1. It has longer wavelengths but lesser frequency than microwaves which are situated in the range of radar which are used in communication fields. Novel electromagnetic wave techniques are enticing the researchers as they leave no toxic substances in the food product and for not induce insect resistance. Radiofrequency waves range from 1-300 MHZ, whereas 13.56, 27.12 and 40.68 MHz are reserved for commercial, technological and medical purposes, to prevent possible interference with other spectrum users.

Fig. 1 Radiation – Electromagnetic spectrum



Higher penetrative intensity, heating efficiency, minimized thermal impact on product quality, shortened treatment time, easy to apply, no environmental contaminants and low energy consumption addresses RF heating as an advanced technology. In RF heating, water molecules present in the insects are continuously spinning and develop friction with cell organelles, which contributes to cell disruption resulting in death. Thus, all stages of insects can be killed without any adverse effects on quality of the product with the application of optimized RF electrode current and product exposure time concerning the lethal temperature of insects.

RF Heating – Working Principle in disinfestation

Radio Frequency heating involves the application of electromagnetic energy to generate heat within the targeted material. In this system, the RF generator establishes an alternate electric field between the electrodes and the material, consisting of atoms and molecules. While some molecules are electrically neutral, the majority are bipolar. The substance to be heated is positioned between the electrodes. The alternating electric field, oscillating at

40.68 MHz (equivalent to 40,680,000 cycles per second), induces polarization, causing molecules to reorient themselves in the opposite direction. When the electric field is applied, the bipolar molecules act like miniature magnets, aligning with the field. This phenomenon occurs due to the presence of water molecules in both, serving as dielectric materials. In insects, these water molecules undergo continuous spinning, generating friction with cell organelles. This friction leads to cell disruption and, ultimately, the death of the insects. Consequently, employing optimized RF electrode current and product exposure time in alignment with the lethal temperature of insects ensures the eradication of all insect stages without compromising the quality of the product.

During RF treatments, heat is generated within the product due to molecular friction resulting from the movement of oscillating dipole molecules, space charge displacement, and the migration of ions triggered by the applied alternate electric field, as illustrated in Fig. 2.

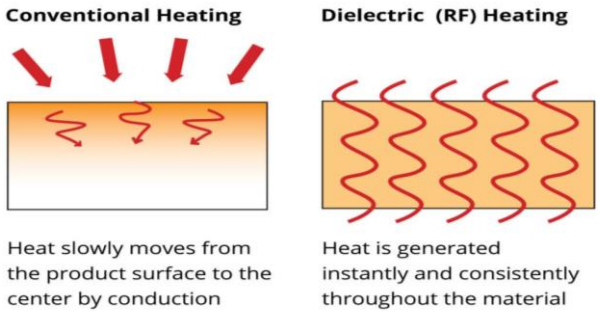
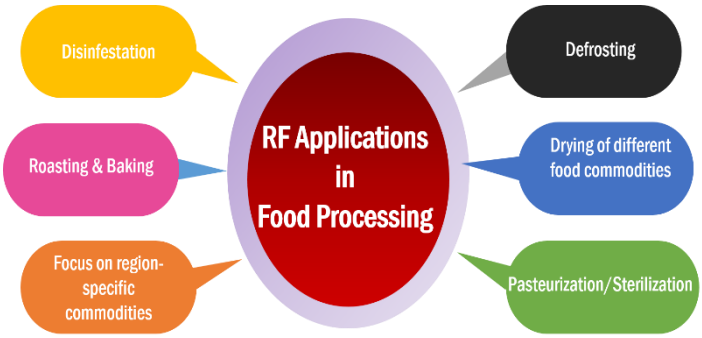


Fig. 2 Mechanism involved in Conventional heating and RF heating

RF Heating System

Two types of RF heating systems are widely applied in the food industry and research, which include free-running oscillators and 50 Ω RF systems. Among these, free running oscillator parallel-plate system is the most applied in the food grains and their products processing research. RF energy in this system is generated by the standard oscillator circuit formed by the triode tubes. Two electrodes and the loaded products between them could form a tuning circuit and be inductively coupled with the output circuit, which results in heat generation. The energy coupled within the product is adjusted by the moveable top electrode and the products can be moved through the RF electromagnetic field by a conveyor belt to achieve a continuous heating processing. The advantages of free free-running oscillator system include high efficiency, simple structure and low cost. However, the capacitance of the working circuit could be changed during RF heating due to the changes in electrode gaps and DPs of products, which would lead to a change in the system frequency.

Fig. 3. Applications of RF treatment in food grains and their product processing



RF Disinfestation Applications in the Food Industry

Numerous research studies have focused on RF heating to suppress the proliferation of insects in farm produce. RF heating has been extensively studied in research laboratories and a few studies are 100% disinfested in-shell walnuts with *Amyelois transitella*, navel orange worm, complete disinfestation of *Cydia pomonella*, codling moth in in-shell walnuts and *Rhyzopertha dominica*, lesser grain borers present in rough rice. Disinfestation of *Plodia interpunctella*, Indian meal moth and *Callasobruchus maculatus*, cow pea weevil using RF heating with a treatment temperature of 55-58 °C for 5-10 min resulted in 100% mortality and no detrimental consequences on legume germination and quality was reported. An efficient treatment approach has been developed to manage *sitophilus oryzae* in milled, rough and brown rice without significant degradation of quality. Radiofrequency energy provides the prospect of rapidly rising temperature in bulk materials such as rice and wheat flour. Experimental studies on stored rapeseeds revealed that 100 % mortality *of T. castaneum* could be achieved at 80 °C for adults and 60 °C for larva phases at different moisture content levels, without significant degradation in seed quality with appropriate RF heating parameters. The red flour beetle, *T. castaneum* is the most strongly connected

insect with the post-harvest infestation, worldwide and the major insect that is present in wheat flour.

Disinfestation of all life stages of grain borers and *Angoumois* grain moths by establishing a correlation between temperature and disinfestation effects. This correlation was instrumental in optimizing the Radio Frequency (RF) protocols for rough rice. Notably, a 100% mortality rate was observed after a 2-hour treatment for grain moths and a 1-hour treatment for Angoumois grain moths, with no emergence of insects during a 120-day storage period. RF disinfestation of wheat flour achieved a 100% disinfestation of *T. castaneum* by employing optimized RF parameters.

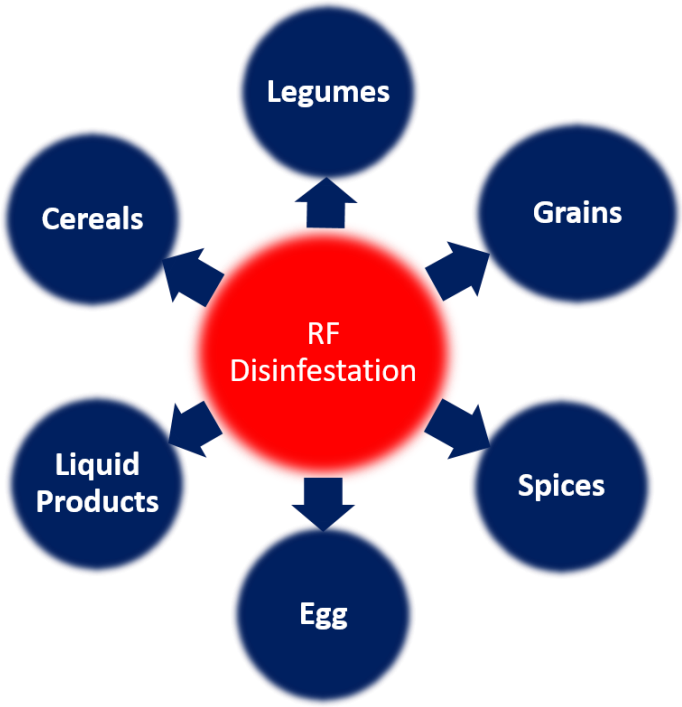


Fig. 4. Applications of RF treatment in various product processing

Conclusion

The advantages of Radio Frequency (RF) Disinfestation lie in its notable benefits for food production. RF heating provides a chemical-free solution, ensuring cleanliness and safety. It enables precise temperature control, preserving the nutritional quality and characteristics of food. The method's energy efficiency reduces overall energy consumption compared to conventional approaches. RF disinfestation also contributes to environmental sustainability by eliminating the need for chemical pesticides. Despite requiring an initial investment, the long-term advantages, such as reduced reliance on pesticides and improved energy efficiency, result in cost savings. The promising future of RF heating aligns with sustainability goals, making it an eco-friendly and high-quality processing method. In conclusion, the exploration of RF heating signifies a significant step towards innovative and sustainable solutions in the food industry, with the potential to reshape practices and contribute to an environmentally conscious and resilient food supply chain.

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