



Sustainable Food Drying Enhancing Efficiency, Nutrition, and Waste Reduction in Food Production

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Article Info	ABSTRACT
<p>Corresponding Author: Nnadikwe Johnson E-mail: Nnadikwe.johnsonnnadikwe@grpng.org</p>	<p>Food drying is crucial for ingredient innovation and product development. Recent breakthroughs in pretreatments, processes, and technologies like microwave and ultrasound drying have transformed the industry, boosting efficiency, preserving nutrients, and reducing waste. These innovations promote sustainability, enabling resource-efficient and technologically advanced food production. Wider adoption of these cutting-edge technologies is crucial to maximize their impact. By embracing modern drying methods, businesses can enhance sustainability, improve production, and increase profitability while preserving nutritional value. This study bridges research and practice, showcasing the benefits of modern drying technologies for sustainable food systems. By adopting these innovations, businesses can foster sustainability, reduce waste, and gain a competitive edge, paving the way for a more efficient and sustainable food future</p> <p>keywords: Modern, Drying Methods, Quality, Energy, Utilization, Efficiency</p>

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INTRODUCTION

Food drying is a crucial process in food production that enables ingredient innovation and product development. Recent advancements in drying technologies like microwave and ultrasound drying have transformed the industry, improving efficiency, preserving nutrients, and reducing waste. These innovations promote sustainability, enabling resource-efficient and technologically advanced food production. Drying is a pivotal preservation method in food processing, impacting product quality, nutritional value, and waste generation (Mujumdar, 2014; Tsotsas & Mujumdar, 2014). Traditional drying methods often compromise nutritional quality and energy efficiency (Chen & Mujumdar, 2009). However, cutting-edge technologies like microwave and ultrasound drying are reshaping the industry, offering enhanced efficiency, quality preservation, and sustainability (Nowacka et al., 2023; Roobab et al., 2022). The adoption of these technologies can improve production processes, reduce environmental impact, and increase profitability (Johnson & Chigozie, 2024). The literature highlights the potential of modern drying technologies in achieving sustainable food production, but wider dissemination and adoption are crucial to maximize their impact (Athira et al., 2022; Zielinska et al., 2020).

Food drying is a cornerstone of food production, enabling ingredient innovation, product development, and preservation. As the global food industry grapples with sustainability challenges, efficient drying technologies are crucial for reducing waste, preserving nutrients, and minimizing environmental impact. Recent breakthroughs in cutting-edge drying methods like microwave, ultrasound, and infrared drying have transformed the landscape, offering opportunities to enhance resource efficiency, product quality, and sustainability. The increasing demand for nutritious, minimally processed foods underscores the need for sustainable drying practices. Traditional methods often compromise nutritional value and energy efficiency, highlighting the importance of adopting modern technologies. This research explores how sustainable food drying can enhance efficiency, preserve nutrition, and reduce waste, aligning with industry goals for eco-friendly production.

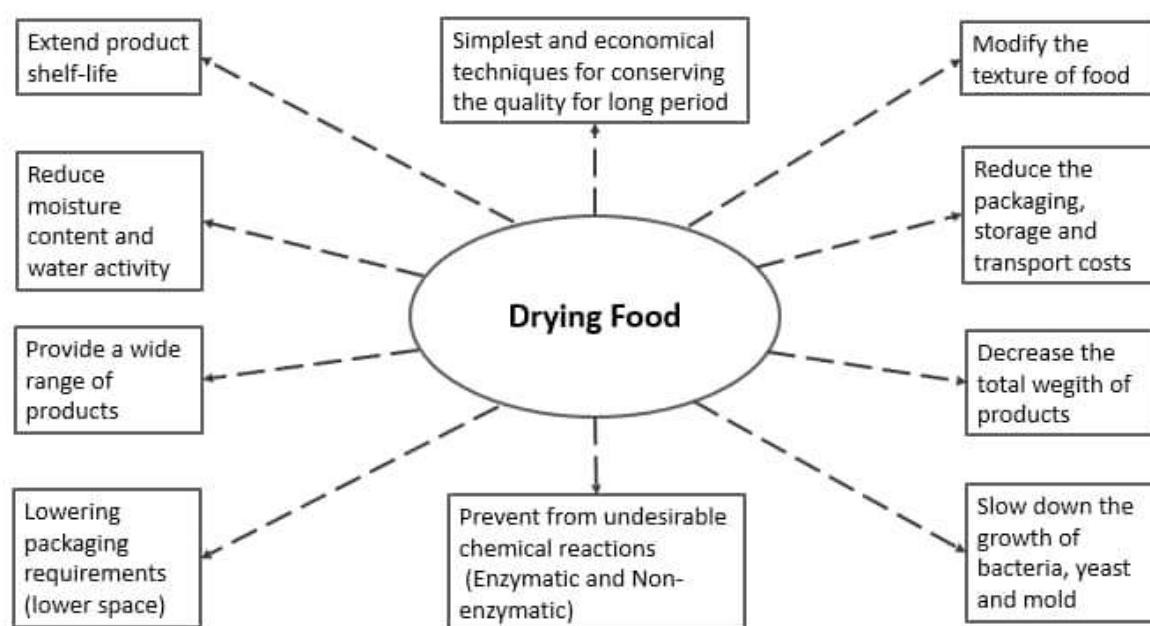


Fig. 1: Modern drying research and development drives

The significance of advancing state-of-the-art food drying methods to optimize efficiency, preserve nutritional value, and minimize waste in contemporary food production is multi-fold:

1. **Enhanced sustainability:** By improving the efficiency of food drying processes, we can reduce energy consumption and minimize the environmental footprint associated with food production. This contributes to a more sustainable and resource-efficient food system.
2. **Reduced food waste:** Optimal drying methods help preserve the nutritional value of food while extending its shelf life. This translates to less food waste throughout the supply chain, addressing the global challenge of food loss and waste.
3. **Improved food quality:** State-of-the-art drying methods help maintain the quality, flavor, and nutritional content of food. This ensures that consumers have access to nutritious and safe products, promoting their well-being and satisfaction.
4. **Economic benefits:** Efficient drying methods can lead to cost savings in food production, as they optimize energy and resource usage. Additionally, by

minimizing waste, businesses can reduce financial losses associated with discarded products.

5. Innovation and competitiveness: Advancements in food drying methods drive innovation in the food industry. Businesses that adopt and implement these technologies gain a competitive edge by offering high-quality products with improved sustainability credentials.

Food security and accessibility: By preserving the nutritional value of food through optimized drying methods, we can ensure a steady supply of nutritious food. This contributes to addressing global food security challenges and enhancing access to safe and nutritious food for all. Overall, advancing state-of-the-art food drying methods holds significant importance in achieving a more sustainable, efficient, and resilient food system that benefit both the environment and system.

The deliverables of advancing state-of-the-art food drying methods to elevate sustainability in design and optimize efficiency, preserve nutritional value, and minimize waste in contemporary food production can be aligned with the Sustainable Development Goals (SDGs) in several ways:

1. SDG 2: zero Hunger: By optimizing food drying methods, we can minimize food waste and ensure that nutritious food remains available for consumption. This contributes to achieving the goal of ending hunger and achieving food security.
2. SDG 3: Good Health and Well-being: Preserving the nutritional value of food through advanced drying methods ensures that people have access to nutrient-rich and food, promoting good health and well-being.
3. SDG 12: Responsible Consumption and Production: Improving efficiency in food drying processes reduces resource consumption and waste generation, aligning with the goal of promoting sustainable consumption and production patterns.
4. SDG 13: Climate Action: Energy-efficient drying methods and reduced waste contribute to lowering greenhouse gas emissions and mitigating the impact of climate change.
5. SDG 15: Life on Land: Minimizing waste in food production helps to protect natural resources and ecosystems, promoting sustainable land use and biodiversity conservation. The deliverables, when viewed through the lens of the SDGs, demonstrate a commitment to sustainable development by addressing various aspects of food production, resource management, and environmental impact. By optimizing food drying methods, we can contribute to achieving multiple SDGs and fostering a more sustainable and resilient food system.

MATERIAL AND METHOD

Drying Technologies, Modern Drying Technologies

Advanced Drying Technologies The implementation of state-of-the-art drying technologies is crucial in the drying process of food products, including fresh fruits and meats. These advanced methods leverage the ability of gases to permeate solids, thus effectively controlling the drying process. By utilizing innovative techniques, we can optimize efficiency, preserve nutritional value, and minimize waste in modern food production.

Ultrasound-Assisted Drying.(UAD)

Enhancing Efficiency and Quality Preservation Ultrasound-assisted drying is a cutting-edge technique that holds immense potential in optimizing efficiency and preserving the quality of food products. By harnessing the power of ultrasound waves, this advanced drying method enhances the drying process by promoting better moisture removal and reducing drying time . The application of ultrasound waves induces vibrations within the food material, facilitating the release of moisture, and facilitating efficient drying. Moreover, ultrasound-assisted drying offers additional benefits such as improved nutritional retention and minimized thermal degradation. The gentle and controlled nature of ultrasound waves minimizes the exposure of food products to high temperatures, thereby preserving their nutritional value and sensory attributes . This technique also aids in reducing the risk of over-drying or under-drying, ensuring the optimal moisture content in the final product. By incorporating ultrasound-assisted drying into contemporary food production, we can elevate sustainability in design by optimizing energy usage, reducing waste, and maintaining the overall quality of dried food products.

High power ultrasound dehydrates faster at low temperatures, reducing food deterioration . Fig. 2 depicts an experimental ultrasound-assisted freeze dryer setup. It's a promising prototype of an innovative freeze-drying technology. The freeze-drying process itself or intermittent ultrasonic power application may regulate temperature generation by ultrasonic treatment in such systems. Unlike traditional drying, this method removes moisture without changing the liquid phase . The impact of ultrasonic energy on raising appropriate water dispersibility and lowering boundary layer thickness reduces processing time (up to 11.5%, according to Schossler et al. Aside from this, additional synergistic approaches may be used, such as the dehydration produced by osmotic pressure

Ultrasound has also been researched in conjunction with other drying processes. Recent uses include ultrasound-assisted osmotic dehydration hot air drying , and infrared drying . However, difficulties with big mass load densities must be addressed at commercial scale-up.

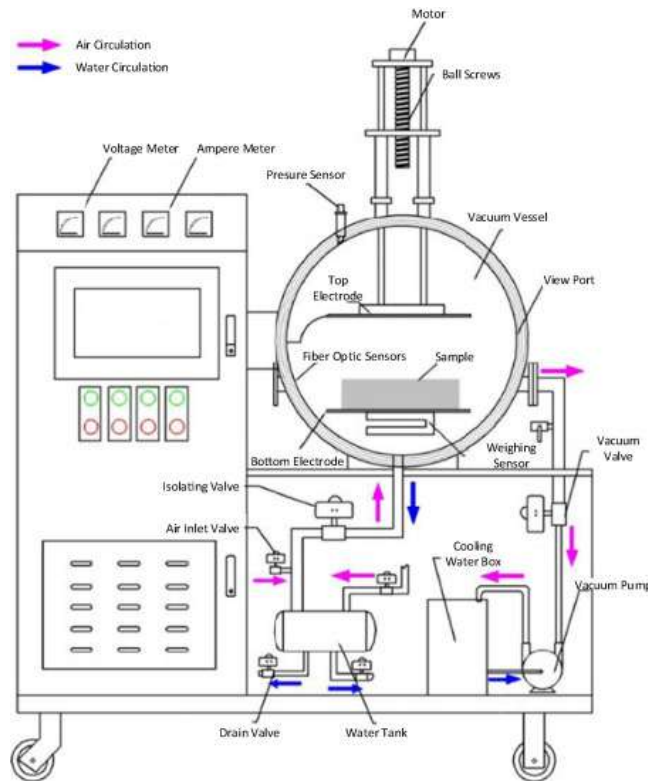


Fig 2: System for ultrasonic freeze-drying

Microwave -Assisted Drying(MAD)

Microwave-Assisted Drying: Innovation in Dehydration Microwave drying is an innovative technique that utilizes microwave radiation with wavelengths ranging from 1 mm to 1 m. Specifically, frequencies of 915 and 2,450 MHz are commonly employed for culinary purposes. As a non-ionizing form of radiation and a fourth-generation technology, microwaves offer unique advantages in the drying process. The application of microwave-assisted drying has gained significant popularity in recent years. Researchers have explored the potential of combining microwave-assisted drying with other approaches to address various drying concerns, as outlined in Table 1. This synergistic approach aims to optimize drying efficiency, enhance the preservation of nutritional value, and improve the overall quality of dried food products. By harnessing the power of microwaves, the drying process becomes more efficient and precise. The targeted heating and penetration depth of microwaves facilitate faster moisture removal, reducing drying time and energy consumption. This approach also minimizes the risk of thermal degradation, as the shorter drying period helps retain the nutritional content, flavor, and color of the food products. Integrating microwave-assisted drying into contemporary food production practices contributes to the advancement of sustainable design by reducing waste, optimizing energy usage, and delivering high-quality dried food products. This innovative dehydration method holds tremendous potential in revolutionizing the food industry's drying processes.

Table 1: MW-assisted drying Techniques

Technique
MW? air dryer
MW? vacuum dryer
MW? spouted bed drying

MW? freeze drying
MW ? fluidity bed dryer
MW? foam matt dryer

Table 1: Microwave-Assisted Drying Techniques Technique Microwave-Air Dryer Microwave-Vacuum Dryer Microwave-Spouted Bed Drying Microwave-Freeze Drying Microwave-Fluidized Bed Dryer Microwave-Foam Mat Dryer These techniques involve the incorporation of microwave technology into various drying methods to enhance efficiency and improve the quality of dried food products. Each technique utilizes microwaves in a specific manner to address different drying concerns, optimize drying parameters, and achieve desirable results. By leveraging the unique capabilities of microwaves in these different drying techniques, we can elevate sustainability in design and advance the state-of-the-art in food drying methods.

While microwave technology can be used in conjunction with various drying systems, the specific type of dryer and the drying temperatures employed have a significant impact on the drying rate and quality of the final product. This phenomenon is well illustrated in the research conducted on potato slices. Figure 3 showcases a specialized microwave heater designed specifically for drying purposes. Through a chemical interaction with an electromagnetic field, microwave heating energy is directly delivered to the substance being dried. The effectiveness of this dielectric heating concept relies heavily on the dielectric properties and loss modulus of the product being processed.

Indeed, the moisture content and dielectric characteristics of the product play crucial roles in microwave drying. Research has shown that intermittent microwave drying outperforms convective microwave drying in terms of efficiency and preservation of product quality. This is because intermittent microwave power reduces exposure duration and the risk of overheating, while also conserving energy. Additionally, MAD has proven to be effective for various food ingredients. It offers advantages such as improved product quality, which can sometimes exceed that of freeze-dried foods. Moreover, this drying method often requires reduced floor space compared to other traditional drying techniques. By leveraging the unique capabilities of microwave technology, we can enhance the efficiency, quality, and sustainability of the drying process, making it a promising approach in the food industry.

MAD has proven to provide better process control in various applications. It has been successfully utilized to dry macadamia nuts, increasing commercial yields and improving kernel quality. Similarly, in the case of spinach, microwave drying helps reduce quality losses that may occur due to over-heating. Carrots can also benefit from microwave drying, as it helps improve their hydration capacity. Furthermore, microwave drying is often employed for finish drying to manage the final moisture content of the product effectively. However, it's worth noting that challenges still exist with non-uniform heating, which can result in hot and cold areas during the heating process. Researchers, such as Wang et al., are actively working to address these challenges and further improve the MD technology. Overall, microwave-assisted drying offers significant advantages in terms of process control, yield improvement, quality preservation, and moisture content management. Continued research and advancements in this field will further enhance its effectiveness and address any remaining challenges.

It's fascinating to learn that variations in magnetron layout and quantity can have a significant impact on drying uniformity, resulting in over an 80% difference. This finding highlights the importance of optimizing the design and configuration of microwave systems for achieving consistent and uniform drying results. While there is existing published work on microwave-assisted drying, it is true that most of it focuses on laboratory-scale systems. To effectively apply this technology in large-scale food production, further research is indeed necessary. Scaling up MD processes involves addressing additional factors such as system design, energy efficiency, process control, and cost-effectiveness. By expanding research efforts in this area, we can bridge the gap between laboratory-scale experiments and practical implementation in commercial food production. Collaborative efforts from researchers, engineers, and industry professionals are crucial to advancing microwave-assisted drying technology and its applications in the food production sector. With continued research and development, we can unlock the full potential of MD for efficient and uniform food production on a larger scale.

Modern Drying Methods

Modern drying methods have evolved significantly, offering improved efficiency, quality, and sustainability in the drying process. Here are a few notable modern drying methods:

1. **Microwave Drying:** As we discussed earlier, microwave drying utilizes microwave radiation to generate heat directly within the product. This method allows for faster drying, reduced energy consumption, and better preservation of nutritional content and product quality.
2. **Freeze Drying:** Freeze drying involves freezing the product and then subjecting it to a vacuum, causing the ice to sublime directly from solid to vapor. This method is commonly used for preserving delicate or heat-sensitive products, as it helps retain their original texture, flavor, and nutritional value.
3. **Spray Drying:** Spray drying involves atomizing a liquid product into small droplets that are rapidly dried by hot air or gas. The droplets are suspended in the air, allowing for quick evaporation of moisture. This method is widely used in the food industry for producing powdered products such as milk powder, coffee, and instant soup mixes.
4. **Vacuum Drying:** Vacuum drying removes moisture from the product by subjecting it to reduced pressure, lowering the boiling point of water and facilitating faster evaporation. This method is often used for heat-sensitive materials and helps maintain product integrity and quality.
5. **Superheated Steam Drying:** Superheated steam drying involves using steam at high temperatures to remove moisture from the product. The high heat transfer efficiency of superheated steam allows for rapid drying while reducing energy consumption.
6. **Fluidized Bed Drying:** Fluidized bed drying involves suspending the product in a stream of hot air or gas, creating a fluidized bed of particles. This method allows for efficient heat and mass transfer, resulting in faster and more uniform drying.

These modern drying methods leverage advanced technologies and techniques to optimize the drying process, improve product quality, and reduce energy consumption. By adopting these methods, industries can enhance their drying operations and contribute to sustainable and high-quality product manufacturing.

Figure 4 showcases an industrial refractance window drying device. In this setup, the wet feed material is spread out in a thin layer onto a plastic conveyor belt. The material receives thermal energy from hot water, and the drying process primarily involves the transfer of sensible heat from water to the dry feed ingredients through

conduction. The hot water itself is heated through a combination of conduction and radiation mechanisms. The water in the drying substance absorbs electromagnetic

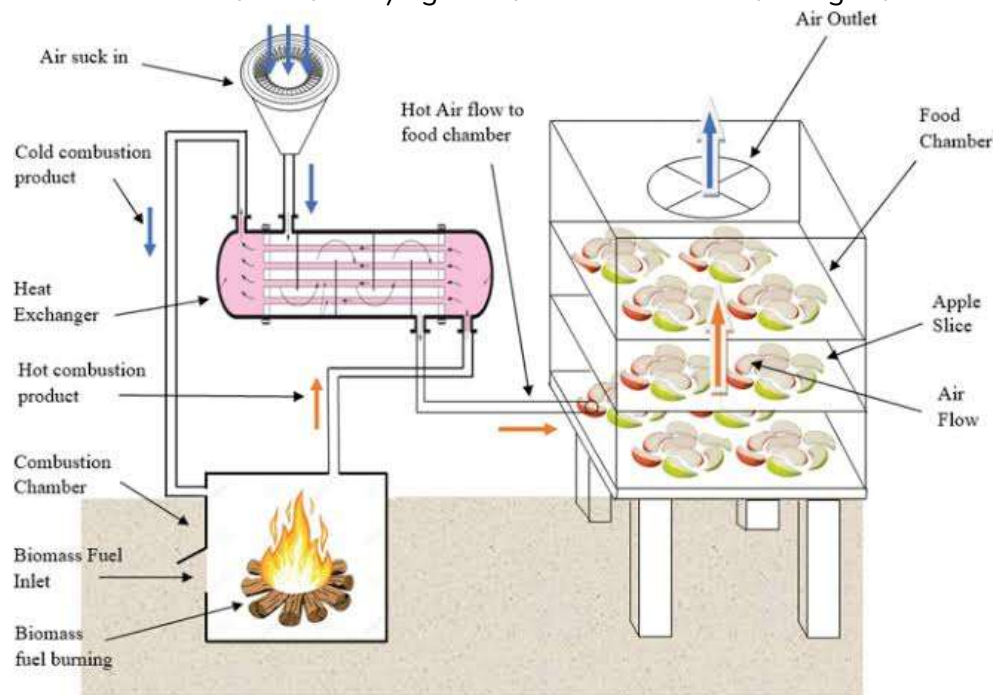


Fig 3: Air-drying method with MW

radiation. The 'infrared window' generated after drying eventually closes. From here, conduction is the major heat transport route. When the belt comes in touch with hot water, it dries quickly. This is done using doctor blades.

Minimizing drying time can indeed result in improved product quality. For instance, studies have shown that refractance window drying of strawberries and carrot purees led to better retention of quality attributes. This method is also known to help preserve the natural color, vitamins, and antioxidants of the dried products, while simultaneously enhancing thermal efficiency and cost effectiveness. In recent times, refractance window drying has found commercial applications in various sectors, including the production of herbal products (such as aloe vera), nutritional supplements, as well as dried fruits and vegetables, scrambled egg mixtures, and avocado powders. The system's inadequate capacity is a serious flaw. Also, high-sugar powders are difficult to manage (due to their hygroscopic nature, they are very sticky).

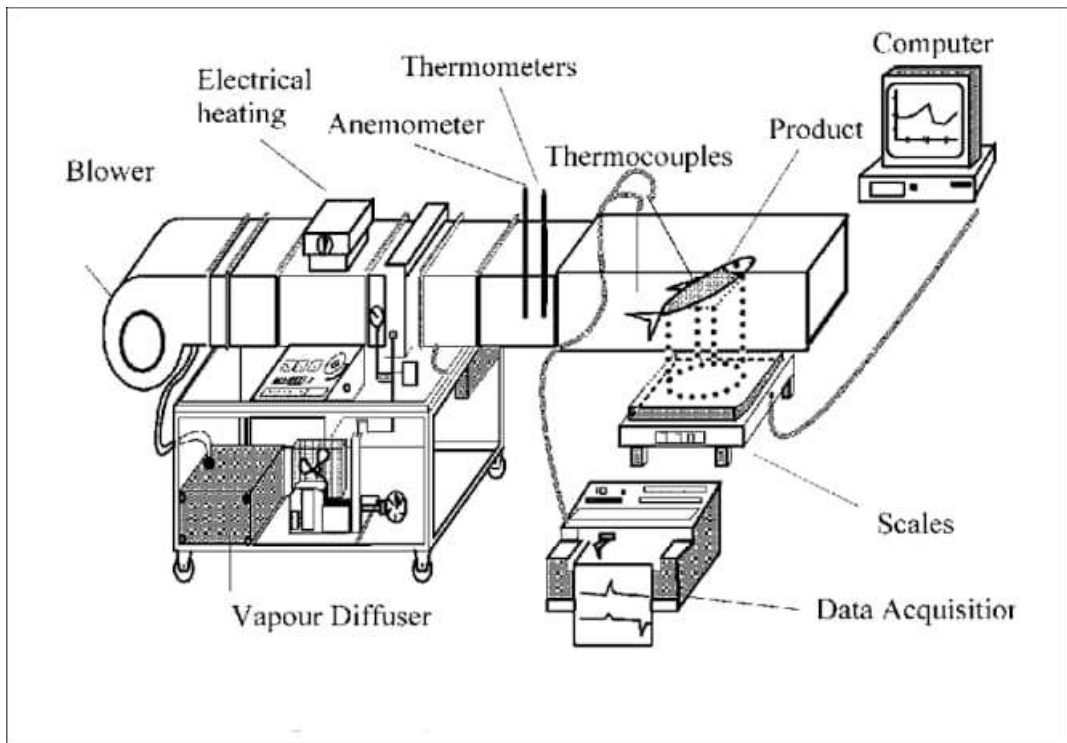


Fig. 4: RW-drying method .

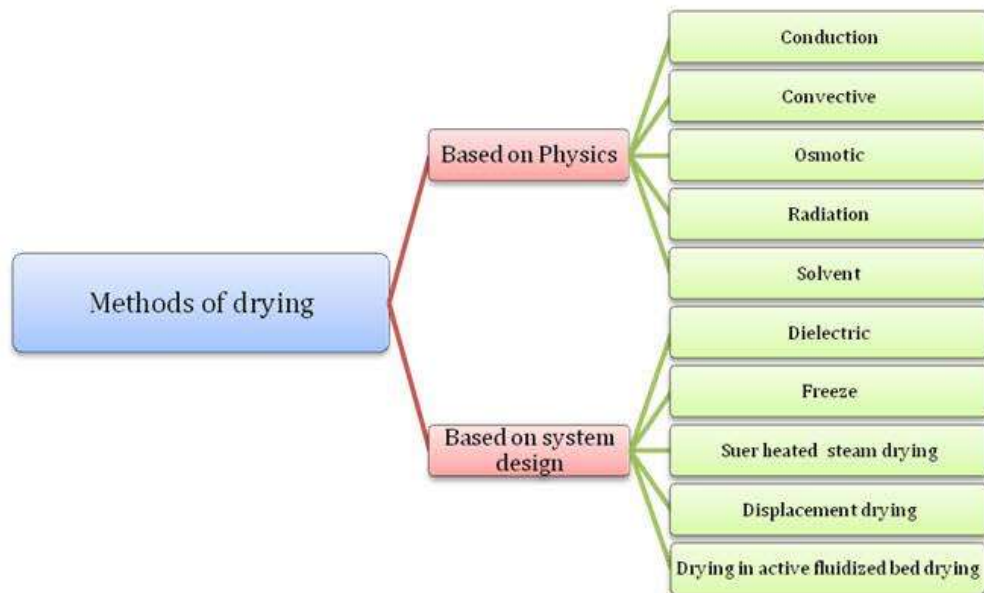


Fig. 4b: RW-drying method

Superheated Steam Drying

Superheated steam (SS) is steam that is hotter than saturation steam at a given pressure. Hot superheated steam at atmospheric pressure may dehydrate materials up to 100°C. Compared to traditional drying, it has longer constant rate durations and lower critical moisture concentrations. Superheating seems to be the major process parameter when operating pressures are reduced. With SSD, you get stronger microbicidal and insecticidal results with less danger of fire and explosion.

Fig. 5 depicts an industrial SD dryer arrangement. Any convective dryer may be converted to a superheated steam drier by adding superheated steam. When

superheated steam is poured over food, it causes boiling and steam to escape from the product. This has been demonstrated to improve product porosity. After removing moisture from the product, superheated steam becomes saturated. This device in a sugar plant reduced dryer equipment and operational expenditures by 15%. While traditional drying causes difficulties including browning, dust explosion, and burning, SS drying improves product quality and safety, as shown in the case of oil palm empty fruit bunches .

Drying wasted grain with superheated steam at 150 C was also utilised. Superheated steam was shown to be a good alternative for the product without affecting the protein or phenolic content]. Other heat-sensitive goods such as pepper seeds , basil , and omega-3 fatty acid rich mackerel press-cake may also benefit from the faster drying time. Using superheated steam to dry and prepare fresh Asian noodles is an intriguing application . The product's drying kinetics was also investigated. Mathematical modelling described procedure drying rates. The noodles have good textural qualities

. This may be useful for items like cereals and certain snacks that need both drying and puffing. Also, since air isn't used to dry, the procedure is less prone to oxidation (whose rates increase with decreasing water activity). Based on a semi-empirical model, investigated the effects of sugar and salt solution on effective diffusivity in seasoned and unseasoned pork. Simulates hot steam-drying temps near 140 C. To combat delayed drying, far-infrared radiation may be employed with superheated steam drying. Studies on banana have shown positive outcomes . Problems with SSD methods include the need for simpler systems and the possibility of condensation and glass transition deterioration.

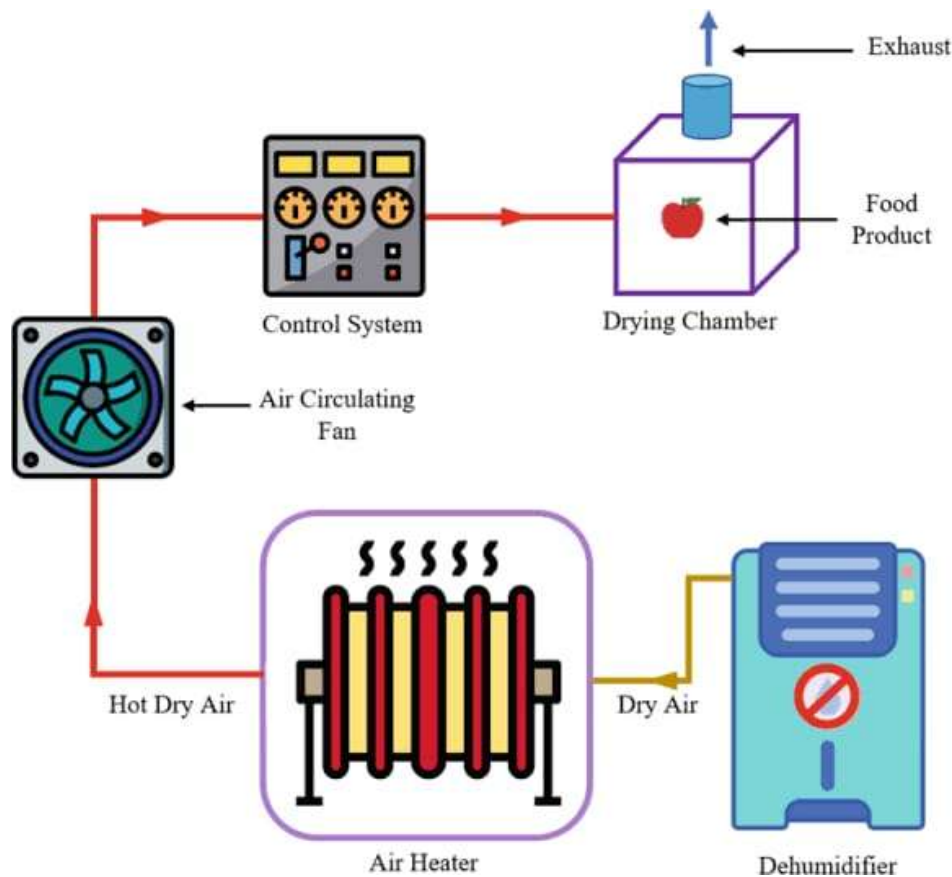


Fig 5: SS-drying method

High-Electric-Field Drying

High-Electric-Field Drying is an emerging technology in the field of food processing that utilizes electric fields to accelerate the drying process. This innovative method offers several advantages, including shorter drying times, reduced energy consumption, and improved product quality. By applying high electric fields during the drying process, moisture removal is enhanced, resulting in faster and more efficient drying of food products. Additionally, this technique can help preserve the nutritional content of foods and minimize quality degradation, making it a promising approach for optimizing food drying methods in contemporary food production. By incorporating this innovative technology into food drying processes, we can optimize efficiency, preserve nutritional value, and minimize waste in contemporary food production. The utilization of High-Electric-Field Drying in this research can offer benefits such as faster drying times, reduced energy consumption, and improved product quality. The high electric fields can help accelerate the moisture removal process, leading to more efficient drying of food products. Additionally, this method can contribute to retaining essential nutrients in food items and maintaining their overall quality during the drying process. By exploring the application of High-Electric-Field Drying in the research on sustainable food drying methods, we can further advance state-of-the-art techniques to promote sustainability, enhance food production practices, and address key challenges in the food industry.

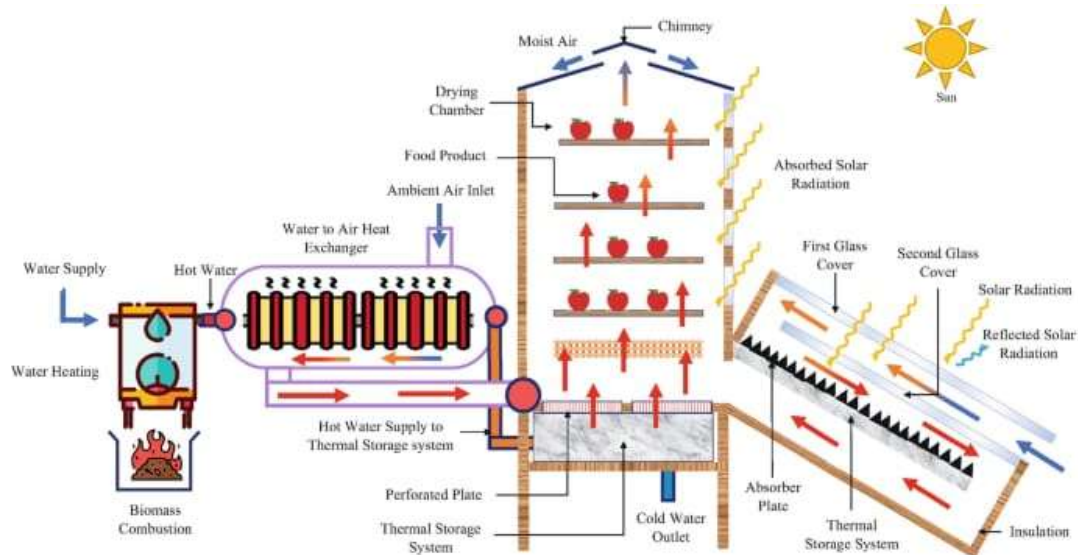


Fig 6: HEF-drying method

Infrared Drying (MD) method represents a cutting-edge and highly advanced approach to enhance sustainability in design within the realm of food drying. This method harnesses the power of infrared radiation to achieve remarkable improvements in efficiency, preservation of nutritional value, and waste reduction in contemporary food production. By utilizing infrared radiation, the Infrared Drying (MD) method revolutionizes the traditional drying process. It capitalizes on the direct transfer of heat to the food surface, leading to significantly shorter drying times and reduced energy consumption. This advanced technique not only increases productivity but also contributes to a greener and more sustainable approach to food drying by minimizing resource usage. Moreover, the Infrared Drying (MD) method goes beyond mere efficiency gains. It prioritizes the preservation of the nutritional value of food products during the drying process. By carefully controlling the application of infrared radiation, this method ensures that essential vitamins, minerals, and other nutrients remain intact, resulting in dried food with enhanced nutritional quality. In essence, the Infrared Drying (MD) method serves as an exceptional tool to propel the field of food drying into a more advanced and sustainable future. Its ability to optimize efficiency, preserve nutritional value, and minimize waste paves the way for a more innovative and eco-friendly approach to contemporary food production.

Infrared Drying(MD) method

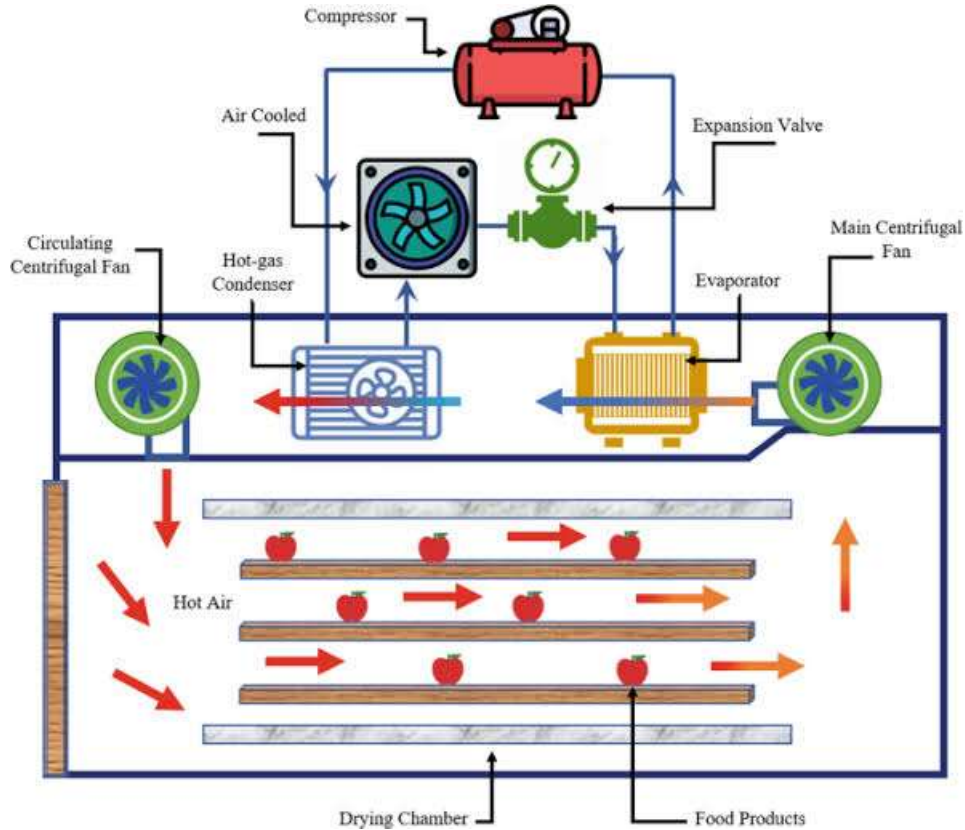


Fig 7a: CIR-drying method .

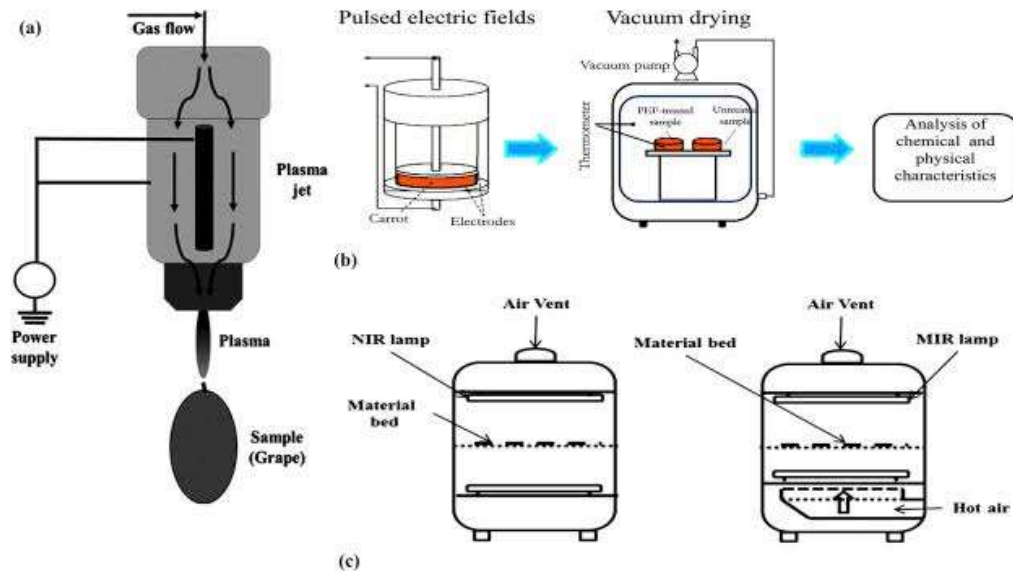
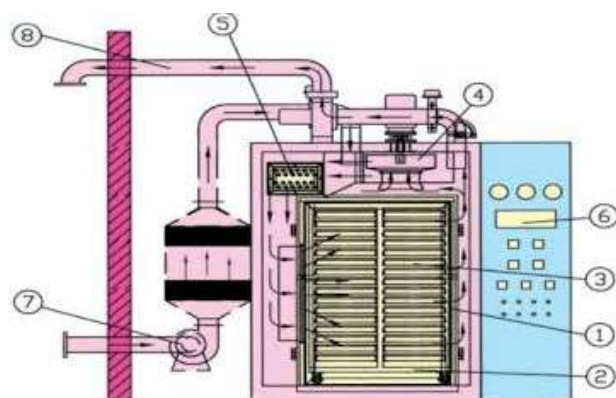


Fig 7b: CIR-drying method .

Drying Methods

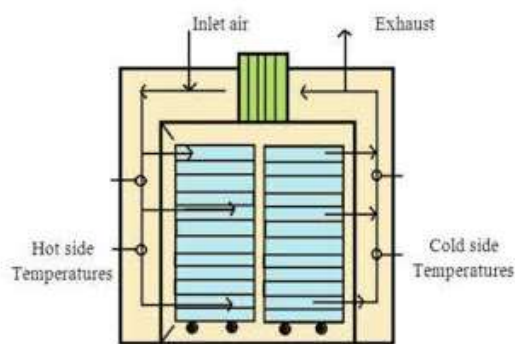
In addition to the Infrared Drying (MD) method, there are several other drying methods that can be explored to further advance sustainability in design within the context of food production. These methods offer unique characteristics and benefits that contribute to optimizing efficiency, preserving nutritional value, and minimizing waste.

1. **Freeze Drying (FD):** Freeze drying is an advanced technique that involves freezing food products and then subjecting them to a vacuum environment. This method enables sublimation, where ice directly transitions from a solid to a gaseous state, bypassing the liquid phase. Freeze drying offers exceptional preservation of both the physical structure and nutritional content of the food, resulting in high-quality dried products with minimal loss of flavor, color, and nutrients.
2. **Vacuum Drying (VD):** Vacuum drying is a method that involves subjecting food products to reduced pressure conditions, which lowers the boiling point of water. By applying heat under vacuum, moisture is effectively evaporated from the food, allowing for gentle drying and preservation of the product's natural attributes. Vacuum drying minimizes the risk of overheating or damaging sensitive food components, leading to improved retention of nutrients and overall product quality.
3. **Spray Drying (SD):** Spray drying is a widely used method in the food industry that involves atomizing a liquid food product into fine droplets, which are then exposed to hot air. As the liquid droplets come into contact with the hot air, rapid evaporation occurs, resulting in the formation of dried particles. Spray drying offers advantages such as high production rates, control over particle size, and the ability to encapsulate sensitive ingredients. However, it may lead to some nutrient loss due to the exposure of the food to high temperatures.
4. **Drum Drying (DD):** Drum drying is a method that involves spreading a thin layer of food product onto the surface of a heated drum. As the drum rotates, the moisture within the food evaporates, leaving behind a dried product. Drum drying is known for its ability to retain flavors and colors and is commonly used for producing dried products such as flakes and powders. However, it may have limitations in preserving heat-sensitive nutrients. By exploring and analyzing these various drying methods, in addition to the Infrared Drying (MD) method, you can gain a comprehensive understanding of how each technique contributes to advancing state-of-the-art food drying methods. This knowledge can aid in optimizing efficiency, preserving nutritional value, and minimizing waste in contemporary food production, thus furthering the goals of your research in elevating sustainability in design.



A: Tray dryer

1 = drying chamber, 2 = drying trolley, 3 = drying tray, 4 = circulation fan, 5 = Heat exchanger, 6 = control panel, 7 = fresh air inlet, 8 = exhaust damper.



B: Tray dryer working principle

Figure 8A, which represents a Tray Dryer.

Here's a breakdown of the components depicted in the figure

1. **Drying Chamber:** This is the main area where the drying process takes place. It provides a controlled environment for drying food products, ensuring proper temperature, airflow, and moisture conditions.
2. **Drying Trolley:** The drying trolley is a movable structure that holds the drying trays. It allows for easy loading and unloading of food products into the drying chamber.
3. **Drying Tray:** These are the trays on which the food products are placed for drying. They provide a flat surface to evenly distribute the food items and allow for efficient airflow during the drying process.
4. **Circulation Fan:** The circulation fan plays a crucial role in maintaining airflow within the drying chamber. It helps distribute heat and moisture evenly throughout the chamber, ensuring consistent drying of the food products.
5. **Heat Exchanger:** The heat exchanger is responsible for transferring heat into the drying chamber. It can be connected to a heat source, such as a burner or an electric heater, and it helps maintain the desired temperature within the chamber.
6. **Control Panel:** The control panel houses various controls and settings to monitor and regulate the drying process. It allows operators to adjust parameters such as temperature, airflow, and drying time to achieve the desired drying conditions.

7. **Fresh Air Inlet:** This is the opening through which fresh air enters the drying chamber. It ensures a continuous supply of fresh air, which aids in the drying process and helps maintain the desired moisture levels.
8. **Exhaust Damper:** The exhaust damper is responsible for controlling the release of air from the drying chamber. It allows for the removal of moisture-laden air, maintaining the desired airflow and preventing the buildup of excessive humidity within the chamber. Overall, Figure 8A illustrates the key components of a Tray Dryer, offering a visual representation of how these elements work together to facilitate the drying process. By analyzing this figure, you can gain insights into the operational aspects of a Tray Dryer and understand the role each component plays in achieving efficient and controlled drying of food products.

Figure 8B, which represents the working principles of a Tray Dryer

Here's a breakdown of the working principles depicted in the figure:

1. **Loading:** The first step in the tray dryer process is loading the food products onto the drying trays. The trays are carefully arranged with the food items, ensuring proper spacing to allow for adequate airflow during drying.
2. **Air Circulation:** Once the trays are loaded, the circulation fan, depicted in the figure, comes into action. The fan creates a flow of air within the drying chamber, ensuring uniform distribution of heat and moisture. This circulation of air helps in achieving consistent and efficient drying of the food products.
3. **Heat Exchange:** The heat exchanger, also visible in the figure, plays a crucial role in providing the necessary heat for the drying process. The heat source, connected to the heat exchanger, transfers heat to the circulating air, raising the temperature within the drying chamber. The heated air then passes over the food products on the trays, facilitating the evaporation of moisture.
4. **Moisture Evaporation:** As the heated air passes over the food products, it absorbs moisture from them. The warm air facilitates the evaporation of water content from the food items. This process continues until the desired level of moisture removal is achieved, resulting in the desired level of dryness in the products.
5. **Exhaust:** The moist air, laden with evaporated moisture, is then expelled from the drying chamber through the exhaust damper, as depicted in the figure. This helps maintain proper airflow and prevents the accumulation of excessive humidity within the chamber.
6. **Monitoring and Control:** Throughout the drying process, the control panel, also visible in the figure, allows operators to monitor and adjust various parameters. This includes temperature control, airflow regulation, and drying time settings. By monitoring and controlling these parameters, operators can ensure optimal drying conditions for the food products. By analyzing Figure 8B, you can gain insights into the working principles of a Tray Dryer. It showcases the loading process, the role of air circulation and heat exchange, the evaporation of moisture, the exhaust of moist air, and the importance of monitoring and control during the drying process. Understanding these principles can help optimize the use of Tray Dryers for efficient and effective food drying.

CONCLUSION

As the food industry prioritizes ecological and economic sustainability, modern drying technologies offer promising solutions to replace traditional methods. This research highlights cutting-edge approaches like microwave, ultrasound, and infrared drying that enhance efficiency, preserve nutrition, and reduce waste. By adopting these innovations, the industry can achieve a more sustainable future with eco-friendly practices. Key opportunities include: Optimizing existing technologies: Enhance energy efficiency, reduce processing times, improve product quality. Exploring novel techniques: Vacuum drying, freeze drying, hybrid methods. Quality assessment: Develop methods to evaluate nutritional content, sensory attributes, shelf life. Industry-specific applications: Tailor drying methods for pharmaceutical, agricultural, pet food sectors.

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