Recent Drying Techniques of Fruits and Vegetables- A Review

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Abstract: *One of the most economical methods of preserving foods of all kinds is drying, which entails the elimination of water through the use of heat. Drying is a key unit activity utilized in many industries and is well known in industrialized countries as a major industrial consumer of fossil fuel-derived energy. As the level of life improves in the developing world, so will the demand for energy-efficient, quicker, ecologically friendly, and cost-effective drying solutions. Numerous technological developments have been made in the areas of pre-treatments, methods, equipment, and quality as well as the economical drying of food. The current work points to and highlights recent drying techniques in important revolutionary drying procedures in the food industry. Because the industry tries to provide advantages such as enhanced energy efficiency, lower cost, higher product quality and reduced environmental impact in the possibilities of revolutionary drying and food preservation technologies. These technologies may replace, at least in part, the traditional entrenched preservation methods. This paper presents a number of drying techniques that have vital role for use in food drying research and development.*

Keywords-Drying, fruits, vegetables, preservation, energy efficient.

1.0 Introduction

India's diverse climate conditions lead cultivated area of fruits stood at 7.05 million hectares while vegetables stood at 11.35 million hectares. It ranks second in fruits and vegetable production in the world, after China. As per National Horticulture Database (3rd Advance Estimates) published by National Horticulture Board, during 2021-22, India produced 107.24 million metric tonnes of fruits and 204.84 million metric tonnes of vegetables. The vast production base offers India tremendous opportunities for export. During 2022-23, India exported fresh fruits and vegetables worth Rs. 13185.30 crores which comprised Fresh Fruits worth Rs. 6,219.46 crores and vegetables worth Rs. 6,965.83 crores (www.Apeda.com). But India's share in global market is insignificant. It is 1.7% in vegetables and 0.5% in fruits. Fresh foods, such as fruits and vegetables, have between 80 and 95% of moisture content; a factor that contributes to their rapid degradation, generating a high volume of losses and food waste (Prosapio & Norton,2018; Waghmare, 2021). To avoid this issue an alternative solution is the use of drying, which is the oldest conservation method developed by mankind (Acar et al., 2020).

Food drying is a method of food preservation that involves removing water from the food by a mass and heat transfer process. Essentially, free water, which is responsible for water activity, is what allows microbes to grow and multiply. Therefore, drying increases the shelf life of food products like vegetables by reducing the water content to a manageable level. The final product's quality is influenced by the drying process, temperature, and water activity. Air temperature, air velocity, and the surface area of the food material are among the variables that influence the transfer of energy for drying. The following are crucial goals that drying procedures must achieve: 1. maintaining fresh food supplies to ensure year-round availability 2. Making the goods lighter and smaller in size for easier storage and transportation 3.

Preserving the nutritive value and standards of food products. 4. It should be a sustainable manner with reduced energy use, which is why modern drying processes are being applied in the field of food commodities today. 4. It has to be sustainable.

The food industry has adopted novel drying methods that include microwave drying, spray drying, refractance window technology, radio frequency drying, ultrasonic drying, infrared drying, osmotic drying, freeze drying, Low-pressure superheated steam drying, heat pump dryer, Explosion puff drying and Pulsed electric field (PEF) drying. These techniques are also used in combination because they have benefits like faster drying times, operational safety, better product quality, non-polluting operations, and higher economics. Researchers have developed novel drying techniques to address issues with traditional drying techniques like sun drying, hot air drying, and oven drying that result in reduced quality attributes like textural change, nutrient loss, browning of the dried food product, etc. while requiring more time and energy. Hence such a novel drying techniques nowadays commonly used everywhere. This review paper basically describes recent new drying technique used by different researchers for drying of fruits and vegetables.

1.1 RECENT DRYING TECHNIQUES: SPRAY DRYING

(Weng Y etal 2023) Spray drying is a flexible method for encapsulating enzymes to increase their shelf life and stability in the food sector. An overview of current developments and advancements in spray-dried enzyme encapsulation is provided in this publication. A summary is provided of newly developed spray drying methods as well as innovative spray drying chamber and atomizer designs. The purpose of the apparatus was to atomize liquids to increase their concentration and drying. Fruit or vegetable juice is shot via an atomizing valve, resulting in tiny droplets that are evenly distributed around a large drying chamber and let to fall into heated air that is blowing upward (Mercer, 2014; Tontul and Topuz, 2017). It is possible to achieve the necessary level of drying by adjusting variables such particle diameter, air temperature, and air speed, among others, so that when the droplets strike the bottom of the dryer, they have transformed into tiny powder particles (Mercer, 2014). Due to the intense shear force that occurs during atomization, the approach might not be appropriate for foods that are delicate to mechanical damage. Food beneficial chemicals are lost during the drying process, and meals high in sugar adhere to the equipment more easily. The size of the apparatus and the expense of installation are also significant. Hence fruit and vegetable juices are frequently preserved as powders by spray drying. The main goal is to obtain premium fruit and vegetable powders, which calls for ideal spray drying conditions.

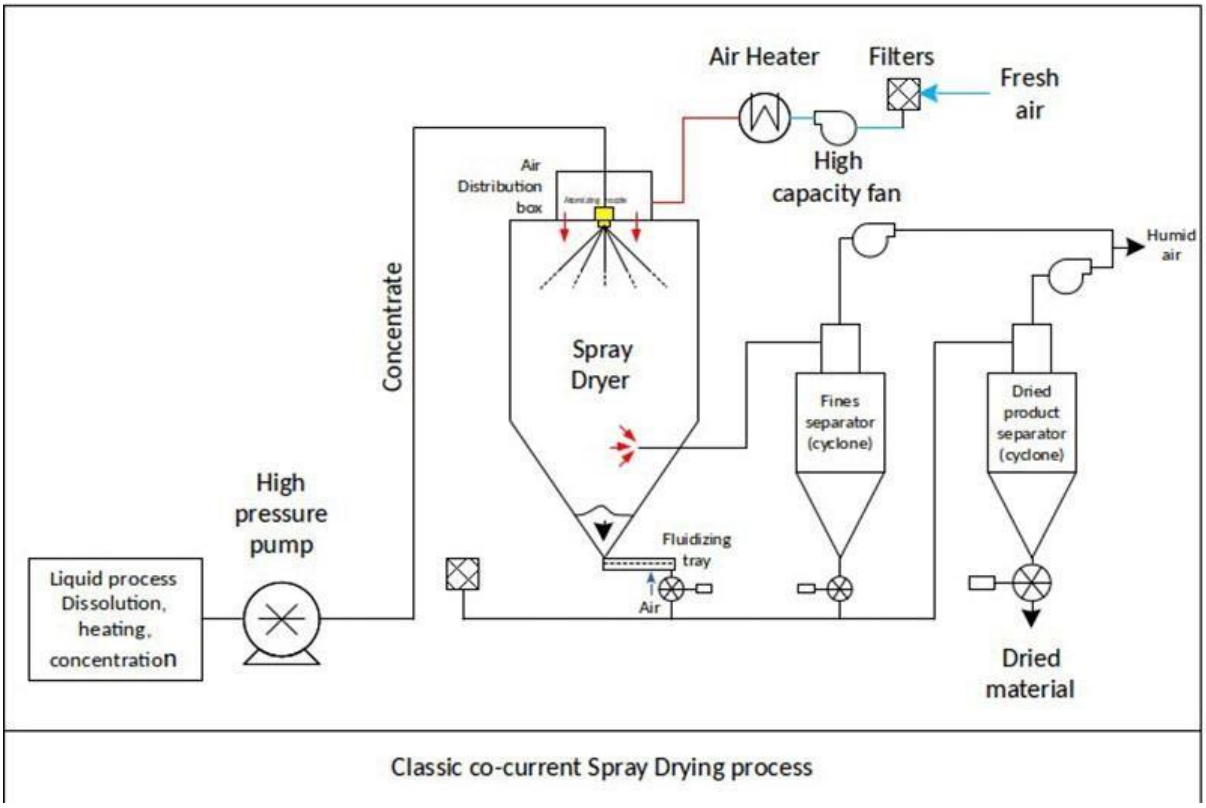

Fig: Schematic diagram of the spray dryer

1.2 MICROWAVE DRYING

Electronic and magnetic fields are used to spread microwaves throughout space. Because it requires less time and heat to lower food moisture content, microwave heating is helpful. (Kahyaoglu et al., 2012). Microwave drying is based on the volumetric heating that happens when electromagnetic waves pass through a medium, forcing its molecules to oscillate.

This oscillation generates thermal energy, which is then applied to remove water from the moist meal. The most used frequencies in the food drying sector are 915 and 2450 MHz. However, according to Gitanjali Behera, et al (2021), comparing the two drying methods, the samples that were dried in the microwave had a higher rehydration ratio. Additionally, compared to samples dried by hot air, microwave-dried carrot samples had the lowest dehydration ratio. Slices of carrot that had been dried in the microwave performed better on a sensory test than those that had been dried by hot air in terms of color and shape. In order to dry carrot slices more efficiently and with less energy, the microwave method may be suggested. Due to the volumetric heating, this drying technology is able to produce dried goods of excellent quality at cheaper costs and with greater energy efficiency than conventional methods. Due to the lower moisture level near the conclusion of the drying process, microwave-dried fruits and vegetables are more likely to burn. As a result, it has been recommended that it be used in combination with other techniques, such as the use of vacuum and microwaves (Joardder et al. 2013).

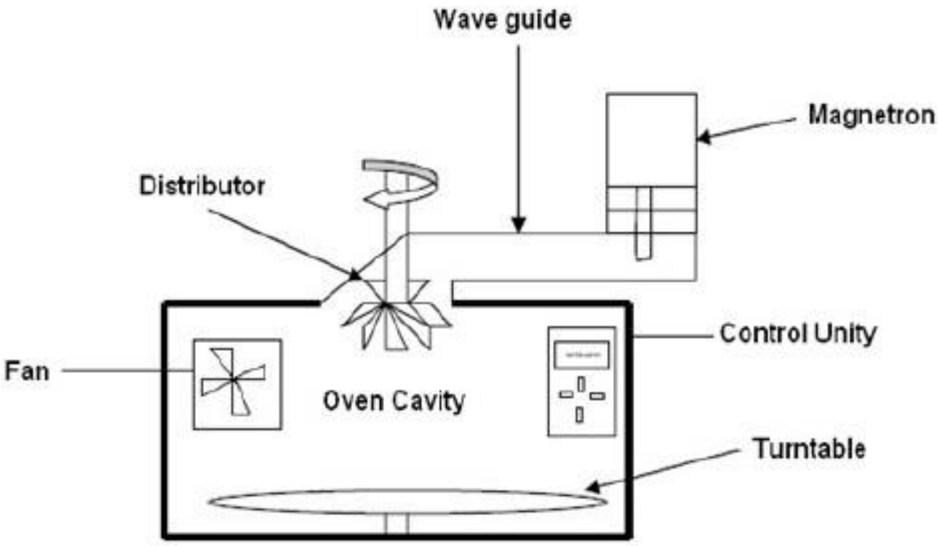

Fig: Schematic diagram of the microwave dryer.

1.3 INFRARED DRYING

One of the promising drying techniques for food goods is infrared (IR) drying. Food goods with high moisture content are dried using infrared radiation; after penetrating the materials briefly, the energy is transformed into heat. Because IR heating has obvious advantages over conventional heating, it is becoming more and more common in the food processing industry. Some of the key benefits of IR drying include quicker and more effective heat transmission, cheaper processing costs, uniform product heating, and improved organoleptic and nutritional value of processed material. (Akansha Bishtet et al,2021) When a fresh fruit or vegetable is exposed to electromagnetic radiation with a wavelength range of 0.8-1000 m, infrared drying takes place. The wavelength range of infrared is 0.75 to 1000 m (Askari et al., 2013). Infrared radiation transfers the heat from the heating source to the food surface. On the other hand, the technique has no impact on the air in the vicinity. Due to the ease of equipment and energy savings, this method is one of the best for combining with conventional drying processes. Additionally, it is advised to transfer heat quickly and efficiently because this increases the item's organoleptic and nutritional value and promotes uniform cooking and lower final costs (Boudhrioua et al., 2009). Infrared radiation results in the accumulation of charge in the electronic state, as well as in the vibrational and rotational states, at the atomic and molecule levels. As a result, the food's temperature rises while the air surrounding it maintains its constant temperature. Infrared drying has been used to dry agricultural products such carrots, sweet potatoes, and tomatoes (Boudhrioua et al., 2009).

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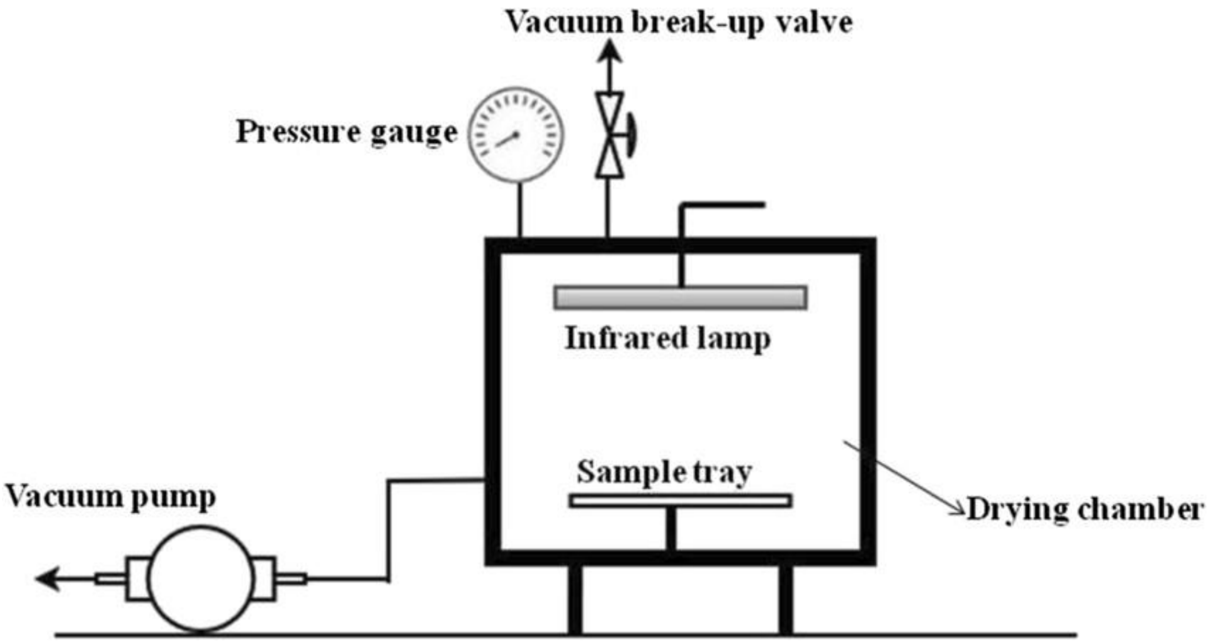

Fig: Schematic diagram of the Infrared Drying

1.4 REFRACTANCE WINDOW TECHNOLOGY

A novel drying technique called "refractance window drying" circulates water at atmospheric pressure while heating dehydrated food (Pragati and Preeti, 2014; Niakousari, 2018; Kigozi et al., 2021). Fruits and vegetables that need to be dried in liquid form are spread out on a clear plastic conveyer belt, and any excess heat is recycled. Unlike hot air tray or tunnel dryers, which can take several hours or even longer to dry food, moving belt dryers can dry food in a matter of minutes. The three types of heat transmission mechanisms used in this drying method are convection, conduction, and radiation. An energy-efficient drying process resulted from a combination of all of these heat transfer techniques. Food must be liquid or semi-liquid in order to be treated. The substance is often put to the surface of a conveyer belt and is an infrared translucent plastic material that floats on the heated circulating water area. The water surface's refractive property acts as a window when infrared energy flows through it. Infrared radiation can be transmitted directly to the material when moist food and clear plastic come into contact, creating an infrared window. In comparison to conventional methods like spray-drying, hot air, and freeze-drying (Acar et al., 2020; Celli et al., 2016), it is a less expensive technique that is used to ensure the quality of dehydrated items. It is also environmentally friendly if used with renewable energy sources like solar. This technique has arisen as a unique, less expensive choice for dehydrating fruits and vegetables, according to Nindo & Tang (2007). The process is affected by the sample thickness and drying temperature, though. Using this technique, berry purée and slices can be dried and turned into powder, flakes, or sheets. In the last few years, RW™ drying has been extensively used for different food applications. This drying technique provides several benefits in terms of retention of quality characteristics of dried food, higher energy efficiency, inactivation of most vegetative bacterial pathogens. Despite the extensive benefits of RW™ drying, limitations of this technology cannot be ignored. The important disadvantage is the higher plastic surface area of belt required for large amount of sample for drying. (Roji Waghmare 2021)

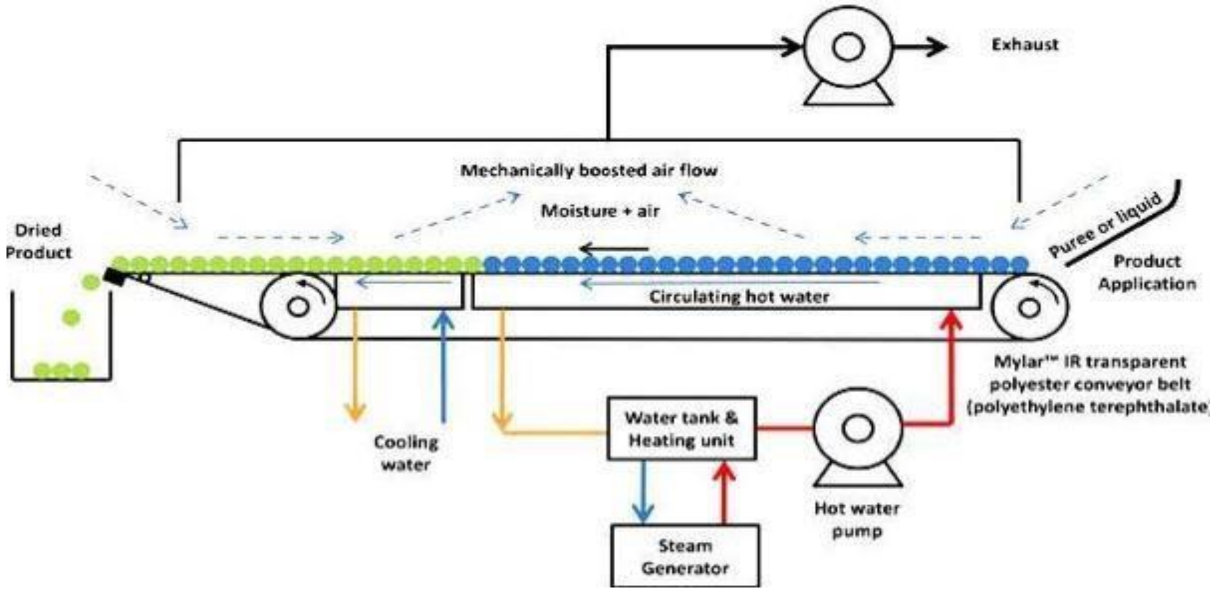

Fig: Refractance window drying.

1.5 RADIO FREQUENCY DRYING

This technology can be utilized for food preparation in addition to wireless communication. According to Caln-Sánchez et al. (2020), radio frequency heating is the interaction of a radio frequency generator's electromagnetic field with a substance's molecular species. The outcome is that the food sample is sandwiched between two electrodes that are exposed to an electric field that changes 40,000,000 times per second. Like the polar molecules in the food, the electric fields alternate, causing friction and heating the whole thing. Water evaporates and warms up because it is bipolar by nature (Babu et al., 2018). Significant drawbacks include larger equipment and expensive operating costs. For horticulture products like apple slices and snack foods, radio frequency has been widely researched as a potential replacement for the standard hot air drying process (Marra et al., 2009). In order to quickly and effectively heat food for drying purposes, radio frequency drying uses radio frequency energy to heat food (Sisquella et al., 2014). This method has gained popularity recently. Based on the combined mechanisms of dipole rotation and conduction effects, radiofrequency radiation has been demonstrated to volumetrically release heat within food, accelerating the drying process of food products (Alfaifi et al., 2014). Nonetheless, it has been noted that radio frequency thermal treatments lessen the deterioration of thermal quality in drying items (Alfaifi et al., 2014). The primary drawbacks of radio frequency heating, however, include uneven heating and overheating in the center, edges, and corners of the food, particularly in foods with intermediate to high moisture contents (Alfaifi et al., 2014).

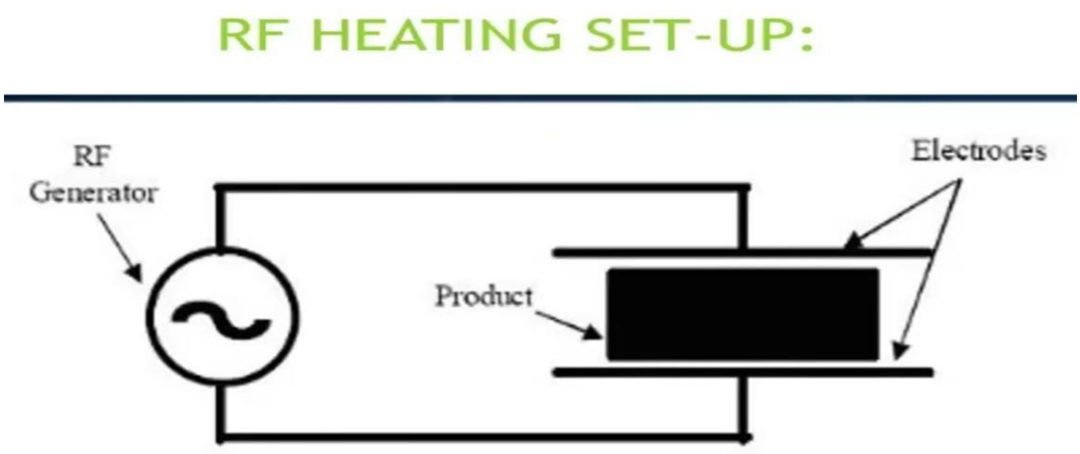

Fig:-Schematic diagram of the radio frequency drying system

1.6 ULTRASONIC DRYING

When compared to traditional hot air drying, the qualities and quality of food could be improved by ultrasound. Both alone and in combination with other energies, such as hot air, ultrasonic energy can be used. By lowering the temperature or length of the treatment, ultrasound enhances the quality of the final product. The use of ultrasound to dry food accelerates the drying process and uses less energy overall, according to Musielak et al., 2016. They noticed that the resulting items had greater quality than those produced by control operations without ultrasonic enhancement due to the slight "temperature effect." According to Musielak et al. (2016), the main barrier to the industrial implementation of ultrasound technology was the absence of an efficient method for producing power ultrasound in air.

Bell pepper was dried by Schossler et al. (2012) using an integrated ultrasound freeze drying system that might also be used to dry other food items. They discovered that the items were heated when ultrasound was applied continuously, even at low ambient pressure. They also discovered that using ultrasound cut drying time by 11.5%.

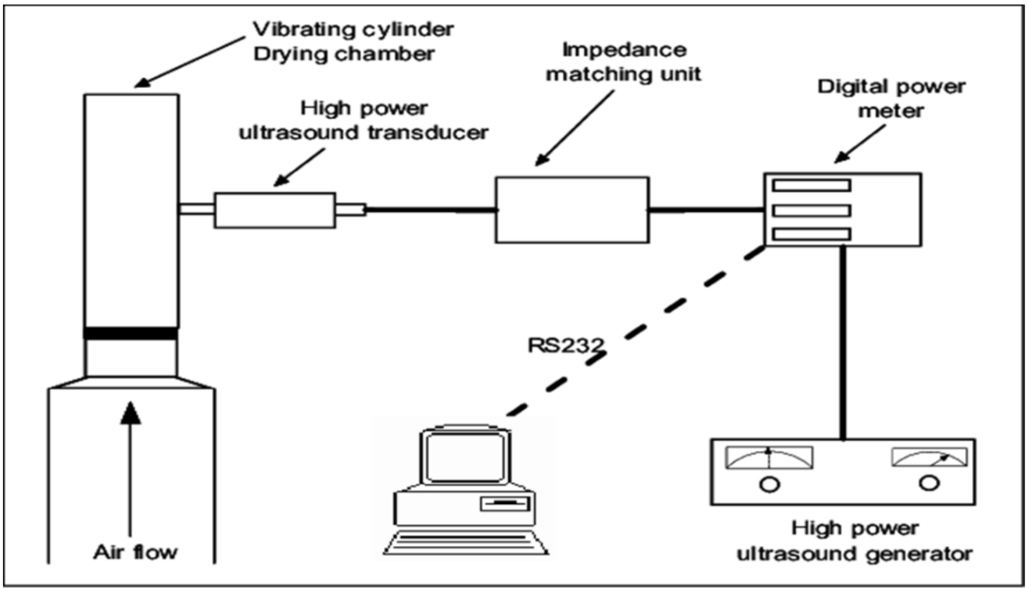

Fig: Scheme of the ultrasonic drying system.

1.7 OSMOTIC DRYING

Fruits and vegetables can be partially dried out by being submerged in a hypertonic solution containing sorbitol, glycerol (high osmotic pressure sugars), or salt. This process is known as osmotic dehydration. Solutes from the solution permeate into the tissue of fruits and vegetables when they are immersed in a hypertonic solution (Mehta et al., 2013). With the use of gentle heat treatments, the pretreatment maintains the food's color, flavor, and nutritional value. As a result, the total dehydration process requires less energy overall. A few of the problems that must be solved are the inability to forecast the product's final chemical composition and flavor, wasteful osmotic solution use, and leaching out of color, acids, carbohydrates, minerals, and vitamins. Osmotic drying "also increases resistance to heat treatment, prevents enzymatic browning, and inhibits activities of polyphenol oxidase," according to Rastogi et al., (2005). The cost-effectiveness of the osmotic drying process depends on a number of factors, including the geometry of the food material and the temperature and concentration of the osmotic solution (Kahyaoglu et al., 2012; Sisquella et al., 2014; Shete et al. 2018).

1.8 FREEZE DRYING

The process includes the freezing of the food, sublimation of the ice, and extraction of bound water molecules. Lack of liquid water results in the development of a higher-quality final product and entirely halts the majority of microbe-mediated processes at freezing and low temperatures (Falade and Igbeka, 2007). The food is first frozen (at - 20°C), and then a controlled amount of heat is applied under vacuum to induce sublimation, in which ice is instantly transformed into vapor and then condenses as ice on a refrigeration coil, which is typically maintained at -55°C (Claussen et al., 2007). The ability of freeze-dried fruits to rehydrate is one of their most important qualities. The enormous cost and energy consumption during the freezing, drying, and condensing operations are drawbacks of freeze-drying products. Because technique requires dehydration at low temperatures through freezing at lower pressure followed by sublimation of the ice, freeze drying is also known as lyophilisation or cryodesiccation (Prosapio et al., 2017).

When compared to other drying techniques, freeze-drying produces dried foods of the finest quality since flavor and structural integrity are maintained (Rey and May, 2016, Fellows, 2017; Prosapio et al., 2017). Although expensive, freeze drying is used to preserve high-value goods including coffee, seasonal fruits and vegetables, and food for the military, astronauts/cosmonauts, and/or hikers (Rey and May, 2016; Fellows, 2017; Prosapio et al., 2017).

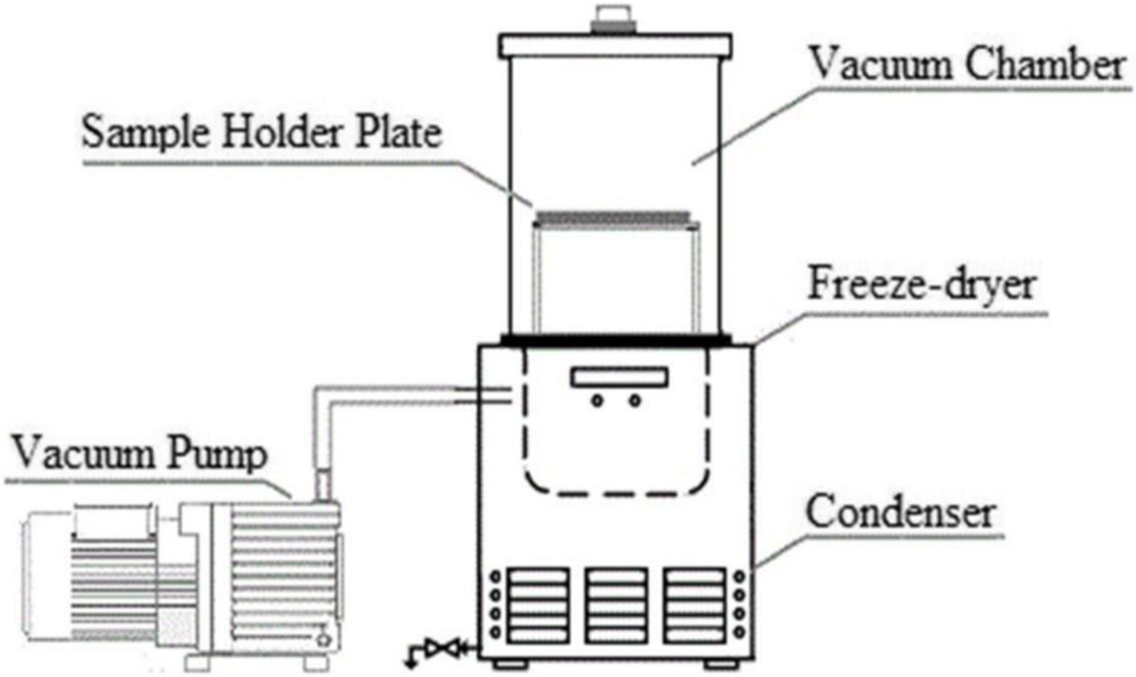

Fig:-Schematic diagram of the Freeze drying

1.9 LOW-PRESSURE SUPERHEATED STEAM DRYING

A vacuum pump keeps the low pressure inside the sealed drying chamber during the dehydration process. The reservoir that receives the drying agent from the boiler has a steam trap built in order to stop excessive steam condensation. During the start-up cycle, the first steam condensation is significantly decreased when a heater equipped with a temperature control device is used. To disperse steam in the drying chamber, Calín-Sánchez et al. (2020) recommended using an electric fan with variable speed. Sehrawat et al. (2016) state that the procedure leads to less oxidative alterations and improved retention of bioactive components. Nevertheless, the steam gathers particulates, dust, and other particles from the raw material during drying. According to Sehrawat and Nema (2018), this method has been effective in drying onions.

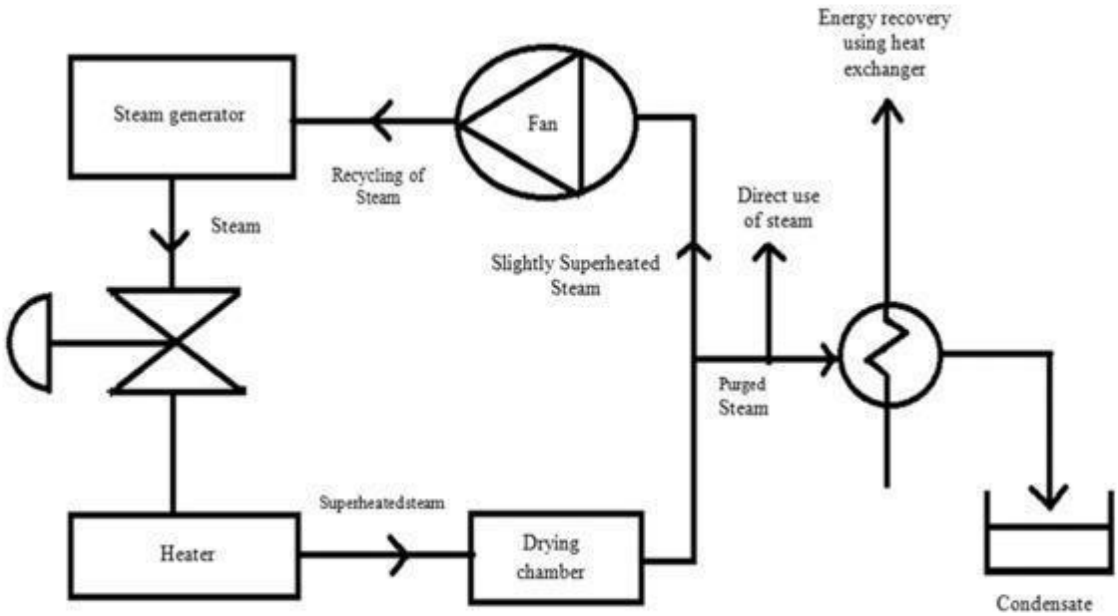

Fig: Low-pressure superheated steam drying setup. Source: Adapted from; Sehrawat et al. (2016).

1.10 HEAT PUMP DRYER

Hot air drying uses a lot of energy and is inefficient. This has led to the development of several strategies that center on recovering exhaust air during the manufacturing process. This goal guided the creation of the heat pump drier (Calín-Sánchez et al., 2013). This kind of dryer uses water condensation and a refrigerator to recover latent heat. Humid air is released from the product as a result of the procedure, which provides it with dry hot air. The air is condensed in the heat pump evaporator, enabling the drying air to be warmed by the latent heat of vaporization. Heat pump dryers reduce the need for fossil fuels while increasing energy efficiency (Fayose and Huan, 2016). Because of the decreased relative humidity, this drying process has an advantage over a typical hot air dryer in terms of reduced time and temperature (Moses et al., 2014; Rahman, 2020). In addition to being simpler to construct and requiring less time to dry than other drying technologies, heat pump drying is perfect for low-tech nations in the Sub-Saharan region (Fayose and Huan, 2016). Combining heat pump drying technology with other drying methods has helped to overcome some of its shortcomings and produce better products with lower energy costs and higher thermal efficiency. Examples of heat pump assisted drying methods include chemical heat pump assisted drying, air freeze drying, infrared drying, fluidized bed drying, microwave drying, and radio frequency drying. For heat-sensitive materials, such as fruits and vegetables, which only need a low temperature, this is particularly important (Fayose and Huan, 2016).

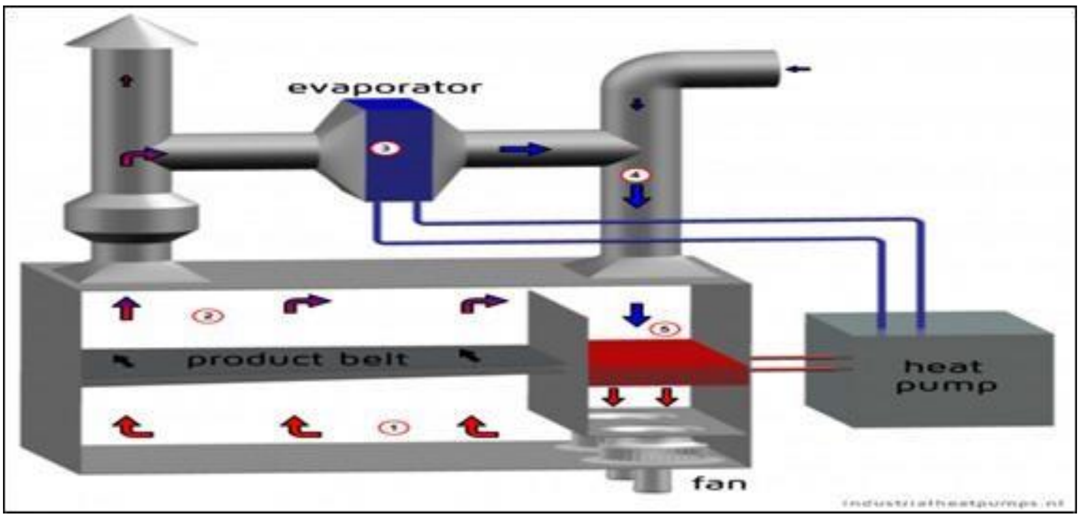

Fig: Heat pump drying for industry.

1.11 EXPLOSION PUFF DRYING

The components of explosive puff drying equipment are the steam generator, air compressor, decompression valve, vacuum chamber, puffing chamber, and vacuum pump (Calín-Sánchez et al., 2013). Once the food has been placed within the puffing chamber, the decompression valve is shut. Using steam from the steam generator, fruit or vegetable samples are heated to 95°C and held there for five minutes while the air compressor increases the internal pressure of the apparatus to 0.2 mPa. Puff samples can be vacuum dried by opening the decompression valve, which lowers pressure (Feng et al., 2021). In order to offer a less expensive option to freeze-dried products, this process combines hot air drying and vacuum freeze drying (Zou et al., 2013; Chen et al., 2017). Poor product quality is caused by inadequate knowledge of the hygroscopic characteristics of the fruit or vegetable to be dried. According to Feng et al. (2021), another major drawback of the approach is the loss of nutrients caused by the high temperatures involved in vacuum drying. With chopped carrots, puff drying produces a product that rehydrates effectively in water and browns minimally (Kerr, 2013).

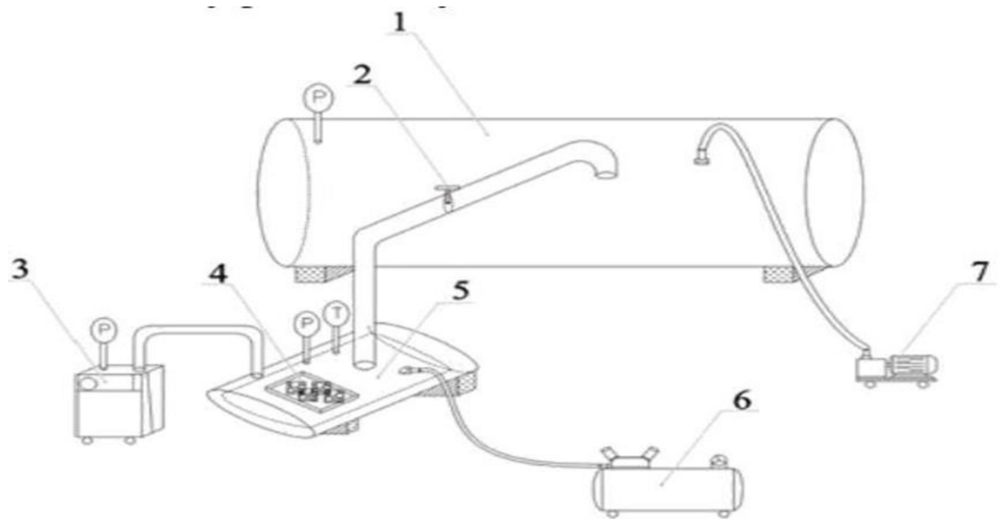

Fig: Schematic diagram of explosion puff drying device and accessories. Source: Fan et al. (

1 = Vacuum chamber, 2 = Decompression valve, 3 = Steam generator, 4 = Food samples, 5 = Puffing chamber. 6 = Air compressor, 7 = Vacuum pump. 2018).

1.12 Pulsed electric field (PEF) drying

PEF is a relatively new method that can permeabilize fruit and vegetable tissue cells without raising the product's temperature or causing the tissue to deteriorate too much. Essentially a non-thermal technology, pulsed electric fields have numerous uses in the food processing industry. Food tissues are subjected to an external electrical field for microseconds during PEF treatments, which results in the disruption of cell membranes and local structural alterations. the application of a pulsed electric field as a temperature-controlled pre-treatment during dehydration, which boosts product mass transfer. The impact of temperature, pulse count, and electric field strength on cell disintegration on product quality and drying time has not been investigated. When compared to dehydration, the pulsed electric field aids in dehydration with reduced energy use. Examine the effects of temperature, the number of pulses applied during treatment, and the strength of the pulsed electric field on the vegetables. Adjust these factors based on the results of energy input, cell disintegration, and drying time (Akansha Bisht et al,2022).

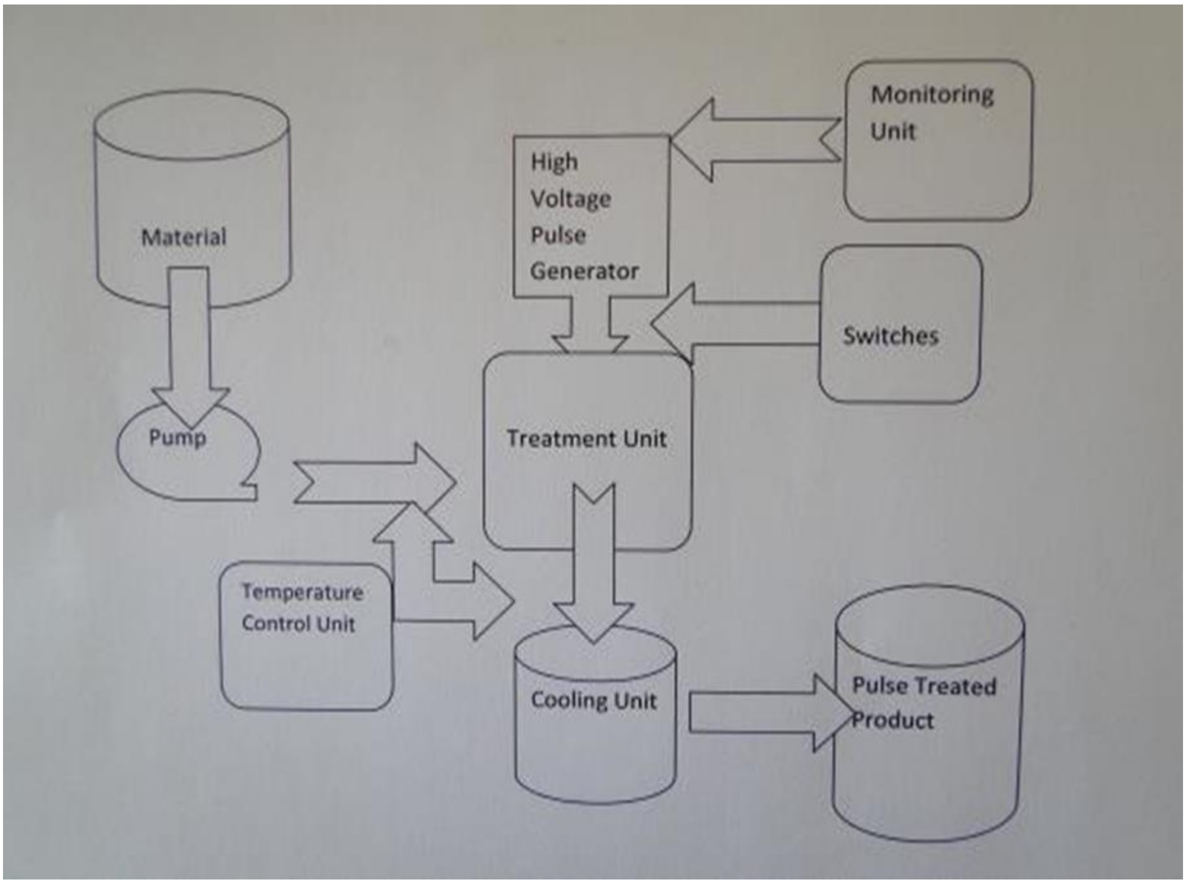

Fig: Pulsed Electric Fields drying

2.0 CONCLUSION

The oldest preservation technique is drying, which involves removing water by the use of heat and mass transfer. Free water, which is essentially what causes water activity, is what allows microbes to proliferate and multiply. Therefore, drying increases the shelf life of food products like vegetables by reducing the water content to a manageable level. The following are the key goals that drying techniques must achieve: preserving fresh food commodities so that they are available throughout the year; reducing the weight and volume of the product for easy transportation and storage; maintaining the nutritional and quality aspects of food commodities; and being an energy-efficient method. As a result, novel drying techniques are being used in today's society. Due to the industry's desire to become more environmentally and economically sustainable, novel drying and food preservation techniques have attracted increased industrial interest and may eventually replace, at least in part, the traditional methods currently used.

Researchers have developed novel drying techniques to address issues with traditional drying techniques like sun drying, hot air drying, and oven drying that result in reduced quality attributes like textural change, nutrient loss, browning of the dried food product, etc. while requiring more time and energy.

Its feasibility can be easily ascertained. Drying of fruits /vegetables makes them available even during off season and hence gets better price. This could help to increase the profitability. The importance of drying though known to many farmers because of drawbacks of traditional methods it doesn’t got popularized but now with the help of these novel drying methods economical and viability issues has been addressed. There is need in future in designing sustainable user friendly hybrid and economically more viable dryers for use of farmers in the country like India.

Table-1: Advantages, limitations and utility of various recent drying techniques

Drying Technique	Advantages	Disadvantages	Utility
Microwave Drying	Less time and heat required to lower food moisture conent with excellent quality of dried foods	Slow and expensive ,it should be used with conjuction with other methods	High value added products
Spray Drying	Long shelf life, low moisture content,high quality products	Expensive and might loss of bioactive compounds due to high temperature	Premium fruits vegetables powder production ,Production of instant powder
Refractance Window technology	Unique and less expensive ,more energy efficient, less time, environmentally effective	The important disadvantage is the higher plastic surface area of belt required for large amount of sample for drying.	heat-sensitive products such as fruit and vegetable juices, purees, slices into powders or flakes or sheet form
Radio frequency drying	Fast and effective thermal treatment	Overheating in intermediate and high moisture foods due to non uniform heating	post-baking drying of baked products
Ultrasonic drying	Reduce adverse effects such as shrinking, discoloration, breaking, and nutritional alterations. a lowcost and energyefficient system,	Oxidation of fats, inactivation of valuable enzymes, and denaturation of proteins are the main problems appearing in ultrasonication	Drying of fruit, vegetables, meat, and fish.
Infrared drying	One of promising technique with improved organoleptic & nutritional value of processed food	limited capacity to penetrate and product burning and overheating.	Drying of grains fruits vegetables and sea food
Osmotic drying	Long shelf life, high quality products, energy saving	overcome by adding fruit acid in the solution, Sugar coating is not desirable in certain products, time taking process	Fruits and vegetables
Freeze drying	prevents the spread of harmful bacteria. Food storage without a cold chain.	expensive equipment. It requires more time. increased energy consumption is necessary.	Dairy industry food industry,pet food,
	Preserve the food's sensory and nutritional qualities. It permits the food's weight and organoleptic characteristics to be restored by rehydration.		

Low-pressure superheated steam drying	Dryer exhaust is steam so it is possible to recover all latent heat, toxic & organic liquids can be recovered easily	More complex than hot air, more time required to dry, limited industrial experience	Onion drying, Sugar beet drying,
Heat pump dryer	Low energy consumption, no vents required, low cost, good product quality	Maintenance cost is high, high capital cost	Useful in high sensitive products
Explosion puff drying	In addition to providing a crispy texture and improved rehydration properties, EP drying offers a porous structure Furthermore, in comparison to traditional drying techniques, EP dried goods showed strong antioxidant activity and a high preservation of phenolics.	Foods high in protein cannot have the anticipated puffing structure produced by EP. Consequently, using EP in meals high in protein is challenging.	food preservation, extraction of valuable compounds, and transformation/conversi on reactions in the food
Pulsed electric field (PEF) drying	Boost the effectiveness of drying Lower the drying temperature. An increase in the diffusivity of moisture Greater ability to rehydrate Reduced shrinking	High capital cost, The processing parameters need to be carefully modified based on the kind of product.	Fruits ,vegetables and meat products
	Increased nutritional compound retention		

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