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Dr. Rajlakshmi Tripathi
Principal, Govt. Lalit Kalan Mahavidyalaya, Jabalpur, Madhya Pradesh, India

Apoorva Soni
Assistant Professor, Govt. M.H. College of Home Science and Science for Women, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Dr. Rajlakshmi Tripathi
Principal, Govt. Lalit Kalan Mahavidyalaya, Jabalpur, Madhya Pradesh, India

A review on fourth generation drying techniques of fruits and vegetables

Dr. Rajlakshmi Tripathi and Apoorva Soni

Abstract
Food is our basic need. In developing countries, where providing enough food according to the population is a complex problem, the wastage of food adds to the problem. Fruits and vegetables are an integral part of our diet, which provide us vitamins, minerals and antioxidants along with fiber. Due to their high moisture content, fresh fruits and vegetables have a low storage capacity and are highly perishable. Fruits and vegetables decay because of microbiological, chemical, or physical damage. Developers and food processors use a range of preservation techniques to reduce post-harvest losses, increase availability, offer variety, and increase the value of the products they produce. Food preservation is a comprehensive procedure that entails numerous food processing steps to maintain the food's internal and external quality at the required level in order to preserve its nutritional value and maximize its benefits. Dehydration technology has seen several alterations due to human curiosity and the expansion of civilization. Successful innovations include fourth generation drying techniques, which need less time and effort to create goods of higher quality. Through this review, the working principles of various drying processes and the outcomes of their use in diverse studies have been examined. While freeze drying can keep the color and shape of the fruit and vegetable, the IR Drying Technique saves more time and energy. One of the simplest and least expensive ways to dehydrate is through microwave drying. The organoleptic qualities of food can be preserved with the osmotic-dehydration approach while still producing a dry product. Depending on the nature of the food product and the available resources, better quality dried products can be prepared by using suitable dehydration techniques as per the requirement.

Keywords: Fourth generation, drying techniques, fruits, vegetables, combined method of drying, preservation

1. Introduction

Due to their high moisture content, fresh fruits and vegetables have a low storage capacity and are highly perishable. Fresh fruits and vegetables have a moisture content of 90 to 95%. Enzymes, respiring products, and the water-losing impact are the main post-harvest properties shared by all fresh fruits and vegetables. Fruits and vegetables decay because of microbiological, chemical, or physical damage. All of these impacts are significant contributory elements that determine the quality of fruits and vegetables as well as consumer preference [Nath S *et al.* 2007] [41]. Fruits and vegetables' acceptability and organoleptic qualities are impacted by these losses [Rehman MS, 2007] [50]. Therefore, to decrease post-harvest losses, increase availability, offer variety, and increase the value of the products they produce, developers and food processors employ various preservation procedures.

The process of preservation entails an examination and comprehension of the entire food production and distribution system, including cultivation, harvesting, tillage, processing, packaging, transportation, storage, and consumption. Food preservation is a comprehensive procedure that entails numerous food processing steps to maintain the food's internal and external quality at the required level in order to preserve its nutritional value and maximize its benefits. Traditional methods for preserving food while maintaining its nutritional and organoleptic qualities include drying, cooling, and fermentation. Advancements with new dimensions have emerged in conservation approaches over time and in response to requirements [Amit *et al.* 2017, Alice L, 2021] [53, 3]. A method of food preservation prevents food from spoiling after harvest and from being wasted. Food waste has recently emerged as a major problem on a global scale.

50 kg of food per capita are wasted each year in Indian households, according to the Food Waste Index Report 2021 [Food Waste Index Report 2021 Nairobi.] [62]. Consumer demand for fresh, wholesome, and nutrient-rich food rises along with population growth. A sustainable answer to both the problem of food waste and the necessity for food is food preservation. As a result, the idea of food preservation quickly spread with the intention of feeding everyone. Food preservation aims to shield food against microbiological and metabolic deterioration [Sridhar *et al.* (2021) [57].
Considering the various causes of food spoilage, different methods of food preservation have been designed based on the following principles:

Prevention or delay of microbial spoilage of food

- Asepsis
- Filtration
- Use of low temperature
- High-Temperature Treatment (Drying)
- Use of irradiation
- Use of chemicals

Prevention or delay of self-decomposition of food

- Enzyme inactivation or destruction through blanching or boiling
- Use of antioxidants to prevent oxidation

Preservation methods can be divided into two major groups according to their mechanism of action and the quality of the final product. Traditional Methods- Drying, Salting, sugaring, boiling, cooling, pickling, canning, etc. Modern and Industrial Methods - Pasteurization, Novel techniques of drying, Vacuum packaging, pressure food preservation, bio-preservation, hurdle technique, modified atmosphere, non-thermal plasma, etc. [Alice L, 2021] [3].

2. Drying Technologies for fruits and vegetables

One of the oldest and most recognizable physical ways for preserving fruits, vegetables, and other foods with high moisture content (over 80%) or that are highly perishable is drying. It is a technique for lowering food moisture content [Moses JA *et al*. 2014] [30]. The advantage of drying fruits and vegetables is not only to preserve crops as food but also to reduce package and transportation costs in terms of weight and volume while providing the possibility of adding value to the items harvested Orsat V (2006)] [63], Singham P. 2014] [56].
Drying, dehydration, and dewatering are three words that are frequently used to describe the process of removing water from any food product. Each word has a certain meaning [Humberto V, 2001] [27]. Drying occurs when water vapor evaporates from the food's surface to its surroundings. This process is known as removing solvent from food that is solid, semi-solid, or liquid. The process of dehydration involves the evaporation of surface water first, followed by the inner surface of the raw material. The elimination of water from substances with a high-water content is referred to as dehydration. Specific procedures including temperature and humidity under controlled circumstances are needed for dehydration. The process of dewatering involves draining or squeezing water out of any substance. These terms are used to define the procedure based on how much water is eliminated. [Mulet A, 2011] [40].
Food items can be dried using a variety of processes. It can be classified into groups based on the methodology used in the process or the level of dryer advancement. The mechanical dehydration method can be divided into four generations based on historical development [Singham P. 2014] [56], [Humberto V, 2001] [27], [Arun S Majumdar] [18].

Table 1: Generations of drying methods

First Generation Drying Cabinet and Bed Type Dryers Ex- Tray, Truck, Rotary, Conveyor and tunnel	**Second Generation Drying** Spray Drying, Drum Drying, Fluidized Bed Drying
Third Generation Drying Freeze Drying, High Vacuum Drying, Osmo-dehydration Drying	**Fourth Generation Drying** Flash Drying, Microwave Drying, Infrared Drying, Combined methods of Drying,

This review is focused on fourth-generation drying techniques.

2.1 Flash Drying

Flash drying is a continuous process that employs either direct or indirect heating of the dryer. The hottest air contacts the wettest product, making them naturally existing dryers. For sensitive products, they can function at inlet temperatures as low as ambient, dehumidified air, or as high as 600 ˚C. As a result of the system's short residence duration and flashing off of the moisture, it cools significantly through evaporation. As contrast to many other dryers, this one allows for a higher inlet temperature without excessively heating the products [47] [Processheating.com]. In the chemical, pharmaceutical, and food sectors, flash dryer is frequently used in the dispersion and drying of granular, powdery, paste-like false agglomerates. The advantages of flash dryers include a compact design, low energy demand, great thermal efficiency, and continuous mass production [70] [zzdldryers.com]. A rotary cutter, air filter, cyclone separator, and collector are provided with flash dryers. One of the dryer's best-known advantages is that it can be customized to satisfy users' needs. Depending on the operation conditions and the amount of bound moisture present in the food, the finished flash-dried product may have residual moisture ranging from 0% to 12% [47] [Processheating.com]

2.2 Microwave Drying

In the area of food processing, microwave heating has a broad spectrum of uses, including cooking, drying, pasteurization, and preservation of food products. [S. Chandrasekaran *et al*, 2013] [15]. Every type of food contains wet elements that behave as electric dipoles. Food heated by microwave radiation in a microwave oven absorbs energy at a frequency of roughly 2.45 GHz, which causes the water to heat (12 cm). Because they have a positive charge at one end and a negative charge at the other, these dipoles rotate to line up with the alternating electric field created by the magnetron. Heat is produced at the molecular level when rotating molecules hit and move other ones. [P.P. Sutar and Suresh Prasad, 2008] [58]. Due to the rapid and consistent drying rates, microwave drying is widely used to dry food items. Some food ingredients' quality can be increased through microwave drying. When drying is at its most advanced, microwave technology can speed up the drying process [Punathil, L., & Basak, T. 2016] [48].

2.3 Infrared Drying

Infrared radiation (IR) is a form of electromagnetic wave from the heat source which does not require any medium for its emission and which is located at the outer border of the visible red light. [Huang *et al* (2021)] [26]. Infrared has effective moisture diffusion and higher thermal sensitivity than air drying [Mesery, *et al* (2019).] [20]. In industry, there are three types of infrared drying (far-, near- and medium-infrared drying), the most emerging of which is far-infrared drying. It can be widely applied in the food industry because it can be used for drying several agricultural products [Wu, *et al* 2019] [65]. This type of drying has many advantages compared to conventional drying, ranging from efficient heating of the products and excellent energy efficiency to the high quality of the dried products, as this type of drying allows not to lose the organoleptic and chemical characteristics of the products. [Zartha S *et al*. (2021)] [68].

2.4 Combined methods of Drying

Over the years, a variety of drying methods, including osmotic dehydration (OD), freeze-drying (FD) etc. have been developed and employed to dehydrate vegetal products. Extensive study has been done to reduce these negative characteristics as well as the energy consumption during the process because these widely used technologies do have certain disadvantages. The food industry may accept novel drying technologies that save energy, such as dryers that use heat pumps, combine existing technologies to optimize the cost and quality of dried products, and use any approach that enables greater control over the conditions of the drying process and the quality of the food. Combined drying reduces the negative aspects that occur when only one technique is applied. [Calín-Sánchez Á *et al*. 2020] [14].

2.4.1 Osmotic Dehydration

Osmotic dehydration is a phenomenon that occurs when water is transferred from a solution with a lower solute concentration to one with a greater concentration through a semi-permeable membrane, creating an equilibrium on both sides of the membrane [RB Tiwari 2005] [60]. It is a widely accepted method of dehydration and preservation of fruits and vegetables. It is a simple process that provides processing and yet can prevent primitive organoleptic characteristics of fruits and vegetables. It consists of two stages removal of water in the presence of an osmotic agent and further dehydration in the dryer to increase the shelf life of the product. As an osmotic agent, a sugar solution can be used. Osmo-dehydration of fruits and vegetables is influenced by a variety of variables, including pretreatment, temperature, sugar concentration, and additions [Chavan 2012] [16].

2.4.2 Freeze Drying

Lyophilization, another name for freeze drying (FD), is a well-known process for creating high-quality food powders and solids [Karam, 2016] [32]. When a frozen sample is placed under a vacuum to eliminate any remaining water or other solvents, allowing the ice to transition directly from a solid to a vapor without first going through a liquid phase, is known as freeze drying. This procedure is known as freeze drying. [Hilgedick, 2020] [25].

Due to its high energy consumption, high operating and maintenance expenses, and ability to generate the highest-quality food product of any drying technology, freeze-drying (FD) is also thought to be the most expensive process for producing a dehydrated product [Xu Duan, 2016] [66]. Despite having only a few steps, freeze-drying is a complicated process because the freezing, sublimation, desorption, and reconstitution processes all affect the success or failure of the final product qualities and each stage can put a product under different kinds of stress [Ward 2021] [64].

Table 2: Results found in some studies on fourth- generation drying techniques.

Method	Feed Type	Result	References
Flash drying	Fruits	1. As the product color is kept due to the usage of moderate temperature, flash drying can be used as an alternative to freeze drying. 2. Because of less energy consumption the process can be cost-effective in comparison to freeze drying.	[Marta *et al*. 2012] [39]
	Pumpkin	Dried pumpkin slices have been prepared in a very short time.	[Ricardo L *et al*. 2018] [52]
	Banana	Similar outcomes, including less energy consumption, color protection, and faster drying times, were observed in this work.	[Ricardo L Monteiro *et al*. 2016] [51]
	Mango	Same findings were observed in this study.	[Jade *et al*. 2017] [52]
Microwave Drying	Frozen Fruits	A key aspect affecting the quality of food materials cooked in microwaves is the impact of the packing materials.	[Punathil, L., & Basak, T. 2016] [48]
	Fruits	If the material does not alter its position in the microwave field, the inhomogeneity of the microwave field may cause hot patches within the material. This could result in scorching during the final drying cycle.	[Chong, *et al*. 2021] [17]
	Onion Slice	Microwave-dried onion slices had better color and phenolic content than sun-dried and oven-dried.	[Arslan, D., & Musa Özcan, M. 2010] [5]
	Red Bell Pepper	Microwave-dried samples showed highest color values than sun-dried samples.	[Arslan, D., & Özcan, M. 2011] [6]
	Carrot and Garlic	When color is a crucial feature, microwave drying could be the alternative to preserve color instead of infrared drying.	[Baysal, T., Icier, F., Ersus, S. *et al*. 2003] [10]
Infrared Drying	Green Pea	Compared to hot air drying alone, the drying time was shorter in infrared drying combined with hot air.	[Barzegar, Maryam & Zare, Dariush & Stroshine, Richard 2015] [9]
	Carrot	With increased infrared power, the drying time was reduced. With infrared power, the rehydration efficiency first improved and then declined. Work was done using 62, 74, 88, 104 and 125 W of infrared power.	[Doymaz 2015] [28]
	Carrot	Work was done with infrared power 100,200 and 300 W. Drying rate and hardness increased with IR power and then declined	[Guo *et al*. 2020] [22]
	Strawberry	Drying time decreased with infrared power 100, 200, and 300. Total phenolic content declined first with increased infrared power and improved.	[Adak *et al*. 2017] [2]
	Mushroom	Because of the decrease in drying time, intermediate infrared drying can result in better color preservation.	[Onwude, *et al*. 2019] [42]
	Similar results were found with banana, sweet potato and okra.		Khampakool, A *et al*. 2019]

			[34] [Onwude, D. *et al*. 2019] [35] Baeghbali, *et al*. 2020] [7]
Osmotic Dehydration	Apple	The researcher has studied the efficiency of the method on apple slices in different osmotic agents. Results showed maltose was more effective than sucrose or any other mixtures of sugars.	[Pani, P *et al*. 2010] [45]
	Green Pea	Organoleptic properties such as color, texture, flavor, aroma and appearance of Osmo-dehydrated green were found acceptable.	[Pokharkar, S.M.2001] [46]
	Strawberries	The osmotic temperature, duration, and solute concentration all have a significant effect on the osmotic dehydration of strawberries.	[Bei Liu, Bangzhu Peng, 2017] [11]
	Pomegranate seed	Pomegranate seed (PS) was osmotically dehydrated while being exposed to apple, bitter orange, and grape juice concentrates as the osmotic solution (OS). The viscosity of (OS), the texture of (PS), and the color parameters of both materials demonstrated the significant impact of the process's usage of concentrated fruit juices. In actuality, the weakening of the cell tissue in the seed pulp of PS caused a decrease in the hardness of PSs.	[Haifa Sebii *et al*. 2022] [23]
Freeze Drying	Green Peas	Heat pump-fluidized bed atmospheric freeze drying conserved the sample size and form with just a small (20%) amount of shrinkage without affecting the starch granules. The final product had a desired porous interior structure thanks to heat pump-fluidized bed atmospheric freeze drying.	[Zielinska 2013] [38]
	Green Peas	The impact of six drying methods was observed on green peas. The Freeze-Drying approach produced the greatest color changes and the least shrinking. The Freeze-Drying technique was discovered to be the most effective strategy to maintain the product's qualities.	[Kaveh 2021] [33]
	Plant Based Foods	One of the best methods for removing water from biological materials is vacuum freeze-drying, which produces the highest-quality results.	[Sagar Bhatta 2020] [13]
Combined Methods of Drying	Green Peas	The drying kinetics are unaffected by the hardness of the material. The drying rate was higher for the samples with smaller diameter granules, as was to be assumed. The activation energies for samples increase with the size of the pea. In the atmospherically freeze-dried samples, the color shift was barely noticeable.	[Alves-Filho *et al*. 2004] [4]
	Review on effect of different drying techniques on food	The nutritional quality (bioactive) and sensory qualities (color, texture, aroma, and flavor) of fresh and cut fruits can be improved using advanced osmotic dehydration techniques such as electric field pulse treatment, ultrasonic and microwave-assisted dehydration, pulsed vacuum, and osmo-dehydro freezing without compromising their dependability.	[Pandiselvam *et al*. 2021] [44]
Microwave-Assisted Convective Drying (CD-MD)	Dragon fruit	The goal of the study was to determine the impact of intermittent microwave convective drying (IMCD) on the total phenolic content, color change, and rehydration ratio of dried dragon fruit. The dried dragon fruit slices made using the IMCD process had less color variation, greater total phenolic content, and higher rehydration ratio values.	[Raj *et al*. 2022] [49]
Ultrasound and microwaves on convective drying	Green pepper	It was shown that hybrid drying methods shorten significantly the drying time, reduce the energy consumption and affect positively the quality factors.	[Szadzińska, J *et al*. 2017] [59]
combined microwave-convective drying	Lemon Slices	The researcher concluded that there is a significant decrease in drying temperature with the combination of these two methods.	[Sadeghei *et al*. 2013] [54]

3. Conclusion
With the curiosity of man and the growing society, there have been many changes occurred in dehydration technology. Through these techniques, not only the food product but the nutritive value and structure also could be preserved. Fourth Generation Drying Techniques are examples of successful advancements, using less time and energy to produce better quality products. Through this review, the working principle of various drying techniques and the results obtained from them in different researches have been reviewed. The IR Drying Technique saves more time and energy, whereas Freeze Drying can preserve the color and shape of the fruit and vegetable. Microwave drying is one of the easiest and cheapest methods of dehydration. The osmotic-Dehydration method is capable of providing a dried product without affecting the organoleptic properties of food. Depending on the nature of the food product and the available resources, better quality dried products can be prepared by using suitable dehydration techniques as per the requirement.

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