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Full Length Research Paper

Food Drying and Its Impact on Nutritional, Sensory, and Physical-Chemical Properties

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Foods have been preserved for longer than their natural shelf life by the ancient technique of drying them. Foods were first exposed to the sun in order to extract a significant amount of their water content, which helped to preserve them. Modern techniques including hot air drying, spray drying, lyophilization, infrared, microwave or radiofrequency drying, osmotic dehydration, or several mixed processes are now employed because the conventional solar dying method, which involved direct exposure to the sun, had numerous drawbacks. Drying can preserve a lot of foods, however it significantly changes their nutritional and organoleptic qualities when compared to their fresh counterparts. This paper's goal is to outline the topics covered in a plenary address presentation regarding the developments in drying techniques and how drying affects the qualities of dried foods. A search of the scientific literature was done for that, and the information was chosen depending on the subjects that were to be discussed.

Key words: Drying methods, Colour, Texture, Organoleptic properties, Chemical composition, Nutrition.

INTRODUCTION

The Drying is without a doubt the oldest of the several techniques used to preserve food, yet it is still widely employed today. It is a method of vaporizing or sublimating food to eliminate water, which decreases the amount of water accessible for microbiological, enzymatic, or chemical breakdown activities. Transfer processes, including food and drying air vapour pressures, temperature and air velocity, product moisture diffusion, thickness, and surface exposed for drying, which was all affect the drying rate [1].

Drying entails both removing the water vapor from the food's surface and using heat to evaporate the water that is present in the meal. Thus, it integrates mass transmission and heat, both of which require energy. The most popular method of transmitting heat to a drying item is to employ hot air flowing over the meal; this process is primarily accomplished by convection [2].

By decreasing the water content and water activity, drying aims to preserve foods and extend their shelf life; it also eliminates the need for costly refrigeration systems for transportation and storage; it reduces the amount of space needed for storage and transportation; and it diversifies the supply of foods with a variety of flavors and textures, giving consumers a wide range of options when making food purchases [3], [4].

It is a truth that the quality of dehydrated food is typically significantly worse than that of the original food, even if drying is an alternative to increase the shelf life of food and also make storage and transit easier by eliminating the need for costly cooling equipment. The goal is to maximize the retention of nutrients, including macronutrients (proteins, sugars, fibers, etc.), micronutrients (vitamins, minerals, etc.), and bioactive compounds (phenolic compounds, carotenoids, isoflavones, etc.), while minimizing chemical changes, such as enzymatic and non-enzymatic browning, during the drying process. Foods that are dried often experience shrinkage, which significantly alters their texture and structure [5].

Drying Methods

Food water loss is a highly energy-intensive process. Drying uses a significant amount of energy—between 20 and 25 percent of the energy used in the food processing sector, or 10 to 25 percent of the energy used in all sectors of the economy in developed nations. Therefore, one of the most important design and operation factors in food processing is energy efficiency combined with time efficiency [6]. The primary causes of slowing down convective drying are limited heat conductivity and case-hardening of materials.

In recent years, drying technology has advanced significantly in terms of pretreatments, methods, tools, and end product quality. For instance, pretreatments are used to speed up the drying process, improve food quality, and increase food safety [7]. Additionally, they aid in lowering energy requirements.

As seen in Table I, there are hundreds of different kinds of dryers that operate according to various principles.

TABLE I. Classification of Driers

Discontinuous functioning	Continuous functioning
• Biggest hand labour costs. • May have greater variations product quality from batch to batch. • More economical for smaller capacities (up to 5 tons/day).	• More economical for large quantities of material.
Direct heating	**Indirect heating**
• The material is placed in contact with the hot gases that provide the latent heat for vaporization of water.	• The food is separated from the heat source by a physical barrier such as a metal surface.

A. *Solar Drying*

The sun is the energy source for solar drying. Because the food is exposed to sources of contamination (insects, birds, and other animals) and is highly subject to weather conditions, it is a very inexpensive drying method, but it also has several disadvantages (Fig. 1). Therefore, when conditions are unfavorable, food may decay before attaining a steady moisture level, compromising sanitary quality and resulting in product losses. These issues might be reduced by solar greenhouses, which are highly effective at using the sun as a source of energy, achieve greater temperatures because of the greenhouse effect, and protect the food [8], [9].

The product is exposed to sunlight during direct solar drying, whereas in indirect solar drying, collectors use the sun's energy to heat the air needed for food drying. Fruit, vegetables, meat, and fish have been exposed to direct sunshine and the elements for ages [4].

Figure 1. Solar Drying of pears.

B. Hot Air Convective Drying

Convective drying of porous materials, such as food, is essential for a number of industrial uses. Air is without a doubt the most widely utilized drying fluid because of its tremendous availability and moisture saturation capability [10]. Hot air drying techniques are one of the most important and diverse methods of food drying. These include drying in rotating drum driers, tunnels with conveyor belts (Fig. 3), chambers with trays (Fig. 2), or even fluidized bed driers.

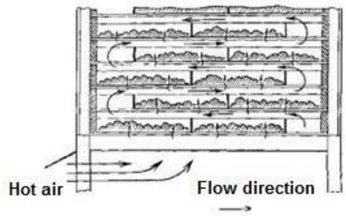

Figure 2. Convective drying in chambers with trays.

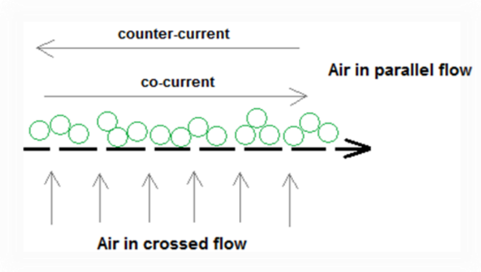

Figure 3. Types of flow in tunnels for convective drying.

As a food preservation technique, hot air drying is still widely used. Nevertheless, it has a negative impact on the product's ultimate quality. Convective drying is regarded as a very damaging process since it causes things that are sensitive to heat, such fruits and vegetables, to shrink, discolor, and lose nutrients. Furthermore, hot air drying is typically an unfavorable, time-consuming, and energy-intensive method of food preservation. Applying hybrid techniques, in which energy is supplied alternatively by combining several energy sources, such as convection with ultrasound or microwave radiation, is one of the suggested strategies to reduce these detrimental effects of convective drying [11].

C. Spray Drying

One popular method for turning a liquid into a powder is spray drying. It is employed for slurries or solutions that are sprayed or atomized to separate the material into droplets (10-200 µm). The qualities or content of the feed solution and the spray dryer's processing parameters have a significant impact on the quality of spray-dried microcapsules [12]. Because of its smaller size, it can be utilized to treat heat-sensitive materials and has a short drying period (1–20 s), limiting damage. Because it controls the process's efficiency and establishes the size of the droplets, the atomizer is crucial. Additionally, the most popular method of microencapsulation is spray drying, which has been shown to be a successful technology for safeguarding probiotics and bioactive substances. It involves turning water suspensions into powdered microparticles, which are made up of an enclosed core and a shell [13], [14].

D. Lyophilization

Water is first frozen and then sublimated under specific pressure and temperature conditions in a process known as lyophilization, also known as freeze-drying or freeze-dehydration.

Because process requires freezing, the creation of a vacuum, and expensive equipment, lyophilization is slower and more expensive [15].

In the food industry, lyophilization is used to preserve microbial cultures used in food production as well as to dehydrate foods with delicate aromas and high value, such as mushrooms, herbs, and spices, fruit juices, meats, seafood, or entire diets for military or sporting expeditions. Since lyophilization is more effective in maintaining the original conformations of heat-sensitive materials, it is typically chosen for converting them into powder. However, this approach has significant drawbacks, including lengthy processing periods, poor production throughput, batch mode of production, and potential chill harm from freezing [16].

Infrared Drying

Infrared drying raises the temperature of the solid food's surface by exposing it to an infrared heating source. Heat transmission to the interior occurs very slowly in most solids due to their low thermal conductivity. Therefore, the primary goal of applying infrared radiation to food is to cure its surface. Under comparable circumstances, infrared heating has numerous advantages over traditional drying. These advantages have been demonstrated by experiments comparing infrared drying to alternative methods. By transferring energy from the heating element to the product, infrared radiation heats the material more quickly and evenly without heating the surrounding air, making the energy consumption more efficient. The drying time is reduced by up to half on the irradiated surface, which also evaporates significantly more water. Because of these benefits, infrared radiation has been used in conjunction with a number of drying techniques. When used in conjunction with hot air pre-drying, infrared heating can reduce drying time by 20% in comparison to infrared drying alone [5].

E. Microwave Drying

This This technique produces a rapid rate of heating without causing any changes to the food's surface, so no crust forms. The high cost and requirement to synchronize the generator for various foods limit the use of industrial microwave treatment. As a result, it is employed in industry for meals with low moisture content or as a last step in the dehydration process. Because microwave drying saves time, uses little energy, and produces high-quality products—all of which are important considerations for the industry—it is an effective postharvest processing technique for agricultural products. More characteristics, including temperature, weight, power, or odor, may be tracked and managed during the drying process thanks to the advancement of new technologies [17]. Microwave drying can have advantages over convection drying because of its volumetric heating and shorter processing time. However, using microwaves under vacuum may greatly reduce the quality degradation of heat-sensitive materials. On the other hand, it may result in particle overheating and undesirable degradation of bioactive substances. However, it's crucial to note that using microwaves under

Combining the two drying methods—microwave vacuum and convection—could minimize the drying costs, which are increased by decreased pressure [18].

F. Radiofrequency Drying

One significant application area that has been investigated as a potential technique for drying agricultural products is the use of radiofrequency radiation for dielectric heating of food components. The product is directly heated by the radiofrequency heating, which causes the interior to heat up more quickly than the exterior. Without causing the surface to overheat or get dehydrated, the water is discharged. As a result, it can be used in conjunction with other drying methods and enables the achievement of extremely low humidity levels—between 1% and 2%—with little effect on quality. Compared to traditional hot air heating, this innovative drying technique offers a quicker drying time, greater energy efficiency, and superior product quality [19], [20].

G. Osmotic Dehydration

The foundation of osmotic dehydration is the idea that, due to the increased osmotic pressure of the hypertonic solution, a driving force for water removal develops when cellular materials are submerged in it. When fruits or vegetables are submerged in a solution of sugar or salt (whose osmotic pressure is higher than the food's), it is typically used to partially remove the water from the fruit or vegetable. Even if the food loses water to the solution, its final moisture content is frequently unstable ($0.90 \leq aw \leq 0.95$). [21], [22].

It may take days to reach balance because the water loss rate is considerable at first but drastically decreases after 1-2 hours. Food is often reduced to 50% of its fresh weight in 4-6 hours, which is why it is utilized in industry as a pretreatment for other processes. Therefore, additional preservation methods must be used to supplement the process, including vacuum air drying and osmotic dehydration with a moderate electric field, microwave assisted air drying, ultrasound assisted osmotic dehydration and air drying, blanching and vacuum pulse, ohmic heating and vacuum impregnation, and others [23].

Hypertonic sugar solutions (40–70%) are used for fruits; sucrose is the most often used sugar, but fructose, glucose, or combinations of glucose/fructose and glucose/polysaccharides are also utilized. Salt solutions (5–20%), often sodium chloride, are used for vegetables [21].

*H. **Combined Processes***

Solar drying, osmotic dehydration, vacuum drying, hot-air drying, fluidized bed drying, and freeze drying are just a few of the traditional drying techniques utilized in post-harvest technologies. Unfortunately, the majority of these drying methods require a lot of energy and a longer drying period, which leads to lower-quality dried goods.

Using self-heat recuperation technology, a novel approach to enhancing the current traditional drying procedures has been proposed. Nevertheless, this approach, which primarily aims to improve the drying process's energy efficiency, is difficult and costly to modify.

Using self-heat recuperation technology, a novel approach to enhancing the current traditional drying procedures has been proposed. Nevertheless, this approach, which primarily aims to improve the drying process's energy efficiency, is difficult and costly to modify. Novel techniques such as microwave, radio frequency, infrared, pulse electric field, ultraviolet, ultrasound, ohmic, supercritical, and heat pump heating have been used extensively in recent studies to dry agricultural crops in terms of pre-treatment, methods, and equipment design that promote process efficiency and improve the quality of the final dried products [24]. Convection and microwaves, convection and osmotic dehydration, convection and infrared radiation, convection and ultraviolet radiation, convection and vacuum, convection and ultrasound, spray drying and lyophilization, lyophilization and ultrasound, lyophilization and infrared radiation, and many more combinations are examples of common combined drying processes.

To reduce browning processes, fruits are typically sulphited by being exposed to fumes from burning sulphur rather than blanched [26].

Pureed fruits, such as bananas, apricots, mangoes, and peaches, can be drum-dried to create powders or flakes. Since some of these items are sticky and hygroscopic, it helps to add glucose syrup to make it easier to remove the product from the drum and handle it later. Spray drying or atomization can be employed to dry fruit juices (Fig. 7) [25].

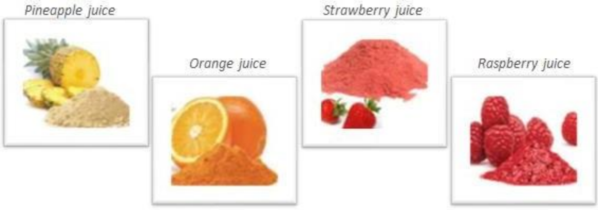

Figure 7. Examples of fruit juices processed by spray drying.

EXAMPLES OF DRIED FOODS

A. ***Fruits***

Using self-heat recuperation technology, a novel approach to enhancing the current traditional drying procedures has been proposed. Nevertheless, a lot of fruits, such as grapes, figs, dates, pears, peaches, and apricots, have been sun-dried for a long time using this technique, which primarily aims to increase the drying process's energy efficiency (Fig. 4). However, fruits like apple slices, apricot halves, pineapple slices, or pears in halves or quarters are also frequently dried with hot air [25].

Figure 4. Examples of fruits dried in the sun.

Fruits including bananas, mangoes, and kiwis can be dried using a variety of techniques, such as vacuum drying (Fig. 5) or a combination of methods [25].

Figure 5. Examples of fruits dried in vacuum.

Oranges, pineapples, kiwis, apples, cherries, papayas, coconuts, strawberries, and many other fruits are subjected to osmotic dehydration (Fig. 6) [25].

Figure 6. Examples of fruits processed by osmotic dehydration.

A. ***Horticultural Products***

Many vegetables are available in dried form; for example, in some Mediterranean-bordering nations, tomatoes are sun-dried. Prior to drying, the majority of vegetables are blanched and/or sulphited. Vegetables are dried using a variety of dryers, including trays, tunnels, and fluidized beds, which employ hot air at temperatures typically between 50 and 110 °C [26].

Green beans, peppers, cabbage, carrots, celery, spinach, and broccoli are among the dry vegetables (Fig. 8). To maintain their delicate flavor and perfume, which would otherwise be greatly impacted, some vegetables, such garlic, mushrooms, peas, and onions, are not sulphited [25].

Figure 8. Examples of dried vegetables.

B. ***Herbs and Spices***

Vacuum dryers can be used to dry herbs and spices, yielding goods with superior organoleptic properties compared to hot air drying. For this reason, aromatic herbs used in cooking are vacuum-dried to retain the volatile chemicals that give them their flavor and scent. It is possible to dry certain herbs, such as thyme or parsley, without bleaching or sulfurizing them. In order to retain the bioactive components that give the infusions their positive health effects, the plants are also vacuum-dried [26].

C. ***Dairy Products***

Since 1902, when milk powders were separated into whole milk and skimmed milk powders, drying has been used to preserve milk for use in infant food. After centrifuging the whole raw milk to create skim milk with 0.05% fat, the milk is heated to a temperature that determines whether the resulting powder is categorized as low-, medium-, or high heat. The amount of soluble serum proteins (globulin and albumin) that remain in the powder decreases with increasing heat treatment intensity. Recombined dairy goods like cheese and baby food are made with low-heat powder; concentrated recombined dairy products are made with medium-heat powder; and the bakery and chocolate sectors are the primary users of high-heat powder. A multiple effect evaporator is then used to concentrate the milk until the total solids content is between 40 and 55 percent. Spray drying is the primary method used to create the skimmed milk [26], [27].

B. ***Fish***

Salting and smoking are two conventional techniques for prolonging the shelf life of fish. When salt is added to fish to lower their water activity, it is equivalent to osmotic dehydration (Fig. 9).

Figure 9. Salted fish.

Fish are exposed to wood smoke during the smoking process (Fig. 10). This can be done at a relatively low temperature, such as 30 °C, in which case the procedure is referred to as cold smoking. Ten to eleven percent of the moisture may be lost during smoking, and cold-smoked fish products have a seven-day shelf life when refrigerated. These goods may have low enough water activity to be stable without refrigeration, and hot smoking is done at temperatures as high as 120 °C. Although lyophilized fish items are also accessible, only relatively expensive species like shrimp are lyophilized due to the high expense of this processing method [25].

Figure 10. Smoked fish.

C. ***Meat***

Hot air can be used in tray dryers, conveyors, fluidized beds, or rotary driers to dry cooked minced meat (chicken, beef, lamb, and pork) until the moisture level reaches 4-6% (wet basis). Pork meat is the least stable when dried, but chicken meat is the most stable. Fat oxidation, which results in rancidity, is the primary cause of such products' degradation. It is also possible to vacuum-dry the cooked minced meat, which results in better products but at a higher expense. At an even higher cost, raw and cooked meat in the shape of steaks, slices, cubes, or mince can be lyophilized to a wet basis moisture content of 1.5–3.0% [25].

I. EFFECTS OF DRYING ON FOOD PROPERTIES

A. ***Microstructure and Texture***

The kind of pre-treatment (blanching, peeling, chopping, etc.) and the degree of severity of the pre-treatment are factors that influence the structure of dried fruits and vegetables [25].

Because it neutralizes the polyphenoloxidase (PPO), blanching is a crucial step before drying materials derived from plants. Even when done correctly, it results in textural alterations because of internal pressures brought on by localized moisture fluctuations, cellulose crystallization, and starch gelatinization. These lead to compressions and ruptures that permanently deform the cells, giving them a roughened appearance. These meals lose the firm texture of the original raw material when rehydrated because they absorb water more slowly [25].

The temperature and rate of dehydration have a significant impact on the food's texture; generally speaking, higher temperatures and quicker procedures result in more significant modifications. Depending on the type of food, its content, and the processing settings, the water that migrates to the surface contains solutes from the meal, creating stresses in the structure. Foods' mechanical qualities, structure, volume, porosity, and density may all alter as a result of drying [18].

The foods' surface undergoes significant physical and chemical changes as a result of the high temperature, creating a hard, impermeable barrier that keeps the food moist on the inside but dry on the outside. Based on the rate of water elimination, the final product's texture is influenced by the structural changes that occur during drying. A very dense structure forms and the dried product becomes harder if shrinkage takes place, as in the case of air-dried meals (Fig. 11). Conversely, a very porous structure forms and the product has a smoother texture if there is no shrinking, as in the case of lyophilized meals (Fig. 12) [25].

Figure 11. Highly porous freeze dried fruits (strawberries and bananas).

Figure 12. Dense air dried fruits (raisins and peaches).

A. ***Colour***

One of the significant browning processes in fruits and vegetables during thermal processing, which includes drying, is enzymatic browning (Fig. 13).

Figure 13. Darkening of apple slices during drying due to polyphenoloxidase activity.

The PPO enzyme is frequently found in plant materials and, when exposed to oxygen during post-harvest processing, can result in undesired color and flavor changes through enzymatic browning. Enzyme deactivation is therefore typically a necessary treatment before any preservation procedure, like drying, and it significantly affects the quality of the final result [28]. Food's surface properties, including color and reflectivity, are changed by dehydration. Heat and oxidation during drying result in chemical changes in pigments like carotene and chlorophyll (Fig. 14). Generally speaking, the losses in these pigments increase with treatment duration and temperature [25].

Figure 14. Discoloration of pigments with drying (carotenoids and chlorophyll).

The PPO is inactive at pH values below 4, since its optimal activity ranges from 6 to 7. Therefore, it is advised to reduce the pH by adding ascorbic or citric acid. However, sulfur compounds—also known as exposure to sulfur fumes from burning sulfur or dipping in bisulphite or metabisulphite aqueous solutions—have also been employed to prevent browning reactions. To prevent disagreeable flavors, we must occasionally be mindful of the concentrations utilized [29]. Last but not least, PPO activity is also suppressed when oxygen is not present, which is why lowering the oxygen content of the drying atmosphere is advantageous, as is the case when drying is carried out under vacuum [25].

The Maillard and caramelization reactions are examples of non-enzymatic browning reactions. Melanoidins are created when amino acids and reducing sugars undergo the Maillard reaction, which results in a loss of nutritional value. The type of sugars in the diet determines how quickly these reactions proceed, and they begin at 70 oC. Additionally, foods that have water activity between 0.5 and 0.8 are more prone to non-enzymatic browning. When sugars are heated over 120 oC, caramelization events take place, producing dark compounds known as caramels [29].

B. ***Chemical Composition and Nutritional Value***

Depending on the food type, drying technique, level of treatment, and operating conditions, drying can drastically change the chemical makeup and nutritional value of food (Fig. 15). Preparation methods (pre-treatments), drying circumstances (especially temperature), or storage conditions (post-drying) can all affect the nutritional content of dried foods. Reducing drying time, using lower temperatures, and maintaining low moisture and oxygen concentration levels during storage are some ways to limit nutrient losses [25].

Figure 15. Effect of drying on food nutrients.

The water solubility of vitamins is variable. As drying proceeds, some vitamins (ex. riboflavin) reach oversaturation and precipitate and therefore lower losses occur. Others (ex. vitamin C) are maintained dissolved until the moisture content in the food is very low, and react with the solutes at a greater rate as the process advances. The vitamin C is particularly affected by heat and oxidation and also the thiamine is relatively sensitive to heat. The liposoluble vitamins are more stable to heat and oxidation (with losses < 10 %), but may react with peroxides resulting from lipid oxidation [25], [29].

Since the majority of the food's dry matter contains the liposoluble nutrients (such as vitamins A, D, E, and K) and essential fatty acids, the losses that occur during drying are not as significant. The dietary minerals, iron and copper, dissolve in the food's aqueous phase and serve as catalysts in the oxidation processes of unsaturated lipids. As a result, water is removed and their reactivity decreases while drying, improving the nutritional value preservation. The majority of foods' proteins retain their biological value and digestibility even after drying. However, under some operational conditions and in certain meals, denaturation may occur [25], [29].

B. Aroma

Depending on the processing temperature, the volatile compounds' vapour pressure, their solubility in water vapor, and the food's solids content, heat causes losses in volatile components.
Using low temperatures and/or vacuum, encouraging the food's natural enzymes to activate, or adding external enzymes that produce aromatic substances from the natural aroma precursors, using compounds that fix aroma, and recovering volatile compounds to reintroduce to the product are some ways to preserve the flavor of dehydrated food [25].

CONCLUSION

Although drying is a very old method of food preservation, it is still used today to treat a variety of food products in quite significant industrial processes. Numerous innovations and technological developments have produced improved drying methods that are more energetically efficient and enable greater preservation of the nutritional and organoleptic properties. This operation holds a major position in the food processing industry due to its capacity to be applied to a wide variety of foods with different properties.

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