Paper No.: 02

Paper Title: The Principles of the Food Processing & Preservation

Module No. : 16

Module Title: Food Drying & Dehydration

16.0 Introduction

The preservation of foods by drying is the time-honored and most common method used by humans and the food processing industry. Dehydration of food is one of the most important achievements in human history, making humans less dependent upon a daily food supply even under adverse environmental conditions. Though in earlier times drying was dependent on the sun, nowadays many types of sophisticated equipment and methods are used to dehydrate foods. During the past few decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during dehydration, and develop methods for preventing undesirable quality losses.

16.1 State of Water in Foods

The terms dried and dehydrated are not synonymous. Dehydrated foods are those with no more than 2.5% water (dry basis), while the term dried foods applies to any food product with more than 2.5% water (dry basis). The concept of bound water and free water has been developed from drying principles, and it is important for dried products ï for its stability during processing and storage. A product containing no water is termed as bone-dry. Water exists in foods in different forms or states. In foods, water having properties different from those of pure water can be defined as bound water. In the literature, different forms of bound water are defined, for example, unfreezable, immobile, monolayer, and nonsolvent water. However, the fraction of bound water depends on its definition and the measurement technique used. The binding energy of different states of bound water affects the drying process, since it requires more energy to remove bound water than free water.

16.2 End Point of Drying

Equilibrium in drying system is the ultimate endpoint for the process. Water activity is commonly used to estimate the equilibrium point in the case of thermal and osmotic drying processes. In mechanical dewatering, the magnitude of the applied force and rheological properties of the foods affect the equilibrium point. Generally meat, fish, and dairy products are dehydrated to moisture content of 3% or less, vegetable products usually to 5%, and cereal products frequently to as much as 12%. A maximum moisture level is usually established for each dried product separately, based on the desired quality after drying and during storage. Different attributes of quality can be targeted; thus, the endpoint should be determined from all aspects, such as safety first and then consumer acceptance.

16.3 Heating Methods in Drying

Heating air using either an electric heater or flue gas is the conventional heating method used for drying foods. In this case, heat transfer from the gas to the product occurs mainly through convection. The heating method is another important aspect of drying, in terms of quality as well as energy cost. Microwave, infrared, radio frequency, refractance window, and dielectric heating use electromagnetic wavelength spectrum as a form of energy, which interacts with the materials, thus generating heat and increasing the drying rate dramatically. Dielectric drying uses frequencies in the range of 1ï 100 MHz, whereas microwave drying uses frequencies in the range of 300ï 300,000 MHz. Microwave heating is rapid, more uniform in the case of liquids, and more energy efficient than the hot-air method. Applying microwave energy under vacuum affords the advantages of both vacuum drying and microwave drying, thereby providing improved energy efficiency and product quality. The energy can be applied in pulsed or continuous mode; however, pulsed microwave drying is more efficient than continuous drying. The use of electro-technology in drying is gaining priority in the food industry to improve drying efficiency as well as quality.

16.4 Drying Methods

Drying processes can be broadly classified, based on the water-removing method applied, as (a) thermal drying, (b) osmotic dehydration, and (c) mechanical dewatering. In thermal drying, a gaseous or void medium is used to remove water from the material. Thus, thermal drying can be divided further into three types: (a) air drying, (b) low air environment drying, and (c) modified atmosphere drying. In osmotic dehydration, a solvent or solution is applied to remove water, whereas in mechanical dewatering physical force is used. Consideration should be given to many factors before selecting a drying process. These factors are (a) the type of product to be dried, (b) desired properties of the finished product, (c) allowable temperature tolerance, (d) the productôs susceptibility to heat, (e) pretreatments required, (f) capital and processing costs, and (g) environmental factors. There is no one best technique of drying that is applicable for all products.

16.5 Thermal Drying

Thermal drying is one of the most widely used methods of drying foods. In this process, heat is mainly used to remove water from the foods. The mechanisms of moisture transfer depend mainly on the types or physicochemical state of food materials and the drying process. Food materials can be classified as (a) homogeneous gels, (b) porous materials with interconnecting pores or capillaries, and (c) materials having an outer skin that is the main barrier to moisture flow. The type or structure of foods always plays an important role in the drying process.

16.6 Drying Curve

Drying curve usually plots the drying rate versus drying time or moisture contents. Three major stages of drying can be observed in the drying curve (Figures 1 and 2):

1. Transient early stage, during which the product is heating up (transient period)
2. Constant or first period, in which moisture is comparatively easy to remove (constant rate period)
3. Falling or second period, in which moisture is bound or held within the solid matrix (falling rate period)

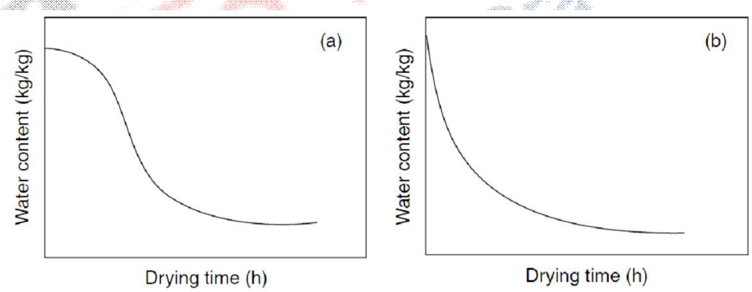

Figure 1: Typical drying curves (water content versus drying time) – (a): with a lag period, (b) without lag period

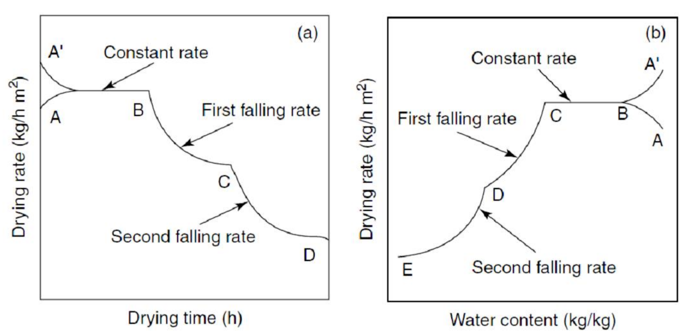

Figure 2: Typical drying curves: (a) drying rate versus drying time, (b) drying rate versus water content

Typical drying rate curves are shown in Figures 1 and 2. The moisture content at which the change from the first to the second period occurs is known as the critical moisture content. Typically, two falling rate periods are observed for both hygroscopic and nonhygroscopic solids. The first falling rate period is postulated to depend on both internal and external mass transfer rates; while the second period, during which drying is much slower, is postulated to depend entirely on internal mass transfer resistance. The slower rate may be due to the solidï water interaction or glassï rubber transition. The drying behaviors of food materials depend on the porosity, homogeneity, and hygroscopic properties. The immediate entrance into the falling rate is characteristic of hygroscopic food materials.

16.7 Air-Drying Methods

In the case of air drying, atmosphere is used as the drying medium and heat as different modes could be applied in the process.

16.7.1 Sun Drying

Earlier, only sun drying was used for drying. In this process, foods are directly exposed to the sun by placing them on the land or left hanging in the air. The main disadvantages of this type of drying are (i) contaminations from the environment, (ii) product losses and contaminations by insects and birds, (iii) floor space requirements, (iv) difficulty in controlling the process, and (v) bad odor. When the climate is not particularly suitable for air drying or better quality is desired, mechanical air drying is mainly used. However, sun drying is the cheapest method of drying foods. Nowadays, solar and mechanical air drying is widely used commercially.

16.7.2 Solar Drying

Solar drying is an extension of sun drying that uses radiation energy from the sun. Solar drying is a nonpolluting process and uses renewable energy. Moreover, solar energy is an abundant energy source that cannot be monopolized. However, solar drying has several drawbacks that limit its use in large-scale production. These are the need for large areas of space and for high labor inputs, difficulty in controlling the rate of drying, and insect infestation and microbial contamination.

16.7.3 In-Store Drying

In-store drying can also be called low-temperature in-bin drying. It may be used when grains are stored until milled or sold. Weather conditions in tropical climates are less favorable for in-store drying, due to high ambient temperatures and relative humidity values. Two-stage drying can produce good quality by preventing discoloration of high-moisture grains and reduced cracking of skin dry kernels.

16.7.4 Convection Air Drying

Cabinet- and bed-type dryers (i.e., kiln, tray, truck tray, rotary flow conveyor, and tunnel) fall into the first generation. This is the simplest drying technique, which takes place in an enclosed and heated chamber. The drying medium, hot air, is allowed to pass over the product, which has been placed in open trays. Convection drying is often a continuous process and is mostly used for products that are relatively low in value. Air drying is usually accomplished by passing air at regulated temperature and humidity over or through the food in a dryer. Factors that affect the rate of drying are temperature, humidity, air velocity and distribution pattern, air exchange, product geometry and characteristics, and thickness. The sample is usually placed on mesh trays in one layer or in bulk on a bed or hung from a string for better air circulation over the product. Air circulation can be horizontal or vertical to the layer or bed. The structure and composition, such as fat content, of a product affects the drying rate. In general, hotter the air temperature, the faster is the drying rate; and similarly, the higher is the velocity, the higher is the drying rate; the lower is the air humidity, the higher is the drying rate. The relative humidity (a measure of dryness) is lower when air temperature is raised. A dryer must expel air to get rid of moisture, thereby allowing new, lower humidity air to enter the system. However, this process causes heat loss from the dryer. In many cases, two or multistage drying with different conditions could be used, for example, initial drying at 90°C and then the second or final stage at 60°C.

16.7.5 Explosive Puff Drying

Explosive puff drying uses a combination of high temperature and high pressure, and a sudden release of the pressure (explosion) to flush superheated water out of a product. This method gives a product of good rehydrability. However, the high heat can degrade food quality, and the explosion puffing may compromise product integrity.

16.7.6 Spray Drying

Spray drying is used to remove water from a free-flowing liquid mixture, thus transforming it into a powder form. The fluid to be dried is first atomized by pumping it through either a nozzle or a rotary atomizer, thus forming small droplets with large surface areas. The droplets immediately come into contact with a hot drying gas, usually air. The liquid is very rapidly evaporated, thus minimizing contact time and heat damage. Disadvantages include the size of the equipment required to achieve drying is very large and very oily materials might require special preparation to remove excessive levels of fat before atomization. Ultrasonication in the chamber can be used instead of complex atomization to produce small-diameter droplets in spray drying.

16.7.7 Fluidized Bed Drying

This technique involves the movement of particulate matter in an upward-flowing gas stream, usually hot air. Fluidization mobilizes the solid particulates, thus creating turbulences on the solid surfaces, which increases the drying rate. The hot gas is introduced at the bottom of a preloaded cylindrical bed and exits at the top. In some cases, a vibratory mechanism is used to increase the contact of the product with the hot gas. Fluidized bed drying is usually carried out as a batch process and requires relatively small, uniform, and discrete particles that can be readily fluidized. The main advantages of fluidized bed drying are uniform temperature and high drying rates, thus less thermal damage. A rotating chamber is also used with the fluidized bed, thus increasing centrifugal force to further increase the drying rate and mixing. The use of a solid carrier, such as sea sand, and wheat bran could prevent the biomaterial from deterioration due to thermal shock.

16.7.8 Spouted Bed Drying

In a spouted bed dryer, a jet of heated gas enters the chamber at the center of a conical base. The food particles are rapidly dispersed in the gas, and drying occurs in an operation similar to flash drying. This works very well with large pieces that cannot be dried in a fluidized bed dryer.

16.7.9 Ball Drying

In this method, the material to be dried is added at the top of the drying chamber through a screw conveyor. The material within the drying chamber comes into direct contact with heated balls made from ceramic or other heat-conductive material. Drying occurs primarily by conduction. Hot air is passed through the bottom side of the chamber. When the product arrives at the bottom of the chamber, it is separated from the balls and collected.

16.7.10 Rotary Drum Drying

Rotary drum dryers are cylindrical shells 1ï5 m in diameter, 10ï40 m in length, and rotating at 1ï8 rpm with a circumferential speed of approximately 0.2ï0.4 m/s. These conditions depend on the product types to be dried. The dryers are designed to operate at a nearly horizontal position, inclined only by 2°ï6° to maintain the axial advance of solids, which are fed from the upper end of the dryer body.

16.7.11 Drum Drying

This technique removes water from a slurry, paste, or fluid that has been placed on the surface of a heated drum. The dryer may comprise either a single or a double drum. Drum drying is typically a continuous operation, and care must be taken to ensure that the product that is to be dried adheres well to the drying surface; in some cases, it may be necessary to modify the liquid product by using additives to change its surface tension or viscosity.

16.8 Low Air Environment Drying

16.8.1 Vacuum Drying

Vacuum drying of food involves subjecting the food to a low pressure and a heating source. The vacuum allows the water to vaporize at a lower temperature than at atmospheric conditions, thus foods can be dried without exposure to high temperature. In addition, the low level of oxygen in the atmosphere diminishes oxidation reactions during drying. In general, color, texture, and flavor of vacuum-dried products are improved compared with air-dried products. In some cases, the product is comparable to the quality of freeze-dried foods.

16.8.2 Freeze Drying

In freeze drying, frozen material is subjected to a pressure below the triple point (at 0°C, pressure: 610 Pa) and heated to cause ice sublimation to vapor. A schematic diagram of the different states of water with triple point is shown in Figure.3. This method is usually used for high-quality dried products, which contain heat-sensitive components such as vitamins, antibiotics, and microbial culture. The virtual absence of air and low temperature prevents deterioration due to oxidation or chemical modification of the product. It also gives very porous products, which results in high rehydration rates. However, freeze drying is a slow and expensive process. A long processing time requires additional energy to run the compressor and refrigeration units, which makes the process very expensive for commercial use. Thus, it is mainly used for high-value products.

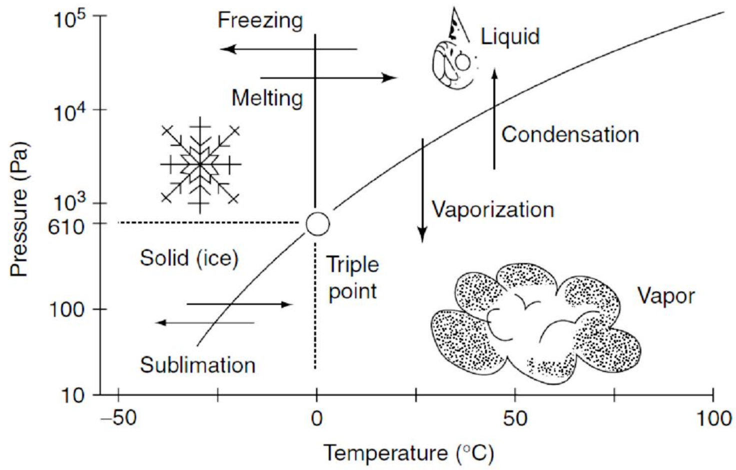

Figure 3: Schematic diagram of the different states of water showing triple point.

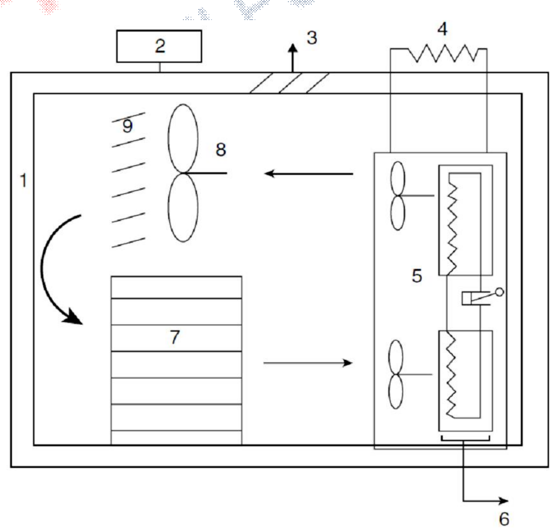

Figure 4: Schematic diagram of operation of a typical heat pump dryer. (1) Vapor – scaled & insulated structure; (2) Humidifier; (3) Over heat vent; (4) External condenser; (5) Heat pump dehumidifier; (6) Condensate; (7) Product tray; (8) Primary sir circulation fan & (9) Air distributor.

16.8.3 Heat Pump Drying

The heat pump dryer is a further extension of the conventional convection air dryer with an inbuilt refrigeration system (Figure. 4). Dry heated air is supplied continuously to the product to pick up moisture. This humid air passes through the evaporator of the heat pump where it condenses, giving up its latent heat of vaporization to the refrigerant in the evaporator. This heat is used to reheat the cool dry air passing over the hot condenser of the heat pump. Thus, the latent heat recovered in the process is released at the condenser of the refrigeration circuit and used to reheat the air within the dryer.

The use of the heat pump dryer offers several advantages over conventional hot air dryers for drying food products, including higher energy efficiency, better product quality, the ability to operate independent of outside ambient weather conditions, and zero environmental impact. In addition, the condensate can be recovered and disposed of in an appropriate manner, and there is also the potential to recover valuable volatile components from the condensate. One of the main reasons of quality improvements in heat pump dried products is due to its ability to operate at low temperatures. If a heat pump dryer is used at low temperatures (10°Cï 60°C) for highly perishable food products, adequate precautions need to be taken. There is also potential to use heat pump drying with modified atmospheres to obtain better quality products.

16.8.4 Superheated Steam Drying
Superheated steam is used as a drying medium. The main advantages of this type of drying are that it can provide an oxygen-free medium for drying, and process steam available in the industry can be used without any capital cost. An oxygen-free medium has the potential to provide high-quality food products; however, it is important to generate more information regarding quality improvement and processing efficiency.

16.8.5 Impingement Drying
Impingement drying is an old technology that has only recently been applied to food products. An impingement dryer consists of a single gas jet (air or superheated steam) or an array of such jets, impinging normally on a surface. There are a great variety of nozzles that can be used, and selection of the nozzle geometry and multinozzle configuration have important relevance on the initial and operating costs, and product quality. Some characteristics of impingement drying include rapid drying, popular for convection drying, and the large variety of nozzles available (multizones). Typically, the temperature and jet velocity in impingement drying may range from 100°C to 350°C and from 10 to 100 m/s, respectively.

16.8.6 Smoking
Smoking foods is one of the most ancient food preservation processes, and in some communities one of the most important. The use of wood smoke to preserve foods is nearly as old as open-air drying. Although not primarily used to reduce the moisture content of food, the heat associated with the generation of smoke also causes a drying effect. Smoking has been mainly used with meat and fish. The main purposes of smoking are it imparts desirable flavors and colors to the foods, and some of the compounds formed during smoking have a preservative effect (bactericidal and antioxidant) due to the presence of a number of compounds. In many cases, smoking is considered as a pretreatment rather than a drying process. It was found that smoke is effective in preventing lipid oxidation in meat and fish products.

16.8.7 Modified Atmosphere Drying
This is a new concept of drying foods using heat pump dryers, which uses modified atmospheres such as nitrogen and carbon dioxide, for better quality and preservation of constituents of foods, prone to oxidation. Technologies to create the modified atmosphere drying are now evolving. Modified atmosphere heat pump dehumidifier (MAHPD) drying is a relatively new development. The fact that heat pump dehumidifier (HPD) drying is conducted in an enclosed, insulated chamber is made use of in the development of the MAHPD drying system. The air in the dehumidifier chamber is replaced with an inert atmosphere such as nitrogen, carbon dioxide, or their mixtures. Replacement of the air inside the chamber is easily carried out by exhausting the chamber using a vacuum pump and then breaking the vacuum using an inert gas. Vacuum exhaustion is a more cost-effective way to replace air than by direct purging with the specific inert gas. Replacement of air with carbon dioxide or nitrogen

by purging requires over 50 volumes to achieve an oxygen level of less than 0.5%. Schematic diagram of the MAHPD drying system is shown in Figure.5. This consists of a sealed drying vessel connected to the heat exchanger unit. The drying vessel has provision for introduction of nitrogen or for evacuation through a valve connection. The MAHPD system shown also has provisions for introducing microwave energy for heating the product, through a slotted waveguide running down the wall of the chamber parallel to the axis of the chamber. A PLC control panel connected to a remote PC and monitor controls the whole system. The product is carried on microwave-transparent plastic trays stacked vertically on a rotating platform, which is mounted on a load cell, so that weight loss can be monitored and recorded on the PC.

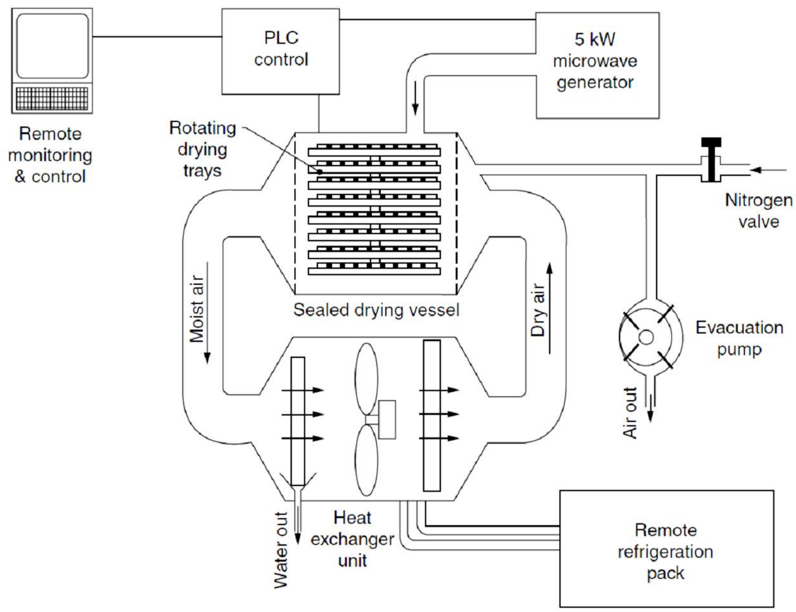

Figure 5: Schematic diagram of MAHPD drying system

16.9 Pretreatments

Pretreatments are common in most of the drying processes in order to improve product quality, storage stability, and process efficiency. In recent years, an improvement in quality retention of the dried products by altering processing strategy and pretreatment has gained much attention.

16.9.1 Blanching: Blanching is a process of preheating the product by immersion in water or steam. The main purpose of blanching is to inactivate the naturally occurring enzymes present in foods, since enzymes are responsible for off-flavor development, discoloration or browning, deterioration of nutritional quality, and textural changes in food materials. Other advantages are that it removes air-bubbles from vegetable surfaces and from intercellular spaces, reduces the initial microbial load, cleans raw food materials initially, facilitating preliminary operations such as peeling and dicing, and improving color, texture and flavor under optimum conditions. Blanching may have disadvantages, for example, it may change the texture, color, and flavor because of the heating process; it increases the loss of soluble solids, such as vitamins, especially in the case of water blanching; it may change the chemical and physical states of the nutrients and vitamins; and it has adverse environmental impacts, such as large water and energy usage, and problems of effluent disposal.

16.9.2 Sulfur Dioxide Treatment: Sulfur dioxide preserves the texture, flavor, vitamin content, and color that make food attractive to the consumer. Sulfur dioxide treatment is used widely in the food industry to reduce the fruit-darkening rate during drying and storage, and preserves ascorbic acid and carotene. Sulfur dioxide taken up by the foods displaces air from the tissue in plant materials, softens cell walls so that drying occurs more easily, destroys enzymes that cause darkening of cut surfaces, shows fungicidal and insecticidal properties, and enhances the bright attractive color of dried fruits.

Permitted levels of sulfur dioxide and other additives (solutes) in dried foods vary from country to country.

16.9.3 Salting or Curing: Salting or curing is a natural type of osmotic dehydration. Curing was originally developed to preserve certain foods by the addition of sodium chloride. In the food industry, the application of curing is related only to certain meat, fish, and cheese products. Today sodium chloride, and sodium and potassium nitrite (or nitrate) are considered as curing salts. Salting is one of the most common pretreatments used for fish products. It converts fresh fish into shelf-stable products by reducing the moisture content and acting as a preservative. In combination with drying, these processes contribute to the development of characteristic sensory qualities in the products, which influence their utilization as food.

16.9.4 Freezing Pretreatment: Freezing treatment affects the drying process. The rehydration rate of air- and vacuum-dried fruits and vegetables subjected to freezing treatment increased to a level comparable with that of freeze-dried products. It is also noticed that the longer the duration of freezing, the better the rehydration kinetics of dried products. This is due to the formation of large ice crystals by slow freezing.

16.9.5 Cooking: Cooking at different pressure levels before drying can destroy microorganisms and affect the physicochemical properties of dried products. The bacterial load on the final product can thus be reduced considerably, and the cooked product can be minced and spread evenly on drying trays with much less trouble than the raw material. Precooking is usually used for rice, beef, fish, and beans. Formation of superficial pellicle (case-hardening) may be avoided by precooking, which considerably retards drying. It is clear that the more severe the initial conditions of cooking, the more stable is the subsequently dehydrated product. Generally, cooked vegetable, meat, or fish is dried more easily than their fresh counterparts, provided that the cooking does not cause excessive shrinkage or toughening. Cooking also results in a decrease in water-holding capacity of meat products.

16.9.6 Other Dipping Pretreatments: Dipping treatment with chemicals is also used in addition to blanching or sulfite treatment. The dipping treatment is a process of immersion of foods in a solution containing additives. Usually, the concentration level is below 5% and the dipping time below 5 minutes, whereas osmotic dehydration is carried out at higher concentrations and for long processing times. The main purpose of the dipping treatment is to improve the drying characteristics and quality. Certain chemicals are used to enhance the rate of dehydration. Among these compounds, methyl and ethyl oleate, or olive oil are the most common. Table.1 shows the chemicals used for dipping treatment.

Table. 1: Chemicals Used for Dipping Treatment

Type	**Compounds**
Chemicals	
Esters	Methyl oleate, ethyl oleate, butyl oleate
Salts	Potassium carbonate, sodium carbonate, sodium chloride, potassium sorbate, sodium polymetaphosphate
Organic acids	Oleic acid, steric acid, caprillic acid, tartaric acid, oleanolic acid
Oils	Olive oil
Alkali	Sodium hydroxide
Wetting agents	Pectin, tween, nacconol
Others	Sugar, liquid pectin
Surfactants	
Nonionic	Monoglycerides, diglycerides, alkylated aryl polyester alcohol, polyoxyethylene sorbitan monostearate, sorbitan monostearate, D-sorbitol, polyoxyethylene

Anionic	Sodium oleate, steric acid, sorbitan heptadecanyl sulfate, dimethyl-benzyl-octyl ammoniumchloride

16.10 Quality changes during drying

16.10.1 Selection of Variety: Optimum freshness plays an important role in determining the quality and stability of dried foods; fresher the raw material, more stable and better is the quality of the product. Suitable varieties of produce with the desired maturity should be used to achieve a product that is best in quality. The quality characteristics of dried foods can be grouped as microbial, chemical, physical, and nutritional (Table.2).

16.10.2 Microflora in Dried Foods: Multiplication of microorganisms should not occur in properly processed dehydrated foods, but they are not immune to other types of food spoilage. If dried foods are safe in terms of pathogenic microbial count and toxic or chemical compounds, then acceptance depends on the flavor or aroma, color, appetizing appearance, texture, taste, and nutritional value of the product. Microbial standards are usually based on the total number of indicator organisms or number of pathogens. The microbial load and its changes during drying and storage are important for establishing a standard that will ensure food safety.

Table. 2: Quality Characteristics of Dried Foods

Microbial	Chemical	Physical	Nutritional
Pathogens	Browning	Rehydration	Vitamin loss
Spoiling	Oxidation	Solubility	Protein loss
Toxin	Color loss	Texture	Functionality loss
	Aroma development	Aroma loss	Fatty acid loss
	Removal of undesired components	Porosity	
		Shrinkage	
		Poresô characteristics	
		Crust formation	
		Structure	

16.10.3 Browning Reactions: Browning reactions change color, decrease nutritional value and solubility, create off-flavors and induce textural changes. Browning reactions can be classified as enzymatic or non-enzymatic, with the latter being more serious as far as the drying process is concerned. The two major types of non-enzymatic browning are caramelization and Maillard browning. In addition to moisture level, temperature, pH, and composition are the other parameters that affect the rate of non-enzymatic browning. The rate of browning is most rapid in the intermediate moisture range and decreases at very low and very high moistures. Browning tends to occur primarily at the center of the drying period. This may be due to the migration of soluble constituents toward the center. Browning is also more severe near the end of the drying period, when the moisture level of the sample is low and less evaporative cooling is taking place that causes the product temperature to rise.

16.10.4 Lipid Oxidation: Dehydrated foods containing fats are prone to develop rancidity after a period, particularly if the water content is reduced too much. Fish oils or fats are more unsaturated than beef or butter, and they are usually classified as drying oils because they contain considerable proportions of highly unsaturated acids. The behavior of drying oils toward atmospheric oxygen is well known, and oxidation is a serious problem for commercial drying of fatty fish and seafood. The flesh of some fatty fish, such as herrings, contains a fat pro-oxidant that is not wholly inactivated by heat. Lipid oxidation is responsible for rancidity, development of off-flavors, and the loss of fat-soluble vitamins and pigments in many foods, especially in dehydrated foods. Factors that affect oxidation rate include moisture content, type of substrate (fatty acid), extent of reaction, oxygen content, temperature, presence of metals and natural antioxidants, enzyme activity, UV light, protein content, free amino acid content and other chemical reactions. Moisture content plays a big part in the rate of oxidation. At water activities around the monolayer (*a*w 0.3), resistance to oxidation is greatest. The elimination of oxygen from foods can reduce oxidation, but the oxygen concentration must be very low.

16.10.5 Changes in Proteins: The protein matrix in muscle has a marked effect upon its functionality and properties. The non-fatty part of fish is very susceptible to changes caused by the high temperature of initial cooking, as well as drying and storage. Every process involved in the conversion of muscle to meat alters the characteristics of the structural elements. Heating is believed to cause the denaturation of the muscle proteins even below 60°C but not enough to greatly shear resistance.

16.10.6 Structural Changes: Structural changes in food during drying are usually studied by microscopy. Microscopy provides a good tool to study this type of phenomenon as well as other types of physical and chemical changes during the drying of food materials. Shrinkage occurs first at the surface and then gradually moves to the bottom as the drying time increases. The cell walls become elongated. As drying proceeds at high temperature, cracks are formed in the inner structure. Rehydration is maximized when cellular and structural disruption such as shrinkage is minimized.

16.10.7 Case Hardening or Crust Formation: During drying, the concentration of moisture in the outer layers of foods is less than in the interior, since the outer layers necessarily lose moisture before the interior. This surface shrinkage causes checking, cracking, and warping. This type of shrinkage causes moisture gradient and resistance near the surface. In extreme cases, shrinkage and drop in diffusivity may combine to yield a skin practically impervious to moisture, which encloses the volume of the material so that the interior moisture cannot be removed. This is called case hardening. In food processing, case hardening is also commonly known as crust formation. The extent of crust formation can be reduced by maintaining flattening moisture gradients in the solid, which is a function of drying rate. The faster the drying rate, the thinner the crust. Crust (or shell) formation may be either desirable or undesirable in dried food products.

16.10.8 Shrinkage or Collapse and Pore Formation: Two types of shrinkage are usually observed in the case of food materialsï ï isotropic and anisotropic shrinkage. Isotropic shrinkage can be described as the uniform shrinkage in all geometric dimensions of the materials. Anisotropic shrinkage is described as the non-uniform shrinkage in the different geometric dimensions. Shrinkage is an important phenomenon impacting dried food product quality by reducing product wettability, changing product texture, and decreasing product absorbency. Depending on the end use, crust and pore formation may be desirable or undesirable. If a long bowl life is required for a cereal product, a crust product that prevents moisture reabsorption may be preferred. If a product (such as dried vegetables in instant noodles) with good rehydration capacity is required, high porosity with no crust is required.

16.10.9 Stress Development and Cracking or Breakage: During air drying, stresses are formed due to non-uniform shrinkage resulting from non-uniform moisture and temperature distributions. This may lead to stress crack formation when stresses exceed a critical level. Crack formation is a complex process influenced interactively by heat and moisture transfer, physical properties, and operational conditions. The relative humidity of air and temperature are the most influential parameters that need to be controlled to eliminate the formation of cracks. Checking and breakage of dried foods has two undesirable consequencesï ï loss of valuable product and loss of consumer satisfaction.

16.10.10 Rehydration: Rehydration is a process of moistening dry material. It is mostly done by applying an abundant amount of water. In most cases, dried foods are soaked in water before cooking or consumption, thus rehydration is one of the important quality criteria. In practice, most of the changes during drying are irreversible and rehydration cannot be considered simply as a process reversible to dehydration. In general, absorption of water is fast at the beginning and thereafter slows down. This rapid moisture uptake is due to surface and capillary suction.

16.10.11 Volatile Development or Retention: In addition to physical changes, drying generates flavor or releases flavor from the foods. Drying changes the composition of volatiles by evaporating most volatiles and forming new volatile odor compounds by chemical reactions. Such changes in volatiles might affect the aroma of fresh foods after drying.

16.10.12 Solubility: Many factors affect solubility, including processing conditions, storage conditions, composition, pH, density, and particle size. It was found that an increase in drying temperature is accompanied by increasing protein denaturation, which decreases solubility. Thus, more protein is denatured and solubility decreased.

16.10.13 Caking and Stickiness: Caking and stickiness of powders, desirable or undesirable, occur in dried products. Caking is desirable for tablet formation and undesirable when a dry free-flowing material is required. To reduce caking during drying, a logical option is to dry rapidly so that the moisture content drops to a level where caking is inhibited. The rapid drying will form a crust, which may be undesirable, thus product optimization or solutes in product formulation may be considered.

16.10.14 Texture: Factors that affect texture include moisture content, composition, variety or species, pH, product history (maturation or age), and sample dimensions. Texture is also dependent on the method of dehydration and pretreatments.

16.10.15 Vitamins Retention: In general, losses of B vitamins are usually less than 10% in dried foods. Dried foods do not greatly contribute to dietary requirements for thiamin, folic acid, and vitamin B-6. Vitamin C is largely destroyed during drying due to heating. From non-fatty vegetables, such as cabbage, as much water as possible should be removed, because this helps to conserve ascorbic acid. The loss of vitamin A and ascorbic acid in dried products could be avoided in the absence of oxygen. Even though most amino acids are fairly resistant to heatingï drying, lysine is quite heat labile and likely to be borderline or low in the diet of humans and especially so in developing countries where high quality animal proteins are scarce and expensive.

16.10.16 Color Retention or development: High temperature and long drying time degrade a productôs original color. Color in foods can be preserved by minimal heat exposure or applying high temperature and short time with pH adjustment. Water activity is one of the important factors degrading chlorophyll. Another cause of color degradation may be due to enzymatic browning causing rapid darkening, mainly of the leafy portions. The formation of dark pigments via enzymatic browning is initiated by the enzyme polyphenol oxidase (PPO). Another reason for discoloration is photooxidation of pigments, caused by light in combination with oxygen.

16.11 Conclusion

Drying reduces the water activity, thus preserving foods by avoiding microbial growth and deteriorative chemical reactions. The effects of heat on microorganisms and the activity of enzymes are also important in the drying of foods. In the case of foods to be preserved by drying, it is important to maximize microorganism and enzyme inactivation for preventing spoilage and enhancing safety, and reduce the components responsible for the deterioration of the dried foods. Also, in the case of drying bacterial cultures, enzymes, or vitamins, minimum inactivation of the microorganism and enzyme is required. Thus, detrimental effects of drying may be desirable or undesirable, depending on the purpose of the drying process.