DEHYDRATION IN FOOD PROCESSING AND PRESERVATION

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Contents

Summary

This article presents an overview of drying as a preservation method. The main focus is on drying methods, pretreatments, and quality characteristics. In many cases, pretreatment is important in achieving the desired level of quality attributes. The microbial, chemical, physical and nutritional quality characteristics of dried products are also summarized.

1. Introduction

1.1. Background of drying

The preservation of foods by drying is the time honored and most common method used by humankind and the food processing industry. The dehydration of food is one of the most important achievements in human history making our species less dependent upon a daily food supply, even under adverse environmental conditions. Drying in earlier times was done in the sun, but today many types of sophisticated equipment and methods are being used to dehydrate foods. In recent decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during dehydration and to develop methods for preventing undesirable quality losses. Foods can be divided into three broad groups based on the value added through processing by drying. In the case of cereals, legumes and root crops, very little value is added per kilogram processed. More value per unit mass is added to foods such as vegetables, fruits and fish; and considerably more to high value crops such as spices, herbs, medicinal plants, nuts, bio-active materials, and enzymes.

1.2. Mode of preservation

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

1.3. State of water in foods

The terms dried and dehydrated are not synonymous. The US Department of Agriculture lists dehydrated foods as those with no more than 2.5% water (dry basis). The concept of bound and free water has been developed from drying principles, and it is important for dried products for its stability during processing and storage. A product containing no water is termed as bone-dry. Water in foods exists in different forms or states. Water in foods having properties different from those of pure water can be defined as bound water. In the literature different forms of bound water are defined, e.g. unfreezeable, immobile, monolayer, and non-solvent water. However the fraction of bound water depends on the definition and measurement techniques. 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.

1.4. Endpoint of drying

Equilibrium in the drying system is the ultimate endpoint for the process. Water activity is commonly used to estimate the equilibrium point in 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 a 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 desired acceptable quality after drying and during storage. Different attributes of quality can be targeted, thus the end point should be determined from all aspects, such as safety first and then consumer acceptance.

1.5. Heating methods in drying

Heating of air by electric heater or flue gas is the conventional heating method used for the drying process. 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 the electromagnetic wavelength spectrum as a form of energy, which interacts with the materials, thus generating heat and increasing the drying rate. Dielectric drying uses frequencies in the range of 1-100 MHz, whereas microwave drying uses frequencies in the range of 300-300 000 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 vacuum-drying and microwave drying, providing improved energy efficiency and product quality. The energy can be applied in a pulsed or continuous mode. Pulsed microwave drying is more efficient than continuous drying. The development of electro-technology in drying is becoming a priority in the food industry, to improve drying efficiency as well as food quality.

2. Drying methods

Drying processes can be broadly classified, based on the water-removing method applied, as (i) thermal drying, (ii) osmotic dehydration, and (iii) mechanical dewatering. In thermal drying a gaseous or void medium is used to remove water from the material. Thermal drying can be divided 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 to remove water. Consideration should be given to many factors before selecting a drying process. These factors include (a) the type of product to be dried, (b) desired properties of the finished product, (c) allowable temperature tolerance, (d) the product's susceptibility to heat, (e) pretreatments required, (f) capital and processing cost, and (g) environmental factors. There is no single best technique for drying of all products

3. Thermal drying

3.1. Air drying

3.1.1 Sun drying

Formerly, sun drying was the only method used for drying food. The main disadvantage is the contamination and product loss by insects and birds. Where the climate is not particularly suitable for air drying or better quality is desired, mechanical air-drying is mainly used. Today, solar and mechanical air-drying is widely used commercially.

3.1.2 Solar drying

In solar drying, radiation energy from the sun is used. Solar drying is a non-polluting process and uses renewable energy. Moreover, it is an abundant energy source that cannot be monopolized. Solar drying has several drawbacks, however, and these limit its use in large-scale production. These are the need for large areas of space and for high labor inputs, the difficulty in controlling the rate of drying, and insect infestation and microbial contamination. More options in designing are now available in the literature.

3.1.3 In-store drying

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

3.1.4 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, taking 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 most often 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 affect the rates 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 a bulk bed or hangs from a string for better air circulation. The 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 the hotter the air temperature, the faster is the drying rate; and similarly the higher the velocity the higher the drying rate. Lower air humidity causes a higher drying rate. The relative humidity (a measure of dryness) falls when air temperature is raised. The drier 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 drier. In many cases, two or multistage dryers are used, with different conditions, e.g. initial drying at 90 ^{o}C and then the second or final stage at 60^{o}C. Re-circulating exhaust air in dryers is popular because of energy conservation and its effect on grain quality.

Drying is one of the most energy-intensive processes in the food industry. Apart from the rise of energy cost, legislation on pollution and sustainable and environmentally friendly technologies have created greater demand for energy-efficient drying processes in the food industry. Thus, novel thinking could save much money by avoiding costly energy waste. Heat losses during drying can be grouped as: heat loss with the exhaust air, heat loss with the product, radiation heat loss from the dryer, heat loss due to leakage of air from the dryer, and heat loss due to over drying of products. Changing the dryer design can reduce energy losses while achieving higher product quality, such as by reducing drying time or increasing throughput (better control), avoiding heat losses, and heat recovery from exhaust gas and dried product.

3.1.5 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 the product good rehydrability. However, the high heat can degrade the food quality, and explosion puffing may compromise the product integrity.

3.1.6 Spray-drying

Spray-drying is used to remove water from a free-flowing liquid mixture, thus transforming it into a powder product. 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. Ultra-sonication in the chamber can be used instead of complex atomization to produce small-diameter droplets in spray-drying.

3.1.7 Fluidized bed drying

This technique involves 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 drying rate. The hot gas is introduced into 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 a 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 be used to prevent the biomaterial from deterioration due to thermal shock.

3.1.8 Spouted bed drying

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

3.1.9 Ball drying

In this method the material to be dried is added to 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 drying 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.

3.1.10 Rotary drum drying

Rotary drum dryers are cylindrical shells 1 to 5 m in diameter, 10 to 40 m in length, and rotating at 1 to 8 rpm with a circumferential speed of approximately 0.2 to 0.4 m/s. These conditions depend on the product types used for drying. They are designed to operate at a nearly horizontal position, inclined at only 2 to 6^o to maintain the axial advance of solids, which are fed from the upper end of the dryer body.

3.1.11 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 additives to change its surface tension or viscosity.

3.2. Low air environment drying

3.2.1 Vacuum-drying

Vacuum-drying of food involves subjecting it 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 absence of air during drying diminishes oxidation reactions. In general color, texture and flavor of vacuum-dried products are improved compared to air-dried. In some cases the product is comparable to the quality of freeze-dried.

3.2.2 Freeze-drying

In freeze-drying the material that has been frozen is subject to a pressure below the triple point (at 0 ^oC, a pressure of 610 Pa) and heated to cause ice sublimation to vapor. This method is usually used for high-quality dried products, which contain heat-sensitive components such as vitamins, antibiotics, and microbial culture. Virtual absence of air and low temperature prevent deterioration due to oxidation or chemical modification of the product. It also gives very porous products which results in a high rehydration rate. However, freeze-drying is a slow and expensive process. The long processing time requires additional energy to run the compressor and refrigeration units, which makes the process very expensive for commercial use.

3.2.3 Heat pump drying

The heat pump dryer is a further extension of a conventional convection air-dryer with an in-built refrigeration system. The dry heated air is supplied continuously to the product to pick up moisture. The humid air passes through the evaporator of the heat pump where it condenses, thus 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 the drying of food products, including higher energy efficiency, better product quality, the ability to operate independently 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 for 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 to 60 ^{o}C) for highly perishable food products, adequate precautions need to be taken. There is also potential to use heat pump modified atmosphere drying for better quality products.

3.2.4 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 give high-quality food products, but it is important to generate more information regarding quality improvement and processing efficiency.

3.2.5 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 is a great variety of nozzles that can be used and selection of the nozzle geometry and multi-nozzle 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 ranges from 100 to 350 ^{o}C and 10 to 100 m/s, respectively.

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Biographical Sketch

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Dr. Rahman has initiated the International Journal of Food Properties (Marcel Dekker, Inc.) and has served as the founding Editor for more than six years. He has served as a member in the Food Engineering Series Editorial Board of Aspen Publishers, Maryland (1999-2003). In 2003 he was invited to serve as a member of the Food Engineering Series Board, Kluwer Academic/Plenum Publishers, New York. He was also invited to serve as a Section Editor for the Sultan Qaboos University journal Agricultural Sciences (1999). In 1998 he was invited to serve as a Food Science Adviser for the International Foundation for Science (IFS) in Sweden. Dr. Rahman is a professional member of the New Zealand Institute of Food Science and Technology and the Institute of Food Technologists, and a member of the American Society of Agricultural Engineers and the American Institute of Chemical Engineers. He received B.Sc.Eng. (Chemical) (1983) and M.Sc.Eng. (Chemical) (1984) degrees from Bangladesh University of Engineering and Technology, Dhaka, an MSc degree (1985) in food engineering from Leeds University, England, and a PhD. (1992) in food engineering from the University of New South Wales, Sydney, Australia. Dr. Rahman has received numerous awards and fellowships in recognition of research/teaching achievements, including the HortResearch Chairman's Award, the Bilateral Research Activities Program (BRAP) Award, CAMS Outstanding Researcher Award 2003, and the British Council Fellowship.