Review Article

A comprehensive review of food dehydration and its application in aquatic food products

Abstract

Food dehydration is preferred as the most effective and intricate process within the realm of food processing. Employing methods such as hot air/heated surfaces, this method reduces the water content from various food items, consequently reducing their water activity. The primary objective is to hinder microbial growth and enzyme activity, thereby extending the shelf-life. Nevertheless, it is crucial to acknowledge that the dehydration process can potentially compromise both the quality and nutrition. This necessitates a thoughtful approach in the design and operation of dehydration equipment. Various dehydration methods have been developed to achieve the desired physico-chemical, nutritional, and sensory alterations.

Keywords: Dehydration; seafood; Food preservation; drying; fishery products

1. Introduction

Food preservation through drying is a historic and prevalent method, crucial for human independence from daily fresh food supplies, especially in challenging environments. Initially reliant on the sun, modern technology employs various sophisticated methods for food dehydration. Extensive research in recent decades aims to comprehend chemical changes in dehydration and prevent quality losses. This achievement in human history, reducing dependence on daily food, has evolved from sun-drying to advanced techniques, enhancing food security under adverse conditions (JM Jay, 1995). Both the terms ‘drying’, and ‘dehydration’ mean the removal of water. The terms dried and dehydrated are not synonymous. Drying is a process in which water is removed to halt or slow down the growth of spoilage microorganisms, as well as the occurrence of chemical reactions in a natural condition. Dehydration is the deliberate and controlled removal of water from a substance.Perhaps dehydration is chemical science’s oldest and most versatile way of drying procedures (Gartner E et al.,2017). Dehydrating is essential in many agricultural, food, biotechnological, mineral processing, pulp, wood, polymer, ceramics, pharmaceutical, paper, and chemical applications (Mujumdar.AS 2014). During the drying process, reduction in the moisture content and, therefore, water activity permits the microbial activity in food materials to stabilize while also controlling supplementary deteriorative processes, such as browning, enzymatic and nonenzymatic reactions, lipid oxidation, and many more. Dehydrating food helps prevent bacterial growth that causes changes in chemicals and the occurrence of spoilage and the in food by reducing the moisture content of dietary items (Jayaraman K et al., 2020). There are several goals for dehydrating dietary products. most obvious is food preservation by dehydration. The dehydration technique limits microbial activity and other effects by lowering the humidity level of the item (Tapia MS et al., 2020). This method not only preserves the food from a microbiological aspect but also preserves its flavour and nutritional properties. A dehydrated food item has the benefit of being lightweight, which reduces shipping costs. However, the quality of the dried product is frequently diminished because high temperature is required in most conventional drying processes (Calín-Sánchez Á et al., 2020). The physicochemical concepts associated with food dehydration need to be understood for an appropriate assessment of the drying phenomena in any food product. Water activity, temperature, dehydration mechanisms and theories, and chemical and physical changes should be recognized as key elements for any food dehydration operation.

2.Type of dehydration in food processing

Dehydration of food is done for various purposes (reduce weight, packaging, enhance taste and nutrition) and based on energy source for water removal various types are classified. Some of the effective methods are discussed below.

2.1. Convection drying

Convection drying employs elevated temperatures to systematically accelerate the dehydration of products. In this method, heated air serves as the carrier of the necessary heat to remove water from food. The heated air circulates through the food, consistently exiting from the dryer throughout the process. This cause rise in temperature of water in food and facilitate removal. Various machinery and equipment are required for this technique, depending on the specific characteristics of the dried food material. Cabin dryers, tunnel dryers, fluid bed dryers, and spray dryers are among the commonly used types of dryers in convection drying. (Cemeroglu, B., et. al.2003). Air temperature and air flow rate are an important parameter in convectional hot air drying. They are commonly used for preheating, baking, aging, sterilization, and thermal storage.

2.2. Ultrasonic drying.

High power ultrasound is characterized by low frequencies (20–100 kHz) at high intensities (typically 10–1,000 W/cm) (Tiwari BK, Mason TJ (2012)).The utilization of ultrasound on a porous food item in a water-based environment leads to the creation of micro-channels on its surface, resulting from the deformation of the porous solid material under the influence of ultrasound waves. [Fernandes F and Rodrigues S (2007The drying process can be improved by minimizing the impact of case hardening. Simultaneously, the application of high-intensity ultrasonic waves couples with the drying product material, facilitating the liquid to permeate the solid medium through rapid compressions and expansions. This phenomenon is akin to the "sponge effect," resembling the repetitive squeezing and releasing of a sponge. [Ghafoor M. et. Al 2014]. The mechanical system exerts forces that can exceed the influence of surface tension, responsible for retaining moisture within the capillaries of the material. This process results in the formation of microscopic channels, potentially optimizing moisture removal when employing ultrasound. (De la Fuente-Blanco S, et. Al 2006).

2.3. Microwave heating.

Microwave radiation, falling within the electromagnetic spectrum with wavelengths spanning 1 mm to 1 m, is frequently employed in food applications at common frequencies of 915 and 2,450 MHz Notably non-ionizing, microwaves are recognized as a fourth-generation technology when harnessed for various applications. (Vega-Mercado H, et al.,2001). Microwave dehydration is a food preservation method that utilizes microwave radiation to remove moisture from food products. In this process, microwaves penetrate the food, generating heat by causing water molecules to vibrate, thereby accelerating the evaporation of water. This technique is known for its speed and efficiency in dehydrating various foods, while preserving flavour, colour, and nutritional content. Microwave dehydration is commonly employed in both home kitchens and industrial food processing settings.In contrast to traditional drying methods, microwave heating involves the direct delivery of energy to the material through molecular interactions with the electromagnetic field. This dielectric heating principle incorporates two fundamental mechanisms: dipolar rotation and ionic conduction, heavily dependent on the product's dielectric permittivity and loss factor. Key process parameters include combinations of time and power levels. Essential product parameters encompass the moisture content and dielectric properties. Research indicates that intermittent microwave drying yields superior results compared to convective microwave drying(Chua KJ, Chou SK (2005). This is due to the intermittent use of microwave power, which reduces exposure time and the potential for overheating, thereby providing energy efficiency. Microwave-assisted drying of diverse food materials has demonstrated remarkable outcomes.

This includes significant reductions in drying time (up to 25–90%), substantial increases in drying rate (up to 400–800%), and notable reductions in energy consumption (32–71%) compared to conventional drying methods. Additionally, the process offers superior product quality, surpassing even freeze-dried foods, requires less floor space, and allows for enhanced overall process control. (Wang Y, et al., 2014)

2.4. Pulsed electric field.

Pulsed electric field (PEF) drying stands as a technology capable of enhancing both drying kinetics and product quality. Emerging as a novel approach, PEF induces reversible and irreversible electroporation on cell membranes, promoting increased mass transfer during drying while mitigating damage to cellular structures. The process involves applying very brief, high-voltage pulses to food positioned between electrodes, resulting in electroporation characterized by the formation and growth of membrane pores, cell membrane disruption, and leakage of intracellular content (Rastogi, N.K. et al., 1999), (Knorr, D et al., 2001), (Ngadi, M, O. et al.,2003) The efficiency of electroporation is mostly monitored by an electrical conductivity measurement. (Bazhal, M. et al.,2003), (Wiktor, A. et al., 2012). The electrically induced perforation of the cell membrane is responsible for drying enhancement (and other mass and heat transfer-based processes) as it alters the cellular structure of the plant material that is considered as one of the drying limiting factors.

2.5. Osmotic dehydration

Osmotic dehydration is a gentle method for extracting water from foods, offering the prospect of enhancing their nutritional, sensory, and functional characteristics concurrently. The procedure involves immersing a food product in a concentrated hypertonic solution. The osmotic pressure disparity between the food and the solution triggers two primary mass fluxes: the extraction of water from the food to the osmotic solution and, simultaneously, the incorporation of solids from the solution into the food. (Raoult-Wack, 1994). Sugars, salts, or combinations of them (ternary solutions) have been used as osmotic agents. The rate of water and osmotic solute diffusion into and out of food is influenced by various factors. These include the raw materials characteristics (shape, size), the composition and concentration of the osmotic solution, temperature, the ratio of solution to sample mass, and the intensity of solution agitation. (Chiralt and Fito, 2003;).

2.6. Intermittent drying

Intermittent drying is an approach to drying that involves altering drying conditions over time. This can be achieved by modifying variables such as drying air temperature, humidity, pressure, or the mode of heat input. The control of thermal energy supply is crucial in intermittent drying and can be achieved by adjusting air flow rate, temperature, humidity, operating pressure, or the mode of energy input (e.g., convection, conduction, radiation, or microwave). Consistent energy supply throughout the drying process can lead to quality degradation and surface heat damage. (Zeki,2009) and wastage of heat energy. This occurs because, in the final phases of drying, the drying rate diminishes as samples lack adequate moisture for removal. The sample surface dries out in these later stages, and continuous use of high-temperature air can lead to quality deterioration and surface damage. Employing intermittent drying as a strategy allows sufficient time for moisture to migrate from the center to the surface of the sample during the tempering period. Consequently, the application of intermittent drying can minimize quality degradation and reduce the risk of heart damage.

2.7. Vacuum dehydration

Vacuum dehydration is a food processing method that exposes food to low pressure and heat. The vacuum lowers the water's boiling point, enabling drying at lower temperatures. This process enhances evaporation rates and reduces resistance to mass transfer at the product surface, resulting in shorter drying times compared to conventional hot-air methods. Vacuum drying often yields higher-quality dried products, showcasing a microstructure with increased porosity, less shrinkage, and superior rehydration capabilities. The porosity and pore size of vacuum-dried products are typically 14% higher than those dried with hot air, contributing to improved texture, such as increased crispiness. In the process of vacuum drying, water molecules with high energy migrate to the surface and evaporate under reduced pressure. The lack of air in this method serves to prevent oxidation, preserving the color, texture, and flavour of the dried products.(Amellal and Benamara, 2008).

2.8. Pulsed vacuum osmotic dehydration

Pulsed vacuum osmotic dehydration (PVOD) involves utilizing vacuum pressure to assist in the osmotic dehydration (OD) process. This method entails subjecting food to an osmotic solution for an extended duration following a brief period under vacuum conditions. (Zhao & Xie, 2004).The PVOD operation consists of three steps. In step one, the food sample is soaked in an osmotic medium like sucrose syrup or syrup mixed with active substances, and then immediately subjected to vacuum pressure (~50-100 mbar) for a short time (10-30 min) in a closed tank (Fito et al., 2001). The air and native liquids are removed from food tissue and the expansion of pores occurs due to a pressure gradient. In step two, atmospheric pressure is restored in the tank. The impregnation of pores by external solution and relaxation of deformation phenomena of food tissues will simultaneously occur. In step three, the food sample is soaked in osmotic solution for a certain period (~180-360 min). Vacuum could speed up processing time and allow a reduction in energy during the process (Corzo et al., 2007).

3. Factors affecting dehydration.

The dehydration of food involves the transfer of water mass from the food to the dehydrating environment, while the application of heat serves as the driving force for water removal. The primary objectives of food dehydration operations are to achieve rapid drying at minimal cost while minimizing alterations to food quality.The composition of the food itself plays a significant role in the dehydration rate. Water bound to solutes in the food, for instance, exhibits lower vapor pressure, making it more challenging to remove. The porosity of the food is also crucial, and efforts are made to enhance it, promoting efficient mass transfer, and accelerating the drying rate. Creating porous, sponge-like structures involves generating steam pressure within the product during drying, resulting in a "puffing" effect. Alternatively, stable foams can be created from liquid food before drying to introduce porosity.Beyond food composition, several factors impact heat and mass transfer during dehydration, influencing the undesirable changes mentioned earlier. These factors need careful consideration to maintain control over the dehydration process.

3.1. Atmospheric humidity.

The dryness in contact with solids is influenced by atmospheric humidity. A dynamic equilibrium is established between the moisture in the solids and the vapor in the air. Solids exposed to moist air over an extended period will attain their equilibrium moisture content, which increases with rising relative humidity or falling temperatures. Consequently, solids in a cool, damp environment absorb more moisture than those stored in warm, dry conditions. Conversely, lower humidity accelerates dehydration due to a higher moisture gradient facilitating faster water evaporation. This environmental factor is critical in food dehydration, necessitating adjustments in methods or equipment to optimize the process according to prevailing atmospheric conditions. Effectively managing humidity is essential for achieving efficient and successful results in food preservation.

3.2. Airflow

Airflow stands as a critical factor impacting the dehydration of food, and efficient air circulation is pivotal for expediting the dehydration process. Adequate airflow plays a key role in extracting moisture from the food surface, carrying it away, and establishing a low-humidity environment around the food. This prevents the formation of a stagnant boundary layer, where saturated air hinders further water evaporation. Enhanced airflow, often facilitated by dehydrators or well-ventilated drying systems, ensures a more consistent and rapid dehydration, leading to improved preservation of food with a desirable texture and flavor. Adjusting and optimizing airflow is essential for achieving effective dehydration processes across various food items.

3.3. Air Temperature

In the food industry, hot air is commonly employed as the drying medium, often heated by passing it over electrical heating elements. The temperature of the air is a critical factor in drying, influencing its water-holding capacity. Higher air temperatures result in increased water-holding capacity, enhancing the air's ability to remove water from a product compared to cooler air. However, some products are highly sensitive to heat, and their quality deteriorates significantly when exposed to excessive temperatures. Elevated temperatures can lead to scorching or toasting of the product.Excessive temperatures can also result in a phenomenon known as "case hardening." When wet material is subjected to too much heat, its outer surface quickly becomes dry, forming a shell or crust around the material. This hardened surface traps moisture at the centre of the product, preventing it from reaching the outer surface where it would typically evaporate. This underscores the importance of carefully managing temperatures during the drying process to avoid detrimental effects on product quality.

3.4. Surface area

Specific surface area denotes the amount of surface present in a unit weight of material, measured in square centimetres per gram or square meters per kilogram (m^2/kg), or other relevant units. This concept recognizes that drying primarily occurs at the surface, and a larger surface area facilitates a quicker drying process. This principle is akin to cooking practices where we cut large pieces of food into smaller ones to expedite the heating process. For instance, when boiling fish, cutting it into smaller pieces increases the surface area for heat penetration, reducing the distance the heat must travel to reach the centre. Similarly, in drying, smaller pieces offer more surface area for moisture escape and reduce the thickness, expediting the time it takes for moisture from the centre to reach the surface and evaporate in contact with the drying air.

3.5. Method of drying.

Drying processes can be broadly categorized into natural drying and artificial drying or mechanical dehydration based on the energy source. Natural drying relies on sunlight and wind, encompassing sun, solar, and shade drying. However, in natural drying, temperature, air flow, and humidity is uncontrollable. Ideal conditions for natural drying of foods involve hot days with minimum temperatures around 35°C and low humidity. Poor-quality produce is unsuitable for natural drying to achieve high-quality dried products, and the lower limit of moisture content by this method is approximately 15%. Sun drying, while cost-effective, poses challenges of contamination and intermittent drying and is limited to areas with low humidity.On the other hand, artificial drying, facilitated by methods like hot air drying, freeze-drying, or microwave drying, involves controlled application of heat and air flow to expedite moisture evaporation. This approach enhances food shelf life by inhibiting microorganism growth and preventing spoilage. Artificial drying offers advantages in terms of efficiency, scalability, and year-round applicability compared to traditional sun-drying methods. However, meticulous control of temperature, humidity, and air flow is crucial to ensure optimal results and preserve the sensory and nutritional qualities of the dried product.

3.6. Moisture content of the product

Certainly, the moisture content of the material is a key determinant in the drying process, influencing both the duration and efficiency of the operation. The starting moisture level is especially critical when establishing a target moisture content for the final product. Materials with higher initial moisture content require a more extensive extraction process, translating to additional drying time. Moreover, the interplay between the initial moisture content and the amount of product processed per unit time is a crucial consideration in dryer operations. The volume of material processed per hour, often measured in kilograms or "kg," further affects the overall efficiency and productivity of the drying process. This intricate relationship underscores the need for precise control and optimization of these variables to achieve desired outcomes in terms of both product quality and processing efficiency. In essence, managing the moisture content in the drying material is a dynamic and multifaceted aspect of the overall drying strategy, demanding careful attention to achieve optimal results in various industrial applications.

3.7. Shape of the product

Shape is another important consideration in drying any material. Shape is also important when it comes to cooking a material and getting heat into it. There are only three basic shapes of objects that we must deal with in drying.

i. Spherical objects are those that are round like ball Spherical objects pose a challenge in the drying process due to their configuration. The maximum volume is contained within the smallest surface area for a given weight of material, making drying slower. The diffusion of moisture from the interior to the particle surface, where evaporation happens, is time-consuming. In the case of spherical objects, the total surface area becomes crucial for effective water removal during drying.

ii. Cylindrical objects, characterized by their elongated form with a circular cross-section (like a sausage), present a distinctive drying challenge. As moisture is extracted from cylindrical materials, water must diffuse from the centre of the cylinder outward along the radius to reach the surface, mirroring the process observed in spherical objects. However, a notable difference lies in the fact that the ends of a cylinder are generally considered less crucial in the drying process. These ends represent a relatively small fraction of the surface area compared to the sides of the cylinder, which are more influential in water removal. Drying a cylindrical object typically involves a higher surface area per unit weight of material compared to a spherical object, resulting in a relatively faster drying process for cylinders. It is worth noting that the diameter of the cylinder plays a role; larger diameter cylinders will generally require more time to dry than their smaller counterparts.

iii. Flat plates or slabs may be thought of as looking like a flat piece of wood that has flat top and bottom surfaces and a flat surface around its edge. A steak or a piece of flat cookie dough may be considered as being slabs. In drying, water would be lost from the top and bottom surfaces. The surfaces around the edge would play a minor role in water removal. Because the surface area of a slab is often quite large in relation to its thickness, it may be easier to dry slab shaped objects than it would be to dry spherical or cylindrical objects.

Each of the three fundamental shapes is characterized by a specific dimension that governs the relative drying rate. In the case of spherical objects, the critical dimension is the radius (half of the diameter). Similarly, for cylinders, the radius plays the most crucial role in determining the drying rate. In the case of flat plates or slabs, the characteristic dimension is one-half the thickness, as water only needs to diffuse from the centre to either the top or bottom surfaces.

4. Quality aspects in food dehydration

Drying method and physicochemical changes that occur during drying seem to affect the quality properties of the dehydrated product. More specifically, drying method and process conditions significantly affect the colour, texture, density and porosity, and sorption characteristics of materials. So, the same raw material may end up as a completely different product, depending on the type of drying method and conditions applied.

4.1. Texture

Texture is one of the most important parameters connected to product quality. Textural properties are usually related to mechanical tests, which examine the viscoelastic behaviour of the material. that loss of water and heating during drying causes stress in the cellular structure of food, resulting in changes in shape, volume, shrinkage and increase hardness. There is a direct correlation with porosity and bulk density which depends on the method of drying technique employed. Products dried at lower temperatures with high-pressure drying techniques, such as freeze drying or vacuum drying, show lowest bulk density and highest porosity. This leads to the higher crispness of the final product. On the contrary, air-dried products undergo collapse of structure and lead to higher bulk density resulting in lower porosity (Khan *et al.*, 2018). Better textural quality in the tropical fruits such as mango, papaya and pitaya drying can be successfully preserved by freeze-drying combined with explosion puffing (Yi *et al.*, 2017). Volumetric and cellular shrinkage occurs in solar and hot air drying. Higher textural qualities could be achieved up to a certain level by osmotic dehydration and freeze-drying (Marques *et al.*, 2006).

4.2. Case hardening

Case hardening refers to the formation of a hard shell or crust on the exterior portion of the food particles being dried. It is a result of excessive drying of the surface of the food particle and creates a shell that prevents removal of the water in the interior portion of food.In usual heating the water in the exterior portion of food is removed by evaporation and the water from inner region moves to exterior area and removed as the same.If the outer layer is dried soon then further water removal is hard.As the drying process cannot eliminate internal moisture, it becomes confined within the particle and persists after packaging. Subsequently, this trapped moisture gradually migrates to the surface of the food particle, potentially fostering mold growth. In some instances, the moisture may lead to the softening of the shell or create internal stresses, resulting in the collapse or fragmentation of the particle. 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. (Ashim Datta., 2015)

4.3. Chemical changes

The dried meat's chemical composition is also an essential aspect in determining its quality. The content of the meat varies according to the breed, species, and age of the animal (1). The distinctive quality of dried meat is mainly due to the chemical composition and physical structure of the meat (74). The physicochemical properties are essential indicators used in assessing the various drying techniques of dried meat.

4.3.1. pH

pH is one of the essential characteristics of meat quality since it directly impacts the meat's functional attributes, eating and storage quality. The pH of dried meat products is significantly affected by drying procedures. The pH of commercial dried meat samples ranged between pH 5.4–5.8 (Lim DG, et al.,2012). Low pH values are important to avoid the denaturation of protein in the meat. The pH of dried and fresh biltong and salted-dried South African meat had no significant difference. The pH value for dried biltong was 5.35 and fresh biltong was 5.58, respectively (Petit T, et al.,2013). The freeze-drying method was the most suitable method for producing dried meat with low pH. A study on different processes of dried meat revealed that among all the drying techniques, the freeze-drying method produced the lowest pH value at 5.89. In contrast, the air-drying method had the highest pH value at 6.08. The variation in pH values was caused by the loss of the free acidic group as the result of different drying techniques (Mishra B, et al.,2017). In addition, a study on different drying methods for beef jerky discovered that hot air-dried jerky had a higher pH value than sun-dried and shade dried. The air-dried method obtained a pH value of 6.25, while both the sun-dried and shade-dried processes had a pH value of 6.03. The elevated pH values appear to be caused by the denaturation of beef protein due to the drying processes (Lim DG, et al.,2012)

4.3.2. water activity

One of the critical elements regulating microbial growth and enzymatic activity in dried food is water availability and location. The water activity coefficient, a measure of the thermodynamics chemical potential of water in the system, expresses the condition of water in the food (Aksoy A, et al., 2016). The water activity (aw) is defined as the ratio of the vapor pressure of water in food (p) to the vapor pressure of pure water (p0) at the same temperature (Mishra B. et al., 2017). In dried products, the aw contents are often less than 0.7 as it is responsible for microbiological stability to prevent microbial growth (Taormina PJ, et al., 2014). In the study of beef jerky, all drying processes of meat, such as air-dried and sun-dried, achieved low aw with values of less than 0.75, in which signifies low water contents (Lim DG, et al.,2012). The water content and water activity are not related; however, as the water content decreases, the water activity also decreases. A dried biltong study showed low aw ranging from 0.65 to 0.68. The use of sodium chloride (NaCl) in the meat facilitates the drying process and lowers the aw level of the meat (Petit T, et al., 2014). The salting process on the meat had a considerable influence on the aw, which reduced from 0.98 ± 0.004 for 0% NaCl to 0.92 ± 0.004 for 10% NaCl. The presence of NaCl in excessive amounts will lower the meat's free water content, resulting in a lower raw value. Moreover, the presence of active water may be more significant for food stability than the overall amount of water in the food. Furthermore, lipid oxidation is most significant at extremely high and very low aw as there is efficient movement of pro-oxidants, in which oxidation increases in the latter (Taormina PJ, et al., 2014). Water suppresses lipid oxidation in the early stage but stimulates the subsequent reaction of lipid breakdown products with protein as aw increases (Mishra B. et al., 2017).

4.4. Nutritional composition

Nutritional quality of food can be affected by handling, processing, and packaging. Aside from physical and chemical changes, drying can also cause loss of nutritional value. The major losses of vitamins and other substances take place because of solubility in water, enzymatic oxidation, oxygen and heat sensitivity, and metal ion catalysis during processing. In addition, sugar–amine interactions (Maillard reaction) can occur during drying and storage, causing loss of nutrients. All these losses in food can be reduced by pretreatments, proper selection of drying methods, new and innovative drying methods, and optimization of drying conditions.

4.4.1. Change in protein.

Dehydration of meat induces changes in its protein content through various mechanisms. Firstly, the concentration effect occurs as water is removed, increasing the relative abundance of proteins in the remaining material. Additionally, the application of heat during dehydration can lead to protein denaturation, altering their structural properties. The Maillard reaction, triggered by heat, may also contribute to the formation of new compounds, impacting both colour and flavour. Protein coagulation, involving the aggregation of protein molecules, is another potential outcome during the dehydration process. The specific changes in protein content depend on factors such as temperature, duration, and the dehydration method employed. Consideration of these factors is essential in determining the desired protein characteristics and overall quality of the dehydrated meat, especially in culinary or snack applications.

4.4.2. Changes in lipid

Rancidity poses a significant challenge in dried foods, with higher dehydration temperatures exacerbating fat oxidation. Employing antioxidants effectively safeguards fats from this process. Lipid oxidation, responsible for rancidity, flavour deterioration, and the loss of fat-soluble components, is particularly pronounced in dehydrated foods. Numerous factors, including moisture content, fatty acid composition, oxygen levels, temperature, and product porosity, influence the oxidation rate. Moisture content plays a crucial role, and while reducing oxygen levels can mitigate oxidation, the impact is contingent on achieving exceptionally low oxygen concentrations. Product porosity, notably high in freeze-dried foods, increases susceptibility to oxygen, while air-dried foods, with reduced surface area due to shrinkage, are less affected. Literature recommends minimizing oxygen levels during processing and storage, incorporating antioxidants, and using sequestering agents to prevent lipid oxidation in dehydrated foods.

4.4.3. Changes in carbohydrate

Fruits are primarily abundant in carbohydrates while being low in proteins and fats. The primary form of deterioration in fruits is observed in carbohydrates, often manifesting as discolouration resulting from enzymatic browning or caramelization reactions. In the latter case, discolorations, notably browning, occur due to reactions between organic acids and reducing sugars. To control browning, the addition of sulphur dioxide is a commonly employed method. The preservation of carbohydrate integrity is especially crucial during the drying of fruit and vegetable tissues, where slow sun drying can lead to significant deterioration unless counteracted by sulfates or other suitable agents.

4.4.4. changes in vitamins

Meat and meat products provide a reliable source of most water-soluble vitamins such as vitamin B1, B2, B3, B6, and vitamin B12 except for vitamin C. The concentration of vitamin B ranges from a few micrograms to several milligrams. For fat-soluble vitamins, most of them present at low levels. Vitamin A is detected in a small amount (0–40 mg/100 g), vitamin D at 0.03–0.60 mg/100 g (cholecalciferol), and 0.4–0.20 mg/100 g (25-hydroxy vitamin D). Meat is not an important source of the other fat-soluble vitamins; vitamin E and K . Vitamins are degraded by exposure to heat, water, and sunlight. In conventional drying methods, vitamins in meats are degraded. However, some modern drying techniques such as freeze-drying will not cause protein denaturation or loss of vitamins.

4.5. Colour.

Colour is a major quality parameter in dehydrated food. During drying, colour may change because of chemical or biochemical reactions. Enzymatic oxidation, Maillard reactions, caramelization, and ascorbic acid browning are some of the chemical reactions that can occur during drying and storage. Discolouration and browning during air drying may be the result of various chemical reactions including pigment destruction.Colour is a vital attribute in food evaluation since consumers may immediately appraise it. The drying process has a considerable influence on the lightness (L), redness (a), and yellowness (b) values, which are a source of variation in light scattering from the surface of the meat that represents the degree of browning during drying (Elmas F, et al., 2021). In dried meat, the L value was in the range of 20–50, depending on the different drying methods. Meanwhile, a value was between 6 and 10, and the b value was around 10–20. In dried meat products, a larger meat percentage increased the L, a, and b values. Furthermore, different drying techniques have an impact on the colour of the products as well. Freeze-dried meat products exhibit a whiter colour compared to the sun, air, or vacuum-dried meat products, which is primarily due to uniform light reflection from the surface of large pores (Oyinloye TM &Yoon WB, 2020). Additionally, the L, a and b values in fresh meat were found to be 48.46, 21.33, and 14.13, respectively (Dinçer EA., 2021). The freeze-dried meat produced higher L, a, and b values than other drying techniques, indicating that the freeze-drying had less effect on the protein structures of meat samples. As compared to freeze-drying, sun-drying methods give a darker brown colour and rise in redness, indicating browning effects (Mishra B, et al., 2017). A value of air-dried meat (5.16) was lower than sun-dried meat (5.34). Nevertheless, the value of L and b for air-dried meat were 27.74 and 11.50, respectively, which was generally higher than sun-dried meat with a value of 25.91 and a b value of 7.95 (Dinçer EA., 2021). The colour changes in dried meat on three different drying methods are shown in figure 1.

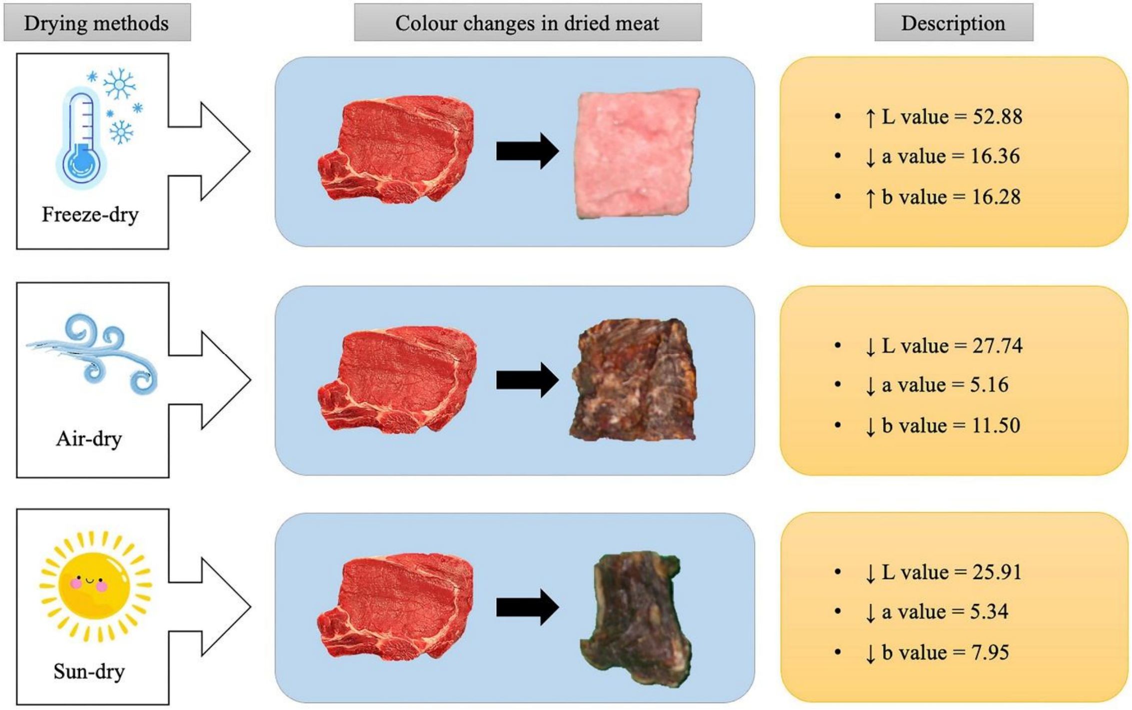

Figure 1. The color changes in dried meat under different drying methods. Source- (Ahmed Mediani. et al., 2022)

4.6. Sensory characteristics

Sensory qualities were assessed for tenderness, colour, taste, juiciness, and overall attractiveness of the meat (Jalarama RK, et al.,2013). In the sensory evaluation and consumer acceptability, a score below 5 was described as less preferable, while a score above 5 was preferable among the consumers (Dinçer EA., 2021). The lower the score in sensory evaluation, the less preferable the dried meat method is. All sensory attributes of air-dried meat products decline with increasing storage time compared to sun-dried meat products. Lim et al. conducted a study on beef jerky using the air-drying technique at a temperature of 80°C for 4 h, while sun-dried at 25–28°C for 3.5 h. It concluded that air-dried beef jerky scored 3.66 in the consumer's overall acceptability while sun-dried meat scored 4.53, resulting in the sun-dried method being the preferable method in the drying process. The air-drying techniques can be attributed to excessive drying and moisture loss on the meat surface caused by elevated temperature during the air-drying process. However, the sun-dried beef jerky exhibited greater tenderness and juiciness compared to the air-dried beef jerky (Lim DG, et al., 2012). On the other hand, there were no apparent differences in colour and flavor between other drying processes. When compared to other techniques, such as air-drying and oven-drying processes, the texture and flavor scores of sun-dried meat products are comparatively higher (Mishra B, et al., 2017). In air-dried meat, the high temperature from hot air leads to more hardness and chewiness, as well as the formation of off flavours along the edges and corners of the meat.

4.7. Microbiological characteristics of dried meat

Microorganisms in dried meat and meat products are significant in determining the quality of the products and processes. Many attributable factors affect the microbial activities in dried meat (figure 2), like the a_w values, which indicate the relative moisture balance or available water ratio that provides conditions for microorganisms' growth. On the other hand, when rigid aerobic microorganism like pseudomonas is unable to grow under anaerobic conditions, lactic acid bacteria (LAB) will usually grow predominantly as the spoilage flora up to a maximum of 108/cm^2 without yet spoiling the meat (Gill Co., 2003). However, the spoilage may be influenced by pH changes (>5.8) or oxygen contamination. As such, the microbiological characteristics of dried meat are usually described based on the standard total plate count (TPC) ($<10^5$ cfu/g) for ready-to-eat food following the food safety guideline, lactic acid bacteria (LAB) and yeast and mold counts. These observations are highly associated with the water and salt content as well as the pH value of the dried meat. Many studies have been performed to evaluate the microbiological characteristics of the dried meat prepared in various preparation conditions, which includes microorganism like *Staphylococcus aureus*, *Salmonella* spp., *Bacillus cereus* and many others (Ratsimba A, et al.,2019).

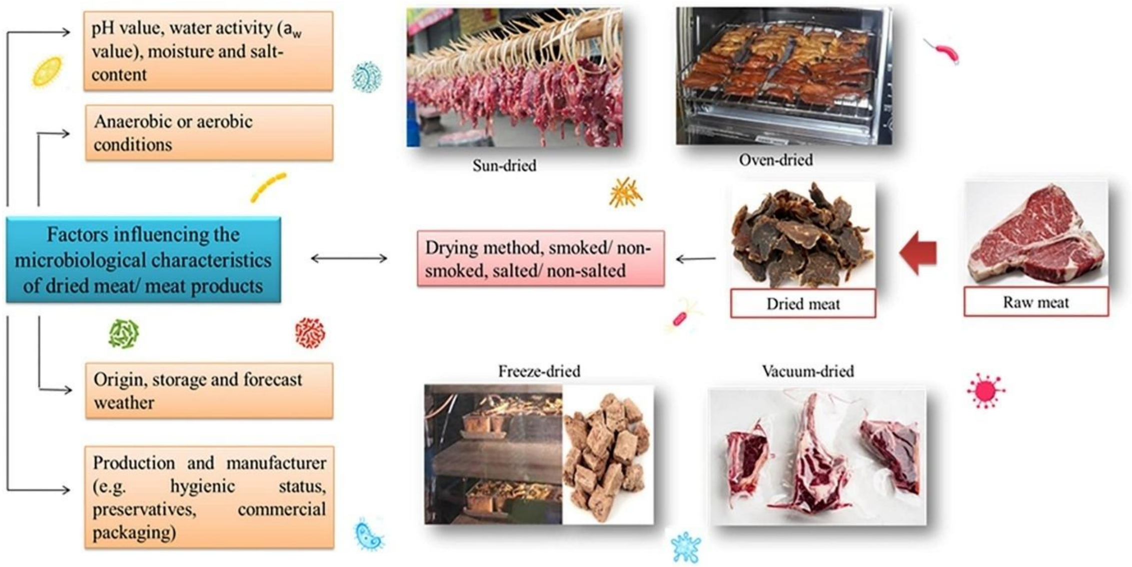

Figure 2. The multifactorial influences on microbiological characteristics of dried meat and meat products. Source- (Ahmed Mediani. et al., 2022)

5. Advantages and disadvantages of dehydration

Dehydrated food has many advantages in industrial and household area. Disadvantages are also do present in dehydration process.

5.1. Advantage of dehydration.

i. Dehydration reduces the moisture content of food, making water unavailable to agents of spoilage like bacteria and enzymes. When safely stored, most dehydrated foods have a shelf life of several years.
ii. Dehydration reduces the weight and volume of food, facilitating storage, conditioning, and transport.
iii. Dehydration maintains more nutrients than other food preservation methods.
iv. Dehydration has a consistent, reliable flavor.
v. Easy to add to meals: Dehydrated foods rehydrate in liquid, making them an easy way to add extra nutrients to meals like soups, casseroles, and stir-fries.
vi. Sun drying is an environmentally friendly drying method because it uses the sun as the heat source and therefore produces no CO2.

5.2. Disadvantages of dehydration

i. Dehydration can lead to the loss of certain nutrients, such as vitamins and enzymes, especially if the drying process involves high temperatures or extended drying times.
ii. The removal of water from food can result in changes to its texture and flavor. Some people find that rehydrated foods do not have the same texture and taste as their fresh counterparts.
iii. :Rehydrating dehydrated foods often takes time, and the process may not fully restore the original texture or taste. This can be a disadvantage in situations where quick meal preparation is essential.
iv. Some dehydration methods, such as hot air drying, can be energy intensive. The use of high temperatures or prolonged drying times may contribute to higher energy consumption, impacting the cost-effectiveness of the preservation process.
v. Quality dehydration equipment can be expensive to purchase and maintain. This initial cost may be a barrier for individuals or small businesses looking to adopt dehydration as a preservation method.

vi. While dehydration inhibits the growth of many microorganisms, it may not eliminate all types of bacteria, molds, or yeasts. Proper storage conditions are still essential to prevent spoilage and ensure food safety.
vii. Not all foods are well-suited for dehydration. Some fruits, vegetables, and meats may not retain desirable qualities after the dehydration process, limiting the range of foods that can be effectively preserved using this method.

6. Dehydration technology in fishery products

Drying stands as a widely adopted method for the processing and preservation of fish, serving as a crucial source of protein globally. Dried fishery products, cherished for their unique flavor, aroma, taste, and texture, are enjoyed by diverse communities, spanning ethnic traditions to the younger generation. The drying and dehydration processes can be categorized into thermal and non-thermal methods. Thermal drying employs heat to eliminate moisture, ranging from traditional sun drying to advanced thermal appliances and techniques. Non-thermal technologies, such as ultrasounds, high-pressure processing, and pulsed electric fields, offer microbial inactivation at near-ambient temperatures, preventing thermal degradation of food components and preserving the sensory and nutritional quality of food products. (Pereira and Vicente, 2010). Non-thermal drying faces limitations in commercial fish processing, with traditional sun drying presenting challenges such as a slow process, dependence on climate, susceptibility to insect infestation, and vulnerability to rodent and bird attacks. Additionally, storage and marketing issues further compound these constraints. To address these challenges, especially to reduce drying time and enhance product quality, various energy-efficient and environmentally friendly thermal drying technologies have been developed and implemented in different countries today. (Wang et al., 2011) Several improved technologies have emerged for fish drying, including controlled mechanical heating, hot air oven drying, heat pump drying, freeze drying, microwave drying, radiofrequency drying, infrared drying, electro-hydrodynamic drying, and hybrid methods that combine two or more of these techniques. Drying serves to eliminate water from fish or products, causing muscle tissues to shrink and create a distinctive rigid yet elastic texture. This process also reduces water activity, inhibiting enzyme activity and microbial growth. In both traditional and advanced fish drying, salts are commonly added to expedite water removal, contributing to texture formation and aroma development. Salt application also aids in preventing spoilage and repelling insect attacks in traditional processing. This overview covers the methods and principles of drying and dehydration for aquatic products, addressing constraints and introducing emerging advanced drying methods and techniques, with a focus on high-quality smart drying and its impact on the final product's quality.

The study explored three distinct types of natural circulation greenhouses designed for drying fermented fish, utilizing species such as Bonga (shads), croakers, threadfin, mackerel, and catfish. The findings indicated that solar dryers yield well-dried products with a reasonably extended storage life. However, caution is advised against the introduction of solar dryers for fish in isolation. To enhance the overall drying process and mitigate losses, attention should be directed towards optimizing parameters such as improved salting practices, enhanced packaging and storage methods, and the establishment of proper sanitary conditions. These integral aspects contribute significantly to the overall efficiency and quality of the drying process (N'Jai AE., 1986). Three different types of dried fish usingnaturalcirculationgreenhousedryers. He reportedanalysisoftechnicalandsocio-economicaspectsofthe artisanalfishprocessingsector. Theresultsshowsthatimplementationandoperationofsolardryingfacilitiesbyfishery technologistsandexperiencedprocessorsrepresentsrealprogress inappliedresearchonartisanalfishtechnologyinSenegal (Diouf N 1986)

7. Recent studies on dehydration of seafood products

Recently, many advancements have been made inhigh performance mechanical andinstrumental drying. Commonly, the quality of such dried and dehydrated products is determined based on some attributes.

Table 1. Products and Quality attributes investigated.

Reference	Products	Quality attributes investigated
(Mario et al. 2016) (Marquez et al. 2009) (Wu & Wand, 2016)	Hot Air-Dried commercial fish	High temperatures in hot air drying can harm dried product quality through lipid oxidation and Maillard browning. Proposed remedies include citric acid, glutathione, and high-pressure treatments to enhance overall quality.
(Shi et al. 2019, Zhu et al. 2021).	aquatic products containing characteristic protein and unsaturated fatty acids which are prone to heat denaturation and oxidative rancidity	coating with hydrocolloid and treating ultrasound are found to be effective innovation in improving the drying efficiency and quality attributes of dried products produced by heat pump drying
(Zhang et al. 2017)	freeze-dried products	Super cold temperature and pressure below the triple point of water provide excellent quality to freeze-dried products
(He at all. 2021) (Pankyamma et al. 2019) (Viji et al. 2019) (Yin et al. 2022).	Sea cucumber, squids, mackerel, and scallops by microwave drying	High frequency microwaves often damage the quality of fishery products and cause huge energy consumption. However, present day combination of microwave application under vacuum has helped lowering drying temperature and increasing drying efficiency, whereby improving the retention of nutrients and colour and rehydration rate of aquatic products. In addition, the oxidation of lipid compounds has been reduced due to the vacuum environment in drying chamber
Huang et al. 2012)	tilapia, grasscarp and	To improve the efficiencyof

	Atlantic krill by hybrid drying	drying in termsof reducingdrying time and maintainingquality of products like texture, colour and flavor, different drying technologies are combined
(Bai & Sun, 2011	Dried fish	Electrohydrodynamic drying
(Uemura et al. 2017)	Shrimp	Radio frequency drying

8.Conclusion.

In conclusion, food dehydration is a vital mass transfer process that plays a crucial role in preserving food, offering both enhanced sensory characteristics and physiological benefits. This method, historically significant for reducing reliance on daily fresh food supplies, has evolved through diverse and cost-effective dehydration techniques. Recent advancements in energy-efficient technologies, such as solar, infrared, and microwave drying, emphasize a commitment to sustainability while preserving the quality of dried products. The preservation achieved through dehydration extends beyond sensory enhancements, actively preventing microbial growth and deteriorative chemical reactions by reducing water activity. Understanding the effects of heat on microorganisms and enzymes is crucial, guiding the optimization of dehydration processes for safety and quality. Whether the goal is to minimize or preserve the activity of microorganisms and enzymes, the impact of drying can be harnessed based on the specific purpose of the process. Overall, innovative food drying technologies not only contribute to food security but also align with environmental protection goals, marking a significant stride in the evolution of food preservation techniques.

References.

1. Aksoy, A., Karasu, S., Akcicek, A., &Kayacan, S. (2019). Effects of different drying methods on drying kinetics, microstructure, colour, and the rehydration ratio of minced meat. Foods, 8(6), 216. doi: 10.3390/foods8060216.
2. Amellal, H., & Benamara, S. (2008). Vacuum drying of common date pulp cubes. Drying Technology, 26(3), 378-382. doi.org/10.1080/07373930801898232
3. Bai, Y., Qu, M., Luan, Z., Li, X., & Yang, Y. (2013). Electro-hydrodynamic drying of sea cucumber (*Stichopus japonicus*). LWT-Food Science and Technology, 54(2), 570-576. https://doi:10.1016/j.lwt. 2013.06.026
4. Bazhal, M., Lebovka, N., & Vorobiev, E. (2003). Optimisation of pulsed electric field strength for electroplasmolysis of vegetable tissues. Biosystems Engineering, 86(3), 339-345..
5. Berk, Z. (2018). Food process engineering and technology. Academic press.
6. Calín-Sánchez, Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel, A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs. Foods, 9(9), 1261.
7. Calín-Sánchez, Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á. A., & Figiel, A. (2020). Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic herbs. Foods, 9(9), 1261.

8. Chiralt, A., & Fito, P. (2003). Transport mechanisms in osmotic dehydration: the role of the structure. Food Science and Technology International, 9(3), 179-186. DOI:10.1177/1082013203034757
9. Chua, K. J., & Chou, S. K. (2005). A comparative study between intermittent microwave and infrared drying of bioproducts. International journal of food science & technology, 40(1), 23-39.
10. Corzo-Martínez, M., Corzo, N., &Villamiel, M. (2007). Biological properties of onions and garlic. Trends in food science & technology, 18(12), 609-625.Doi.org/10.1016/j.tifs.2007.07.011
11. De la Fuente-Blanco, S., De Sarabia, E. R. F., Acosta-Aparicio, V. M., Blanco-Blanco, A., & Gallego-Juárez, J. A. (2006). Food drying process by power ultrasound. Ultrasonics, 44, e523-e527.
12. De la Fuente-Blanco, S., De Sarabia, E. R. F., Acosta-Aparicio, V. M., Blanco-Blanco, A., & Gallego-Juárez, J. A. (2006). Food drying process by power ultrasound. Ultrasonics, 44, e523-e527..
13. Elmas, F., Bodruk, A., Köprüalan, Ö., Arıkaya, Ş., Koca, N., Serdaroğlu, F. M., ... & Koç, M. (2021). The effect of pre-drying methods on physicochemical, textural and sensory characteristics on puff dried Turkey breast meat. Lwt, 145, 111350. doi: 10.1016/j.lwt.2021.111350
14. Fernandes, F. A., & Rodrigues, S. (2007). Ultrasound as pre-treatment for drying of fruits: Dehydration of banana. Journal of Food Engineering, 82(2), 261-267.
15. Fito, P., Chiralt, A., Betoret, N., Gras, M., Cháfer, M., Martínez-Monzó, J., ... & Vidal, D. (2001). Vacuum impregnation and osmotic dehydration in matrix engineering: Application in functional fresh food development. Journal of Food Engineering, 49(2-3), 175-183.Doi.org/10.1016/S0260-8774(00)00220-X.

16. Gartner, E., Maruyama, I., & Chen, J. (2017). A new model for the CSH phase formed during the hydration of Portland cements. Cement and Concrete Research, 97, 95-106.
17. Ghafoor, M., Misra, N. N., Mahadevan, K., & Tiwari, B. K. (2014). Ultrasound assisted hydration of navy beans (Phaseolus vulgaris). Ultrasonics Sonochemistry, 21(1), 409-414.
18. Gill, C. O., & Ahvenainen, R. (2003). Active packaging in practice: meat. Novel food packaging techniques, 365-383.
19. Gulati, T., & Datta, A. K. (2015). Mechanistic understanding of case-hardening and texture development during drying of food materials. Journal of Food Engineering, 166, 119-138. DOI: 10.1016/j.jfoodeng.2015.05.031
20. He, X., Lin, R., Cheng, S., Wang, S., Yuan, L., Wang, H. & Tan, M. (2021). Effects of microwave vacuum drying on the moisture migration, microstructure, and rehydration of sea cucumber. Journal of Food Science, 86(6), 2499-2512.. doi:10.1111/1750-3841.15716.
21. Huang, L. L., Zhang, M., Wang, L. P., Mujumdar, A. S., & Sun, D. F. (2012). Influence of combination drying methods on composition, texture, aroma and microstructure of apple slices. LWT-Food Science and Technology, 47(1), 183-188. doi:10.1016/j.lwt.2011.12.009.
22. Jayaraman, K. S., & Gupta, D. D. (2020). Drying of fruits and vegetables. In Handbook of industrial drying (pp. 643-690). CRC Press.
23. Khan, M. I. H., Nagy, S. A., & Karim, M. A. (2018). Transport of cellular water during drying: An understanding of cell rupturing mechanism in apple tissue. Food Research International, 105, 772-781.

24. Knorr, D., Angersbach, A., Eshtiaghi, M. N., Heinz, V., & Lee, D. U. (2001). Processing concepts based on high intensity electric field pulses. Trends in Food Science & Technology, 12(3-4), 129-135.
25. Lim, D. G., Lee, S. S., Seo, K. S., & Nam, K. C. (2012). Effects of different drying methods on quality traits of hanwoo beef jerky from low-valued cuts during storage. Food Science of Animal Resources, 32(5), 531-539. doi: 10.5851/kosfa.2012.32.5.531
26. Marques, L. G., Silveira, A. M., & Freire, J. T. (2006). Freeze-drying characteristics of tropical fruits. Drying technology, 24(4), 457-463.
27. Marquez-Rios, E., Ocaño-Higuera, V. M., Maeda-Martínez, A. N., Lugo-Sánchez, M. E., Carvallo-Ruiz, M. G., & Pacheco-Aguilar, R. (2009). Citric acid as pretreatment in drying of Pacific Lion's Paw Scallop (Nodipectensubnodosus) meats. Food chemistry, 112(3), 599-603. Doi: 10.1016/j. foodchem. 2008.06.015
28. Mishra, B., Mishra, J., Pati, P., & Rath, P. (2017). Dehydrated Meat Products—A Review. International Journal of Livestock Research, 7(11), 10-22. Doi: 10.5455/ijlr.20170812035616
29. Mujumdar, A. S. (2014). Drying: Principles and practice. In Chemical Engineering Handbook (pp. 1667).
30. Ngadi, M. O., Bazhal, M. I., & Raghavan, G. V. (2003). Engineering aspects of pulsed electroplasmolysis of vegetable tissues. Agricultural Engineering International: CIGR Journal.
31. N'Jai, A. E. (1987). Outlook for solar drying of fish in the Gambia. In Solar drying in Africa: proceedings of a workshop held in Dakar, Senegal, 21-24 July 1986. IDRC, Ottawa, ON, CA.

32. Pankyamma, V., Mokam, S. Y., Debbarma, J., & Rao B, M. (2019). Effects of microwave vacuum drying and conventional drying methods on the physicochemical and microstructural properties of squid shreds. Journal of the Science of Food and Agriculture, 99(13), 5778-5783.. Doi.10.1002/jsfa.9846
33. Pereira, R. N., & Vicente, A. A. (2010). Environmental impact of novel thermal and non-thermal technologies in food processing. Food Research International, 43(7), 1936-1943.Doi.org/10.1016/j.foodres.2009.09.013
34. Pérez-Won, M., Lemus-Mondaca, R., Tabilo-Munizaga, G., Pizarro, S., Noma, S., Igura, N., & Shimoda, M. (2016). Modelling of red abalone (Haliotisrufescens) slices drying process: Effect of osmotic dehydration under high pressure as a pretreatment. Innovative Food Science & Emerging Technologies, 34, 127-134. doi:10.1016/j.ifset.2016.01.014
35. Petit, T., Caro, Y., Petit, A. S., Santchurn, S. J., &Collignan, A. (2014). Physicochemical and microbiological characteristics of biltong, a traditional salted dried meat of South Africa. Meat science, 96(3), 1313-1317.Doi: 10.1016/j.meatsci.2013.11.003
36. Rastogi, N. K., Eshtiaghi, M. N., & Knorr, D. (1999). Accelerated mass transfer during osmotic dehydration of high intensity electrical field pulse pretreated carrots. Journal of food science, 64(6), 1020-1023.
37. Reddy, K. J., Pandey, M. C., Harilal, P. T., & Radhakrishna, K. (2013). Optimization and quality evaluation of freeze dried mutton manchurian. International Food Research Journal, 20(6)..
38. Saurel, R., RAOULT□WACK, A. L., Rios, G., & Guilbert, S. (1994). Mass transfer phenomena during osmotic dehydration of apple II. Frozen plant tissue. International journal of food science & technology, 29(5), 543-550.

39. Shi, Q., Tian, Y., Zhu, L., & Zhao, Y. (2019). Effects of sodium alginate□based coating pretreatment on drying characteristics and quality of heat pump dried scallop adductors. Journal of the Science of Food and Agriculture, 99(10), 4781-4792. Doi:10.1002/jsfa.9728
40. Taormina, P. J., & Sofos, J. N. (2014). Low-water activity meat products. The microbiological safety of low water activity foods and spices, 127-164.Doi: 10.1007/978-1-4939-2062-4
41. Tapia, M. S., Alzamora, S. M., &Chirife, J. (2020). Effects of water activity (aw) on microbial stability as a hurdle in food preservation. Water activity in foods: Fundamentals and applications, 323-355.
42. Tiwari, B. K., & Mason, T. J. (2012). Ultrasound processing of fluid foods. In Novel thermal and non-thermal technologies for fluid foods (pp. 135-165). Academic press. ISBN: 978-0-12-381470-8,
43. Uemura, K., Kanafusa, S., Takahashi, C., & Kobayashi, I. (2017). Development of a radio frequency heating system for sterilization of vacuum-packed fish in water. Bioscience, Biotechnology, and Biochemistry, 81(4), 762-767.Doi:10.1080/09168451.2017.1280660
44. Vega-Mercado, H., Góngora-Nieto, M. M., & Barbosa-Cánovas, G. V. (2001). Advances in dehydration of foods. Journal of food engineering, 49(4), 271-289.
45. Viji, P., Shanmuka Sai, K. S., Debbarma, J., Dhiju Das, P. H., Madhusudana Rao, B., & Ravishankar, C. N. (2019). Evaluation of physicochemical characteristics of microwave vacuum dried mackerel and inhibition of oxidation by essential oils. Journal of food science and technology, 56, 1890-1898. Doi:10.1007/s13197-019-03651-7
46. Wang, W., Wang, S., Ma, X., & Gong, J. (2011). Recent advances in catalytic hydrogenation of carbon dioxide. Chemical Society Reviews, 40(7), 3703-3727.Doi.org/10.1039/C1CS15008A
47. Wang, Y., Zhang, L., Johnson, J., Gao, M., Tang, J., Powers, J. R., & Wang, S. (2014). Developing hot air-assisted radio frequency drying for in-shell macadamia nuts. Food and Bioprocess Technology, 7, 278-288.
48. Wang, Y., Zhang, L., Johnson, J., Gao, M., Tang, J., Powers, J. R., & Wang, S. (2014). Developing hot air-assisted radio frequency drying for in-shell macadamia nuts. Food and Bioprocess Technology, 7, 278-288.
49. Wu, S., & Wang, L. (2016). Antibrowning of the adductor muscles of bay scallop by glutathione during hot air drying. Journal of Aquatic Food Product Technology, 25(8), 1278-1283.. Doi:10.1080/10498850. 2015.1056397
50. Yi, J. Y., Lyu, J., Bi, J. F., Zhou, L. Y., & Zhou, M. (2017). Hot air drying and freeze drying pre□treatments coupled to explosion puffing drying in terms of quality attributes of mango, pitaya, and papaya fruit chips. Journal of Food Processing and Preservation, 41(6), e13300.
51. Yin, M., Matsuoka, R., Yanagisawa, T., Xi, Y., Zhang, L., & Wang, X. (2022). Effect of different drying methods on free amino acid and flavor nucleotides of scallop (patinopectenyessoensis) adductor muscle. Food Chemistry, 396, 133620.Doi: 10.1016/j.foodchem.2022.133620
52. Zhang, M., Chen, H., Mujumdar, A. S., Tang, J., Miao, S., & Wang, Y. (2017). Recent developments in high-quality drying of vegetables, fruits, and aquatic products. Critical reviews in food science and nutrition, 57(6), 1239-1255.
53. Zhao, Y., & Xie, J. (2004). Practical applications of vacuum impregnation in fruit and vegetable processing. Trends in food science & technology, 15(9), 434-451. Doi: org/10.1016/j.tifs.2004.01.008.