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Food Drying: A Review

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ABSTRACT

Foods are complex biological substances that are obtained from animal or plant origin and because of that they contain high moisture contents which make them highly perishable and thereby requiring preservation in some forms. This review assessed different techniques of drying food and optimization of drying parameters to obtain good and acceptable quality food products. Among the useful processes used in preserving food products reviewed is minimal processing, dehydration or drying. The authors explored the available literature from journals, textbooks and search engines to develop this review paper. Food dehydration or drying is used to reduce losses and improving food commercial value. The use of artificial dryers has been found to reduce drying time when compared with natural drying method although at higher consumption level. Natural drying methods are sun drying and solar drying which could involve the use of solar dryers. Artificial drying methods are radiation, freeze drying, osmotic drying, dielectric drying *etc*. Novel technologies like microencapsulation and nanotechnology are increasingly used in food drying. Microencapsulation has been found to improve the stability of nutrients, preventing ingredient interactions and degradation as the coating matrix effectively separates particles and prevents them from contacting each other. Nanotechnology has found wide applications in food production, processing and packaging. Nanotechnology is an emerging technology that could impact every aspect of food system from cultivation and production of food to processing, packaging, transportation, shelf life and bioavailability of nutrients in foods.

Key words: Drying methods, Drying, Encapsulation, Food, Kinetics, Nanotechnology, Quality.

Foods are complex substances because of their biological origin and are mainly derived from animal or plant sources. Most foods are highly perishable because of high moisture contents which make them susceptible to biochemical reactions and microbial spoilage, thereby requiring preservation in one way or the other. Among the common methods used in preserving food products are minimal processing, refrigeration, smoking and dehydration or drying (Pinheiro *et al*., 2010, Damiani *et al*., 2010, Fernandes *et al*., 2010; Corrêa *et al*., 2010). Drying has been used as a method of reducing post-harvest losses in many agricultural produce for a long time (Gatea, 2011) and as well as improving their commercial value. Drying of foods reduces the moisture contents to preserve the foods and prolong their storage life so that the dried products could be made available at locations where they are not produced and all year round. Apart from reduction in bulkiness and weight, drying also reduces the costs of packaging, handling and transportation (Gatea, 2011). However, the drying of foods could also lead to physical, sensory, nutritional and microbiological quality changes.

Drying is a mass transfer process of removing moisture from food products to reduce the bulkiness of agricultural produce (Gatea, 2011; Gupta *et al*., 2011, Radhika *et al*., 2011). Drying has been used to preserve agricultural produce for a long time and this could be due to fact that it is simple, easy to operate and cost-effective. However, apart from these benefits, drying reduces the bulkiness of foods as well as the costs of packaging, handling, storage and transportation thereby improving handling and processing operations (Gupta *et al*., 2011; Radhika *et al*., 2011).

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Several researchers have worked on different drying techniques of agricultural produce, for example, solar drying, vacuum drying, foam mat drying and spray drying (Patel and Kar, 2012; Gatea, 2011; Radhika *et al*., 2011). Drying has been found to cause physical modification of the dried products in terms of colour change, shrinkage, porosity and texture (Gatea, 2011, Radhika *et al*., 2011). Based on these, important drying process variables that have influence on drying process and help in obtaining dried products with good quality should be considered like cultivar, pre-treatments and drying conditions (Gatea, 2011). Therefore, this review assesses drying of food and optimization of drying parameters to obtain desirable products.

Drying techniques

Drying is a mass transfer process of removing moisture from food products to reduce the bulkiness of agricultural produce (Gatea, 2011; Radhika *et al*., 2011). Drying involves heat transfer, therefore, reducing energy consumption, improving the drying process efficiency and obtaining high quality products with minimal costs will be the goal of modern drying (Doymaz, 2011; Darvishi *et al*., 2014).

Convective hot air drying of agricultural produce is the most common method used to remove moisture from food products. However, the shortcomings of this method include slow and long drying period, high energy consumption and contamination of food products as a result of poor handling, low energy efficiency (Sarimeseli, 2011). However, in order to reduce the problems and to achieve a more effective and faster thermal drying process, the use of microwave and dielectric heating methods for drying agricultural produce is encouraged (Sarimeseli, 2011). Microwave and dielectric heating methods are characterized by higher drying rate, shorter drying time, decreased energy consumption and better quality dried products which make them more preferred than the convective hot air drying (Sarimeseli, 2011).

Drying methods are broadly divided into two namely, natural and artificial drying methods. The natural drying method uses the solar energy to remove moisture from food products. This method depends on variability of weather conditions which makes it highly unreliable (Toshniwal and Karale, 2013). On the other hand, artificial drying method is more preferred than natural method of drying because of faster drying rate and efficiency and effectiveness in removing large amount of moisture from produce which result into better quality dried products (Toshniwal and Karale, 2013). In addition, there is better control of various factors involved in the drying process such as temperature, drying air flux and time of drying. In artificial drying effectiveness and efficiency of drying operation could be improved through the use of mechanical or electrical equipment such as fans.

Natural drying methods

Solar drying

Sun is as old as the universe itself and is a free and an inexhaustible source of energy, used for drying of agricultural produce since the beginning of mankind. Solar drying is divided into direct and indirect method of drying.

This is a traditional method which uses the sunlight to dry food products. Foods are exposed to the sunlight for several days to remove moisture from the produce before packing. This is very common in developing countries where fuel is scarce and expensive. Sun drying is a commonly used method of drying due to its simplicity and cheapness (Sontakke and Salve, 2015). However, the major shortcomings of this drying method are poor products quality as a result of insect attack, contamination with dust and dirt, long drying time, unregulated exposure sunlight and poor heat transmission rate because of condensation of evaporated moisture (Sontakke and Salve, 2015). In order to improve on the sun drying method, solar drying could be used. Examples of solar dryers are chamber type, chimney type and wind-ventilated dryers. Solar system is used to generate heat in indirect method of solar drying and this is directed into foods to be dried *via* air flow which heats the product. The drying chamber is vented at the top to remove the moisture that is evaporated (Toshniwal and Karale, 2013).

Artificial drying methods

Convective drying

Convective method of drying is used to remove water from agricultural produce through heat transfer in modern heating equipment. This involves the use of hot air to transfer heat to the food products and remove moisture effectively from the food products (Brennan and Grandison, 2015).

Hot air tunnel dryer could be used for the drying of food (Morales-Delgado *et al*., 2014). Osmotic and convective drying methods have been combined to dry different fruits and vegetables like ginger (Loha *et al*., 2012), jack fruit (Kaushal and Sharma, 2014), button mushroom (Mehta *et al*., 2013) and grapes and these methods could be applied to drying of many food products.

Drying by radiation

It has been discovered and reported that heat sensitive components of foods are lost as a result of long drying time and high temperature of hot air drying. Drying by radiation is an alternative method that could be used to overcome the problems encountered in hot air drying. Microwave radiation involves the use of electromagnetic radiation to dry food products. This involves the use of electric and magnetic field to propagate microwave heat through space. Drying of food products by use of microwave heating has been found to produce better quality dried products requiring less time and temperature to remove moisture from food products (Kahyaoglu *et al*., 2012). However, scorching has been a problem with microwave heating due to reduced moisture towards the end of the drying process. Microwave drying has advantage of ease of combination with other methods of drying like vacuum drying (Borquez *et al*., 2014).

Freeze drying

According to IFT, “freeze-drying is the process by which the solvent (usually water) and/or suspension medium is crystallized at low temperature and removed by sublimation. Sublimation is the direct transition of water from solid state to gaseous state without melting”. Therefore, freeze drying is a process of drying a food product through freezing and removal of solvents associated with the food through direct sublimation (Rey and May, 2016; Fellows, 2017; Prosapio *et al*., 2017). Freeze drying is also called as lyophilisation or cryodesiccation, because it involves dehydration at low temperature through freezing at lower pressure followed by sublimation of the ice (Prosapio *et al*., 2017). This differentiate freeze drying from most conventional methods

where water is removed by application of heat (Fellows, 2017; Prosapio *et al*., 2017).

Superior quality dried product as a result of absence of liquid water during freezing and low temperature of drying with cessation of reactions involving microorganisms have been reported during the first phase of freeze drying and the ability of the food products to rehydrate effectively (Kahyaoglu *et al*., 2012). However, they found out that differences in the rehydration property of freeze dried fruits as a result of salt concentration due to desorption of water, pectin cells break down, water crystal size and porosity (Kahyaoglu *et al*., 2012).

Freeze-drying leads to dried foods with highest quality when compared with other drying methods as flavor and structural integrity are preserved (Rey and May, 2016, Fellows, 2017; Prosapio *et al*., 2017). However, freeze drying is costly and thereby used for drying high-value products such as seasonal fruits and vegetables like coffee and foods used for military, astronauts/cosmonauts and/or hikers (Rey and May, 2016; Fellows, 2017; Prosapio *et al*., 2017).

Freeze dried products exhibit rapid rehydration, good organoleptic property, low chemical change, minimal volume reduction and loss of volatile components, better retention of vitamins, antioxidants and colorants (Kahyaoglu *et al*., 2012). Despite the advantages, freeze drying is faced with several challenges like high cost of equipment and high energy consumption during freezing, drying and condensing process. Collapse of the product can happen during drying due to high freeze drying time which may result in aroma loss and tough product characterized by low rehydration capacities (Harnkarnsujarit and Charoenrein, 2011; Rey and May, 2016).

Ultrasound drying

Food could be dried with ultrasound to improve characteristics and quality of the products when compared with conventional hot air drying. Ultrasonic energy can be applied alone or combined with other kind of energies like hot-air. Ultrasound in this way reduces temperature or treatment time which improves product quality.

According to Musielak *et al*. (2016), application of ultrasound to dry food shortens the drying time and reduces total energy consumption. They observed that due to the small "temperature effect", the quality of the obtained products was better than that of control processes without ultrasound enhancement. Musielak *et al*. (2016) also observed that "lack of an effective technology for generating power ultrasound in air was distinguished as the primary constraint for industrial application of ultrasound technology".

Schossler *et al*. (2012) dried bell pepper with an integrated ultrasound freeze drying system which could be applied to dry other food products. They found that continuous application of ultrasound was found to impart heating effect to the products at reduced ambient pressure. They also found that application of ultra sound reduced the drying time by 11.5%.

Osmotic drying

Osmotic drying involves the use of hypertonic solution to effect drying of food products. The drying process involves removal of water from plant tissues by immersion in a hypertonic solution which results into a concentration differential between the moisture of food to be dried and the solution (Ishfaq *et al*., 2016; Shete *et al*. 2018). In osmotic drying, the removal of water is due to the natural and non-destructive phenomenon of osmosis across cell membranes (Ishfaq *et al*., 2016; Shete *et al*. 2018). The high osmotic pressure of the hypertonic solution provides the driving force needed for the diffusion of water from the tissue into the solution (Ishfaq *et al*., 2016; Shete *et al*. 2018). The diffusion of water is accompanied by the simultaneous counter diffusion of solutes from the osmotic solution into the tissue and solutes also diffuse from the solution into the tissue of the food products (Mehta *et al*., 2013). However, mass transfer during osmosis have been found to be responsible for physical, chemical, nutritional values, taste and structural changes in the properties of the final dried products (Kahyaoglu *et al*., 2012, Sisquella *et al*., 2014).

Osmotic drying is used to improve the quality of the dried product over conventional drying process. Colour and flavour retention are also achieved when mild heat treatment is applied after osmotic dehydration resulting to superior organoleptic characteristics (Kahyaoglu *et al*., 2012, Sisquella *et al*., 2014; Shete *et al*., 2018). According to Rastogi *et al.* (2005), "osmotic drying also increases resistance to heat treatment, prevents enzymatic browning and inhibits activities of polyphenol oxidase". However, the osmotic drying process is economical and depends on: temperature of osmotic solution, concentration of the osmotic solution, osmotic agent used, process duration and geometry of food material (Kahyaoglu *et al*., 2012; Sisquella *et al*., 2014; Shete *et al*., 2018).

Dielectric drying

Dielectric drying involves the use of electromagnetic energy to dry food products. Electromagnetic energy of microwave and radio frequency are directed and allowed to interact with food interior which quickly raise the centre temperature to effect drying of the products. This is because food products are dielectric materials which can store electric energy and convert it into heat energy (Abbasi and Azari, 2009). Unlike conventional drying, dielectric heating rapidly raises the temperature of food products to target temperature due to volumetric heating phenomenon (Wang *et al*., 2012).

Microwave for drying

This involves the use of microwave in drying food products. Microwave energy penetrates food products and heats the products without creating thermal gradients, resulting in heat transfer during dehydration of food products (Jiang *et al*., 2010). Microwave energy can be absorbed by food products and thereby converts it to heat. But microwave heating has several shortcomings like non-uniformity drying materials, limited heat penetration depth and "puffing" phenomenon.

Radio frequency drying

Radio frequency drying involves the use of radio frequency energy to heat foods to achieve fast and effective thermal treatment for drying purpose (Sisquella *et al*., 2014) and has received higher acceptance in recent times. Radio frequency energy has been found to volumetrically release heat within food on the basis of combined mechanisms of dipole rotation and conduction effects which augment drying process of food products (Alfaifi *et al*., 2014). However, radio frequency thermal processes have been observed to reduce thermal quality degradation in drying products (Alfaifi *et al*., 2014). But, the major setbacks of radio frequency heating are non-uniform heating and runaway heating which could lead to overheating in corners, edges and center parts, especially in foods of intermediate and high moisture contents (Alfaifi *et al*., 2014).

Electro-hydrodynamic drying

Electro-hydrodynamic drying is a new drying method which is a less known when compared with conduction, radiation, or other types of heat transfer (Esehaghbeygi and Basiry, 2011). It is a novel non-thermal drying technique which is used for drying heat-sensitive materials. In this method drying is achieved by use of a high electric field of one or multiple point electrode and to improve its drying rate a plate electrode is also used (Kieu *et al*., 2018). Drying is achieved at reduced drying temperature and entropy due to rapid evaporative cooling and dipole orientation in electric field. Electro-hydrodynamic drying systems have been found to be simple to design and consume less energy when compared with convective and freeze drying methods (Kieu *et al*., 2018).

Air Impingement

Drying of food products could be achieved by use of air impingement drying. This drying process involves the use of air impinges placed on surface of the product at high velocity to remove the moisture boundary layer and cold air, thereby accelerating heat transfer and reducing drying time of the products (Moreira, 2011). This method has been used for drying of corn tortillas (Kieu *et al*., 2018), carrot cubes (Xiao *et al*., 2010a) and grapes (Xiao *et al*., 2010b).

Fluidized-bed drying

Fluidized-bed drying is used to dry granular food materials. It has several advantages such as good performance, cheap and robust equipment for drying (Xiao *et al*., 2010b). This drying method allows products to mix well and good heat and mass transfer between food materials and drying medium. Apart from giving higher drying rate, it also yields high-quality dried food materials (Moreira, 2011). This method has been used for drying granular food stuffs such as waxy rice (Peglow *et al*., 2011), sliced potato (Jaiboon *et al*., 2011), maize (Lozano-Acevedo *et al*., 2011), carrots (Janas *et al*., 2010), olive pomace (Zielinska and Markowski, 2010).

Low-pressure superheated steam drying

Superheated steam drying has been used to dry several food products. This method is environment-friendly; it prevents fire and explosion hazards, it consumes lower energy; it has high drying rate and produces high quality dried products (Meziane, 2011). But, it has some disadvantages when used to dry heat-sensitive foods (Sa-adchom *et al*., 2011). However, superheated steam at reduced pressure has been applied to dry heat- and oxygen-sensitive products resulting in good and effective preservation of both physical and chemical properties of such food products (Köse and Erentürk, 2010).

Recent advanced drying techniques for food drying

New drying techniques are used to reduce drying time and improve final quality of dried food products (Huang *et al*., 2012). Different combinations of drying methods are used to provide synergy to overcome the shortcomings of individual or single drying method (Patel and Kar, 2012). These are:

Radio frequency assisted hot air drying

This drying method heats and evaporates water from the food product at relatively low temperature. Patel and Kar, (2012) reported that shortcoming of heat transfer in convective hot air drying alone can be improved on by combining radio frequency heat with conventional convective hot air drying. Roknul *et al*. (2014) reported that radio frequency assisted hot air drying produced a uniform dried and better quality of products than hot air drying, infrared drying and microwave-assisted hot air drying.

Radio frequency assisted heat pump drying

Radio frequency energy combined with heat pump batch drier has showed several improvements when compared with a single drying process (Roknul *et al*., 2014). The radio frequency assisted heat pump drying process reduces discolouration of dried products, especially those that are highly sensitive to surface colour change. Patel and Kar, (2012) reported that RF assisted drying removed cracking in dried products caused by stress due to uneven shrinkage during drying.

Microwave-enhanced spouted bed drying

This method has been found to produce more uniform drying of products. Through pneumatic agitation of the food products, uniform exposure of food to microwave energy is achieved. Heat and mass transfers could also be facilitated during fluidization as a result of constant renewal of boundary layer of particle surface. Combining fluidized or spouted bed drying could effectively resolve the problem of uneven microwave drying of food products (Roknul *et al*., 2014; Yan *et al*., 2010).

Novel technologies

Through microencapsulation technology, food products could be converted into a dry and free-flowing powder or

flour that can be easily handled and applied into a dry food system (Yan *et al*., 2013). Microencapsulation technology has wide application in packaging solid, liquid and gaseous food materials into small capsules with special reference to food substances that are sensitive to temperature, light, oxygen and humidity (Christelle and Elisabeth, 2013) to control rates of release of active ingredients in foods over prolonged period (Rocha *et al*., 2012). Microencapsulation applications in food industry have received increased and wider acceptance in the last two decades for the development of novel food products.

Microencapsulation has been found to improve the stability of nutrients, preventing ingredient interactions and degradation as the coating matrix effectively separates particles and prevents them from contacting each other (Christelle and Elisabeth, 2013). Other benefits that could be derived from microencapsulation are:

- Food products could have enhanced or increased nutritional and health benefits.
- Wide range of specific food products are available for consumers to choose from.
- Microencapsulated ingredients do not interfere with other ingredients in the food products.
- Consumers are unable to taste the added capsules.
- The microencapsulated ingredients can be added at any time in the processing and remained unaltered.
- Sensory properties of the food products remain unaltered.
- Shelf life of microencapsulated food products may be extended or increased.

Nanotechnology

Nanotechnology is the control of particles at dimensions of nano-scale in the range of 1-100 nm. It is a phenomenon that could be applied in drying and utilization of food products. Reducing size particles of food products to nano-scale range will increase the surface to volume ratio and reactivity of food particles. This may result into changes in mechanical, electrical and optical properties of food particles (Neethirajan and Jayas, 2010). Kalpana Sastry *et al*. (2012) reported that nano-scale inorganic materials have high dielectric constant and loss factor, which could be used to improve dielectric drying rates.

Nanotechnology has found wide applications in the food industry. This is a new and emerging technology that is rapidly impacting every aspect of food system from cultivation and production of food to processing, packaging, transportation, shelf life and bioavailability of nutrients in foods. Commercial applications of nano-materials in food processing and packaging will continue to impact the food industry because of their unique and novel properties. However, consumer acceptance of food and food products containing nano-materials will depend on the safety of the materials in foods. Therefore, a proactive and international regulatory framework for nanotechnology in food is necessary to safeguard the health of the consumers (Hayes and Sahu, 2017).

Optimization of drying conditions of food products using response surface methodology

Drying of food products involves mass transfer phenomenon which results in simultaneous reduction in volume or shrinkage during drying process and it is an undesirable phenomenon in dried products. The reduction in volume is due to moisture transfer from dried food products. This could be as a result of heat transfer into food products and mass transfer from the inside to the surroundings thereby causing unfavourable changes in dimensions and shape of the dried products (Ikrang and Umani, 2019; Chang-Cheng Zhao *et al*., 2017).

Response surface methodology (RSM) utilizes statistical and mathematical techniques to develop, improve and optimize processes (Graziela *et al*., 2016; Abano *et al*., 2012). RSM is used to reduce number of experimental trials require to evaluate multiple parameters and their interactions, thereby, reducing time and labour requirements. RSM has wide applications in process optimization in the food industry (Ikrang and Umani, 2019; Chang-Cheng Zhao *et al*., 2017; Graziela *et al*., 2016; Abano *et al*., 2012, Arévalo-Pinedo *et al*., 2010; Parthasarathi *et al*., 2014; Tsuruta *et al*., 2015). It is used for product quality improvement in the drying process and has been widely used new product development, as well as in the improvement of existing product designs (Tsuruta *et al*., 2015).

There are already a number of studies on RSM applications in optimization of food processes that include optimization of dried food products and processing parameter for dried food products, processing parameter optimization for obtaining dried fish with reduced cooking time, optimization of microwave-assisted hot-air drying conditions of food products and optimization of microwave-assisted hot-air drying conditions of food products (Wang *et al*., 2010; Jideani *et al*., 2010).

CONCLUSION

Foods are complex biological substances that are obtained from animal or plant origin and because of that they contain high moisture contents which make them highly perishable and thereby requiring preservation in some forms. Foods could be preserved by using minimal processing, refrigeration, smoking and dehydration or drying. Drying is a process of removing moisture from food products through vaporization into a gas to get a relatively liquid free substance to reduce the bulkiness of foods. Drying is applied to reduce food losses and to improve food commercial value. Drying also reduces food bulkiness, the costs of packaging, handling, storage and transportation.

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