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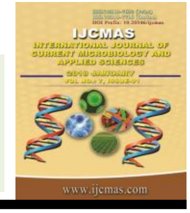

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Dehydration of Strawberry-A Review

Haseeba Muzaffar[1], A.Rouf[1], Varsha kanojia[1]*, Zulhuma Muzaffar[2] and Faisal Noor[3]

[1]*Division of Food Science and Technology, Sher-e-Kashmir University of Agricultural Science and Technology Shalimar-190025, India*
[2]*Division of livestock production and technology, PAU, Ludhiana, India*
[3]*Division of Olericulture, Sher-e-Kashmir University of Agricultural Science and Technology Shalimar-190025, India*
**Corresponding author*

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A B S T R A C T

Drying of fruits is an economical and an effective preservation method practiced since ages by ancestors throughout the world. Strawberry is a seasonal fruit and is available in abundance during particular season of the year. It is a very delicate fruit with low shelf-life, hence needs proper preservation techniques. Preservation of strawberry through sun drying techniques results in poor quality and product contamination. Energy consumption and quality of dried product are critical parameters in the selection of drying process. An optimum drying system for the preparation of quality dehydrated products is cost effective as it shortens the drying time and causes minimum damage to the product. To reduce the energy utilization and operational cost, new dimensions came up in drying techniques. Among the technologies freeze drying, osmotic dehydration and swell drying have great scope for the production of quality dried products.

Introduction

Strawberry (*Fragaria ananassa*) is a non-climateric fruit largely consumed around the world during the seasons due to its attractive organoleptic properties. Strawberry is native to temperate regions around the world. It is grown in annual or perennial production systems in the field or is planted in soilless media or in greenhouses to target “off-season” markets. The main contributors of strawberry production are USA, Turkey, Spain, Egypt, and Mexico. About4 million tones of strawberry are produced annually by USA (FAO, 2014). In India, strawberry is cultivated in the hills. Its main centers of cultivation are Nanital and Dehradun in Uttar Pradesh, Maharashtra, Kashmir valley, Bangalore and West Bengal. Strawberry displays a wide range of health benefits with anthocyanins present in it with having potential including antioxidant, anti-inflammatory, antimicrobial and anti-carcinogenic activities, improvement of vision, induction of apoptosis and neuroprotective effects (Mazza, 2007). The antioxidant power of the phenolic compounds present in the strawberries has the potential to lower risk of heart disease (Giampieri *et al.*, 2012). Strawberry is strongly associated with reduced the risk of chronic diseases especially cancer and cardiovascular diseases. Recent studies have indicated that the antioxidant activity of strawberries has the potential to provide benefits to the aging brain (Fernandes *et al.*, 2012).

Strawberry has unique, highly desirable taste and flavor and is one of the most popular summer fruits. Consumers mainly purchase strawberries for an enjoyable eating experience. It is deep red in colour with unique shape and flavor. It is a good source of essential vitamins and minerals, and has diverse phytochemical compositions that relate to consumer satisfaction and health (da Silva *et al.*, 2007).

The chemical composition strawberry can be highly variable depending on the cultivar, growing location, ripeness stage, and harvest and storage conditions. Around the world, it is consumed “in natura” or in processed form, such as jams, juices, and jellies by their sweet taste and potential benefitsto the health (Giampieri *et al.*, 2012). Antioxidant activity of strawberry is mainly due to the presence of phenolic compounds and anthocyanins (Panico *et al.*, 2009). Strawberry have nearly 2 to 11 fold greater antioxidant capacity than apples, peaches, grapes (Scalzo *et al.*, 2005). The antioxidant activity of strawberry finds its application in various fields of medicine. They are important in the prevention of certain types of cancers, as well as, anti-inflammatory functions, cardiovascular, obesity and other chronic diseases (Crecente-Campo *et al.*, 2012).

Preserving processes of strawberry

FAO (2005) classified strawberry as one of the world’s largest fruit crops and also as one of the most delicate and highly perishable fruits, due to respiration, weight loss and susceptibility to fungal contamination. Like other fruits, strawberries can be consumed in natural, which turns out to be advantageous to consumers since there are no nutritional losses due to processing. On the other side the preference for fresh fruits is challenging because they have a very short shelf-life, due to their sensitivity to fungal attack and excessive textures oftening caused by the natural ripening process (Cordenunsi *et al.*, 2005).Therefore, it can be preserved by freezing and drying processes such as freeze, osmotic, microwave and air drying (Modise, 2008). Besides, it could consume fresh or in many other forms such as juice, concentrate jam, and jelly and dried rehydrated with yoghurt and bakery products (El-Beltagy *et al.*, 2006).

Drying

The main objective of drying is to remove water until the water activity is low enough to prevent growth of microorganisms and increase the shelf life of product. However, the drying process not only decreases the water content of the product, but also affects other physical and chemical properties which will change the shape, crispness, hardness, aroma, flavor and nutritive value of the fresh product. Strawberry drying must consider the effect of temperature on all factors that determine the nature of the fruit, such as phenol content, soluble fiber content and vitamins (Ioannou and Ghoul, 2012). The use of high temperatures can produce a harmful effect in the product instead of maintaining the qualities for which these products are especially appreciated (Hung and Duy, 2012). Drying process should be used with special care in strawberry to avoid chemical changes that may lead to the loss of these important functional components (Ioannou and Ghoul, 2012).

Hot air drying

Hot air drying is one of most widely used technology for food preservation. This unit operation is applied to reduce the water content of products such as fruits, vegetables, agricultural and herbal products, etc. after harvest (Di Scala *et al.,* 2011; Toontom *et al.*, 2012). A mechanical device is used to carry out this kind of drying. The strawberry may be either static or moving and hot air is conducted in different directions. The variables of this system can be well controlled, including the feeding rate, air velocity, air humidity inside the apparatus, air recirculation conditions, and final moisture content in the product (Doymaz, 2008). The principal phenomenon associated with hot air operation is convection wherein the hot air is in contact with the humid material. The method presents some advantages as inexpensive process, simple method, and control of operating conditions. However, it gives to the product a significant aromatic and nutritional degradation, shrinkage, and loss of rehydration potential (Marques *et al.,* 2006). Chemical pretreatments are necessary to accelerate the hot air drying process but the problem of fruit shrinkage is persistent with this method.

Freeze-drying

It is considered as the reference process for manufacturing high-quality dehydrated products. The process involves a preliminary freezing of the products followed by placing them under reduced pressure (< 300 Pa) with a sufficient heat supply to sublimate ice (2800 J per gram of ice) (Shukla, 2011). The product gets stiffened and it subsequently prevents solute and liquid motion during freeze-drying. The process of sublimation(direct change from ice to vapor) helps to remove the freezing water from the strawberry and it helps to explain the capacity of the freeze-dried fruit to rehydrate almost instantaneously (Shukla, 2011). Main advantages of this process is the preservation of most of the initial raw material properties such as shape, appearance, taste, color, flavor, texture, biological activity and the rehydration capacity of the freeze-dried product is also high. It avoids the undesirable shrinkage in the fruit.

The disadvantages associated with this method is that it has a high operating cost, long drying time and high vacuum level (Marques *et al.,* 2006). Sometimes poor quality product is obtained which are generally linked to the quality of the raw material (nature and degree of ripeness) and to processing conditions (operating pressure, heating temperature, freezing rate, freeze-drying process control). Strawberries contain high freezable water content so freezing implied to cellular damage and decreasing the product quality (Martinez- Navarrete *et al.*, 2001).As this preservation method results in the change of quality, textural damage due to formation of ice crystals particularly in fruits which contain high moisture content so osmotic dehydration was applied to upgrade the quality of the frozen foods (Li and Sun 2002).

Osmotic dehydration

The pioneer research on osmotic dehydration of food was done by Pointing and coworkers in 1966. Monograph of apple was calculated the drying rate of osmotic dehydration was provided by Farkas and Lazar (1969). OD (kinetics) of papaya and kiwi in sucrose and glucose solutions were studied by Vial *et al.*, (1991). The constancy of osmotically processed cherry was studied by Torregianni *et al.,* (1987) to analyze the sugar content, color, acidity, vitamin C, pH and organoleptic distinctiveness. Osmotic dehydration has gained more interest during the recent times and is being applied to many fruits. It can be used successfully for weight reduction in the material and require further drying or processing for longer shelf life. Based on the process advantages in terms of energy savings and quality improvement, it is predicted that osmo-air drying process has good potential for utilization of several fruits such as strawberry, and other fruits (Jain, 2003).Strawberries are the most delicate fruits with an extremely short postharvest life. Therefore they are consumed fresh, rapidly processed into jams, juices, desserts and yogurts (Terefe *et al.,* 2009). Water as a main constituent of strawberries affects food stability, both microbial and chemical and is responsible for the consumer perception of many organoleptic attributes, like juiciness and texture (Blanda *et al.*, 2009). It is generally accepted that it is not the quantity of water in food but its thermodynamic state that is responsible for its influence on food stability and texture. The lowering of water activity can be achieved by the application of osmotic dehydration (OD) (Lewicki and Lenart, 2006). During this process, water is partially removed from the cellular materials when these are placed in a concentrated solution of soluble solute (Dermesonlouoglou *et al.,* 2008). In addition, osmotic dehydration has been used as a pretreatment to many processes and improves nutritional, sensorial and functional properties of food without changing its integrity (Rastogi *et al.*, 2002).The osmotic dehydration does not reduce water activity sufficiently to hinder the proliferation of microorganisms. The process extends to some degree the shelf life of the material, but it does not preserve it.

Osmotic dehydration is one of the energy efficient means of removing moisture from a food product, as the water doesn't have to go through a phase change to be released from the product. It is stated that some of the advantages of direct osmosis in comparison with other drying processes include minimized heat damage to color and flavor, and less decolorization of fruit by enzymatic oxidative browning (Krokida and Marinos-Kouris, 2003). Osmotic dehydration is a water removal process, involving soaking foods, mostly fruits and vegetables, in a hypertonic solution such as concentrated sugar syrup. Two major simultaneous counter-current flows occur during osmotic dehydration; Water flows out of the food into the solution and a simultaneous transfer of solute from the solution into the food (Azoubel and Murr, 2004).

Water elimination is a suitable way to protect foods from spoilage. Indeed, the lack of water prevents foods from the microbial development. In these conditions, little enzymatic activity is possible and the major part of chemical reactions is slowed down. Osmotic dehydration is a partial dehydration method applied to fruits and legumes. It consists in immerging the entire or piece of products in highly concentrate solutions.

Osmotic dehydration is a partial water removal technique by direct immersion of food pieces in hypertonic solutions. During osmotic dehydration, three mass transfer processes are established: (1) water diffusion from the food material to the surrounding osmotic medium due to the concentration gradient between them, (2) solute diffusion from the osmotic solution to the food, and (3) leaching of natural solutes from the food. This process can be applied as an intermediate dehydration step prior to further drying processes such as convective hot air drying, freeze drying, vacuum drying (Naknean, 2012).

Types of osmotic medium used in osmotic dehydration of strawberry

Selection of osmotic medium for osmotic dehydration of strawberry is of major importance. It provides driving force for concurrent flows of water and solute and then measures the rate and extent of solute uptake and removal of water as well as sensory and physical properties of the end product. Different types of solutes such as fructose, corn syrup, glucose, sodium chloride and sucrose are used as osmotic agent for OD (Azuara and Beristain, 2002). Three different osmotic agents are used for osmotic dehydration of strawberry, sucrose (70%), sucrose (70%)-glycerol (65%) 1:1 and ethanol. Water activity in strawberry was lowered and promoted the constituents of flavor and moving of anthocyanins to osmotic solution by using of this practice (Osorio *et al.*, 2007). The loss of water and solid gain was caused by the application of osmotic treatments. The most helpful effect of osmotic dehydration was on lycopene, ascorbic acid and on the color quality.

Product quality and advantages of osmotic dehydration

Osmotic dehydration is an important intermediate step or pretreatment technology in the preservation of fruits. It improves the product quality by reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decreases the energy costs (Torres *et al.*, 2006). This process is done at room temperature to avoid the degradation of color, texture and nutritional values of the food. In this process loss of volatile compounds and oxidative changes is also lowered (Marani *et al.*, 2007).Osmotic treatment has many advantages over conventional methods; which includes its mechanical simplicity, processed flexibility, and decreased the cost of energy. In food industry the two important parameters associated with osmotic dehydration are maintaining the quality as well as stability of product and energy competence. Work has been done on the kinetics of solute /exchange of water in and out of food tissues (Giraldo *et al.*, 2003), application of vacuum pulse during osmotic treatments and special effects on impregnation time (Mujica-Paz etal.,2002). Foods containing 20 to 30% water can be removed by the process of osmotic dehydration. This process made the food to semi dried, frozen or treated with chemicals. Osmodehydrated products can be utilized in bakery, dairy and candy industries. The dehydration technology is also utilized to produce the concentrates of vegetables and fruits.

Innovative drying methods

Innovations in strawberry dehydration include sugar infusion and impregnation under high or low pressure, microwave dehydration under vacuum, pulsed-mode microwave applications and instant controlled pressure drop (Ioannou and Ghoul, 2012).

Instant controlled pressure drop (DIC)

Instant controlled pressure drop was developed, defined and studied by Allaf and Vidal (1988).DIC is a thermo-mechanical processing induced by subjecting the product to an abrupt transition from a high steam pressure to close to a vacuum (Ben Amor and Allaf, 2009). Hence, DIC is perfectly adapted to texture-sensitive products such as strawberries.DIC is defined as a high-temperature/short-time (HTST) treatment that consists of subjecting a partially dried material (usually the humidity is close to 30% db) to vapor pressure ($P<1.0$ MPa) at high temperature (below 180 ºC) for a short time (less than a minute).This high temperature-short-time stage is followed by an abrupt pressure drop to a vacuum (3–5 kPa) inducing a mechanical effect such an abrupt pressure drop, provokes simultaneously autoevaporization of a part of water contained in the product and an instantenous cooling of the product which stops their thermal degradation and give a controlled expansion of the product. A DIC pressure drop is characterized by a very high pressure drop rate. As DIC technology needs products partially dried (water content around 30% db) to the treatment, the solution proposed was assisted it by hot air drying process, forming the swell-drying process (Mounir *et al.*, 2011).

Swell-drying (SD)

Swell-drying (SD) is a new process that could greatly intensify the conditions given by hot air drying, such air flux, temperature, speed and humidity. Texturing operations are proposed to improve both the performance of hot air drying as well as the quality of the final (Mounir *et al.*, 2012). Hence, DIC within SD could help to texturize the strawberry and give it an attractive alternative (Allaf, 2012). Albitar *et al.*, (2011) reported that the onions treated by SD process improved in terms of kinetics and quality of the end product. Mounir *et al.*, (2011) reported that the apples treated by SD process preserved their vitamins but the thermal degradations were weak.

Applications of dried strawberry

Dried strawberry has many applications. It can be used as a food by itself or an ingredient in other food. It can be used as snack which is an innovation and has a very good acceptance by consumers. The snack contains wild or cultivated strawberry or another berry and is popular due to various health benefits associated with their antioxidant activity, scavenging of free radicals, and high content on soluble dietary fiber (Potter *et al.*, 2013). Dried strawberries along with cereals are used in breakfast. Addition of strawberry or another berry to breakfast cereals has a double benefit because of the soluble dietary fiber from berry complement very well the insoluble. Dried strawberry as food ingredient is very popular. It can be an ingredient of ice cream, toppings, fruit pieces in pastries and cookies, yogurt, snacks, and pressed for fruit leathers (Harris, 2007). However, in some of these products, a second heat treatment could damage the dried fruit chemical quality (Ioannou and Ghoul, 2012). So, it is better to use dried fruits that are protected against deterioration of these compounds.

Postharvest life of strawberry is relatively short, due to their highly fragile structure and their high rates of respiration. It is highly susceptible to bruises and fungal attacks. This problem affects also its bioactive compounds and antioxidant activity. Hence, to extent the shelf-life strawberry and preserve its bioactive activity, large range of unit operations have been proposed and used to preserve it. New operations such swell-drying (instant controlled pressure drop, DIC-assisted hot air drying), osmo air drying, hot air drying, freeze drying have been proposed to extend the shelf life of strawberry. Drying is one of the most common methods to preserve strawberries. However, the disadvantage of drying process is that it not only decreases the water content of the product, but also affects other physical and chemical properties which will change the shape, crispness, hardness, aroma, flavor and nutritive value of the fresh product.The traditional food hot air drying commonly includes two stages. The first involves quick water removal (until the critical moisture point) often associated with product's shrinkage which finally reduces the diffusivity of water within the material with almost great deformation of the product. The second has limited water removal as a result of the low diffusivity value, implying long-time period, high heating temperature and hence thermal degradation revealed by a loss of vitamins and bioactive molecules, degradation of pigments and color, and poor nutrition value with a high energy consummation. The disadvantage associated with hot air drying method is that it results in fruit shrinkage so this method has been replaced by freeze drying. Freeze drying process leads to the preservation of most of the initial raw material propertiessuch as shape, appearance, taste, color, flavor, texture, biological activity and the high rehydration capacity of the freeze-dried product. However due to the high operating cost, long drying time and high vacuum level this method is mostly used at commercial scale.Traditional processes such as osmotic dehydration have recently gained a renewed and increased interest, mainly as a pretreatment in combined techniques. Osmotic dehydration (OD) is one of most important complementary treatment and food preservation technique in the processing of dehydrated foods, since it presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decrease the energy costs. Reduction of drying time and processing costs have recently been reported by the use of osmotic dehydration at the experimental scale. Recently there has been much progress towards the drying of strawberry by various innovative methods viz. dehydration including sugar infusion and impregnation under high or low pressure, microwave dehydration under vacuum , pulsed-mode microwave applications and instant controlled pressure drop. Besides swell drying method is a new process has been found to be promising method which improves both performance of hot air drying as well as quality of final product.

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