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Recent developments in drying technologies for retention of nutritional/functional quality of papaya: A review

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Abstract

Papaya is a well-liked tropical fruit with a distinctive aroma, flavour, and high nutritional qualities. A common preservation method used to decrease post-harvest losses and lengthen shelf life is drying. Traditional convective drying, however, takes a long time and has an immediate impact on the finished product's quality. The shortcomings of popular papaya drying procedures are discussed, along with potential ways to enhance the quality of dried papaya by combining several drying techniques. Color, porosity, shrinkage, phytochemicals, antioxidant capacity, carbohydrates, proteins, volatile compounds, and sensory characteristics are among the quality criteria being investigated. Drying, in general, causes all analyzed parameters to decrease. However, an innovative or combination technology must guarantee high-quality dried papaya. This review also emphasises the most current developments in papaya fruit drying techniques that preserve the fruit's nutritional value and functionality. Furthermore, to explain the key advantages of a few recently developed drying processes, with an emphasis on hybrid drying methods that combine microwave and ultrasonic assistance to provide high-quality drying with exceptional efficiency for papaya fruit.

Keywords: Drying technologies, retention, nutritional, functional quality, papaya

Introduction

Papaya (*Carica papaya*) is commonly produced in tropical and subtropical nations including Australia, Brazil, Malaysia, Thailand, and South America. Papaya yield is the third highest in the world, after only that of mango and pineapple [1]. Papaya is a year-round fruit that is a nutritional powerhouse and the three potent antioxidants: vitamin C, vitamin A, and vitamin E, and minerals: magnesium and potassium are abundant in it. Along with all of this, it also contains papain, a digestive enzyme that successfully relieves the underlying causes of trauma, allergies, and sports injuries. Collectively, papaya's nutrients strengthen the cardiovascular system, defends against heart conditions like heart attacks, and strokes, and fend off colon cancer. The fruit is a valuable source of beta-carotene, which defends against the damages inflicted by free radicals, which can result in some types of cancer. According to the reports, it assists in preventing diabetes and reduces high cholesterol [2]. Although papaya is primarily produced (>90%) and consumed in developing countries, it is rising rapidly to prominence as a major fruit on the global market in both its fresh and processed forms [3]. It is a very perishable fruit, and postharvest losses impact roughly 30% of the output [4]. Among other products, commercially ripe papaya can be used to make syrups, dried products, yogurt, jam, jellies, nectars, and sweets [5]. Papaya is a fruit with high perishability and a very quick ripening cycle, which makes it challenging to preserve and market despite its strong demand on the market. Protein, fat, fibre, carbohydrates, calcium, iron, vitamin C, thiamine, riboflavin, niacin, carotene, amino acids, citric acid, malic acid, and volatile compounds like benzyl isothiocyanate, cis and trans 2, 6-dimethyl-3, 6 epoxy-7 octen-2-ol, alkaloids, and carpaine are all chemical components of ripe papaya fruit [6]. Due to its high nutritional value, ripe papaya must be preserved by quality processing (Table 1). Post-harvest storage of ripe papaya is quite challenging since they are a perishable agricultural product. According to reports, papaya fruits may only be kept fresh for three weeks when stored in conditioned settings (10 °C with 90–95% relative humidity) [7]. This is a significant obstacle, especially in light of global export market demands. Dehydration or drying is considered one of the most effective ways to maintain the quality of agricultural produce [8]. Fruits' nutritious content may also be preserved by drying them, which enhances their relative concentration, lengthens their shelf

Life, and reduces the cost of packaging, handling, and transportation [9]. Additionally, drying is an affordable postharvest management technique to increase the surplus of fruits in the market. When compared to other drying methods, freeze-drying helps to preserve colour, flavour, and taste most efficiently [10]. However, the freeze-drying procedure is time- and energy-consuming, and it also has substantial facility expenses [11]. This review presents the effects of a few different combination drying technologies with the objective of effective drying of papaya with preservation of the most important quality aspects of the dried papaya.

Table 1: Papaya (ripe) nutritional values (Per 100 g edible portion only)

Nutrient	Values
Water	88.06 g
Energy	43 Kcal
Protein	0.47g
Fats	0.26 g
Carbohydrates(total)	10.82 g
Carbohydrate(sugar)	7.82 g
Dietary fibre	1.7 g
Cholesterol	Nil
Sodium	3 mg
Potassium	182 mg
Calcium	20 mg
Magnesium	21 mg
Iron	0.25 mg
Zinc	0.08 mg
Beta-carotene	47 µg
Thiamin	0.023 mg
Riboflavin	0.027 mg
Niacin	0.357 mg
Vitamin C	60.9 mg
Vitamin A eq.	47 µg
Vitamin K	2.647 µg
Vitamin E	0.3 mg

Source: [6]

Convective air drying

One of the most used drying methods in the food industry is forced convection drying, a sophisticated technique that couples heat and mass phenomena [12]. Fruit and vegetable drying is mostly diffusion driven [13, 14, 15], and drying rates are constrained by internal resistances to water removal and surface diffusion. Faster water mobility is caused by greater drying air temperatures; however, this leads to product quality degradation and increased energy usage. According to reports, the length of time needed to finish drying using various drying procedures varies depending on the thickness, variety, sugar content, and drying temperatures of the sample [16]. Convective drying of papaya is reported to be completed in 5-7 hours. Temperature and air velocity are thought to have a substantial impact on the kinetics of nutrient loss. Additionally, lower air temperatures (40 and 50 °C) exposed to any air velocities are advised in order to acquire dried papaya with better nutritional content, as this will result in a 50% retention of initial nutritional value [17]. The ambient temperature for papaya convective drying to retain the colour is reported to be 60 °C, resulting in the production of dried papaya with a high concentration of bioactive components [18]. When papaya cubes are dried by convection, the cubes' colour deteriorates, their volume decreases, and their cubic structure breaks down and deforms near the completion of the drying process. The same study identified that there is an increase in hardness during convective drying of papaya cubes that directly correlated to the gumminess and the chewiness [19]. It is noteworthy that the majority of air-dried products undergo structural collapse, producing harder textures and more chewiness [20]. Convective drying of papaya has been the subject of a substantial number of investigations, and these studies support the idea that convective drying procedures significantly influence the sensory quality of dried papaya. However, if convective drying is employed in conjugation with pretreatments, then preservation of quality can be achieved depending on the drying techniques, pretreatment, and thickness of the sample.

Coating followed by convective drying

In order to counteract the negative effects of drying fruits are pretreated in order to create edible semipermeable membrane coatings on them. Edible coatings are formed on food products using thin layers of substances that may be digested, such as lipids, proteins, and polysaccharides [21, 22]. The composition and concentration of coating ingredients, as well as the agitation, duration, temperature, and other OD drying parameters, have a noticeable impact on drying efficiency [23]. By reinforcing cellular integrity to survive the increased osmotic pressure, edible coatings aid to keep the aroma and flavour of meals by acting as a barrier to oxygen and carbon dioxide but not water [24, 25]. After drying, coated fruits displayed cell structures similar to those of fresh samples, while strong cell membrane rupturing is observed in the uncoated dried samples. It is possible that the high moisture diffusivity within the pectin coating is the reason coated papaya slices had higher moisture-effective diffusion coefficients than the uncoated papaya slices. The coated papaya slices had better vitamin C retention and colour preservation than the uncoated samples, indicating that pectin coating had a protective effect against vitamin C and colour degradation during drying. The results demonstrated that this technology is a promising alternative to improve the quality of dehydrated foods, given that convective drying is the drying technique most frequently used in the food industry and that the coating did not affect the drying efficiency while also facilitating improved nutritional quality for the dried papaya slices [26]. In another investigation, the impact of the starch coating on the papaya's drying qualities and antioxidant capabilities is assessed. To retain the functional and nutritional value of the papaya slices before drying, the combined effects of calcium salt and potato starch are investigated as an edible coating. The water activity of papaya slices is significantly decreased after drying. It enabled long-term storage of the slices without microbial deterioration. In comparison to the uncoated sample, the calcium salt with potato starch coating maintained the highest colour intensity as Chroma values. The thermal loss during the drying process is decreased as all the bioactive components in the samples were retained when the edible coating is done [27].

Osmotic pretreatment followed by convective drying

The immersion of a solid in a hypertonic solution causes osmotic dehydration (OD). As a result, the solid gains solutes while losing water [28]. When compared to convective drying, this approach saves energy [29], improves mechanical characteristics [31], boosts colour and flavour retention [30], and produces food with lower water activity [32]. However, because capillary flow and diffusion are what drive the mass transfer, it takes a while to complete [33]. Additionally, the products developed have a medium amount of moisture content. So, this process includes the benefits of both techniques when OD pretreatment is combined with subsequent convective drying [34]. As a result, the changes in fruit tissue promoted by OD shorten the subsequent drying time and minimize the quality deterioration brought on by hot air drying [33, 34]. Even while this combination might speed up the overall drying process, it is still a lengthy procedure. In a study papaya cubes are air dried at two distinct air velocities (1.25 and 3.25 m/s) and temperatures (40 and 60 °C) after being osmotically pretreated at 70°Brix. It has been noted that an increase in air temperature and air velocity led to a decrease in the drying time for the finished product. When drying fresh papaya cubes, air temperature and air velocity both had a significant impact on the drying rate. The increase in the internal resistance to water transport brought on primarily by shrinkage and solute accumulation during the osmotic pretreatment may be the origin of the observed variations between fresh and osmosed papaya drying times [35]. In a separate investigation, papaya slices were subjected to osmotic dehydration with agitation, followed by air drying, at various osmotic solution temperatures (50 and 70 °C) and TSS (50 and 70 °Brix). The findings demonstrate that when using high concentrations of sucrose solution (70 °Brix) in the process, using osmotic dehydration followed by air-drying is advantageous. Hence the procedure may be expedited by employing an osmotic solution with high sucrose concentrations (70 °C and 70 °Brix), which reduces the drying time from 11.3 hours when utilising only the air-drying method. Osmotic dehydration is very helpful to shorten the drying processing time of papayas, as demonstrated by the fact that the complete process is decreased to 6.6 hours even when utilising low sucrose concentrations (50 °C and 50 °Brix). High temperatures (50–70 °C) were utilised in certain experimental tests to promote the efficient mass transfer of water from the fruit to the osmotic solution. Papaya can withstand these temperatures without losing its quality, according to tests that have already been conducted [36]. Additionally, it may be deduced from experimental research that papaya that was osmotically pretreated before being dried by convection had a faster water removal rate [37].

Ultrasound-assisted osmotic dehydration followed by convective drying

In the expanding field of research, ultrasound is being used in various applications and it is finding its way into food processing also [38]. In solid/liquid food systems, it has been utilised to improve mass transfer [39]. Similar to how a sponge expands and contracts rapidly when pressed and released repeatedly, ultrasonic waves may also generate fast sequences of alternate compressions and expansions (sponge effect). Additionally, cavitation, which is another effect of ultrasound, may be useful for removing strongly bound moisture. The development of minute capillaries in porous materials, such as fruits, due to the sponge effect created by ultrasonic treatment may lower the diffusion boundary layer and increase convective mass transfer in the fruit [40]. The most often mentioned pretreatment before air drying is osmotic dehydration [41], which may be utilised to enhance the nutritional, sensory, and functional qualities of food without compromising its integrity [42, 43]. Ultrasonically aided osmotic dehydration, on the other hand, is one of the newest and most promising technologies since it can be done at low temperatures, lowering the likelihood of food deterioration [44] and removing moisture content from solids without causing a liquid phase transition [45]. Due to the increased solute intake during osmotic dehydration, osmosed samples showed slower drying rates and required a longer time to attain the same ultimate moisture content as fresh and ultrasound-pretreated papaya. Interestingly, there was a lower carotenoid loss in those samples [46].

Ultrasound and vacuum-assisted drying

An alternate dehydration technique ideal for heat-sensitive materials, such as fruits, is vacuum drying [47]. It benefits from shorter drying times, low energy consumption, and reduced oxidation of food molecules due to the elimination of oxygen during drying [48]. As a result, food's sensory and nutritional properties can be preserved. It is more favourable to combine vacuum drying technology with ultrasonic-assisted dehydration. In order to assist in the removal of water, microscopic channels are formed using ultrasonic waves. Additionally, the ultrasound creates a cavity that can help with the removal of the material's tightly bound water [49]. This method, which was first described in 2014, relies on vacuum drying and ultrasonic treatment to speed up processing [50]. The water evaporates at lower pressure in this method because vacuum drying lowers the drying chamber pressure below atmospheric pressure. Additionally, by increasing the transport of water, using a vacuum speeds up the drying process. The second part of the process, ultrasonic treatment, uses mechanical vibrations to speed up the transfer of water from the materials inside to its surface while also assisting heat transfer. Therefore, this novel method uses vacuum drying, which lowers ambient pressure and promotes a faster drying rate, as well as an ultrasonic process, which accelerates the transfer of heat and mass [48]. Papaya drying techniques using vacuum and ultrasound have been evaluated. The quality of the dried fruit was examined in terms of colour, texture, total carotenoid content, and ascorbic acid content. Papaya that had undergone ultrasound-assisted vacuum drying (USVD) required 270 minutes to reach the dynamic equilibrium condition, compared to 450 minutes for a papaya that had undergone air drying. Ultrasound and vacuum-assisted dried samples had the lowest ascorbic acid loss (41.3%), while after processing ultrasound-assisted dried samples had a lower carotenoid loss (9.7%). All of the dried samples showed an increased red tone, decreased brightness, and yellow hue. The USVD-dried sample had the lowest hardness value in terms of texture, whereas the air-dried sample had the greatest value [51]. According to the findings of these investigations, papaya drying using an ultrasonic-assisted vacuum has a beneficial impact and may be done quickly and efficiently. After drying, the bioactive components were significantly retained. The outcomes also showed that the combination of vacuum and ultrasound can be useful in minimizing the nutritional loss of dried papaya while also producing dehydrated fruits with improved colour and texture properties.

Modified atmosphere heat pump drying

To produce the best products, several methods, including hot air drying, vacuum drying, and freeze drying, have been developed or modified. However, it is generally accepted that heat pump drying (HPD) is one of the most promising technologies when all three of the previously stated considerations are taken into account. It is appealing because it can transform the latent heat of vapor condensation into the sensible heat of an air stream flowing through the condenser [52]. According to research, heat pump dryers use between 60 to 80 percent less energy than conventional dryers while operating at the same temperature. By replacing the atmospheric air in closed HPD with a specific inert gas, the environment in the drying chamber may be modified, bringing about additional benefits including porous end products and fast rehydration [53]. Dried apples had good colour and high vitamin C retention, according to Perera [54]. Hawlader *et al*. discovered that dried commodities have improved rehydration capabilities in addition to colour [55]. The improvement of modified atmosphere heat pump drying was not only in drying kinetics but also in the quality of dried products when papaya cubes were dried using inert gases like nitrogen and carbon dioxide as a drying medium, drying temperature of 45 °C, relative humidity of around 10%, and circulating air velocity at 0.7m/s. Most deteriorative quality changes are avoided since inert gas greatly lowers the amount of oxygen in the chamber. Studies revealed that it improved the physical appearance, efficiency of rehydration, and nutritional retention of dried fruits [55].

Microwave-assisted foam mat drying

Juices and pulps can be dried more effectively using foam mat drying than with conventional hot air drying. The surface area of liquid food is increased by foaming, which speeds up the drying process. Foods with low glass transition temperatures that are often difficult to dry can be dried using this approach since it is affordable and effective enough [56]. One method of processing and preserving papayas is to dry the pulp into papaya powder, which is then used to make a variety of culinary items including nectar, ice cream flavours, and ready-to-eat fruited cereals. Papaya powder has the potential to be employed in a variety of culinary processes as a nutritious ingredient. Papaya has been dried using foam mat drying, and the authors observed that at all the chosen temperatures, the drying time for foam mat dried papaya is faster than the conventional method [57]. Fruit pulp with high moisture content, high viscosity, and a high heat sensitivity is suited for microwave-assisted foam-mat drying (MFD), which combines the benefits of both foam-mat drying and microwave drying to create powder [58, 59]. A suitable formulation of foaming agents, including additives and ratios, may form stable foam in liquid or semi-liquid foods [60], which tends to increase the evaporation surface of liquid material and weakens the surface tension between the liquid and gaseous phase [58]. This is a necessary condition for the achievement of MFD for hard-drying pulp to produce a powder with high efficiency and quality. The expansion, porosity, and stability of powder may also be greatly controlled by foaming agents, allowing for the achievement of desirable physicochemical quality traits such as acceptable colour, immediate water solubility, and excellent flowability [61]. As chosen components of foaming agents, the egg white powder (EWP), maltodextrin (MD), and carboxyl methylcellulose (CMC) have been shown to successfully boost the MFD process [62] and improve the physicochemical quality of the pulp powder [54, 63]. Additionally, papaya foam mat drying with microwave assistance was modeled using machine learning techniques. The drying period of papaya foam was shortened by employing the combination of these techniques. Microwave power increases and cause deeper penetration, which accelerates the heating of foam. The foam dries more quickly as a result of the greater drying rates. The influence of microwave power and intake air temperature on drying rate was less significant than that of the foam thickness. With an increase in microwave power, a drop in foam thickness, and a rise in inlet air temperature, the drying rate was significantly enhanced [56].

Conclusion

Dehydration of fruit has been used since ancient times using various drying techniques. Each drying method affects sensory qualities differently and to varying degrees, although in most circumstances, high-temperature drying methods degrade sensory qualities more than low-temperature drying methods do. Additionally, it is clear that the likelihood of changes in colour, texture, taste, and aroma increase with drying time. The form and variety of fruit utilised affect how quickly these attributes change. Given the perishable nature of papaya, the best option would be to choose combination drying methods comparable to freeze drying, which has been proven to be the best method for the food industries. This is true even though the best way to have a lot of natural antioxidants is by consuming fresh fruits or juice. From the research that is currently accessible, it may be inferred that combining drying procedures or hybridising drying processes will result in the retention of some of the significant bioactive components in dried papaya. Additionally, using several drying techniques increases the overall acceptability of the dried product. Therefore, additional research is needed to determine how hybrid drying procedures affect nutritional value retention, sensory qualities including scent and taste, and shelf-life stability. To make these technologies more sustainable for the food industry, research must also be done to assess various hybrid drying procedures and incorporate a wide range of drying parameters.

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