Quality Assurance and Safety of Crops & Foods, 2025; 17(3): 375–397

Drying of persimmon fruit: effect on various quality characteristics and applications of the dried product

Vimal Challana[1], Nikita Bhatkar[2]*, Shivanand Shirkole[3]*

[1]Department of Processing and Food Engineering, College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, Punjab, India; [2]Department of Chemical & Materials Engineering, Faculty of Engineering, University of Auckland, New Zealand; [3]Department of Food Technology, School of Engineering and Technology, D.Y. Patil Agriculture and Technical University, Talsande, Kolhapur, Maharashtra, India

***Corresponding Authors**: Nikita Bhatkar, Department of Chemical & Materials Engineering, Faculty of Engineering, University of Auckland, New Zealand. Email: nbha092@aucklanduni.ac.nz; Shivanand Shirkole, Department of Food Technology, School of Engineering and Technology, D.Y. Patil Agriculture and Technical University, Talsande 416112, Kolhapur, Maharashtra, India. Emails: ss.shirkole@iocb.ictmumbai.edu.in; shivanandshirkole@gmail.com

Academic Editor: Ravi Pandiselvam, PhD, Scientist, ICAR-Central Plantation Crops Research Institute, Kerala, India

Received: 18 December 2024; Accepted: 19 June 2025; Published: 17 July 2025

REVIEW PAPER

Abstract

With the surge in research on underutilized fruits, more focus is on utilizing these fruits for value-added products. Persimmon (*Diospyros kaki*), with its numerous health benefits and product development potential, represents one such underutilized fruit. However, its widespread utilization confronts challenges due to its seasonal availability and short shelf life. Drying technologies provide a possible solution to extend the shelf life of persimmons and make them available throughout the year. The drying process of such underutilized fruits involves interactions between various factors that can influence the drying kinetics and final product quality. These factors include appropriate drying method, pretreatment application, fruit maturity at harvest, and inherent characteristics of fruit. This review examines the effects of these factors on the drying processes of persimmon. It focuses on how different drying approaches influence the quality attributes of the final dried product. Furthermore, the paper discusses the potential applications of dried persimmon in various food products.

Keywords: persimmon; drying; preservation; pretreatment; quality; shelf life

Introduction

Persimmon (*Diospyros kaki*) is a premium fruit native to China (Matheus *et al.*, 2022). The fruit belongs to the *Ebenaceae* family and is mainly grown in China and other countries, such as Spain, Republic of Korea (since the 14th century), Japan (since the 7th century), Brazil, Italy, and Iran (Hanif *et al.*, 2015). During the 20th century, fruit production rapidly spread in countries such as Australia and New Zealand (Matheus *et al.*, 2022). In 2021, the fruit was cultivated over 1.032 billion hectares, yielding 4.332 billion tons of fresh produce. In 2021, China was the leading producer of persimmon, followed by the Republic of Korea, Azerbaijan, and Japan (Food and Agriculture Organization [FAO], 2023).

As fruit cultivation is limited to particular regions, persimmon is not grown globally, although the fruit is gaining popularity because of its attractive color, appearance, sweet taste, astringency, and unique chewiness

(Yang *et al.*, 2022). Persimmon is an underutilized tree fruit with an orange-red color, fibrous flesh that is sweet in taste, and a round shape. Depending on its tannin content and organoleptic properties, it is further categorized into two types: astringent and non-astringent fruit (Jung *et al.*, 2005).

In today's modern era, the demand for foods with additional health benefits is increasing. Most foods provide nutritional benefits to the consumer whereas functional foods offer nutritional value and other health benefits. They help to reduce the risk of chronic diseases. Persimmon is one of the fruits that can satisfy some of these functional food demands. The fruit is fully loaded with nutrition and many bioactive components, such as soluble tannins (vary from 0 to 4% fresh weight), polyphenols, ascorbic acid (approximately 50 mg/100 g fresh pulp; immature fruit contains relatively more vitamin C), carotenoids and vitamins A, B_6, B_{12}, D, and E, and amino acids (19 amino acids are identified in the flesh). Minerals such as potassium, sodium, iron, and calcium, high levels of sugars (mainly fructose and glucose together share 90% of the total sugars present with a ratio of 1:1), pectic substances (varying from 0.7% to 1% of fresh weight) are also present (Testoni, 2002). The main organic acids in the fruit are citric, ascorbic, malic, and succinic acids. Both sugars and organic acids contribute to flavor and sensory properties. The total fiber and protein contents in fruit are 3.86% and 0.54%, respectively. Tannins, carotenoids, and phenolic compounds contribute to the fruit's antioxidant activity (Matheus *et al.*, 2022). Owing to its abundant bioactive components, this fruit is anticarcinogenic, anti-inflammatory, cardioprotective, and anti-hypercholesterolemic and has antioxidant effects on regular consumption (Yang *et al.*, 2022). Several studies have reported that fruit flesh is more nutritious than its pulp (Direito *et al.*, 2021).

Persimmon can be found in Europe from September to early December (Direito *et al.*, 2021). In India, fruit harvesting is done from late autumn to early winter, from October to December (Anjum *et al.*, 2021). Owing to the presence of moisture (82–83%), nutrients, and climacteric properties, the microbes can quickly thrive over the fruit, resulting in spoilage and deterioration. The fruit has a limited shelf life and harvesting time; hence, it is inaccessible around the whole year. Therefore, there is a massive demand for the processing of this fruit to make it available to consumers aound the year. Furthermore, the fruit must be processed into various products to maintain its bioactivity and nutritional and sensorial characteristics (Anjum *et al.*, 2021).

Drying is one of the methods by which food or fresh produce could be preserved for a long period. Drying inhibits or prevents microbial growth and increases food stability, facilitate storage, and reduce transportation costs by removing excess moisture (Yang *et al.*, 2022). Dried persimmon has many applications in the food industry as it can be incorporated into snacks, cakes, breakfast cereals, and muesli. Dried persimmon slices can also be consumed as a snack. Besides, the drying of persimmon opens a window for utilizing this underutilized fruit in the form of different dried products, such as persimmon dried slices, partially dehydrated fruits, powder, and many more forms. Studies are conducted on the drying of persimmon in different forms. The present article reviews the studies conducted on the drying of persimmon and its effect on various quality characteristics of its dried form.

Drying of Persimmon

Persimmon contains abundant water in the form of moisture (approximately 81% on wet basis), which restricts its shelf life (Karaman *et al.*, 2014). Moreover, it is available only in a particular season, which limits its consumption and usage. Drying can help to store it for a longer period with less risk of microbial contamination because of lessening of free water. Luo (2006) reported maximum ethylene and carbon dioxide production after four days in 'Qiandaowuhe' persimmon fruit. Harima *et al.* (2003) observed that persimmon fruit becomes soft and degrades to an unacceptable quality after 5 days of harvesting. With the help of drying and packaging techniques, the shelf life of dried persimmon could be extended from 1 month by storing in polythene to 8 months if stored in aluminum or polypropylene, with carbon dioxide and nitrogen flushed inside the package (Park *et al.*, 2006). Limited shelf life and immediate deterioration after harvesting necessitate its drying as a processing method. Moreover, drying also decreases fruit's volume or weight, which helps to reduce economic cost of shipping or transportation.

Persimmon is dried in various forms, such as slices, slabs, pulp, peels, and complete fruit. Multiple methods are used for drying, such as hot air drying (HAD), which consists of various drying methods, such as tray dryers, conventional oven dryers, sun drying, flat plate solar collectors, pulsed vacuum osmotic dehydration (PVOD), ultrasound-assisted osmotic dehydration (USOD), commercial dehydration, ultrasound-assisted vacuum drying (USV), pulsed vacuum drying, vacuum oven drying (VOD), vacuum freeze-drying (VFD), and combined hot air-microwave (MW) drying. A hot air oven drier is the preferred one. Figure 1 enlists various drying methods employed for drying of persimmon.

Numerous factors affect the drying of fruit that can be classified as intrinsic to the fruit, such as the variety,

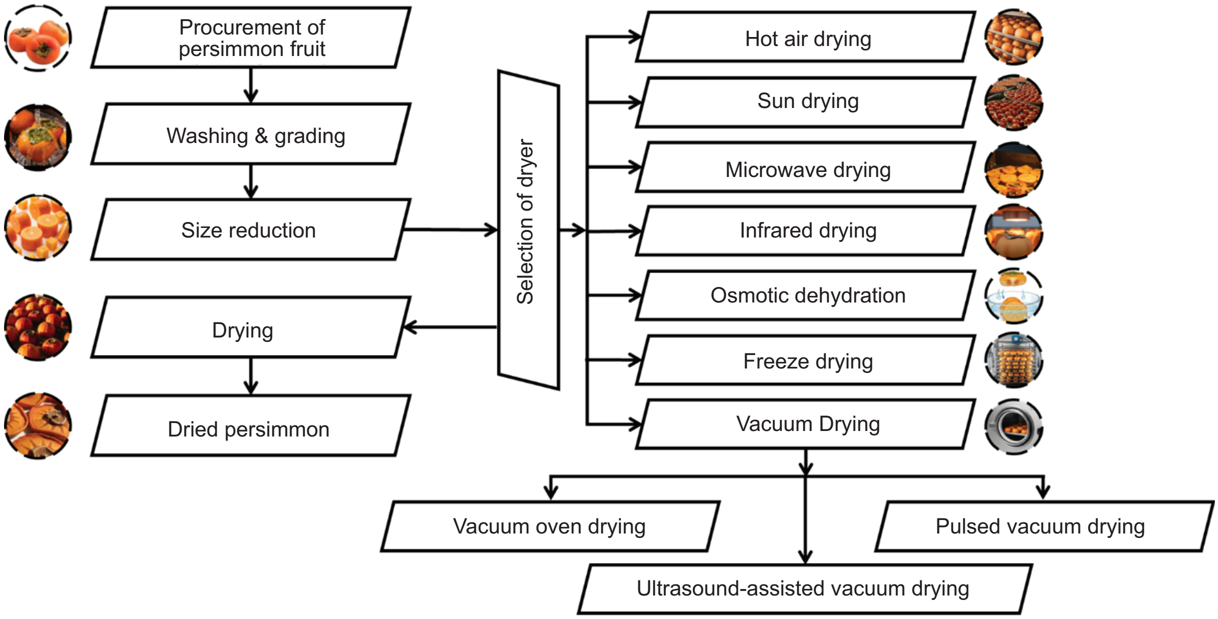

Figure 1. Drying of persimmon: different pretreatemts and methods.

shape, size, and form of the fruit (slice or pulp). The maturity of the fruit also plays a crucial role in drying, as Vilhena *et al.* (2020) observed when fruits of two different maturities were dried. The authors observed a considerable difference in the drying time and evaluated the physicochemical and microstructural changes of two maturity stages (S_1 and S_2) of 'RojoBrillante' persimmons. Different maturity levels have different microstructures, affecting rate and time of fruit drying. Owing to structural differences, the moisture loss was faster in S_1 than in S_2; 0.5-g H_2O/g was observed in S_1 and S_2 after 21 days and 28 days, respectively. The authors also observed a different effect on the color concerning the maturity stage, a decrease in L* values of S_1 and S_2 at the end of the drying period as against the initial average values, with a slight increase in the initial days of drying. L* values for S_1 were more, compared to S_2. The same trend was observed for chroma (C*) and hue angle (h*).

Another study showed that as the fruit matured, carotenoids increased with increase in the maturity of the fruit ($M_3 > M_2 > M_1$). In contrast, the antioxidant activity (AA) discovered by 2,2-diphenyl-1-picrylhydrazyl (DPPH) showed that AA was maximum in M_2 than in M_3 and M_1 (González *et al.*, 2021). Thus, it was concluded that drying was affected by different factors. Thus, it can be interpreted from the above two cases that maturity index is a crucial factor that governs drying rate and quality of the dried product. Other critical factors could be the variety of fruit, type of feed (form, size, and shape), dryer, drying conditions, pretreatment, and environmental conditions. Drying period for persimmon slices was reduced by 220 min when the drying temperature was increased from 45°C to 65°C (Senadeera *et al.*, 2020). Karaman *et al.* (2014) observed that the total dry matter of dried persimmon was maximum in the case of oven-dried samples, compared to vacuum oven-dried and freeze-dried samples. It intends that an oven-dried sample retained less moisture, and removal of more free water was evident.

The drying of fruit requires various preceding unit operations. After harvesting, the fruits are usually washed to remove adhering dirt and foreign particles. The fruits are sorted and graded based on the size, color, and degree of firmness to get the desired characteristics and uniformly dried forms. Based on the desired product and the drying method, the fruits are cut into different shapes or slices of the required thickness or pureed to have the dried form, such as powder or flakes. Different pretreatments, as explored in the literature, are rendered for persimmon fruits, similar to other fruits. The effect of different pretreatments and changes in the nutritional and functional properties of dried fruits are reported in the literature.

Effect of Pretreatments

It is worth noting that different pretreatments have different effects on the drying time and quality of the dried persimmon. For instance, Demiray and Tulek (2017b) concluded that dipping in water at 70°C as a blanched pretreatment, followed by HAD, provided better color retention than immersing in 20% sucrose solution as a pretreatment. Generally, drying by hot air usually takes longer time, but with the help of pretreatments, the drying time could be decreased, compared to conventional drying. The same authors observed that drying time for the fruit sample immersed in sugar syrup (20%) was 5 h less at 55°C, 6 h less at 65°C, and 4 h less when drying was carried out at 75°C because of osmotic dehydration (Demiray and Tulek, 2017b).

It was also observed that the effective diffusivity values vary more with pretreatment than with drying temperatures. Igual *et al.* (2011) reported 3.05×10^{-10} m^2/s diffusivity of water for the pretreated sample before drying and 3.43×10^{-10} m^2/s for the control dried sample, which indicated lower moisture content in the pretreated sample, resulting in a lower driving force. Pretreatment with an ultrasonication bath decreased the drying period of persimmon by 46%, compared to the control samples. Drying period and ultrasonication treatment are inversely proportional to each other; as the ultrasound treatment increases, the cell disruption increases, resulting in easy moisture loss. Average drying proportions increase with increase in the frequency of ultrasound. Doymaz (2012) observed a 21–42.8% decrease in the drying time of persimmon slices when blanching was done prior to drying.

For osmotic dehydration, 24% and 34% moisture were reduced when dipped in 30 °Brix and 45 °Brix fructose solutions, respectively. Interestingly, applying edible coatings of guar gum, gum Arabic, and xanthan gum was also explored as a pretreatment for persimmon slices. Using these coating not only accelerated the drying process but also preserved the color (Or *et al.*, 2024).

Similarly, a combination of pretreatments, such as blanching followed by osmotic treatment, was also carried out; this was found to be quite promising for retention of color, along with the observation that blanching pretreatment resulted in better retention of antioxidant activity whereas osmotic pretreatment affected the phenolic content of the fruit (Yildiz *et al.*, 2024). Similarly, some pretreatments adversely affect the quality of the fruit. The dried product, as observed for the drying of persimmon control samples, showed a better rehydration ratio (RR) than carbon dioxide-treated slices (Khademi *et al.*, 2019). Various pretreatments executed before drying are reported to affect product quality (nutritional, functional, and nutritional properties) and drying coefficients as summarized in Table 1. Figure 2 shows the schematic for effects of pretreatment.

Different Methods of Drying

The drying of any product depends on various factors, such as the product's shape and size, initial and final moisture content, bulk density, feed thickness, air velocity, temperature and humidity, and other environmental factors (Tiwari, 2016). Apart from this, the drying method dominates the product's characteristics. In literature, sun drying, solar drying, tray drying, infrared drying (IRD), microwave drying (MWD), vacuum drying, and spray drying (SD) are used for persimmon drying. Table 2 highlights different forms of persimmon used for hot air and sun drying with different drying conditions. Similarly, Table 3 shows vacuum, spray, and radiation-based methods for drying.

Sun drying

Sun drying happens to be the oldest drying method employed by farmers on a large scale to preserve fruits and vegetables; however, it has limitations and drawbacks, such as longer drying periods, poor drying rate, and contamination of the product by dirt and microbes (Sontakke and Salve, 2015). These drawbacks have restricted the use of sun drying. Period of the year, area's geographical location, and weather conditions affect the duration and intensity of sunlight (Tiwari, 2016). These factors lead to varying diffusion and drying rates and product quality. The drying of a product is highly dependent on environmental conditions and usually takes a longer time than other drying methods. The product's characteristics are a function of surrounding conditions, such as weather, amount of oxygen in the atmosphere, and relative humidity. Hence, variable characteristics of the final product are expected from the sun drying of persimmon. In addition, it is worth noting that different pretreatments could be used to have the desired characteristics of the final product. The sucrose-pretreated persimmon slices showed better retention of color, rehydration ratio, and antioxidant activity, compared with the control and astringency-reduced persimmon sun-dried slices. This could be attributed to the de-astringent process leading to reduced tannin content, which ultimately affected antioxidant activity (Khademi *et al.*, 2019).

The use of newly designed techniques, such as solar drying or sun drying with some modifications, is now in the trend. Drying temperature is important for the retention of bioactives. As sun drying is carried out at a lower temperature, it provides a product of greater preeminence than conventional drying. Vitamin C retention is better in sun-dried samples (Khademi *et al.*, 2019) or solar-dried samples (Karakasova *et al.*, 2013). Park *et al.* (2006) reported better retention of polyphenols, antioxidant activity, trace elements (such as manganese and copper), and fibers in sun-dried persimmon than in cabinet-dried persimmon. As drying time increases, antioxidant activity and retention of polyphenol content decrease (Park *et al.*, 2006). Temperature also affects quality of the dried product.

Table 1. Different pretreatments prior to drying and their purpose or effects.

Drying method	Form of persimmon (dimension)	Pretreatments condition	Effects	References
HAD	Cylindrical slices (65-mm diameter and 5-mm thickness)	Dipping in 63° Brix sugar solution for 3 h at room temperature	Flavor improves and maintains structural integrity	Igual *et al.*, 2011
HAD	Slices (5 mm)	Dipped in 2% sucrose solution at 22°C for 10 min	To remove astringency	Khademi *et al.*, 2019
HAD	Slices (5 mm)	Atmosphere of 95% CO_2 was maintained at 20°C for 24 h	De-astringency treatment	González *et al.*, 2021
HAD	Slices (5 mm)	Blanching in hot water at 70°C for 2 min	Shorter drying time and higher RR, higher moisture diffusivity, and lesser activation energy	Doymaz, 2012
Tray drying	Slabs (12 × 12 × 12 mm)	Ultrasonic bath was performed for 10, 20, and 30 min at 10, 20, and 30 U.S., respectively, with 100% power at 30°C, and the frequency was 35 kHz with 480 W/50 g of sample and then dipped in sugar solution with 70 °Brix, with shaking plate (at 100 R) at 30°C	Reduces drying time and increases diffusion coefficients, drying rate, and RR	Bozkir and Ergün, 2020
Tray drying	Whole peeled fruit	Dipped in 20% sucrose solution for 15 min at 20°C	Improves functional, nutritional, and sensory properties	Demiray and Tulek, 2017a
Sun drying	Round sheets	Freezing was done for 24 h; afterwards sheets were dipped for 5 min in 5% citric acid, 3% potassium metabisulfite, and 2% ascorbic acid solution separately	Increases total dry matter, acid, vitamin C, and sensory properties	Karakasova *et al.*, 2013
Flat plate solar collector (1.8 m^2)	Slices (5, 10, and 15 mm)	Blanching at 90°C for 5 min	Better color retention	Hanif *et al.*, 2015
Flat plate solar collector (1.8 m^2)	Slices (5, 10, and 15 mm)	Dipping in 8% sodium metabisulfite solution and water for 5 min	Antimicrobial action reduces the oxidation of some minerals	Hanif *et al.*, 2015
PVOD	Slab (40 × 20 × 5 mm)	The fructose solution of 30 and 45 °Brix was prepared with a vacuum pressure of 655 mm Hg and local pressure of 755 mm Hg, having concentration and vacuum pulsation time of 0, 10, and 30 min at the beginning of the 40-min experiment	Increased drying rate, lower shrinkage	Corrêa *et al.*, 2021
USOD	Slab (40 × 20 × 5 mm)	Total of 40 min of treatment time with three-time intervals combination: 0, 10, and 30 min, operates at a frequency of 25 kHz with the energy intensity of 8 kW m^{-3}	Increased drying rate, higher RR	Corrêa *et al.*, 2021
Convective drying and MWD	Slices (5 mm) and puree	Blanching at 100°C for 5 min and dipping in 25% sucrose solution for 2 min	Better retention of antioxidant activity. Reduction in bioaccessible phenolic content	Yildiz *et al.*, 2024
IRD	Slices (5 mm)	Dipped in gum solutions for 3 min. Guar gum (0.0025%), gum arabic (0.0025%), and xanthan gum (0.0025%)	Higher drying rate and better retention of color	Or *et al.*, 2024

Notes: RR: rehydration ratio; HAD: hot air drying; MWD: microwave drying; USOD: ultrasound-assisted osmotic dehydration; IRD: infrared drying; PVOD: pulsed vacuum osmotic dehydration.

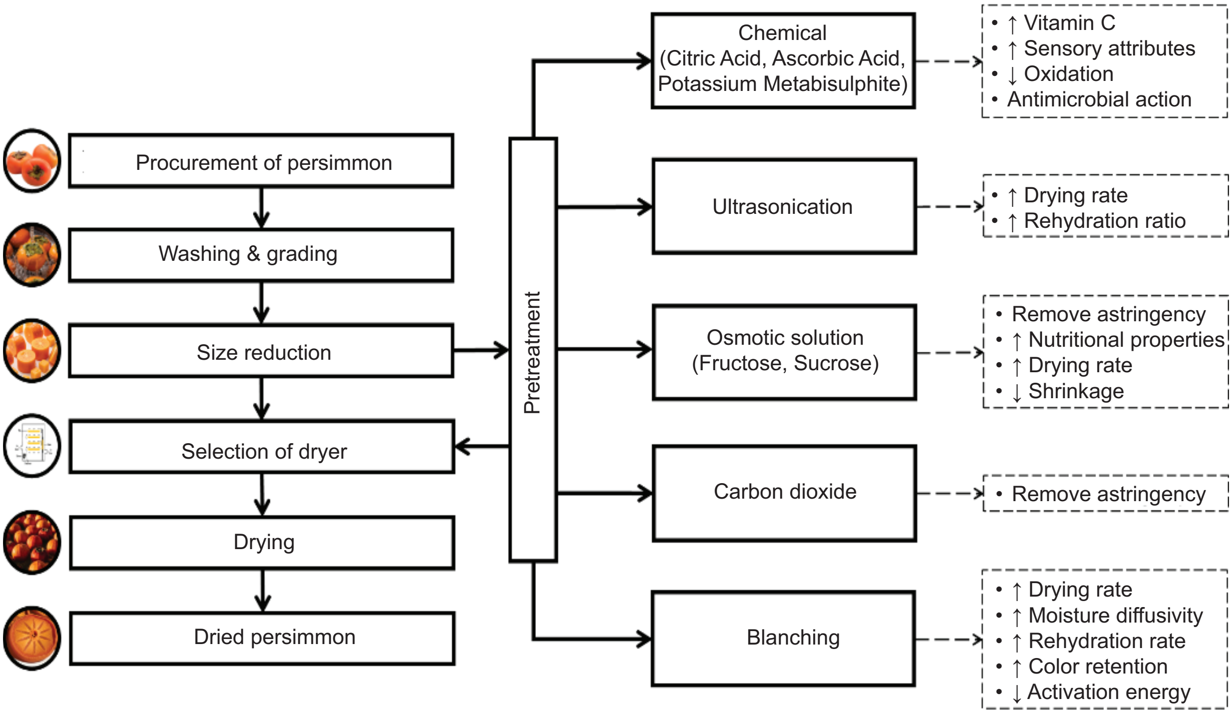

Figure 2. **Effects of pretreatment on persimmon.**

Concentration of vitamin C is reduced by approximately 20% when the drying temperature of flat plate solar collector increases from 45°C to 65°C (Hanif *et al.*, 2015).

Hot air drying

Hot air drying is the most commonly used method for drying fruits and vegetables; in this method, hot air is passed over the products to be dried. The effect of pretreatment (Bozkir and Ergün, 2020; Demiray and Tulek, 2017b; Doymaz, 2012; Igual *et al.*, 2011), varying temperatures (Demiray and Tulek, 2017b), varying thickness (Mosavi Baygi *et al.*, 2015) with drying rate, effective diffusivity, activation energy, sensory characteristics, rehydration ratio, and quality characteristics are studied in the literature. The drying of persimmon occurs mostly in a falling rate period, where the moisture from the food sample travels from the interior to the surface and thus the drying rate continuously decreases (Doymaz, 2012; Igual *et al.*, 2011; Khaled *et al.*, 2020). Air temperature and drying period are more important for the quality of dried product than air velocity, as observed by Vivek *et al.* (2021). The authors also reported that the thickness of slices affects the drying time, ascorbic acid, browning index, and rehydration ratio. Increasing hot air velocity can lead to more loss of vitamin C in persimmon (Nicoleti *et al.*, 2007). Senadeera *et al.* (2020) concluded that drying time of the product decreases if temperature increases. It is interpreted that drying time and temperature are inversely proportional; if drying temperature increases from 45°C to 55°C, then drying time decreases by 120 min (Senadeera *et al.*, 2020).

Effective diffusivity also increases with an increase in drying temperature. Better color retention and lower shrinkage were observed when the fruit was dried quickly at higher temperatures (Senadeera *et al.*, 2020). Color is one of the main factors influencing consumer acceptability; hence, a drying method with better color retention is preferable. Coefficient of diffusivity of 6.45×10^{-7}, 7.48×10^{-7}, and 9.08×10^{-7} m^2/s were reported for drying temperatures of 50°C, 60°C, and 70°C, respectively (Zhao *et al.*, 2021). Nutritional parameters, such as phenolic compounds, flavonoids, β-carotene, proanthocyanidin, and ascorbic acid concentration vary with drying temperature. Jia *et al.* (2019) and Zhao *et al.* (2021) observed that increased drying temperature decreases phenolic content, flavonoids, β-carotene, ascorbic acid, and total proanthocyanidin values.

The effect of pretreatment on drying time cannot be overlooked, as observed in the previous section. HAD is now mostly used with techniques such as pulsed vacuum, ultrasonication treatment, etc. Osmotic dehydration reduces the moisture content of persimmon by 24% and 34% when dipped in 30 °Brix and 45 °Brix fructose solution, respectively. However, 35% and 43% decrease in moisture was observed in PVOD. In contrast, only 23% and 31% decrease was observed in USOD. In USOD,

Table 2. Different forms of persimmon used for hot air and sun drying with different drying conditions.

Drying methods	Form of persimmon (dimension)	Drying condition	Key findings	References
HAD	Cylindrical slices (diameter 30 mm and thickness 6 mm)	45, 50, 55, 60, and 65°C with air velocity of 2.3 m/s for 9, 7.75, 7, 6, and 5.33 h, respectively	• ↑Temp → ↑Color retention	Senadeera *et al.*, 2020
HAD	Slices (2 and 6mm)	52°C (18 h), 63°C (5/10 h)	• Acceptable quality after 1 year • ↓Ascorbic acid (78–96.5%)	Milczarek *et al.*, 2020
HAD	Slices (1 mm)	Dried at 60, 70, and 80°C with an air velocity of 1.0 m/s	• ↓Nutritional quality compared to FD • ↓Sensory score than the other method	Jia *et al.*, 2019
HAD	Slices (4 mm)	65°C, with air velocity 3 m/s → 15% moisture	• ↓Tannins, TPC, and antioxidants, compared to pulsed vacuum drying (PVD)	Yang *et al.*, 2022
HAD	Slices (5 mm)	65°C, 24 h → 15% moisture	• ↓Color, RR, tannins, sugars, and antioxidants than sun drying	Khademi *et al.*, 2019
HAD	Slices (5 mm)	50, 60, and 70°C with a constant airflow rate of 1.5 m/s	• ↑Temp → ↓Drying time • ↑Exposure time → ↑Quality degradation	Mosavi Baygi *et al.*, 2015
HAD	Pulp	60°C to constant weight	• ↑Minerals (Ca, Mg, K, Fe, and Mn), compared to VFD	Anjum *et al.*, 2021
HAD	Cylindrical shape (2-mm thickness with a length of 50 mm)	55°C with an air velocity of 2 m/s	• ↓Phenolics, carotenes • ↑HMF, color change • ↑Bioaccessibility	Kayacan *et al.*, 2020
HAD	Slices (3 mm)	50, 60, and 70°C with an air velocity of 1.2 m/s	• ↑Temp → ↑Diffusivity • ↑Temp → ↓Bioactives	Zhao *et al.*, 2021
HAD	Slices (5 and 8 mm) with a 56-mm diameter	50, 60, and 70°C and an air velocity of 1.10 m/s	• ↓a* (redness/greenness) at 60°C	Khaled *et al.*, 2020
HAD	Slices (5 mm)	50°C (6 h), 65°C (4 h), 80°C (3 h)	• 50°C: ↑RR, ↑ascorbic acid • ↓TPC vs. 65/90°C	Bölek and Obuz, 2014
HAD	Slices (5 mm)	Fruit at three different maturity stages was chosen 40°C (23 h), 60°C (9 h), 9 m/s, 30% RH	• ↑Temp → ↑Carotenoids • ↑Temp → ↑Antioxidants	González *et al.*, 2021
HAD	Slab (40 × 20 × 5 mm^3)	40–60°C, 0.5 m/s	• Drying time: 260–740 min	Corrêa *et al.*, 2021
HAD	Slices (5 mm)	50, 60, and 70°C, 2.0 ± 0.1 m/s	• RR: 60°C > 50°C > 70°C	Doymaz, 2012
HAD	Whole (peeled)	35, 40, and 45°C, 2 m/s dried till 30% w.b. moisture	• ↑Temp → ↑Toughness of the fruit • Drying reduces astringency	Cervera-Chiner *et al.*, 2024
SD	Slices (5 mm)	30°C, ≤60% RH with 220–712-W/m^2 radiation intensity	• ↑Quality vs. conventional methods (taste and color)	Khademi *et al.*, 2019
SD	Round sheets	65°C (day)/45°C (night), 52 h	• Before the drying process of persimmon fruit, previously freezing and thawing of fruits, and as a pretreatment using $K_2S_2O_5$	Karakasova *et al.*, 2013
SD	Whole fruit	30 days of natural drying	• Fresh > dried: ↑Polyphenols, ↑Antioxidant activity	Park *et al.*, 2006
Tray drying	Peeled	55, 65, and 75°C, 0.2 m/s, 19–21% RH	• ↑Temp → ↑Drying rate	Demiray and Tulek, 2017a
Tray drying	Peeled	40–70°C, 0.8–2.0 m/s	• ↑Temp → ↑Degradation rates	Nicoleti *et al.*, 2007

(*continues*)

Table 2. Continued.

Drying methods	Form of persimmon (dimension)	Drying condition	Key findings	References
Tray drying	Slices (4, 6, and 8 mm)	Box–Behnken design for optimization with independent variables: temperature (50, 60, and 70°C), air velocity (0.5, 1.0, and 1.5 m/s), and thickness (4, 6, and 8 mm). The R^2 values ranged from 0.87 to 0.99, with adjusted R^2 values between 0.70 and 0.98	• Optimized: 58°C, 1.4 m/s, 4 mm • Optimal: 442.55 min, 8.61 mg/g Ascorbic Acid, Browning Index = 0.396, RR = 5.47%	Vivek *et al.*, 2021
Cabinet dryer	Whole fruit	60°C, 12 h	• ↑Polyphenols, ↑Antioxidants, compared to HAD	Park *et al.*, 2006
Natural drying	Whole peeled fruit	60°C, RH 49–83%	• S1 (less mature): 21 days to reach ~50% moisture. Faster drying, harder final product. • S2 (more mature): 28 days to reach ~50% moisture. Slower drying, softer final product	Vilhena *et al.*, 2020
Flat plate solar collector (1.8 m^2)	Slices (5, 10, and 15 mm)	45–65°C, airflow 2.5 → 0.5 kg/s	• ↑Temp (45 → 65°C): ↑Drying rate (↓vit C) • ↑Thickness: ↓Rate but ↑vit C retention	Hanif *et al.*, 2015

Notes: HAD: hot air drying; TPC: total phenolic content; RR: rehydration ratio; FD: freeze-drying; VFD: vacuum freeze-drying; RH: Relative humidity; R^2: coefficient of determination for the applied model; w.b.: Wet basis moisture content.

prolonged treatment period leads to a loss in cell rigidity, thus hindering mass transfer during dehydration. The formation of channels by cavitation during treatment with mass transfer takes place.

In pulsed vacuum, syrup penetrates due to macroscopic pressure gradients and capillary action. However, a longer run time in PVOD (structure of the sample disintegrates) can also hinder mass transfer (Corrêa *et al.*, 2021). Sucrose-pretreated hot air-dried slices showed better rehydration ratio, antioxidant activity, and vitamin C retention, compared to control (Khademi *et al.*, 2019); it also reduced drying period and lowered activation energy (Demiray and Tulek, 2017b). Ultrasonication-assisted HAD results in faster drying kinetics, and the increased value of effective diffusivity at lower air velocity was observed, compared to normal HAD (Cárcel *et al.*, 2007). Pretreatment with dipping persimmon slices in sodium metabisulphite before dehydration leads to better color and phenolic content retention than the control dried samples (Akyıldız *et al.*, 2004). Blanched persimmon showed a higher value of effective diffusivity (Demiray and Tulek, 2017b) and improved the drying rate (reduced drying time), reduced activation energy, and showed better rehydration ratio (Doymaz, 2012).

Vacuum drying

The vacuum drying of fruits and vegetables helps to accomplish drying at lower temperatures, thus offering better retention of bioactive and quality aspects, similar to the fresh ones. Vacuum drying operates by removing moisture under reduced pressure. By lowering the pressure, the boiling point of water is reduced, which allows drying at a lower temperature than HAD (Coşkun *et al.*, 2024; Lekjing *et al.*, 2024). This lower temperature minimizes the degradation of heat-sensitive bioactive components, resulting in better retention than HAD (Papoutsis *et al.*, 2017; Yang *et al.*, 2024). Reduced pressure also prevents oxidation and enzymatic reactions, which can degrade bioactive components (Jiang *et al.*, 2013; Papoutsis *et al.*, 2017; Yang *et al.*, 2024). However, limited studies are conducted on the vacuum drying of persimmon, with more studies accomplished on the application of pulsed vacuum drying or ultrasonication treatment.

Compared to HAD, VOD showed better retention of total phenolic content (TPC), condensed tannins, total flavonoids (Karaman *et al.*, 2014), and total sugars (Khademi *et al.*, 2019). Sample dried in VOD showed lesser L*, a*, b*, and h* values than HAD samples. However, Khaled *et al.* (2020) reported more color change in vacuum-dried samples, compared to HAD samples, and a lesser activation energy for vacuum drying of 8-mm samples whereas effective diffusivity was reported to be lower.

Table 3. Radiation-, vacuum-, and spray-based methods for drying of persimmon.

Drying methods	Form of persimmon (dimension)	Drying condition	Key findings	References
Infrared drying (IRD)	Slices (5 mm)	Dried at 200, 300, and 400 W at 50-, 100-, and 150-mm distance between lamp and sample	• 400 W: ↓drying time by 599% • 300 W: least color change • 50→150 mm: drying time ↑ from 30 to 49 min (at 200 W)	Fadaie *et al.*, 2020
IRD	Slices (5 mm)	1,300 W, 200-mm distance	• ↓Drying time • ↓Energy • ↑Quality retention	Mosavi Baygi *et al.*, 2015
IRD	Cylindrical shape (2-mm thickness with a length of 50 mm)	88-W infrared (IR) power	• ID can be an alternative drying method to FD and conventional drying	Kayacan *et al.*, 2020
PVD	Slices (4 mm)	60–75°C, 8.0 kPa, 12:4 pulse ratio	• ↑RR, ↑tannins, ↑TPC, and ↑antioxidants than HAD • Peak values at 70°C	Yang *et al.*, 2022
VOD	Slices (5 mm)	65°C, 24 h → 15% MC	• Quality attributes are comparable to sun-dried sample	Khademi *et al.*, 2019
VOD	Slices (5 and 8 mm)	50–70°C, 50 mbar	• 70°C/8 mm: ↓L* • Max color change at 70°C/8 mm	Khaled *et al.*, 2020
VFD	Slices (1 mm)	–40°C, 1–20 Pa, 48 h	• ↑Bioactives • ↑Rehydration • ↑L* (lightness)	Jia *et al.*, 2019
VFD	Slices (3 mm)	–80°C→ –70°C, 20 Pa	• ↑Phenolics, flavonoids, tannins, and carotenoids than HAD	Zhao *et al.*, 2021
VFD	Pulp	Pulp was frozen at –18°C and then dried at -60°C, 4 × 10^{-4} mbar	• ↑Polyphenols • ↑Color retention • ↓Ascorbic acid loss than HAD	Anjum *et al.*, 2021
VFD	Pulp	18% (w/w) maltodextrin DE 20 mixed with pulp. The mixture was then frozen at -18°C for 24 h	• ↑Bioactive and aroma retention	de Jesus *et al.*, 2023
VFD	Puree	-40°C → -48°C, 13.33 Pa	• L↑ (32.20 ΔE), a/b*↓	Çalışkan and Dirim, 2015
USV	Cylindrical shape (2-mm thickness with a length of 50 mm)	55°C, 40 kHz/590 W	• Alternative to FD: ↑Rate, ↓Degradation	Kayacan *et al.*, 2020
MWD	Slices (20 mm)	140–420 W, loading capacity of 1.6 kg/m² At 280 W, slices ranging from 1.0 to 3.0-mm thick were used, and for 20-mm thick slices, loading capacities of 1.0, 1.3, 1.6, 1.9, and 2.2 kg/m² were applied	• 280 W: ↑vit C • 420 W: ↑Antioxidants • 2.0-cm thickness optimized vit C retention • 1.5 cm minimized sugar loss (36.3% total sugar)	Wei *et al.*, 2022
MWD	Slices (5, 7, and 9 mm)	MW frequency: 2,450 MHz, at power levels of 120 W (3-min intervals), 350 W (1-min intervals), 460 W (1-min intervals), and 600 W (30-s intervals) until the samples reached 0.10 bulk density (d.b.) moisture content	• 460 W/7 mm: optimal energy • 600 W/5 mm: fastest drying	Çelen, 2019

(*continues*)

Table 3. Continued.

Drying methods	Form of persimmon (dimension)	Drying condition	Key findings	References
Intermittent MWD	Slices (2 mm)	280–560 W, 2 mm	• ↑Power → ↓Drying time and ↓Drying rate • ↑Power → ↑Nutrients	Qin *et al.*, 2022
Combined hot air-MW drying	Slices (1 mm)	Initial drying at 70°C in HAD until 10% moisture content, followed by MW operation at power densities of 6.8, 10.7, 22, 30.8, and 40 W/g with 20-s ON and 10-s OFF cycles	• ↑Bioactives, ↑RR than HAD	Jia *et al.*, 2019
SD	Pulp	Feed flow rate: 25 rpm, fan frequency: 35 Hz, compressor air pressure: 0.2 MPa, inlet temperature: 110 ± 1°C, outlet temperature: 85 ± 1°C	• SD at 110°C inlet/85°C outlet with maltodextrin effectively preserves phenolics, solubility, and sensory qualities in persimmon powder	Chen *et al.*, 2016
SD	Pulp	Mixing of pulp with 18% (w/w) maltodextrin DE 20, air flow: 4.00 m^3/min, air pressure: 4 kgf/cm^2, injector nozzle: 1.2-mm diameter orifice, feed rate: 0.44 L/h	• Max phenolic compounds (15)	de Jesus *et al.*, 2023
SD	Pulp	Two-fluid nozzle: 1.0-mm diameter, atomizer feed rate: 25 rpm, fan frequency: 35 Hz, compressor air pressure: 0.2 MPa, inlet air temperature: 110 ± 1°C, outlet air temperature: 85 ± 1°C	• Proteins are cost-effective for high yield but may compromise polyphenol retention • MD/SSOS are ideal for functional powders (high antioxidants, solubility) • Low drying temp (110°C) prevents sugar degradation but causes particle agglomeration	Du *et al.*, 2014
SD	Pulp	Mixing pulp with maltodextrin (7%, 14%, 21%, 28%, and 42%) Inlet temperatures (110°C, 130°C, 150°C, 170°C, and 190°C)	• Maltodextrin at 28% with inlet temperature of 130°C gave the best result for optimal physiochemical properties and antioxidant acitivity	Zhang *et al.*, 2025

Notes: ID: infrared drying; FD: freeze-drying; VOD: vacuum oven drying; VFD: vacuum freeze-drying SD: sun drying; MWD: microwave drying; PVD: pulsed vacuum drying; USV: ultrasound-assisted vacuum drying; DE: dextrose equivalent; MD/SSOS: Maltodextrin/starch sodium octenyl succinate.

The effectiveness of the treatment was more with the application of pulsation and ultrasonication. Yang *et al.* (2022) achieved the drying of persimmon slices with vacuum pulsation. With decreased drying temperature, the L* value decreased and a* and b* values increased. Vacuum pulsation increased color change and improved rehydration ratio. At the same time, ultrasonication decreased total color change and drying time (Kayacan *et al.*, 2020). Ultrasonication and pulsation help in a better retention of tannin content, TPC, and antioxidant activity (Kayacan *et al.*, 2020; Yang *et al.*, 2022).

Infrared drying

Infrared drying has been used in food processing for the past few decades. IRD serves the heating purpose and replaces the old heating instruments driven by fuels because of its simple and compact designs and energy saving. IRD is applied for pasteurization, blanching, sterilization, baking, roasting, and drying (Krishnamurthy *et al.*, 2008). It enables a faster drying rate, uniform distribution of temperature, better quality of dried product, and saving of space.

Infrared radiation is essential for interaction between water and energy. The presence of O-H bonds results in the absorption of IR radiation. Owing to these linkages, water molecules vibrate at the same frequency as the incoming IR light, facilitating its efficient absorption. Water's temperature rises when it absorbs IR radiation, causing increased molecular mobility, resulting in evaporation (Aboud *et al.*, 2019). The frequency of electromagnetic waves was 60,000–150,000 MHz, resulting in internal heating. IRD depends on IR power density, distance between lamp and sample, and lamp intensity.

The drying time reduces with increased lamp power (El-Mesery *et al.*, 2024; Fadaie *et al.*, 2020). The drying time is reduced by approximately 2½ times for IRD persimmon, and the retention of bioactive components and the color is better, compared to HAD persimmon (Kayacan *et al.*, 2020). This could be attributed to the direct transfer of IR energy from lamp to food without high-efficiency losses, which hastens the drying process. Moreover, it has been found that the drying time decreases by 63.04% if the distance is decreased from 150 mm to 50 mm. The total color change increases with an increase in lamp distance, as it increases the drying time, and the same trend was observed if lamp with lesser power was used (Fadaie *et al.*, 2020).

Freeze-drying

Freeze-drying removes water or moisture from the product with the help of sublimation process. Water is present in ice, which is carried at low pressure. The three main drying stages are freezing, primary, and secondary (Nowak and Jakubczyk, 2020). Drying at low temperatures (temperatures lower than the freezing point of water) maintains the quality parameters of food product, such as retention of maximal color, and nutrient and bioactive components. Water present in solid form during drying does not affect much the texture of food samples and has minimal volume reduction (Bhatta *et al.*, 2020). Freeze-drying is widely recognized for its ability to preserve heat-sensitive bioactive components (phenolic content and antioxidant activity) because of its sublimation-based dehydration process, which minimizes the thermal degradation of food products while drying. The freeze-dried food sample has less volume reduction or less shrinkage, more rehydration ratio (Ratti, 2001), and retains volatile flavor and aroma (Stapley, 2008). Reducing sugar is one of the most important factors to consider, as it contributes to food taste, flavor, and the overall acceptability (Song *et al.*, 2015). Heat-induced reactions during drying affect reducing sugar to a greater extent; however, freeze-drying helps to overcome this effect, as it does not involve higher temperatures. Freeze-drying poses considerable energy consumption and cost challenges despite its numerous benefits. The process requires a freeze dryer, which works under vacuum conditions, leading to prolonged drying time and high energy consumption (Bhatta *et al.*, 2020; Uscanga *et al.*, 2021). Capital investment is also high for freeze-drying equipment, contributing to the overall cost (Bhatta *et al.*, 2020). Bhatta *et al.* (2020) also reported that freeze-drying requires 4 to 10 times more energy than the traditional HAD, which makes it economically a less feasible option for large-scale applications. Similarly, a recent study compared the energy cost of freeze-drying with IRD of persimmon and reported that freeze-drying was more than 11–13 times more expensive than IRD (Polat *et al.*, 2024).

To overcome these drawbacks, recent development has focused on incorporating pretreatment methods, such as pulsed electric field, high hydrostatic pressure, and ultrasound to enhance mass transfer and reduce drying time (Rybak *et al.*, 2021; Xu *et al.*, 2021; Zhang *et al.*, 2022). Uscanga *et al.* (2021) suggested that a higher shelf temperature could help to shorten processing time without affecting quality of the product. This signifies that the research efforts are focused on overcoming the drawbacks of the energy-intensive nature of freeze dryers and making this drying process more sustainable and economically feasible.

The reduced sugar content during freeze-drying was highest, compared to HAD, and combined hot air-MW drying (Jia *et al.*, 2019). Presence of oxygen-less atmosphere and low temperatures during drying help to reduce degradation reactions during drying. Hence, these two main reasons promote the retention of more bioactive compounds during freeze-drying. This also justifies the retention of ascorbic and phenolic contents after freeze-drying. Similarly, the browning index is observed to be lowest in the case of freeze-dried powder. The freeze-dried sample recorded the highest value for lightness among all three methods of drying, namely HAD, VOD, and freeze-drying (Anjum *et al.*, 2021; Çalışkan and Dirim, 2015; Karaman *et al.*, 2014; Kayacan *et al.*, 2020). This could be attributed to higher pigment concentrations, such as β-carotene and lycopene in freeze-dried samples.

Retention of β-carotene content in freeze-dried samples was better with the combined hot air-MW drying technique and HAD chips. Freeze-dried samples retained more total flavonoids, phenolic content, and β-carotene because of the lower extent of thermal and chemical degradation, and the icecrystals that were formed during freeze-drying could rupture the cell membrane and lead to the extraction of bioactive components (Kayacan *et al.*, 2020; Zhao *et al.*, 2021). On the contrary, ice crystals sometimes lead to cell rupturing and result in the loss of pigments and other bioactive components. Considering all these, freeze-drying offers a better quality of dried product, compared to other forms. However, the major difficulty with freeze drier is its complexity, longer running time, and high expenditure.

Microwave drying

Microwaves are parts of electromagnetic spectrum having a frequency range of 300 MHz–300 GHz (Wray and Ramaswamy, 2015). MWD has gained popularity in the food industry for the last two decades; for industrial usage, two narrow bands are designed, which are 915 MHz and 2,450 MHz. MW heating is faster than conventional heating methods (Zahoor *et al.*, 2023). MW heating is also known as dielectric heating. Rather than heat transfer, electromagnetic energy is converted into thermal energy during MW heating (Sun *et al.*, 2016). The MW–matter interaction involves two major mechanisms: dipolar rotation and ionic conduction. Dipole rotation tends to orient itself in the direction of electric field. This results in the rotation of nonpolar molecules in food. The molecules change their rotation 0.915 billion times in the case of 915-MHz frequency (Changrue *et al.*, 2006; Wray and Ramaswamy, 2015). In ionic conduction, ions start to align themselves in a direction similar to changing electric fields, which can lead to collisions and friction that result in heat generation (Changrue *et al.*, 2006). MWD is considered as fourth-generation drying, and factors, such as power density, loading amount, power, and exposure time, affect MW-assisted drying (Zhang *et al.*, 2006).

Nonuniform drying is the main issue associated with MWD, leading to the formation of hotspots, where excessive energy damages the quality of fruit and under-dried regions, which compromise the drying efficacy and product consistency. To mitigate these issues, several efforts are made; for instance, optimization of MW parameters (power, frequency, and pulse modulation) (Jia *et al.*, 2019; Jiang *et al.*, 2020; Song *et al.*, 2013), application design, and material handling (stirrers, rotating trays, and pretreatments) (Jahanbakhshi *et al.*, 2020; Rattanadecho and Makul, 2016; Zhanyong, 2009), and using the hybrid methods of drying (Dai *et al.*, 2022; Jia *et al.*, 2019; Tomas-Egea *et al.*, 2021).

Increase in power reduces drying time. The drying time was found to reduce by 87.47% when the MW power was increased by five times from 120 W to 600 W for 5-mm persimmon slices, and drying time increased by 1.86 min at 600 W when the thickness of the slices was increased from 5 mm to 9 mm (Çelen, 2019). Increase in both thickness of slices and MW power increases effective diffusivity whereas activation energy decreases with an increase in slice thickness. The shrinkage of slices increased with an increase in power, and decrease was observed with increased thickness of slices.

The color change observed was lower with an increase in thickness whereas an increase in power from 120 W to 460 W lead to a decrease in color change by 56% for 5-mm slices (Çelen, 2019). This could be ascribed to a longer drying duration at lower power levels, resulting in burnt regions formed due to the nonuniform distribution of liquid content. Vitamin C, total sugars, soluble tannins, TPC, and antioxidant activity increased with an increase in MW power and slice thickness (Wei *et al.*, 2022). Retention of vitamin C could be attributed to lower exposure time at high temperatures. This results in comparatively high retention of vitamin C at high MW, and less thickness of slices resulted in a lower value of vitamin C, as its contact with air increased, causing oxidation. TPC and tannin content increased on drying with MWD. It could be possible because higher MW energy leads to the breakage of bonds inside fruit cells, and the cell wall structure also changes, which results in bounded phenols from the cell wall. Increasing soluble tannins and phenols also increases antioxidant activity, as these are the main contributors. Increase in slice thickness increases soluble tannins, TPC, and antioxidant activity. This could be attributed to thermal effect with an increase in thickness, which decreased thermal degradation and better retention of components (Wei *et al.*, 2022).

The loading of sample in MWD also plays a crucial role in the retention of its bioactivity. Increase in loading from 1.0 kg/m^2 to 1.9 kg/m^2 results in better retention of vitamin C and total sugars. Soluble tannins, total phenols, and antioxidant activity decreased as loading increased (Wei *et al.*, 2022). This could be possible because increase in loading resulted in longer exposure that resulted in the formation of polyphenol hydroxyl structure with unstable chemical properties, resulting in lower values of soluble tannins, total phenols, and antioxidant activity.

Combined hot air-MW drying system and intermittent MWD are some of the advances in the field of MW drying to save energy and prevent nonuniform drying. The drying time gets reduced with increased power density in both advanced drying systems (Jia *et al.*, 2019; Qin *et al.*, 2022). Similar to conventional drying methods, conjugated systems, such as these, are also associated with changes in the composition of persimmon on drying. The percentage of soluble sugars increases with an increase in power density; this could be ascribed to the fact that degradation of polysaccharides at higher temperatures is due to lower water-holding capacity as the cell membrane is damaged, resulting in higher soluble sugar content. Soluble tannins and vitamin C contents increased with the power density of intermittent MWD. However, soluble proteins and the overall sensory acceptance decreased with increasing intermittent MW power density. The decrease in proteins could be possible as higher temperature caused the disintegration of protein structure, resulting in lower soluble protein, and a reduced sensory score could be attributed to overheating that degraded pigments and imparted poor sensory properties (hard texture and bitter taste; Qin *et al.*, 2022).

Spray drying

In spray drying, the convective heat medium converts atomized droplets into fine solid particles or powders. Short drying time, low heat stress (suitable for heat-sensitive food materials), high flavor, nutrient retention, and great economic potential are some features that match requirements of the food industry. Fruit juices or purees contain high amounts of sugars that directly hinder their conversion into powders. Direct conversion results in the stickiness of powders because of hygroscopicity and thermoplasticity, and is facilitated by drying air humidity and high temperature. This could be attributed to the fact that low glass transition temperatures (T_g) of sugars, such as fructose, glucose, and sucrose, were 26°C, 31°C, and 62°C, respectively. A lower glass transition temperature (due to sugar-rich foods) can cause collapsing and also result in caking and stickiness (Silva-Espinoza *et al.*, 2019). However, addition of carrier agent can overcome this effect. Hence, addition of carrier agent to juice or purees is required to increase T_g (Etzbach *et al.*, 2020). Feed material (temperature, flow rate, and initial concentration), atomization (feed pressure, air pressure, and rotation speed), inlet airflow (temperature, flow rate, and humidity), and outlet airflow (temperature and humidity) are the main operating parameters of spray drying. These factors also influence quality of the product (Woo and Bhandari, 2013).

Du *et al.* (2014) studied the effect of different carrier agents (gum arabic, maltodextrin, whey protein concentrate, starch sodium octenyl succinate, and egg albumin) on the physicochemical properties of powder and its recovery. Pulp with 30% gum arabic gave the highest powder yield whereas the lowest yield was observed when the concentration of maltodextrin was 25%. Maltodextrin and starch sodium octenyl succinate-containing pulp showed better retention of polyphenols and reconstitution properties. SD helps to better retain phenolic components than freeze-dried samples (de Jesus *et al.*, 2023). Chen *et al.* (2016) observed that different cultivars have different characteristics, such as powder recovery (%), moisture content (%), hygroscopicity (g/100 g), solubility (g/100 mL), vitamin C value, and phenolic retention (%). It was observed that pectin and sugar influenced powder recovery, solubility, and hygroscopicity.

Alterations in Various Quality Characteristics of Persimmon

The drying of persimmon renders the fruit with poor quality characteristics. This section describes the changes in such characteristics. Physical characteristics, such as color, texture, sensory attributes and rehydration ratio are discussed. Similarly, the effect of drying on bioactive components of persimmon, such as carotene, ascorbic acid, phenolic content, and antioxidant activity, is also summarized.

Physical characteristics

Color

Color is considered as one of the most essential and primary parameters for the quality of any food product. Color influences customer's perception, which affects procuct's market value. Change in color of food during drying depends on different parameters, such as time and temperature combination; if the temperature is high, then the time required for drying is less, which means less exposure time and less effect on product's color, compared to low temperature and long time combination. Changes in the color of food product is attributed to different reactions during drying, such as browning (both enzymatic and nonenzymatic), oxidation, degradation, decomposition, and so on. The longer the exposure time, the more prominent is the effect of these reactions. The effect of drying temperature on the color of dried persimmon is graphically depicted in Figure 3.

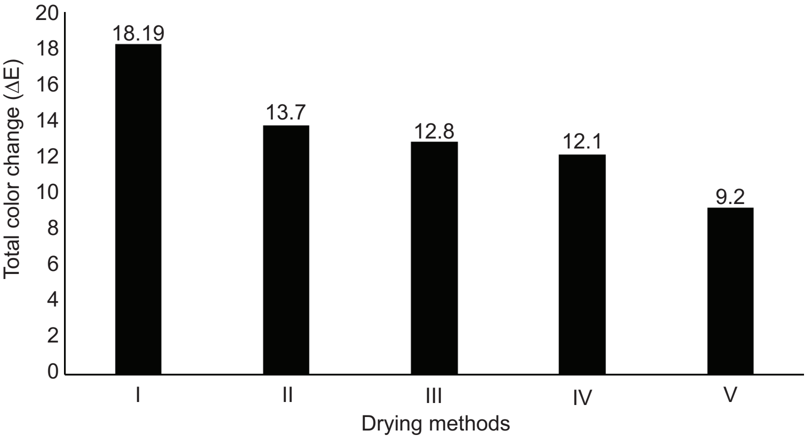

Figure 3. Effect of drying temperature and time on total color change of persimmon slices (Senadeera *et al.*, 2020). I: 45°C (540 min); II: 50°C (465 min); III: 55°C (420 min); IV: 60°C (360 min); and V: 65°C (320 min).

When dried at 65°C, persimmon slices show better color retention than at 45, 50, 55, and 60°C temperatures, as the exposure time was the least at 65°C. The authors observed the least total color change at 65°C, and the highest was at 45°C (Senadeera *et al.*, 2020). At lower temperatures, the drying time increases, which increases the value of the total color change, which could be attributed to the fact that the browning reactions take longer at lower drying temperatures. At higher temperatures, the total color change value decreases as the reaction time for the browning reaction reduces, which cannot alter the pigments much (Xu *et al.*, 2019). The thickness of the slices also decides the fate of the color of the dried form; as reported by one of the authors, slices with a lower thickness on drying witnessed a less total color change than the thicker slices in VOD. This could be attributed to the longer drying duration amidst the slice's higher thickness.

Texture

Texture is also an essential factor that must be considered for quality assurance and food safety in the food industry because it gives a clear idea of how a particular product affects consumer acceptance and its market value (Kadam *et al.*, 2015). The texture of dried products depends upon various parameters, such as the type of dryer used, drying temperature, final moisture content, type of the product, and maturity level.

Pretreatment, such as dipping in osmotic solution, impact the texture of dried persimmon. The syrup-treated sample needs more force for the probe to penetrate, compared to the control HAD sample, as sugar syrup replaces the voids in between the dried sample, and the distance of penetration is less in the case of treated sample (Igual *et al.*, 2011). The HAD sample exhibited a penetration depth of nearly 1.5 mm, while the syrup-treated sample showed a depth of ~2.0 mm, where maximum force was applied. The maximum force required for penetration was 20 N for HAD sample whereas the syrup-treated sample recorded more than double this force (~46 N). This hardening effect could be due to sugar replacing air during osmotic pretreatment, which was more dominant when the product's water ratio was low.

Drying methods significantly influence the texture of dried products; freeze-dried samples exhibited superior crispiness compared to combined hot air-MW drying and HAD, which could be attributed to their porous structure and improved rehydration capacity (Jia *et al.*, 2019). Crispiness is inversely related to rupture time, with shorter rupture time indicating better crispness. Freeze-dried samples had the shortest rupture time (0.32 s) and 545.28 g firmness whereas hot air-MW drying recorded a rupture time of 0.44 s and firmness of 743.21 g; HAD samples had the highest firmness of 929.43 g among the three drying methods, reflecting a less crispy texture.

The rupture time and firmness value of slices increase with the power density of MW. In MWD, power density is the most dominant criterion for deciding product characteristics. An increase in power density leads to higher firmness and rupture energy in dried samples; at power density of 6.8 W/g, firmness was 874.99 g and rupture energy was 1537.92 gs whereas at power density of 40.0 W/g, firmness increased to 1000.94 g and rupture energy was 1648.47 gs (Jia *et al.*, 2019). The hardness value of HAD samples increased with increase in drying temperature. The sample dried at 50°C demonstrated a hardness value of 2,890 g, which was increased to 3,400 g at 65°C. With an increase in temperature by 15°C , the hardness value increased by 560 units (Bölek and Obuz, 2014). This could be attributed to improved moisture removal, structural shrinkage, and sugar crystallization.

It is worth noting that not only the drying method but also the variety and maturity index affect the textural properties of dried product. This was observed when the recorded deformative force was lower for the samples dried for 14 days after harvest than the samples dried for 21 days after harvest (Vilhena *et al.*, 2020). A thicker secondary epidermis developed in the first maturity, offering much deformation resistance.

Sensory attributes

Sensory attributes are one of the prominent parameters that decide customer acceptance. Freeze-dried samples have the highest consumer acceptability, compared to hot air-MW-dried and hot air-dried samples (Jia *et al.*, 2019). Among sun drying, conventional oven, and VOD, the sun-dried sample has maximum sweetness, color, chewing ability, and the least astringency sensory scores. Sensory attributes varied with drying temperature. Bölek and Obuz (2014) observed that the texture and color scores increased with an increase in hot air temperature, with decrease in flavor scores. This could be ascribed to increased drying temperature, reduced exposure time, and prevention of color degradation.

Pretreatments also influence the sensory attributes of the dried product. Igual *et al.* (2011) reported that slices without osmotic dehydration were the preferred samples for taste and texture. In contrast, acceptable color was observed in the case of sucrose-pretreated samples. Sucrose pretreatment decreased astringency and increased sweetness and chewing ability, compared to the control dried sample (Khademi *et al.*, 2019). Astringency removal pretreatment resulted in color degradation and decreased astringency and chewing ability. The appearance and texture scores improved when slices were pretreated with a 3% ascorbic acid solution whereas pretreatment with 3% sodium metabisulfite increased appearance scores (Bölek and Obuz, 2014). The overall acceptability of the product decreased with an increase in MW power density in the case of MWD (Qin *et al.*, 2022).

Rehydration ratio

Rehydration ratio is a critical quality parameter that reflects the dried product's microstructure. A higher rehydration ratio signifies better dried product quality, as it indicates the ability of a dried product to gain moisture effectively. Drying air temperature has a more significant impact on rehydration ratio than air velocity and thickness of slices (Vivek *et al.*, 2021). This is attributed to rapid removal of moisture at elevated temperatures, which may lead to the formation of hardened outer layer. This hardened surface restricts the removal of bound moisture and causes structural shrinkage, ultimately reducing the product's ability to absorb water during rehydration (Gupta and Shukla, 2017). Higher HAD temperature and increased power density decrease rehydration ratio due to structural damage and case hardening (Bölek and Obuz, 2014). Higher power density increases temperature that alters food's structure and surface properties, diminishing water absorption and retention (Jia *et al.*, 2019). For instance, drying at 10.7 W/g resulted in a rehydration ratio of approximately 4.30, which declined to 3.40 at 40 W/g, highlighting the adverse impact of higher power levels. Rehydration ratio was lower at higher drying temperature, compared to the samples dried at lower temperatures.

Sun drying often results in a better rehydration ratio among vacuum and conventional oven drying; this is attributed to a lower temperature that minimizes structural damage and shrinkage (Khademi *et al.*, 2019). Freeze-drying exhibited a rehydration ratio of 4.16, comparable to combined hot air-MW drying with a rehydration ratio of 3.96, as both methods effectively preserve structural integrity (Jia *et al.*, 2019). PVD further improved the capacity of rehydration (~3.05) (Yang *et al.*, 2022), outperforming conventional HAD (~2.35 at 65°C), as vacuum conditions created pore surface and internal pores that enhanced water absorption (Yang *et al.*, 2022).

Pretreatments, such as blanching and application of chemicals, improved rehydration ratio by reducing shrinkage during drying (Bölek and Obuz, 2014; Doymaz, 2012) when the balanced sample subjected to HAD at 55°C achieved a rehydration ratio of ~3.30, compared to ~3.00 for unblanched samples under similar drying conditions (Doymaz, 2012). Figure 4 provides the approximate values of rehydration ratios for various drying methods and conditions.

Bioactive components

β-carotene

Persimmon fruit is a rich source of bioactive components, including carotenoids, with β-carotene being the most predominant constituent. During ripening, level of β-carotene increases, and is enzymatically converted into β-cryptoxanthin (Butt *et al.*, 2015; González *et al.*, 2021). β-carotene is responsible for color pigments, such as yellow, orange, and red, and serves as a precursor of vitamin A (Zhou *et al.*, 2011). However, β-carotene is highly susceptible to degradation through oxidation, isomerization, and cleavage reactions. The trans-form of β-carotene is biologically more active and can be readily converted into the less active cis-form, particularly under conditions promoting oxidation, such as prolonged exposure to increased temperatures (Bhatkar *et al.*, 2021). Activation energy required for the degradation of β-carotene is small; it is reportedly 33.33 kJ/mol for carrot β-carotene (Demiray and Tulek, 2017a).

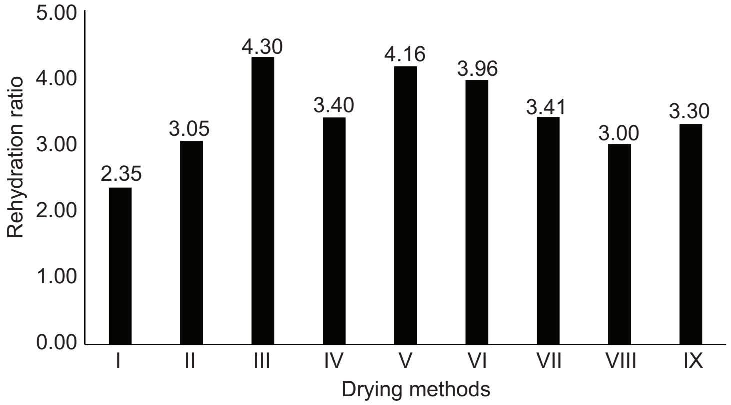

Figure 4. Rehydration ratios with respect to different drying methods and conditions, I: HAD (65°C) (Yang *et al.*, 2022); II: PVD (65°C) (Yang *et al.*, 2022); III: MWD (at 10.7 W/g power density); IV: MWD (at 40 W/g power density); V: freeze-drying; VI: combined hot air-MW drying (70°C and 10.7 W/g power density); VII: HAD (70°C) (Jia *et al.*, 2019); VIII: control HAD (55°C,1.2 m/s air speed) (Doymaz, 2012); and IX: blanched (70°C for 2 min), then HAD (55°C, 1.2 m/s air speed) (Doymaz, 2012).

The drying method employed significantly influences the retention of β-carotene, as depicted in Figure 5. Freeze-drying exhibited the highest retention (97.97%), outperforming IRD (88.14%), USV (79.18%), and HAD at 55°C (67.12%) (Kayacan *et al.*, 2020). This trend is attributed to low temperature used in freeze-drying, which minimizes thermal degradation, and the formation of ice crystals, which rupture the cell walls and enhance the extraction of bioactives (Zhao *et al.*, 2021).

Higher drying temperatures generally accelerate β-carotene degradation because of increased oxidation and isomerization (Zhao *et al.*, 2021). Jia *et al.* (2019) and Zhao *et al.* (2021) reported that freeze-dried samples had significantly higher β-carotene levels than HAD at 50°C, 60°C, and 70°C, while hot air-MW drying showed the lowest retention of β-carotene among the three drying methods. However, González *et al.* (2021) observed an exception, noting improved β-carotene retention at higher temperatures (0°C and 60°C for 23 h and 9 h, respectively). The improvement could be attributed to the reduced exposure time, which minimized oxidative and thermal stress (González *et al.*, 2021).

Ascorbic acid

Ascorbic acid is one of the main components of persimmon (Khademi *et al.*, 2019). Ascorbic acid prevents diseases, such as scurvy, and serves as an important biological antioxidant . L-ascorbic acid or dehydro L-ascorbic acid (oxidized form) are the two forms of vitamin C present mainly in persimmon (Domínguez Díaz *et al.*, 2020). Vitamin C is easily degraded by light, presence of enzymes, pH, oxygen, temperature, and metallic catalysts (Santos and Silva, 2008). The degradation of vitamin C increases with temperature (Jia *et al.*, 2019). Bölek and Obuz (2014) observed this trend when the temperature increased from 50°C to 65°C, with approximately 21% degradation. A 17.32% decrease in vitamin C was reported when the temperature increased further by 15°C. Ascorbic acid in the sample dried at 60°C was more than that dried at 70°C and 80°C (Jia *et al.*, 2019). Vitamin C is a thermo-sensitive bioactive compound, meaning that its concentration decreases because of thermal degradation when exposed to high-temperature drying. In contrast, samples dried at lower temperatures retained higher levels of vitamin C, as the reduced heat exposure minimized nutrient loss (Mieszczakowska-Frąc *et al.*, 2021; Mphahlele *et al.*, 2016).

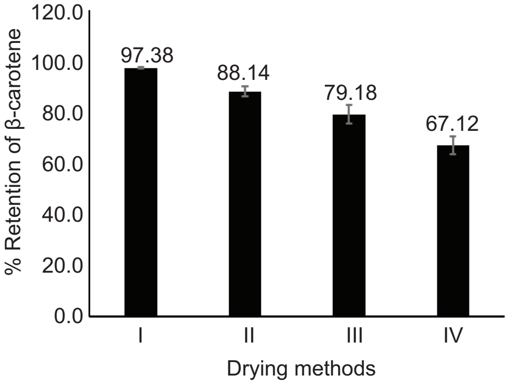

Figure 5. Retention of β-carotene by different drying methods (Kayacan *et al.*, 2020). I: freeze-drying; II: IRD (at 88-W power); III: USV (at 55°C); and IV: HAD (at 55°C).

Vivek *et al.* (2021) reported that ascorbic acid concentration was mainly affected by temperature, followed by thickness of the sample and air velocity. The freeze-dried product retains better vitamin C than the hot air-dried sample. The concentration of vitamin C decreases with increase in the power of MWD. The sun-dried sample showed better retention of vitamin C than HAD and vacuum-dried samples(Khademi *et al.*, 2019).

The freeze-dried and hot air-MW-dried samples showed almost similar retention of vitamin C whereas HAD showed less retention. Khademi *et al.* (2019) reported that ascorbic acid in the HAD persimmon pulp decreased by 36.724%, compared to fresh pulp.

Khademi *et al.* (2019) also reported that pretreatments can potentially affect vitamin C content in persimmon. It was observed that the least vitamin C retention was in astringency removal pretreatment dried slices whereas the highest vitamin C was retained in sucrose-pretreated slices, followed by control dried slices. This was because osmotic treatment cut the exposure of samples from air, reducing oxidative losses. At the same time, the least retention in astringency removal pretreatment (ARP) was due to the presence of CO_2, which accelerated the oxidation of vitamin C. Likewise, pretreatment with 3% ascorbic acid and 3% sodium metabisulfite showed better retention of vitamin C.

Total phenolic and flavonoid contents, and antioxidant activity

Phenolic components are known for their numerous health benefits, with antioxidant, antiviral, antimicrobial, anti-tumor, and antibacterial properties (Haminiuk *et al.*, 2012). The other component contributing to antioxidant activity is flavonoids, a subgroup of phenols. Drying conditions, temperature, exposure time, thickness, and pretreatments are some of the influencing factors that decide the concentration of these components. Increase in drying temperature results in thermal and chemical degradations. Zhao *et al.* (2021) reported that total phenolic and flavonoid concentrations were better at 50°C than at 60°C and 70°C. Reduced phenolic content during high-temperature drying is attributed to two possible mechanisms: the release of bound phenolic compounds from the plant matrix, which makes them more susceptible to degradation; and the onset of thermal degradation of these compounds. As a result, the antioxidant capacity of dried samples may decline due to these combined effects (Maillard and Berset, 1995; Méndez-Lagunas *et al.*, 2017). The freeze-dried sample has better retention of TPC, compared to HAD (Anjum *et al.*, 2021; Jia *et al.*, 2019; Karaman *et al.*, 2014; Kayacan *et al.*, 2020; Zhao *et al.*, 2021), VOD (Karaman *et al.*, 2014), IRD, USV (Kayacan *et al.*, 2020), and hot air-MW drying (Jia *et al.*, 2019). The sun-drying method was better for retaining TPC than other dehydration methods (Park *et al.*, 2006). Among HAD and PVD at the same temperature, PVD was found to provide better retention of TPC and antioxidant activity; this could be attributed to the fact that PVD samples had shorter drying time to reduce heat exposure, and limitation of oxygen during drying could result in better retention of TPC (Park *et al.*, 2006). Maximum total flavonoid content (TFC) was reported in freeze-dried samples among vacuum oven drying, oven drying, and other drying techniques. The antioxidant activity (%) was better for freeze-dried samples than HAD, USV and IRD (Anjum *et al.*, 2021; Kayacan *et al.*, 2020). Maximum antioxidant activity was observed in sun-dried samples, compared to conventional oven drying or dehydrators (Khademi *et al.*, 2019; Park *et al.*, 2006) and VOD (Khademi *et al.*, 2019) as higher drying temperature decreases antioxidant activity (González *et al.*, 2021). The percentage retention of TPC in different drying techniques is graphically depicted in Figure 6. Furthermore, the percentage retention of TFC in different drying techniques is shown in Figure 7. In addition, Figure 8 represents the percentage retention of antioxidant activity during different drying techniques.

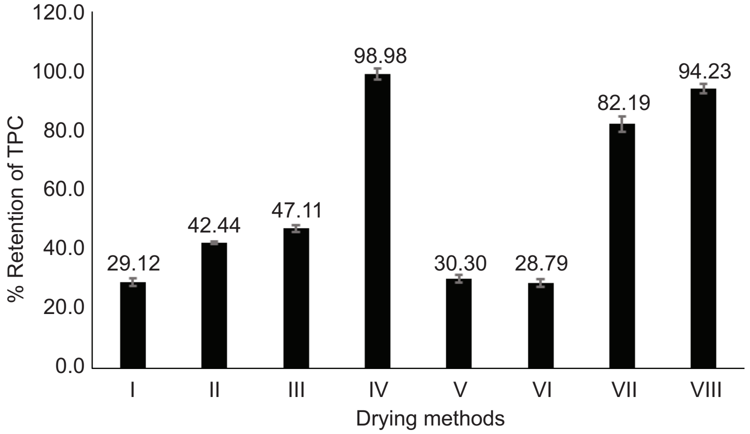

Figure 6. Retention of total phenolic content during different drying methods. I: HAD (at 55°C) (Kayacan *et al.*, 2020); II: IRD (at 88-W power) (Kayacan *et al.*, 2020); III: USV (at 55°C) (Kayacan *et al.*, 2020); IV: freeze-drying (Kayacan *et al.*, 2020); V: PVD (at 65°C) (Yang *et al.*, 2022); VI: HAD (at 65°C) (Yang *et al.*, 2022); VII: HAD (at 60°C) (Anjum *et al.*, 2021); and VIII: freeze-drying (operating temperature 60°C and at pressure 4 × 10^{-4} mbar) (Anjum *et al.*, 2021).

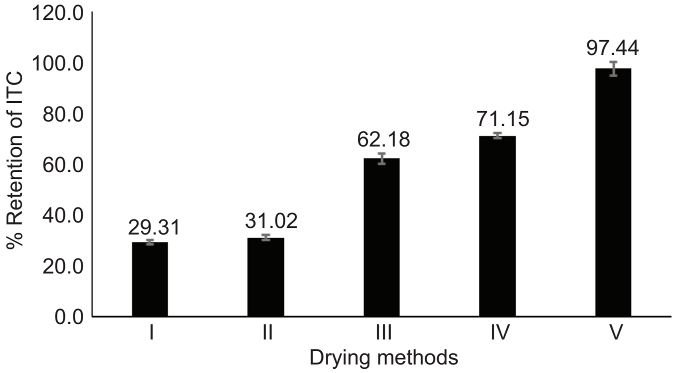

Figure 7. Percentage retention of total flavonoid content (%TFC) in different drying methods. I: HAD (at 65°C) (Yang *et al.*, 2022); II: PVD (at 65°C) (Yang *et al.*, 2022); III: IRD (at 88-W power) (Kayacan *et al.*, 2020); IV: USV (at 55°C) (Kayacan *et al.*, 2020); and V: freeze-drying (Kayacan *et al.*, 2020).

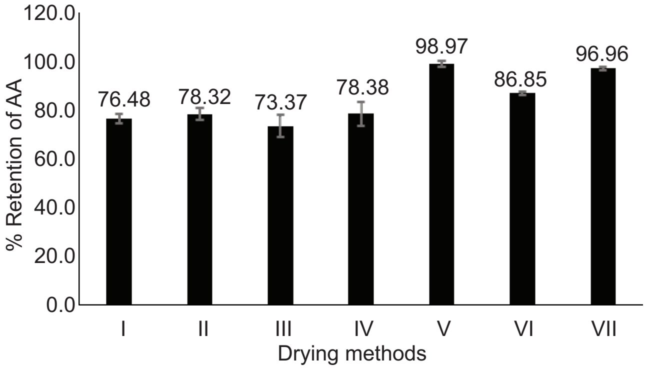

Figure 8. Percentage retention of antioxidant activity during different drying methods. I: HAD (at 65°C) (Yang *et al.*, 2022); II: PVD (at 65°C) (Yang *et al.*, 2022); III: IRD (at 88-W power) (Kayacan *et al.*, 2020); IV: USV (at 55°C) (Kayacan *et al.*, 2020); V: freeze-drying (Kayacan *et al.*, 2020); VI: HAD at 60°C (Anjum *et al.*, 2021); VII: freeze-drying (operating temperature -60°C and at pressure 4 × 10^{-4} mbar) (Anjum *et al.*, 2021).

Overall, the thermal degradation of phenolic components during drying is a major concern, as these heat-sensitive compounds, including flavonoids, phenolic acids, and anthocyanin, are valued for their antioxidant properties. Both drying temperature and drying time influence the stability of phenolic components. Drying at lower temperatures reduces thermal degradation but requires a longer drying time, which increases enzymatic activity and oxidative losses.

On the other hand, moderate temperature accelerates the drying process, significantly reducing drying time. A shorter exposure to heat restricts the duration of enzymatic activity and oxidative reactions, potentially leading to better retention of phenolic compounds, compared to elevated temperatures. Faster drying helps to preserve heat-sensitive phenolic compounds by removing moisture speedily, which otherwise acts as a source of enzymatic and oxidative degradation.

Applications of Dried forms of Persimmon Fruit

There is a huge demand for products with therapeutic benefits as an ingredient for developing new food formulations.. Dried persimmon has vast applications in various products. The hot air-dried persimmon is used to make chips with more than 1-year shelf life (Milczarek *et al.*, 2020). Dried persimmon powder is used to develop gluten-free muffins whereas addition of persimmon in a dried form increases the antioxidant activity of muffins (Hosseininejad *et al.*, 2022). Similarly, persimmon powder is used as a sugar substitute in cakes, as the cakes developed with 40% sugar replacement are more acceptable and exhibit good antioxidant properties (YeŞİLkanat and Savlak, 2021). Another potential application of the dried form of persimmon is the extraction of bioactive compounds. It is worth noting that the waste from persimmon possesses ample bioactives to be extracted and used for various applications. Conesa *et al.* (2020) demonstrated that the waste from persimmon has an appreciable amount of carotenoids, tannins, phenolic content, flavonoids, and lycopene. The same study demonstrated that persimmon waste is a suitable substrate for production of bioethanol. Dried peels of persimmon are a rich source of β-carotene, and some researchers have patented the technology for extracting β-carotene from these peels (바다누리, 2008). Therefore, demand for the dried form of persimmon is expected to grow in the future.

Conclusions

Persimmon is an underutilized fruit with huge potential as an ingredient for developing food products. Limited shelf life and seasonal availability hinder its application; hence, fruit drying is performed to preserve it for a longer period. Its quality characteristics, such as color, texture, sensory properties, and nutritional profile, are important. Hot air is the most commonly employed method in for drying. Freeze-drying is the best among all the available drying techniques to preserve its quality during drying process. However, it involves high initial investment and operation cost, making it economically inviable. Drying techniques, prevailing conditions during drying, and feed characteristics, such as variety and maturity stage, influence the quality of the final product. Undesirable changes to the quality characteristics of dried persimmon are inevitable. However, different drying techniques and pretreatments are studied to overcome such changes. The scaling up of process parameters and their optimization for industrial scale are required.

Data Availability Statement

Data sharing does not apply to this study as no new data were generated or analyzed.

Author Contributions

Vimal Challana: Conceptualization, Data Curation, Investigation, writing – Original draft, Writing – Review and Editing; Nikita Bhatkar: Conceptualization, Writing, Review, and Editing; Shivanand Shirkole: Conceptualization, Writing, Review, and Editing.

Conflict of Interest

The authors declared no conflict of interest.

Funding

This research received no external funding.

References

Aboud, S.A., Altemimi, A.B., R.S. Al-HiIphy, A., Yi-Chen, L. and Cacciola, F. 2019. A comprehensive review on infrared heating applications in food processing. Molecules 24(22): 4125. https://doi.org/10.3390/molecules24224125

Akyıldız, A., Aksay, S., Benli, H., Kıroğlu, F. and Fenercioğlu, H. 2004. Determination of changes in some characteristics of persimmon during dehydration at different temperatures. Journal of Food Engineering 65(1): 95–99. https://doi.org/10.1016/j.jfoodeng.2004.01.001

Anjum, N., Bhat, A. and Hameed, F. 2021. Effect of drying methods on chemical composition, color and bioactive compounds of persimmon (*Diospyros kaki* l.) pulp. Plant Cell Biotechnology and Molecular Biology 22(39): 67–76.

Bhatkar, N.S., Shirkole, S.S., Mujumdar, A.S. and Thorat, B.N. 2021. Drying of tomatoes and tomato processing waste: a critical review of the quality aspects. Drying Technology 39(11): 1720–1744. https://doi.org/10.1080/07373937.2021.1910832

Bhatta, S., Stevanovic Janezic, T. and Ratti, C. 2020. Freeze-drying of plant-based foods. Foods 9(1): 87. https://doi.org/10.3390/foods9010087

Bölek, S. and Obuz, E. 2014. Quality characteristics of trabzon persimmon dried at several temperatures and pretreated by different methods. Turkish Journal of Agriculture and Forestry 38(2): 242–249. https://doi.org/10.3906/tar-1303-41

Bozkir, H. and Ergün, A.R. 2020. Effect of sonication and osmotic dehydration applications on the hot air drying kinetics and quality of persimmon. Food Science and Technology (LWT) 131: 109704. https://doi.org/10.1016/j.lwt.2020.109704

Butt, M.S., Sultan, M.T., Aziz, M., Naz, A., Ahmed, W., Kumar, N. and Imran, M. 2015. Persimmon (*Diospyros kaki*) fruit: hidden phytochemicals and health claims. EXCLI Journal 14: 542. https://doi.org/10.17179/excli2015-159

Çalışkan, G. and Dirim, S.N. 2015. Freeze-drying kinetics of persimmon puree. Gıda 40(1): 9–14. https://doi.org/10.15237/gida.GD14056

Cárcel, J., García-Pérez, J., Riera, E. and Mulet, A. 2007. Influence of high-intensity ultrasound on drying kinetics of persimmon. Drying Technology 25(1): 185–193. https://doi.org/10.1080/07373930601161070

Çelen, S. 2019. Effect of microwave drying on the drying characteristics, color, microstructure, and thermal properties of Trabzon persimmon. Foods 8(2): 84. https://doi.org/10.3390/foods8020084

Cervera-Chiner, L., Vilhena, N.Q., Larrea, V., Moraga, G. and Salvador, A. 2024. Influence of temperature on 'Rojo Brillante' persimmon drying. Quality characteristics and drying kinetics. Food Science and Technology (LWT) 197: 115902. https://doi.org/10.1016/j.lwt.2024.115902

Changrue, V., Raghavan, V., Orsat, V. and Vijaya Raghavan, G. 2006. Microwave drying of fruits and vegetables. Stewart Postharvest Review 2(6): 1–7. https://doi.org/10.2212/spr.2006.6.4

Chen, J., Du, J., Ge, Z.-z., Zhu, W., Nie, R. and Li, C.-m. 2016. Comparison of sensory and compositions of five selected persimmon cultivars (*Diospyros kaki* L.) and correlations between chemical components and processing characteristics. Journal of Food Science and Technology 53: 1597–1607. https://doi.org/10.1007/s13197-015-2102-y

Conesa, C., Laguarda-Miró, N., Fito, P. and Seguí, L. 2020. Evaluation of persimmon (*Diospyros kaki* Thunb. cv. Rojo Brillante) industrial residue as a source for value added products. Waste and Biomass Valorization 11(7): 3749–3760. https://doi.org/10.1007/s12649-019-00621-0

Corrêa, J.L.G., Lopes, F.J., De Mello Júnior, R.E., De Jesus Junqueira, J.R., De Mendonça, K.S., Macedo, L.L. and Salvio, L.G.A. 2021. Drying of persimmon fruit (*Diospyros kaki* L.) pretreated by different osmotic processes. Journal of Food Process Engineering 44(10): e13809. https://doi.org/10.1111/jfpe.13809

Coşkun, N., Sarıtaş, S., Jaouhari, Y., Bordiga, M. and Karav, S. 2024. The impact of freeze-drying on bioactivity and physical properties of food products. Applied Sciences 14(20): 9183. https://doi.org/10.3390/app14209183

Dai, J.-W., Fu, Q.-Q., Li, M., Li, L.-J., Gou, K.-Y., Zhou, J.-K., Liu, Y.-W., Qin, W., Yin, P.-F., Li, Y.-L. and Xu, L.-J. 2022. Drying characteristics and quality optimization of papaya crisp slices based on microwave vacuum drying. Journal of Food Processing and Preservation 46(5): e16506. https://doi.org/10.1111/jfpp.16506

de Jesus, M.S., Araujo, H.C.S., Denadai, M., Sandes, R.D.D., Nogueira, J.P., Leite Neta, M.T.S. and Narain, N. 2023. Effect of different drying methods on the phenolic and volatile compounds of persimmon (*Diospyros kaki* L.). Journal of Food Measurement and Characterization 17: 1–19. https://doi.org/10.1007/s11694-022-01803-6

Demiray, E. and Tulek, Y. 2017a. Degradation kinetics of β-carotene in carrot slices during convective drying. International Journal of Food Properties 20(1): 151–156. https://doi.org/10.1080/10942912.2016.1147460

Demiray, E. and Tulek, Y. 2017b. The effect of pretreatments on air drying characteristics of persimmons. Heat and Mass Transfer 53: 99–106. https://doi.org/10.1007/s00231-016-1797-2

Direito, R., Rocha, J., Sepodes, B. and Eduardo-Figueira, M. 2021. From *Diospyros kaki* L. (Persimmon) phytochemical profile and health impact to new product perspectives and waste valorization. Nutrients 13(9): 3283. https://doi.org/10.3390/nu13093283

Domínguez Díaz, L., Dorta, E., Maher, S., Morales, P., Fernández-Ruiz, V., Cámara, M. and Sánchez-Mata, M.C. 2020. Potential nutrition and health claims in deastringed persimmon fruits (*Diospyros kaki* L.): variety "Rojo Brillante," PDO "Ribera del Xúquer." Nutrients 12(5): 1397. https://doi.org/10.3390/nu12051397

Doymaz, İ. 2012. Evaluation of some thin-layer drying models of persimmon slices (*Diospyros kaki* L.). Energy Conversion and Management 56: 199–205. https://doi.org/10.1016/j.enconman.2011.11.027

Du, J., Ge, Z.-Z., Xu, Z., Zou, B., Zhang, Y. and Li, C.-M. 2014. Comparison of the efficiency of five different drying carriers on the spray drying of persimmon pulp powders. Drying Technology 32(10): 1157–1166. https://doi.org/10.1080/07373937.2014.886259

El-Mesery, H.S., Ashiagbor, K., Hu, Z. and Rostom, M. 2024. Mathematical modeling of thin-layer drying kinetics and moisture diffusivity study of apple slices using infrared conveyor-belt dryer. Journal of Food Science 89(3): 1658–1671. https://doi.org/10.1111/1750-3841.16967

Etzbach, L., Meinert, M., Faber, T., Klein, C., Schieber, A. and Weber, F. 2020. Effects of carrier agents on powder properties, stability of carotenoids, and encapsulation efficiency of goldenberry (*Physalis peruviana* L.) powder produced by co-current spray drying. Current Research in Food Science 3: 73–81. https://doi.org/10.1016/j.crfs.2020.03.002

Fadaie, M., Hosseini Ghaboos, S.H. and Beheshti, B. 2020. Characterization of dried persimmon using infrared dryer and process modeling using genetic algorithm-artificial neural network method. Journal of Food Science and Technology (Iran) 17(100): 189–200. https://doi.org/10.52547/fsct.17.100.189

Food and Agriculture Organization (FAO). 2023. Food and Agriculture Organization Statistics. Available at: https://www.fao.org/faostat/en/#data/QCL (Accessed 5th May, 2024).

González, C.M., García, A.L., Llorca, E., Hernando, I., Atienzar, P., Bermejo, A., Moraga, G. and Quiles, A. 2021. Carotenoids in dehydrated persimmon: antioxidant activity, structure, and photoluminescence. Food Science and Technology (LWT) 142: 111007. https://doi.org/10.1016/j.lwt.2021.111007

Gupta, N. and Shukla, R.N. 2017. Preparation and quality evaluation of dehydrated carrot and onion slices. Journal of Food Processing & Technology 8(9): 6. https://doi.org/10.4172/2157-7110.1000692

Haminiuk, C.W.I., Maciel, G.M., Plata-Oviedo, M.S.V. and Peralta, R.M. 2012. Phenolic compounds in fruits – an overview. International Journal of Food Science & Technology 47(10): 2023–2044. https://doi.org/10.1111/j.1365-2621.2012.03067.x

Hanif, M., Khattak, M., Ali, S., Khan, M., Ramzan, M., Amin, M. and Khan, A. 2015. Impact of drying temperature and slice thickness on retention of vitamin c in persimmons (*Diospyros kaki*. l) dried by a flat plate solar collector. Pakistan Journal of Food Science 25: 66–70.

Harima, S., Nakano, R., Yamauchi, S., Kitano, Y., Yamamoto, Y., Inaba, A. and Kubo, Y. 2003. Extending Shelf-life of astringent persimmon (*Diospyros kaki* Thunb.) fruit by 1-MCP. Postharvest Biology and Technology 29(3): 319–324. https://doi.org/10.1016/S0925-5214(03)00058-9

Hosseininejad, S., Larrea, V., Moraga, G. and Hernando, I. 2022. Evaluation of the bioactive compounds, and physicochemical and sensory properties of gluten-free muffins enriched with persimmon "rojo brillante" flour. Foods 11(21): 3357. https://doi.org/10.3390/foods11213357

Igual, M., Castelló, M.L., Roda, E. and Ortolá, M.D. 2011. Development of hot air-dried cut persimmon. International Journal of Food Engineering 7(5). https://doi.org/10.2202/1556-3758.2149

Jahanbakhshi, A., Kaveh, M., Taghinezhad, E. and Rasooli Sharabiani, V. 2020. Assessment of kinetics, effective moisture diffusivity, specific energy consumption, shrinkage, and color in the pistachio kernel drying process in microwave drying with ultrasonic pretreatment. Journal of Food Processing and Preservation 44(6): e14449. https://doi.org/10.1111/jfpp.14449

Jia, Y., Khalifa, I., Hu, L., Zhu, W., Li, J., Li, K. and Li, C. 2019. Influence of three different drying techniques on persimmon chips' characteristics: a comparison study among hot air, combined hot-air-microwave, and vacuum freeze-drying techniques. Food and Bioproducts Processing 118: 67–76. https://doi.org/10.1016/j.fbp.2019.08.018

Jiang, H., Zhang, M. and Adhikari, B. 2013. Fruit and vegetable powders. In: Bhandari, B., Bansal, N., Zhang, M. and Schuck, P. (Eds.), Handbook of Food Powders. Woodhead Publishing, Sawston, Cambridge, UK, pp. 532–552

Jiang, N., Liu, C., Li, D., Lagnika, C., Zhang, Z., Huang, J., Liu, C., Zhang, M. and Yu, Z. 2020. Dielectric properties of *Agaricus bisporus* slices relevant to drying with microwave energy. International Journal of Food Properties 23(1): 354–367. https://doi.org/10.1080/10942912.2017.1373666

Jung, S.T., Park, Y.S., Zachwieja, Z., Folta, M., Barton, H., Piotrowicz, J., Katrich, E., Trakhtenberg, S. and Gorinstein, S. 2005. Some essential phytochemicals and the antioxidant potential in fresh and dried persimmon. International Journal of Food Sciences and Nutrition 56(2): 105–113. https://doi.org/10.1080/09637480500081571

Kadam, S., Brijesh Kumar, T. and O'Donnell, C. 2015. Improved thermal processing for food texture modification. In (pp. 115–131).

Karakasova, L., Babanovska-Milenkovska, F., Lazov, M., Karakasov, B. and Stojanova, M. 2013. Quality properties of solar dried persimmon (*Diospyros kaki*). Journal of Hygienic Engineering and Design 4(1): 54–59.

Karaman, S., Toker, O.S., Çam, M., Hayta, M., Doğan, M. and Kayacier, A. 2014. Bioactive and physicochemical properties of persimmon as affected by drying methods. Drying Technology 32(3): 258–267. https://doi.org/10.1080/07373937.2013.821480

Kayacan, S., Karasu, S., Akman, P.K., Goktas, H., Doymaz, I. and Sagdic, O. 2020. Effect of different drying methods on total bioactive compounds, phenolic profile, *in vitro* bioaccessibility of phenolic and hmf formation of persimmon. Food Science and Technology (LWT) 118: 108830. https://doi.org/10.1016/j.lwt.2019.108830

Khademi, O., Farrokhzad, Y. and Khangholi, S. 2019. Impact of different pretreatments and drying methods on quality and antioxidant properties of dried persimmon (*Diospyros kaki* L.) slices. International Journal of Postharvest Technology and Innovation 6(2): 137–150. https://doi.org/10.1504/IJPTI.2019.105898

Khaled, A.Y., Kabutey, A., Selvi, K.Ç., Mizera, Č., Hrabe, P. and Herák, D. 2020. Application of computational intelligence in describing the drying kinetics of persimmon fruit (*Diospyros kaki*) during vacuum and hot air drying process. Processes 8(5): 544. https://doi.org/10.3390/pr8050544

Kim, J.H. and Lee, S.Y. 2008. A high efficient method for extracting beta-carotene from persimmon skin (KR100853313B1). Korean Intellectual Property Office. Retrieved from https://patents.google.com/patent/KR100853313B1/en

Krishnamurthy, K., Khurana, H.K., Soojin, J., Irudayaraj, J. and Demirci, A. 2008. Infrared heating in food processing: an overview. Comprehensive Reviews in Food Science and Food Safety 7(1): 2–13. https://doi.org/10.1111/j.1541-4337.2007.00024.x

Lekjing, S., Venkatachalam, K., Charoenphun, N. and Noonim, P. 2024. Effect of different drying methods on the phytochemical and antioxidant properties of soursop leaves at two stages of maturity. ACS Omega 9(38): 40095–40109. https://doi.org/10.1021/acsomega.4c06071

Luo, Z. 2006. Extending shelf-life of persimmon (*Diospyros kaki* L.) fruit by hot air treatment. European Food Research and Technology 222: 149–154. https://doi.org/10.1007/s00217-005-0156-1

Maillard, M.-N. and Berset, C. 1995. Evolution of antioxidant activity during kilning: role of insoluble bound phenolic acids of barley and malt. Journal of Agricultural and Food Chemistry 43(7): 1789–1793. https://doi.org/10.1021/jf00055a008

Matheus, J.R.V., Andrade, C.J.d., Miyahira, R.F. and Fai, A.E.C. 2022. Persimmon (*Diospyros kaki* L.): chemical properties, bioactive compounds and potential use in the development of new products – a review. Food Reviews International 38(4): 384–401. https://doi.org/10.1080/87559129.2020.1733597

Méndez-Lagunas, L., Rodríguez-Ramírez, J., Cruz-Gracida, M., Sandoval-Torres, S. and Barriada-Bernal, G. 2017. Convective drying kinetics of strawberry (*Fragaria ananassa*): effects on antioxidant activity, anthocyanins and total phenolic content. Food Chemistry 230: 174–181. https://doi.org/10.1016/j.foodchem.2017.03.010

Mieszczakowska-Frąc, M., Celejewska, K. and Płocharski, W. 2021. Impact of innovative technologies on the content of vitamin C and its bioavailability from processed fruit and vegetable products. Antioxidants (Basel) 10(1): 25. https://doi.org/10.3390/antiox10010054

Milczarek, R.R., Vilches, A.M., Olsen, C.W., Breksa, A.P., Mackey, B.E. and Brandl, M.T. 2020. Physical, microbial, and chemical quality of hot-air-dried persimmon ("Diospyros kaki") chips during storage. Journal of Food Quality 2020: 7413689. https://doi.org/10.1155/2020/7413689

Mosavi Baygi, S.F., Farahmand, A., Taghi Zadeh, M. and Zia Foroghi, A. 2015. Modeling on hot air and infrared thin layers drying of persimmon slices. Journal of Food Science and Technology (Iran) 13(53): 161–171.

Mphahlele, R.R., Fawole, O.A., Makunga, N.P. and Opara, U.L. 2016. Effect of drying on the bioactive compounds, antioxidant, antibacterial and antityrosinase activities of pomegranate peel. BMC Complementary and Alternative Medicine16(1): 143. https://doi.org/10.1186/s12906-016-1132-y.

Nicoleti, J.F., Silveira, V., Telis-Romero, J. and Telis, V.R.N. 2007. Influence of drying conditions on ascorbic acid during convective drying of whole persimmons. Drying Technology 25(5): 891–899. https://doi.org/10.1080/07373930701370365

Nowak, D. and Jakubczyk, E. 2020. The freeze-drying of foods – the characteristic of the process course and the effect of its parameters on the physical properties of food materials. Foods 9(10): 1488–1514. https://doi.org/10.3390/foods9101488.

Or, D., Arkain, B. and Kocabiyik, H. 2024. The effect of pretreatments on the drying of persimmon with infrared energy. Journal of Food Process Engineering 47(5): e14632. https://doi.org/10.1111/jfpe.14632

Papoutsis, K., Pristijono, P., Golding, J.B., Stathopoulos, C.E., Bowyer, M.C., Scarlett, C.J. and Vuong, Q.V. 2017. Effect of vacuum-drying, hot air-drying and freeze-drying on polyphenols and antioxidant capacity of lemon (*Citrus limon*) pomace aqueous extracts. International Journal of Food Science and Technology 52(4): 880–887. https://doi.org/10.1111/ijfs.13351

Park, Y.-S., Jung, S.-T., Kang, S.-G., Delgado-Licon, E., Ayala, A.L.M., Tapia, M.S., Martín-Belloso, O., Trakhtenberg, S. and Gorinstein, S. 2006. Drying of persimmons (*Diospyros kaki* L.) and the following changes in the studied bioactive compounds and the total radical scavenging activities. Food Science and Technology (LWT) 39(7): 748–755. https://doi.org/10.1016/j.lwt.2005.05.014

Polat, A., Taskin, O. and Izli, N. 2024. Assessment of freeze, continuous, and intermittent infrared drying methods for sliced persimmon. Journal of Food Science 89(4): 2332–2346. https://doi.org/10.1111/1750-3841.16994

Qin, Y., Duan, Z., Zhou, S. and Wei, Z. 2022. Effect of intermittent microwave drying on nutritional quality and drying characteristics of persimmon slices. Food Science and Technology 42. https://doi.org/10.1590/fst.37422

Rattanadecho, P. and Makul, N. 2016. Microwave-assisted drying: a review of the state-of-the-art. Drying Technology 34(1): 1–38. https://doi.org/10.1080/07373937.2014.957764

Ratti, C. 2001. Hot air and freeze-drying of high-value foods: a review. Journal of Food Engineering 49(4): 311–319. https://doi.org/10.1016/S0260-8774(00)00228-4

Rybak, K., Wiktor, A., Witrowa-Rajchert, D., Parniakov, O. and Nowacka, M. 2021. The quality of red bell pepper subjected to freeze-drying preceded by traditional and novel pretreatment. Foods 10(2): 226. https://doi.org/10.3390/foods10020226

Santos, P.H.S. and Silva, M.A. 2008. Retention of vitamin C in drying processes of fruits and vegetables—a review. Drying Technology 26(12): 1421–1437. https://doi.org/10.1080/07373930802458911

Senadeera, W., Adiletta, G., Önal, B., Di Matteo, M. and Russo, P. 2020. Influence of different hot air drying temperatures on drying kinetics, shrinkage, and colour of persimmon slices. Foods 9(1): 101. https://doi.org/10.3390/foods9010101

Silva-Espinoza, M.A., Ayed, C., Foster, T., Camacho, M.D.M. and Martínez-Navarrete, N. 2019. The impact of freeze-drying conditions on the physico-chemical properties and bioactive compounds of a freeze-dried orange puree. Foods 9(1): 32–54. https://doi.org/10.3390/foods9010032

Song, G., Choudhary, R. and Watson, D.G. 2013. Microwave drying kinetics and quality characteristics of corn. International Journal of Agricultural and Biological Engineering 6(1): 90–99. https://doi.org/10.3965/j.ijabe.20130601.009

Song, C., Cui, Z.-W., Jin, G., Mujumdar, A. and Yu, J. 2015. Effects of four different drying methods on the quality characteristics of peeled litchis (*Litchi chinensis* Sonn.). Drying Technology 33: 583–590. https://doi.org/10.1080/07373937.2014.963203

Sontakke, M.S. and Salve, S.P. 2015. Solar drying technologies: a review. International Refereed Journal of Engineering and Science 4(4): 29–35.

Stapley, A. 2008. Freeze drying. In: Frozen Food Science and Technology. pp. 248–275.

Sun, J., Wang, W. and Yue, Q. 2016. Review on microwave-matter interaction fundamentals and efficient microwave-associated heating strategies. Materials (Basel) 9(4): 231–254. https://doi.org/10.3390/ma9040231

Testoni, A. 2002. Post-harvest and processing of persimmon fruit. In: Bellini, E., Giordani, E. (Eds.), First Mediterranean Symposium on Persimmon.

Tiwari, A. 2016. A review on solar drying of agricultural produce. Journal of Food Processing & Technology 7: 583–588. https://doi.org/10.4172/2157-7110.1000623

Tomas-Egea, J.A., Traffano-Schiffo, M.V., Castro-Giraldez, M. and Fito, P.J. 2021. Hot air and microwave combined drying of potato monitored by infrared thermography. Applied Sciences11(4): 1730. https://doi.org/10.3390/app11041730

Uscanga, M.A., Salvador, A., Camacho, M.d.M. and Martínez-Navarrete, N. 2021. Impact of freeze-drying shelf temperature on the bioactive compounds, physical properties and sensory evaluation of a product based on orange juice. International Journal of Food Science and Technology 56(10): 5409–5416. https://doi.org/10.1111/ijfs.15086

Vilhena, N.Q., Gil, R., Llorca, E., Moraga, G. and Salvador, A. 2020. Physico-chemical and microstructural changes during the drying of persimmon fruit cv. rojo brillante harvested in two maturity stages. Foods 9(7): 870. https://doi.org/10.3390/foods9070870

Vivek, K., Subbarao, K. and Srivastava, B. 2021. Effect of thin-layer drying on the quality parameters of persimmon slices. International Journal of Fruit Science 21(1): 587–598. https://doi.org/10.1080/15538362.2021.1919278

Wei, Z., Duan, Z., Tang, X., Qin, Y., Zhou, S., Duan, W. and Liu, Y. 2022. Effects of microwave drying on nutrient component and antioxidant activity of persimmon slices. Journal of Food Measurement and Characterization 16(2): 1744–1753. https://doi.org/10.1007/s11694-021-01273-2

Woo, M.W. and Bhandari, B. 2013. Spray drying for food powder production. In Bhandari, B., Bansal, N., Zhang, M. and Schuck, P. (Eds.), Handbook of Food Powders. Woodhead Publishing, Sawston, Cambridge, UK, pp. 29–56.

Wray, D. and Ramaswamy, H.S., 2015. Novel concepts in microwave drying of foods. Drying Technology 33(7): 769–783. https://doi.org/10.1080/07373937.2014.985793

Xu, L., Fang, X., Wu, W., Chen, H., Mu, H. and Gao, H. 2019. Effects of high-temperature pre-drying on the quality of air-dried Shiitake Nushrooms (*Lentinula edodes*). Food Chemistry 285, 406–413. https://doi.org/10.1016/j.foodchem.2019.01.179

Xu, X., Zhang, L., Feng, Y., Zhou, C., Yagoub, A.E.A., Wahia, H., Ma, H., Zhang, J. and Sun, Y. 2021. Ultrasound freeze-thawing style pretreatment to improve the efficiency of the vacuum freeze-drying of okra (*Abelmoschus esculentus* (L.) Moench) and the quality characteristics of the dried product. Ultrasonics Sonochemistry 70: 105300. https://doi.org/10.1016/j.ultsonch.2020.105300

Yang, K.-W., Wang, D., Vidyarthi, S.K., Li, S.-B., Liu, Z.-L., Wang, H., Chen, X.-J. and Xiao, H.-W. 2022. Pulsed vacuum drying of persimmon slices: drying kinetics, physicochemical properties, microstructure and antioxidant capacity. Plants 11(19): 2500. https://doi.org/10.3390/plants11192500

Yang, L., Zheng, Y., Zhang, S., Wang, X. and Guo, Q. 2024. Effects of boiling, centrifuging and drying methods on bioactive compounds in antarctic krill meal. International Journal of

Food Science & Technology 59(9): 6409–6420. https://doi.org/10.1111/ijfs.17386

YeŞİLkanat, N. and Savlak, N. 2021. Utilization of persimmon powder in gluten-free cakes and determination of their physical, chemical, functional and sensory properties. Food Science and Technology 41: 637–645. https://doi.org/10.1590/fst.31020

Yildiz, E., Yilmaz, A., Gurbuz, O. and Alibas, I. 2024. Effect of drying methods and pretreatments on bioactive potential of persimmon (*Diospyros kaki* L.). Journal of Food Measurement and Characterization 18(3): 2014–2029. https://doi.org/10.1007/s11694-023-02252-5

Zahoor, I., Mir, T.A., Ayoub, W.S., Farooq, S. and Ganaie, T.A. 2023. Recent applications of microwave technology as novel drying of food – review. Food and Humanity 1: 92–103. https://doi.org/10.1016/j.foohum.2023.05.001

Zhang, M., Tang, J., Mujumdar, A.S. and Wang, S. 2006. Trends in microwave-related drying of fruits and vegetables. Trends in Food Science & Technology 17(10): 524–534. https://doi.org/10.1016/j.tifs.2006.04.011

Zhang, S., Zhao, Y., Yao, X., Zheng, Z., Zheng, C. and Jiang, Z. 2022. Effect of high hydrostatic pressure pretreatment on flavour and physicochemical properties of freeze-dried carambola slices. International Journal of Food Science & Technology 57(7): 4245–4253. https://doi.org/10.1111/ijfs.15748

Zhang, X., Yang, Z., Jiang, X., Zhang, B. and Zhao, H. 2025. Expanding the potential of persimmon (Diospyros kaki L. cv. Mopan): a promising strategy for the development of stable spray-dried Mopan persimmon pulp powder with high nutritional value. Food Chemistry 477: 143493. https://doi.org/10.1016/j.foodchem.2025.143493

Zhanyong, L. 2009. Microwave drying based on heating uniformity. Chemical Industry and Engineering Progress.

Zhao, C.-C., Ameer, K. and Eun, J.-B., 2021. Effects of various drying conditions and methods on drying kinetics and retention of bioactive compounds in sliced persimmon. Food Science and Technology (LWT) 143: 111149. https://doi.org/10.1016/j.lwt.2021.111149

Zhou, C., Zhao, D., Sheng, Y., Tao, J. and Yang, Y. 2011. Carotenoids in fruits of different persimmon cultivars. Molecules 16(1): 624–636. https://doi.org/10.3390/molecules16010624

바다누리, 주. (2008). South Korea Patent No. KR100853313B1.