PRODUCTS FROM DRYING PERSIMMONS OF VARYING DEGREES OF MATURITY

Hafizov S.
Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan
Hafizov Gh.
Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan
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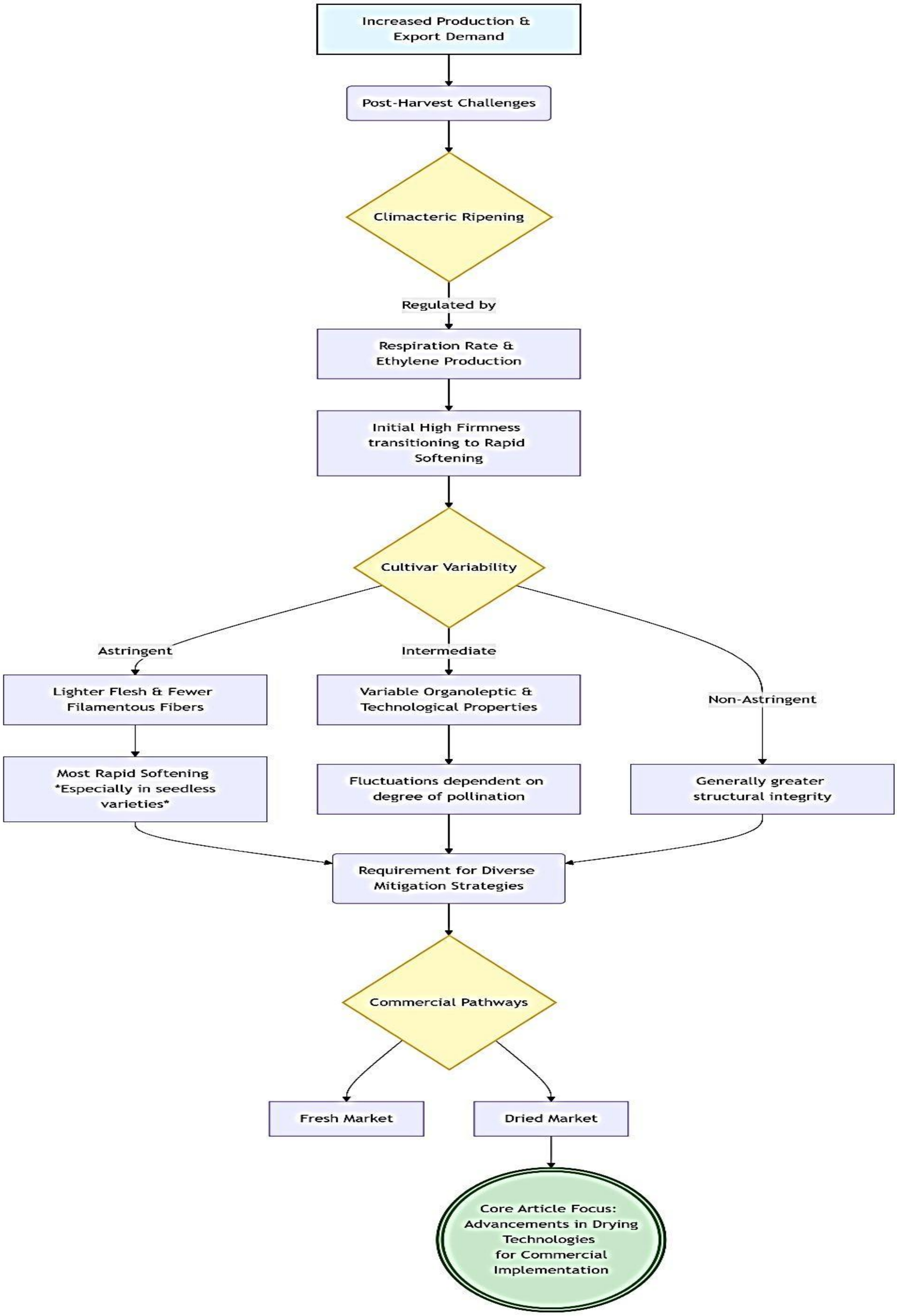
Abstract

The production of dried persimmons is a dynamically developing segment of the dried fruit market, especially in countries with a high level of fresh persimmon cultivation (Azerbaijan, China, Uzbekistan). Due to the high concentration of fruits during drying (about 300 grams of dried fruit is obtained from 1.5 kg of fresh fruit), production volumes in terms of fresh product are very significant. Currently, the possibility of using this fruit as a raw material for obtaining not only natural dried persimmons, but also other products from its drying is being actively studied. This article provides a brief updated overview of the potential industrial use of persimmon fruits in this area, focusing on the suggestions of the authors of this article.

Keywords: Freshly harvested hard persimmon fruits, aged softened persimmon fruits, processed by drying.

Graphic abstract



İntroduction

Recently, research on persimmon fruits has primarily focused on their physiological functions, including their antioxidant, lipid-lowering, anti-atherosclerotic, antitumor, and antiviral activities [1-2]. Nevertheless, thousands of tons of persimmons are discarded annually due to high production volumes, stringent quality standards, and consumer expectations regarding shape, size, and color [3]. Furthermore, the persimmon has a limited shelf life; as a seasonal and perishable fruit, it presents significant challenges for storage and transportation [4-5]. Although typically firm at harvest, the fruit undergoes rapid softening after one to two weeks of storage under ambient conditions; as senescence progresses, structural integrity diminishes and handling becomes increasingly difficult [6]. Consequently, post-harvest losses can account for up to 20% of the total annual production volume [7-8].

Inadequate post-harvest handling, microbial contamination, and high respiration rates are primary factors contributing to the short shelf life of perishable commodities. Therefore, effective preservation techniques are essential to mitigate spoilage and extend shelf life. Preservation encompasses the processes applied to perishable commodities to maintain their quality and consumer acceptability over extended periods [9].

A significant increase in persimmon production, coupled with a higher proportion of fruit intended for export, has necessitated the adaptation of post-harvest technologies to ensure the fruit reaches the end consumer in optimal condition. As the persimmon is a climacteric fruit, its ripening during storage is regulated by respiration rate and ethylene production. Depending on the cultivar, the fruit may initially be astringent or non-astringent. At the time of commercial harvest, persimmon flesh is typically very firm across all varieties, but it subsequently undergoes rapid softening, which poses significant challenges during transport. The flesh of astringent varieties is generally lighter than that of non-astringent varieties. However, astringent varieties possess fewer filamentous fibers to support their structural integrity; consequently, during post-harvest senescence, seedless astringent fruits soften more rapidly than less astringent fruits containing one or more seeds. Furthermore, numerous intermediate varieties exist, whose organoleptic and technological properties fluctuate annually based on the degree of pollination. This variability requires growers to adopt diverse strategies to mitigate post-harvest losses. Commercially, persimmons are predominantly marketed either fresh or dried. This article provides a concise, upto-date overview of recent advancements in persimmon drying technologies, intended to inform growers and commercial enterprises seeking to implement projects in this sector.

Tradiotional drying method

Air drying is the oldest and simplest method for persimmon dehydration; the process is terminated at a moisture content of approximately 50% (yielding semi-dried persimmons) or continued until the moisture content reaches 35% or lower [10-11].

The production and consumption of semi-dried and dried persimmons are traditional in Asian countries such as South Korea, China, and Japan, employing various processing methods to yield high-quality, shelf-stable products with desirable organoleptic properties [12-13].

In Azerbaijan (and neighboring Georgia), firm, ripe fruits are selected for this traditional drying method. The fruits are carefully peeled while leaving the stems intact, which are then used to tie them with strong threads, ensuring no physical contact between individual fruits. The resulting strings are suspended under a canopy (Fig. 1, **A**). During the drying process, some producers periodically massage the fruits to improve their final shape and accelerate surface sugar crystallization (Fig. 1, **B**). The drying process typically requires one month; however, the fruits are occasionally left suspended until March.

Figure1. Stages of the traditional drying method: (A) - Peeled fruits suspended on threads for air-drying under a canopy; (B) - Dehydrated persimmons exhibiting characteristic surface sugar crystallization.

Bundles of dried persimmons tied with threads (Fig. 1) are sold in Georgian markets at a relatively low price, starting from 3.5 GEL ($1.10) per kg. However, prices for seedless dried persimmons (typically produced from the "Hachiya" cultivar) are twice as high, starting at 7.5 GEL ($2.30) per kg. For comparison, the cost of prunes, which are also popular in Georgia, starts at 10 GEL ($3.03) per kg.

Prices for dried persimmons and prunes in Azerbaijan are largely comparable to those in Georgia.

In these markets, dried persimmons attract notably less consumer interest compared to dried apricots, raisins, and plums. This is partly due to the product's inconsistent appearance; although typically sold as whole, peeled fruits, their visual characteristics vary significantly from batch to batch.

Producers often delay the sale of dried persimmons until a white, fluffy efflorescence of sugar crystals develops on the surface. However, this practice increases the risk of microbial contamination [14].

Although this traditional drying method is well-established, research has investigated how the final product's qualitative characteristics vary depending on the persimmon cultivar and cultivation region. Notably, Spanish researchers have identified the physicochemical and microstructural changes occurring during the natural drying of "Rojo Brillante" persimmons harvested at two different maturity stages [15]. Fruits at the first maturity stage had a lower average weight (195.3 g) compared to those at the second stage (252.0 g). A moisture content of 50%, classifying the persimmon as semi-dried, was reached after 21 and 28 days for the 195.3 g and 252.0 g fruits, respectively. Drying induced slight browning, resulting in color degradation. Dehydration also led to a significant decrease in soluble tannin content; by the 28th day of drying, the fruits had completely lost their astringency.

The natural canopy drying of whole persimmons is a traditional practice in Asian countries (e.g., China, South Korea, and Japan), yielding a product with desirable organoleptic and nutritional properties that is consumed and produced on an industrial scale. The standard preparation involves removing the calyx and skin, followed by suspending the fruit on threads. In China and Japan, the partially dried fruits are manually kneaded toward the end of the process to ensure uniform moisture distribution and to shape the final product [16].

González et al. [1] applied this drying method to "Rojo Brillante" persimmons, comparing the properties of naturally astringent fruits with those pretreated with CO_2 to remove astringency prior to drying. After 20 days, a natural reduction in soluble tannin content occurred; ultimately, both the initially astringent and the pretreated non-astringent fruits exhibited similar final concentrations (20-30 mg/100 g). Furthermore, the flesh of the untreated astringent fruits retained an orange hue, whereas the CO_2-treated fruits exhibited browning. Consequently, pretreatment to reduce astringency is unnecessary when utilizing this drying method.

Villena et al. [17] analyzed the physicochemical and microstructural changes during the natural drying of "Rojo Brillante" persimmons harvested at an early maturity stage (S1) and a late maturity stage (S2). Water loss induced shrinkage, leading to the formation of a secondary epidermis and the gelation of the internal flesh. Compared to S2 fruits, S1 fruits developed a thicker secondary epidermis and a smaller internal gelated region, resulting in a firmer final product. Microstructural analysis revealed the degradation of parenchyma cells in both the secondary epidermis and the internal flesh following drying, with S1 exhibiting a more rapid rate of degradation than S2. Consequently, the final characteristics of the dried persimmon are highly dependent on the maturity stage at harvest.

Although dehydration under a canopy or in direct sunlight remains one of the most common methods for drying persimmons [1], it presents hygiene concerns; furthermore, the drying period can extend to several weeks under uncontrolled environmental humidity [18].

A successful dehydration process relies on a slow, consistent application of heat to ensure uniform drying [9]. Modern, advanced drying techniques involve either the use of mechanical dehydrators [20-21] or sun drying intensified by solar air heaters [22-23].

Drying persimmons with the concentration of solar energy using solar air heaters

On an industrial scale, solar drying is utilized for persimmon dehydration, resulting in an extended shelf life [24], reduced microbial spoilage [25], enhanced quality, and the retention of nutritional properties [26-27]. Hanif et al. [28] and Senadeera et al. [24] reported that increasing slice thickness and decreasing drying temperature influence the vitamin C content in persimmons. They concluded that to maximize vitamin C retention, persimmons should be dried at temperatures below 50 °C with a slice thickness of 1.0 cm.

Another study demonstrated that elevating the drying temperature reduced fungal infections by up to 22.1%, while the application of honey was more effective than aloe vera gel in decreasing the aflatoxin content of the dried fruit [29]. Similarly, the exogenous application of a 10.0% persimmon peel extract aided in preserving the nutritional and mineral composition of the fruit. Furthermore, this peel extract demonstrated superior efficacy in maintaining nutritional value when compared to commercially available synthetic preservatives [26,30]. Bolek and Obuz [31] pretreated fruit samples with sodium metabisulfite prior to drying at various temperatures; they observed the highest rehydration capacity and ascorbic acid retention at 50 °C. Moreover, during storage, control treatments exhibited the maximum activity of mesophilic aerobic bacteria, whereas the treated samples displayed the lowest activity, indicating the antimicrobial efficacy of sodium metabisulfite.

Blanching duration and drying temperature significantly impact hourly moisture loss and overall drying time. The shortest drying time and highest rehydration values were achieved with a 5-minute blanching period [26].

Pretreatment of persimmons with nitrogen or carbon dioxide demonstrated that both gases contribute to preserving texture and nutritional quality after three weeks of storage; nitrogen-treated fruits exhibited a superior visual appearance, while carbon dioxide-treated fruits possessed superior organoleptic taste properties [32].

Sun-dried persimmons (dehydrated for 12 hours at 60 °C) contained lower polyphenol levels than fresh fruit, although differences in the concentrations of trace elements, minerals, and dietary fiber were insignificant [27].

Persimmons pretreated with citric acid exhibited the highest contents of dry matter, glucose, fructose, and vitamin C. Additionally, sulfur treatment significantly influenced the physicochemical characteristics and volatile profile of the dried fruits, resulting in the identification of approximately 45 aromatic compounds [3].

A study investigated the individual and interactive effects of varying temperatures, alongside natural and artificial preservatives, on the drying kinetics and organoleptic characteristics of the 'Fuyu' persimmon cultivar. The fruit was harvested from the experimental orchard at Peshawar

Agricultural University, Khyber Pakhtunkhwa, Pakistan (34.02° N, 71.48° E, elevation 359.0 m) [34]. Harvested fruits were washed, blanched in water at 70 °C, and arranged on the trays of a solar dryer. The experimental design incorporated two factors: drying temperature and food preservatives (two natural and three artificial). Three temperature regimens (40, 45, and 50 °C) and five preservative treatments were evaluated: a 25% honey solution, a 25% aloe vera solution, a 2% sodium benzoate solution ($C_7H_5NaO_2$), a 1% potassium metabisulfite solution ($K_2S_2O_5$), and a 2% citric acid solution ($C_6H_8O_7$). An experimental setup was constructed, comprising a forcedconvection solar dryer equipped with a flat-plate solar collector, a drying cabinet, and an exhaust fan (Fig. 2).

The total drying duration was approximately 13.0 hours. An evaluation of the drying temperatures indicated an hourly moisture loss of 8.2% at 50 °C, followed by 6.8% at 45 °C, with the minimum loss (6.1%) recorded at 40 °C. Regarding the preservatives, the highest hourly moisture loss (7.8%) occurred in persimmons treated with the 2% citric acid solution, while the lowest (6.4%) was observed with the 1% potassium metabisulfite solution. Overall, the maximum hourly moisture loss (9.3%) was recorded at a drying temperature of 50 °C combined with the 2% citric acid treatment, whereas the minimum (6.1%) occurred at 40 °C with the 25% honey solution treatment. The individual and interactive effects of drying temperature and preservatives also significantly influenced the pH of the dried persimmons. The highest (6.32) and lowest (6.13) pH values were observed at drying temperatures of 45 °C and 50 °C, respectively. Sugar and vitamin C contents, alongside titratable acidity, peaked in samples subjected to the citric acid pretreatment and dried at 50 °C.

Figure2. Experimental setup of the forced-convection solar dryer utilized for persimmon dehydration, comprising a flat-plate solar collector, a drying cabinet, and an exhaust fan [34].

Consequently, the temperature of the air utilized in the dehydration process is a primary factor dictating the drying rate. Excessively high drying temperatures can cause thermal damage to the product or induce the undesirable phenomenon of "case hardening." Furthermore, elevated temperatures can lead to the significant degradation or complete destruction of beneficial chemical constituents. Therefore, strict limitations must be imposed on the drying temperatures applied to most food commodities. Conversely, raising the temperature accelerates the dehydration process and enhances the microbial safety of the final product.

The use of special devices with a forced change of factors affecting the intensity of drying

Persimmon Chips

Although the comparable yield in mass between naturally and artificially dried persimmons may create an illusion of economic advantage for natural drying, the functional versatility of natural drying is significantly lower. This is particularly true regarding its potential to yield novel products with targeted functional properties.

In recent years, crisp fruit snacks have gained increasing popularity among modern consumers [35]. However, persimmon snacks produced via natural drying are unlikely to satisfy consumer demand for a crisp texture.

Freeze-drying yields a crisp product rich in biologically active compounds [1]. Furthermore, this method achieves superior retention of these bioactive compounds compared to alternative drying techniques. However, freeze-drying is a highly time-consuming, energy-intensive, and costly process [36]. Additionally, prior to freeze-drying, pretreatment is necessary to eliminate astringency, as naturally astringent samples retain high concentrations of soluble tannins and consequently exhibit an excessively astringent mouthfeel [37]. Conversely, persimmon chips dried utilizing a combination of hot air and microwave drying demonstrated similar color, texture, flavor, and overall acceptability to their freeze-dried counterparts [38].

Because every individual drying process possesses inherent limitations, combining multiple methods represents a practical strategy for producing high-quality dried products, effectively bridging existing quality gaps [39]. While microwave drying is rapid and highly efficient, its primary challenges include high operating costs and process control difficulties stemming from rapid and uneven heating, which can result in localized overheating during dehydration [40].

Fruits utilized for chip production must be sufficiently firm to withstand mechanical peeling and slicing by electric processing equipment. In small-scale operations, an abrasive peeling machine (e.g., Hitrees), with a capacity of up to 1000 kg per shift, can be utilized for this purpose (Fig. 3, **A**). For slicing, an electric food processor, such as the "Robot Coupe CL50 Ultra," with a processing capacity of 5 kg of fruit per minute, is highly suitable (Fig. 3, **B**); this specific model is equipped with a large-volume feed hopper possessing a surface area of 139 cm².

Figure 3. Mechanical equipment utilized in the preparation of persimmons for chip production: A- Abrasive peeling machine; B -Electric food processor used for slicing.

Soluble tannins are responsible for the astringency of persimmon fruits, and Gonzalez et al. [1] reported that consumer perception of astringency directly correlates with the soluble tannin content in persimmon snacks.

Firm persimmons are typically astringent, and their slices rapidly darken upon exposure to atmospheric oxygen.

Addressing this issue, the Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan has developed a technology for producing natural chips. This method allows for the near-complete preservation of the color of persimmon slices, while simultaneously improving their flavor profile [41].

Fig. 4 provides a visual representation of this process.

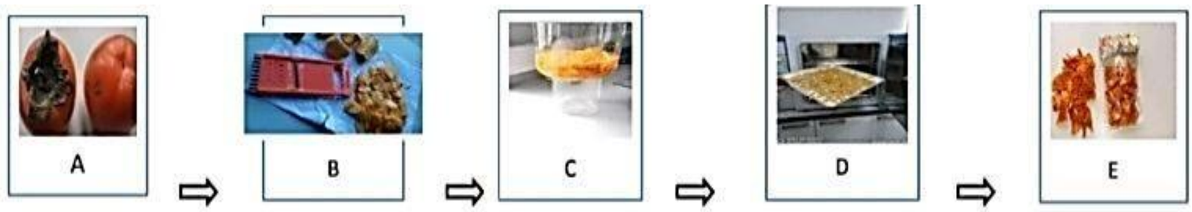


Figure 4. Sequential process to produce natural chips from firm persimmons - the stages illustrate: (A) raw fruit selection; (B) peeling and slicing; (C) pre-treatment for color preservation; (D) dehydration; and (E) the final packaged product.

The fruits (Fig. 4, **A**) are first washed, and the peduncle is removed from each fruit along with the calyx. Subsequently, the fruits are cut into distinct segments (typically 4 or 8, depending on the fruit's size). The waste generated during this initial processing is negligible, not exceeding 20 g per 1 kg of raw material.

These segments are then sliced to a thickness of 2–3 mm and immediately immersed in a prepared aqueous solution comprising 1 part citric acid, 2 parts sodium chloride (table salt), and 40 parts water (Fig. 4, **B**; Fig. 4, **C**). When utilizing an electric food processor for this operation, the solution is dispensed directly into the slicing receptacle.

With each subsequent batch, a fresh volume of the acid-salt solution is added to replenish the mixture. The residual solution remaining after processing four consecutive batches of slices is repurposed for the preparation of other canned fruit products.

The treated slices are carefully extracted using a slotted spoon and arranged on grates to drain excess solution.

The slices treated with the acid-salt mixture are arranged in a single layer on extruded mesh grids with 5 × 5 mm square apertures. Mesh grids are utilized instead of solid aluminum baking trays to prevent the slices from adhering to the surface during dehydration. A single grid measuring 35 cm × 35 cm accommodates 600 g of processed slices.

The grids containing the slices are transferred to mobile racks and loaded into a drying chamber (Fig. 4, **D**). Dehydration is conducted at a temperature of 70–72 °C and is completed after 3 hours, at which point the residual moisture content of the product decreases to 11%.

The yield of dried slices from 1 kg of 'Hiakume' persimmons (average fruit weight 268 g; waste components consisting of a peduncle and calyx weighing 2.7 g, and 3 seeds weighing 3.3 g) is 216 ± 0.4 g. To impart a crisp texture, the slices undergo a secondary microwave drying phase to achieve a final moisture content of 5–6%.

The dried slices are packaged in resealable plastic bags (Fig. 4, **E**), wherein they retain their original organoleptic characteristics (including color) for six months or longer.

This preservation of quality is illustrated in Fig. 5, which depicts the appearance of three samples of the aforementioned persimmon chips after six months of storage at temperatures not exceeding 10 °C.

The results indicate that while all three samples retained the color of the raw material well, the chips produced from slices pre-treated with Solution 1 (comprising 1 part citric acid, 2 parts sodium chloride, and 40 parts water) prior to dehydration exhibited the most attractive visual appearance. Subsequent chemical analysis confirmed the superiority of Sample 1; it demonstrated greater vitamin C retention and a lower concentration of polyphenols-particularly the astringent forms-compared to the other two samples.

In conclusion, the pretreatment of persimmon slices with stabilizing solutions, coupled with a combination of hot air and microwave drying, enables the production of high-quality persimmon snacks while simultaneously conserving time and energy.

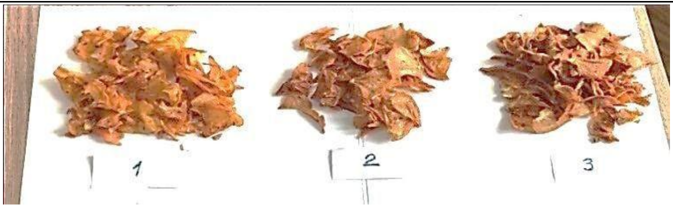


Figure 5. Visual comparison of 'Hiakume' persimmon chips following pretreatment in various stabilizing solutions: (1) citric acid, table salt, and water (1:2:40 ratio); (2) table salt, granulated sugar, and water (1:10:20 ratio); and (3) citric acid, table salt, and water (1:2:80 ratio).

Natural dried persimmon without flavoring additives

A study investigated the effect of four drying methods on the total concentration of biologically active compounds in persimmons and the *in vitro* bioavailability of total phenolic content (TPC). The results indicated that ultrasound-assisted vacuum drying, infrared drying (ID), and hot air drying (HAD) enhanced the bioavailability of TPC. Conversely, the bioavailability of lyophilized (freeze-dried) samples did not differ significantly from that of fresh persimmons. This increase in bioavailability was attributed to the thermal treatment applied during dehydration, as heat facilitates the release of biologically active compounds from the food matrix. Consequently, ID and HAD exhibited the highest bioavailability, as these drying methods impose the greatest thermal load [42].

Park et al. [43] conducted dehydration experiments on wafer-thin persimmon slices, achieving complete drying in 12 hours at 60 °C.

Pretreating persimmons with hot steam prior to dehydration resulted in a final dried product that was more astringent than the fresh fruit [44].

Due to pronounced inter-varietal differences, developing a single, universal pretreatment method for persimmon dehydration is considered impractical. For certain cultivars, a pretreatment consisting solely of epidermal peeling is sufficient. For other cultivars, slicing prior to drying is preferable; these slices may be dried directly or subjected to preliminary soaking in stabilizing solutions to enhance the final flavor and texture of the dried persimmons [14].

From a processing standpoint, firm persimmons are easier to handle, segment, and arrange on drying trays. However, at this maturity stage, the fruit's astringency remains at its peak; consequently, it is challenging to produce premium dried fruit from raw materials that are not fully ripe and have not yet developed optimal organoleptic properties.

Furthermore, firm persimmons require peeling prior to drying, resulting in physical losses and a reduced yield of the target product. Across various cultivars, the usable flesh of under-ripe, firm persimmons accounts for only 49.70% to 85.79% of the total fruit mass [45], with the remainder discarded as peeling waste.

Conversely, fully senescent, softened persimmons develop a tender texture and superior flavor profile that eliminates the necessity of peeling. Following any mechanical disruption of its integrity (which, at this stage of ripeness, must be performed manually), the flesh retains its original color for an extended period without significant browning. The softened fruit can be manually scored with a sharp knife, making several longitudinal incisions from the apex toward the calyx while leaving the base intact. The segments are then gently separated to resemble an open flower, and the fruit is dehydrated in this configuration.

Fig. 6 illustrates the core components of the dehydration technology for aged, softened persimmon fruits developed at the Research Institute of Fruit and Tea Growing of the Ministry of Agriculture of the Republic of Azerbaijan [46, 47, 48].

According to this technology, the preparation of aged, softened fruits for drying proceeds as follows.

First, each fruit (Fig. 6, **A**) is carefully washed under running water and scored with a sharp knife from the apex to the base, creating 4–8 approximately equal segments. These segments remain attached at the basal end where the calyx is located, and the fruit is then placed on a wire mesh baking tray. Subsequently, these interconnected segments are gently spread apart to create substantial interstitial spaces, giving the fruit the appearance of an open flower with 4–8 "petals" (Fig. 6, **B**).

Figure 6. Sequential dehydration process for aged, softened persimmons. The stages illustrate: (A) whole washed fruits; (B) fruits scored and expanded into attached "flower-like" segments to facilitate drying; (C) dehydrated fruits on the mesh drying tray; (D) close-up of the fully dried product; and (E) the final packaged fruit.

The dehydration of aged, softened persimmons in this configuration is conducted in a single layer at 70–72 °C for 9.5–10.5 hours, achieving a final moisture content of 24%.

The dried fruits (Fig. 6, **C**) are manually separated into sections, which may consist of paired segments connected at the base (Fig. 6, **D**); during this step, the peduncles and calyces are removed. The dried segments are then packaged in resealable plastic bags (Fig. 6, **E**). Alternatively, plastic containers with hinged lids may be utilized for this purpose.

The resulting fully dried persimmon product is stored at a temperature not exceeding 10 °C to optimally preserve its initial color, which closely resembles that of the raw material.

The shelf life of the fully dried persimmon is 6 months. After this period, a white efflorescence consisting of sugar crystals typically develops on the surface of the segments (Fig. 7).

Fig.7. Fully dehydrated 'Hachiya' persimmon segments demonstrating the development of surface sugar efflorescence (crystallization) after 6 months of storage at ambient temperature with continuous air exposure.

The yield of the final product from 1 kg of aged, unpollinated (seedless) 'Hachiya' persimmons (average fruit weight 205.5 g) was 284 g; waste generated from trimming the dried fruits (calyx and peduncle) amounted to 15 g.

The yield of the final product from 1 kg of partially pollinated (containing 1–2 seeds) aged 'Hiakume' persimmons (average fruit weight 290 g) was 280 g.

Table.

The component composition of 100% dried persimmons obtained after aging Hachia and Hiakume persimmons until completely softened (g/100 g of air-dry product).

100% dried persimmon	Water	Mono saccharides	Sucrose	Titrated acids (in terms of citric acid)	Total polyphenols, (Mg/100 g)	Vitamin C, (Mg/100 g)
"Hachiya"	24.0±1.0	49.45±2.06	8.70±0.36	1.18±0.05	280.0± 11.67	7.79±0.33

The table with a detailed description of the biochemical evaluation of the finished samples shows that the concentration of simple sugars and polyphenols in natural air-dry persimmon "Hachiya" is significantly higher than in natural air-dry persimmon "Hiakume". This compositional variance provides a rationale for recommending each variety to distinct consumer demographics based on specific dietary profiles.

Conclusion

Thus, in recent years, global persimmon production has increased concurrently with a growing interest in the study of the fruit's nutritional composition, bioactive compounds, and postharvest technologies.

To mitigate post-harvest losses, the utilization of surplus persimmons for dehydration is of particular interest.

A review of the current state of the field demonstrates that the potential to optimize persimmon drying technologies has been, and continues to be, extensively investigated. Of specific interest are recent developments aimed at enhancing the organoleptic properties of dried persimmons, alongside the establishment of appropriate hygienic standards and optimal product forms for consumer presentation.

As evidenced by these technological advancements, adhering to a processing paradigm that utilizes firm fruits during the primary commercial harvest, followed subsequently by aged, softened fruits, can significantly extend the operational season for dried persimmon production.

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