



# Valorization of Persimmon Fruit Through the Development of New Food Products

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Persimmon (*Diospyros kaki* Thunb.) fruits are among the most widely cultivated fruit crops worldwide, they are widespread in Asian countries and Europe, and their production is increasing along with the demand of consumers. Persimmon is a good source of nutrients and bioactive compounds, especially dietary fiber, carotenoids, and phenolic compounds, among other bioactive phytochemicals. However, persimmon is among the fruits, with a significant postharvest loss over the last few years. The cultivation of persimmon has a limited shelf life; it is a seasonal fruit and is perishable and difficult to store and transport; therefore, many persimmons are discarded. Currently, there is an increase in the valorization of the discarded persimmon fruits to generate opportunities and create a more sustainable system, in line with a possible circular economy. Therefore, in this review, we aim to compile an updated and brief revision of persimmons' main chemical and bioactive compounds and the potential use of persimmon surpluses and by-products in developing new food products.

**Keywords:** *Diospyros kaki*, polyphenols, carotenoids, fiber, food waste reduction. 1

## INTRODUCTION

Over the last decades, the improved life quality, with an increasing worldwide population, has led to excessive consumption of resources and, consequently, to large waste production. Therefore, this global phenomenon has had relevant environmental, social, and economic consequences (Scialabba, 2013). The current economic model has led to this global phenomenon. The named linear model is based on that inherited from the industrial revolution under the concept of constant supply of products with a short useful life, compelling to produce more to satisfy the continuous needs of the consumers (Osorio et al., 2021). Regarding foods, and according to the FAO, most losses and waste come from fruits and vegetables, accounting for ~50%; most waste results from consuming fresh fruit and their industrial processing (Russo et al., 2021). Therefore, the circular economy has received considerable interest in the scientific field. The circular economy could be an efficient option to prevent, reuse, or recover natural resources and derived by-products. The purpose is to reintroduce them to the production line as raw materials to obtain new products with health benefits and added value in the food industry through sustainable technology (Osorio et al., 2021).

Persimmon (*Diospyros kaki* L.) is consumed in many countries worldwide. Nowadays, FAOSTAT (2020) statistical databases indicate a world production of 4,241,366 tones and 1,005,544 ha of cultivated area in 2020, as well as a continuous increase in production since 2,000. The largest producer of persimmons is China, followed by Spain, South Korea, Japan, Azerbaijan, and Brazil (FAOSTAT, 2020). Different persimmon varieties are cultivated in different parts of the world. Varieties such as *Tone Wase*, *Hachiya* and *Saijo* are widely cultivated in Japan; *Fuyu*, *Hana-Fuju*, *Jiro*,

*Yongding*, *Hohrenbo*, *Ichidagaki* and *Mopan* are cultivated in China; *Kaki Tipo* is typical in Italy; and *Rojo Brillante*, together with *Triumph*, are cultivated in Spain (González et al., 2021a). Recently, research on persimmon fruit has mainly focused on its bio-physiological functions, including antioxidation, hypolipidemic, arteriosclerosis prevention, anticancer, and antiviral activities (González et al., 2021b). In spite of that, thousands of tons of persimmon fruits are discarded every year because of high production volumes, and the high quality standards, and consumer expectations related to shape, size, and color (Gea-Botella et al., 2021). Furthermore, persimmons have a limited shelf life; it is a seasonal fruit that is perishable and difficult to store and transport (Méndez et al., 2021). Therefore, persimmon surpluses, damaged persimmon fruits, and those unacceptable to the consumer require the development of new derived products. However, large amounts of by-products such as peels, seeds, or unused pulp are also generated, because fruits must be processed to facilitate their consumption and for commercial, logistic, and economic reasons (Gea-Botella et al., 2021). Therefore, the persimmon surpluses and by-products, due to their large amount bioactive compounds (Giordani et al., 2011), can be used as potential functional products and ingredients in different industries; carrying out a circular economy. Furthermore, the actions to reuse plant by-products agree with Sustainable Development Goal number 12 (SDG 12) of the 2030 Agenda for Sustainable Development of the United Nations (Johnston, 2016).

Persimmons are habitually commercialized as fresh, although in recent years, several kinds of persimmon products have been industrialized, including fruit juices, jams, and dehydrated persimmons. Dehydrated persimmons are commonly commercialized in countries such as China, Korea, and Japan (Masahiko et al., 2012). Persimmon flour has been used in pork liver pâté or pasta formulation (Lucas-González et al., 2018; Lucas-González et al., 2019; Lucas-González et al., 2021). Ice cream and dairy products with persimmon (Karaman et al., 2014; Hernández-Carrión et al., 2015); vinegar (Moon and Cha, 2008), wine (Liu et al., 2018), and persimmon snacks (González et al., 2020; González et al., 2021d), have also been prepared.

Therefore, in this review, we aim to compile an updated and brief revision of persimmons' chemical and bioactive compounds and the potential use of persimmon surpluses and by-products in developing new food products.

## Bioactive and Nutritional Compounds of Persimmon

The most prominent macro- and micronutrients present in persimmon are carbohydrates, fiber, organic acids, phenolic compounds, and carotenoids, which give antioxidant, cytotoxic, and antidiabetic properties (Matheus et al., 2020). According to scientific evidence, foods rich in bioactive compounds such as persimmon reduce the risk of cardiovascular disease, kidney disease, and colon and rectal cancer (Yaqub et al., 2016). Besides, components such as fiber helps to regulate obesity and being overweight, reduce type II diabetes and regulate the glycemic index, as well as reducing the

risk of cardiovascular disease (Chandalia et al., 2000; Slavin, 2005).

## Antioxidant Capacity

Antioxidant concept in food could be defined as the capacity of any substance that delays or inhibits the oxidation of substrates (Gülçin, 2012). Clinical and epidemiological studies have shown that certain micronutrients and secondary metabolites present in fruits and vegetables are beneficial for health because they are antioxidant, anti-inflammatory, and hypocholesterolemic. Therefore, there is a relationship between the consumption of foods with high antioxidant activity and their health benefits, the higher the consumption, the lower the incidence of diseases. The most prominent micronutrients and secondary metabolites with antioxidant capacity are phenolic compounds, carotenoids, water-soluble and fat-soluble vitamins, and phytochemicals (Yahia et al., 2018). Persimmon is a fruit with higher antioxidant capacity because of its high content of phenolic compounds (especially tannins), carotenoids, and water-soluble vitamins, such as vitamin C (Kondo et al., 2004; Yaqub et al., 2016). Several studies have shown that the antioxidant potential of persimmon is much higher ( $\approx 406 \mu\text{mol Trolox/g}$ ) when compared to other fruits such as apples ( $\approx 110 \mu\text{mol Trolox/g}$ ) (Gorinstein et al., 2011), blueberries ( $\approx 187 \mu\text{mol Trolox/g}$ ), or strawberries ( $\approx 163 \mu\text{mol Trolox/g}$ ) (García-Alonso et al., 2004).

## Phenolic Compounds

Phenolic compounds are secondary metabolites that contain at least a phenol group in their structure and can be classified as extractable (soluble) and non-extractable (insoluble). Extractable polyphenols (EP) are soluble in water-soluble organic solvents, and non-extractable polyphenols (NEP) are retained in the residue after extraction of EP therefore, in the food matrix. NEP have often been ignored, although they are also bioactive compounds with potential health properties (Arranz et al., 2010). EP and NEP are mostly flavonoids and non-flavonoids. Among flavonoids, monomeric flavan-3-ols (catechin, epicatechin, and epigallocatechin) and polymerized proanthocyanidins (condensed tannins) with various structural variations (dimers, oligomeric and polymeric), are vast in persimmon. Non-flavonoid polyphenols (phenolic acids) such as benzoic and cinnamic acid derivatives; ferulic, coumaric, and gallic acid have also been found (Giordani et al., 2011). Furthermore, EP are a complex mixture of low molecular monomeric compounds, including extractable proanthocyanidins along with other flavonoids and phenolic acids. NEP are polymeric polyphenols, including high molecular non-extractable proanthocyanidins and low molecular polyphenols bound to cell wall constituents (polysaccharides and proteins) or trapped within the food matrix (Arranz et al., 2010).

The phenolic profile of 11 varieties of persimmon conducted by (Veberic et al., 2010) concluded that the most important compounds were gallic acid (0.72–2.43 mg/100 g) and catechin (0.39–1.90 mg/100 g). The varieties with the highest concentration of gallic acid in fresh persimmon were *Triumph* and *Tone Wase* and those with the highest concentration of catechin were *Jiro*, *Triumph*, *Thiene*, *Fuji*, *Cal-Fuyu*, and *Tipo*.

Using HPLC, Sentandreu et al. (2015) detected 32 low molecular phenolic compounds in the variety of *Rojo Brillante* persimmon. Gallic acid and coumaric acid were found as the highest proportion as well as monomeric and polymeric flavonoids. Studies show that among the phenolic compounds of persimmon fruit, there are mainly simple and polymerized polyphenols (condensed tannins or proanthocyanidins) (Jiménez-Sánchez et al., 2015). Researchs conducted by Gorinstein et al. (2001) and García-Alonso et al. (2004) show a higher content in phenolic compounds of persimmon (1.50 mg/100 g –10.2 mg/100 g) than pomegranate (4.48 mg/100 g) or apple (1.10 mg/100 g). However, due to differences in climatic conditions, harvest characteristics, harvest time, processing, available nutrients, etc., the phenolic content of different cultivars varies greatly (Pérez-Burillo et al., 2018).

It should be noted that soluble phenols are responsible for the astringent character in astringent varieties of persimmons. The astringent varieties are not edible in early stages of maturity when they have a firm texture, and for the fruits to be consumed, it is necessary to apply postharvest astringency reduction techniques. The introduction of technologies based on the application of high concentrations of CO<sub>2</sub> has made it possible to remove astringency and commercialize some varieties, which were previously discarded due to astringency, also offering advantages in handling and long-distance transportation.

## Carotenoids

Carotenoids are a group of fat-soluble compounds responsible for the yellow, orange, and red color of persimmon fruit. Carotenoids are divided into carotenes and xanthophylls and the structure comprises conjugated double bonds, which provide a certain color in the UV-visible spectrum (Giordani et al., 2011). The health benefits of carotenoids, especially  $\alpha$ -carotene,  $\beta$ -carotene, and  $\beta$ -cryptoxanthin, come primarily from their provitamin A activity. Vitamin A is essential for skin, eyes, heart, and the immune system (Díaz et al., 2020). Furthermore, carotenoids have antioxidant properties associated with cell protection, regulation of cell growth, apoptosis (Pachisia, 2020), the prevention of certain types of cancer, and atherosclerosis (Krinsky and Johnson, 2005; Hu et al., 2009).

Persimmon contains a high content of carotenoids, such as  $\alpha$ -carotene,  $\beta$ -carotene and  $\beta$ -cryptoxanthin, which contribute to the intake of provitamin A (Giordani et al., 2011). Veberic et al. (2010) studied the profile of carotenoids in 11 varieties of persimmon.  $\beta$ -carotene was the main carotenoid found in ripe persimmon; the highest concentration of this compound was found in the peel of the *Hana-Fuyu* variety (8.75 mg/kg). The concentration of  $\beta$ -carotene was higher in the peel than in the pulp, and the most abundant carotenoids in the pulp were  $\beta$ -carotene,  $\beta$ -cryptoxanthin,  $\alpha$ -carotene, and zeaxanthin.

Bordiga et al. (2019) determined the carotenoid content in both the peel and the pulp of Kaki Tipo variety in 13 ripening stages. As the ripening stage advanced, the carotenoid content increased both in the peel and in the pulp, being  $\beta$ -cryptoxanthin the most abundant carotenoid. The carotenoid content increases as the fruit ripens from  $\approx 2$  mg/kg in early ripening stages to 42 mg/kg in advanced ripening stages; the content of  $\beta$ -

cryptoxanthin is usually the highest, followed by lycopene,  $\beta$ -carotene, zeaxanthin, and lutein (Yaqub et al., 2016). The average value of  $\beta$ -carotene in the fresh persimmon pulp of *Rojo Brillante* variety, according to Hernández-Carrión et al. (2014) is 5.81 mg/kg. González et al. (2021a) observed that the *Rojo Brillante* variety also presented  $\beta$ -cryptoxanthin,  $\beta$ -carotene, violaxanthin, zeaxanthin, and lutein; in addition, as the ripening stage advanced, the content of  $\beta$ -cryptoxanthin also increased. Multiple factors affect the carotenoid profile of different varieties of persimmon, such as environmental conditions (climate, cultivation techniques, and post-harvest conditions), the ripening process, and genetic factors (Qi et al., 2019). Based on the literature, the carotenoid content of persimmon is within the range of other fruits such as apricots (15–38 mg/kg) (Sass-Kiss et al., 2005), apples (2.19 mg/kg), grapes (8.02 mg/kg) and plums (7.55 mg/kg) (Kim et al., 2007), oranges (44.8 mg/kg) or watermelons (30.1 mg/kg) (Setiawan et al., 2001).

## Dietary Fiber

According to the World Health Organization (WHO), dietary fiber is defined as carbohydrate polymers with 10 or more monomeric units not hydrolyzed by endogenous enzymes of the human small intestine, but it is partial or totally fermented in the large intestine by the action of the microorganisms. Total dietary fiber comprises two fractions, insoluble and soluble. Insoluble fiber is poorly fermented and has a marked laxative and intestinal regulating effect; soluble fiber is fermented in the colon, favoring the development of intestinal flora, intestinal transit speed, and decreasing blood cholesterol concentration and glucose (Tungland and Meyer, 2002).

Persimmon has both soluble and insoluble fiber in the peel and in the pulp, with a higher content in the peel (Gorinstein et al., 2001). The average fiber content is around 3.9 g/100 g (fresh weight); this data was obtained from varieties such as *Fuyu* and *Hachiya* (Celik and Ercisli, 2008; Altuntas et al., 2011). The *Triumph* variety showed average values of 1.5 g/100 g (fresh weight) where the content of insoluble fiber was found in a proportion higher than soluble fiber (Park et al., 2006). In the *Rojo Brillante* variety, the fiber content was 3.11 g/100 g, where around 1.97 g/100 g were insoluble fiber (Hernández-Carrión et al., 2014). The fiber content in persimmon is relatively high compared with fruits such as apple (2.4 g of fiber/100 g of fruit), orange (2.4 g of fiber/100 g of fruit), and grapefruit (1.6 g/100 of fruit) (Dreher, 2018). Moreover, some studies hypothesize that various bioactive benefits of dietary fiber are determined by the action of some bound compounds, such as phenolic compounds (Quirós-Sauceda et al., 2014). Persimmon fiber interacts with antioxidant phenolic compounds such as condensed tannins, which may play an important role in the human body (Mamet et al., 2018).

## Persimmon-Derived Products

Persimmon fruits have been industrialized in recent years to obtain different derived products and there has been increased research on these products. **Table 1** shows a summary of the main studies related to the investigation of persimmon products.

**TABLE 1** | Some studies in the last years related to persimmon products.

Persimmon product	Persimmon variety	Ingredient	References
Whole dried persimmon	<i>Ichida-gaki, 'Koshu-Hyakume, Hiratanenashi and Dojo-Hachiya</i>	Persimmon dried by natural drying	Sugiura and Taira, (2009)
Whole dried persimmon	—	Persimmon dried by natural drying	Hur et al. (2014)
Whole dried persimmon	<i>Rojo Brillante</i>	Persimmon dried by natural drying	Vilhena et al. (2020), González et al. (2021b)
Persimmon snack	—	Persimmon dried by hot-air drying, hot-air-microwave drying, and freeze-drying	Jia et al. (2019)
Persimmon snack	—	Persimmon dried by hot-air drying, ultrasound-assisted vacuum drying, freeze-drying and infrared-drying	Kayacan et al. (2020)
Persimmon snack	<i>Rojo Brillante</i>	Persimmon dried by freeze-drying and hot-air drying	González et al. (2020), González et al. (2021c)
Persimmon puree	<i>Gosho, Hachiya, Hlakume</i>	Persimmon pulp	Hafizov, (2022)
Persimmon puree	<i>Rojo Brillante</i>	Persimmon pulp	Tárrega et al. (2013)
Persimmon puree	<i>Fuyu</i>	Persimmon pulp	Rodríguez et al. (2020)
Persimmon puree	<i>Rojo Brillante and Sharon</i>	Persimmon pulp	De Ancos et al. (2000)
Persimmon juice	—	Persimmon pulp	Hu et al. (2022)
Persimmon juice	<i>Fuyu</i>	Persimmon pulp	da Silva et al. (2021)
Persimmon flour in pork pâté	<i>Rojo Brillante and Triumph</i>	Persimmon flour (3% and 6% )	Lucas-González et al. (2019)
Persimmon flour in pork pâté	—	Persimmon flour (0.5% and 1%)	Ramachandraiah and Chin, (2018)
Persimmon flour in spaghetti	<i>Rojo Brillante and Triumph</i>	Persimmon flour (3% and 6%)	Lucas-González et al. (2021)
Persimmon ice cream	—	Persimmon puree (8, 16, 24, 32, and 40% )	Karaman et al. (2014)
Persimmon yogurt	—	Persimmon marmalade or puree (10% and 12%)	Arslian and Bayrakçi, (2016)
Persimmon milkshake	<i>Rojo Brillante</i>	200 g/L fresh persimmon	Hernández-Carrion et al. (2015)
Persimmon milkshake	<i>Hachiya</i>	100, 200, 300 g/L fresh persimmon	Jokar and Azizi, (2022)
Persimmon vinegar	<i>Saijo and Hiratanenashi</i>	Persimmon vinegar purchased from the market	Sakanaka and Ishihara, (2008)
Persimmon vinegar	<i>Jixin</i>	Mashed persimmon	Zou et al. (2017)
Persimmon vinegar	<i>Sharoni</i>	Mashed persimmon	Ubeda et al. (2011)
Persimmon vinegar	—	Mashed persimmon	Wang et al. (2022)
Persimmon wine	<i>Mopan</i>	Persimmon pulp	Lu et al. (2020), Lu et al. (2021)
Persimmon wine	<i>Aizumishirazu</i>	Persimmon juice	Liu et al. (2018)

## Dried Persimmon

Dried persimmons—in many formats—are the most important processed persimmon products. They are interesting for consumers and global markets because they can be used as a valuable ingredient in different preparations or be consumed directly as a snack. By drying, microorganisms cannot develop and biochemical reactions cannot be initiated, so fruit consumption can be extended throughout the year.

The natural drying of whole persimmon has traditionally been used in Asian countries (China, South Korea, and Japan) as a method to obtain a product with good sensory and nutritional attributes, which are often consumed and commercially produced. The standard method for preparing this dried product entails removing the calix sepals and skin, followed by hanging the fruit on strings. Dried fruit is kneaded in China and Japan, near the conclusion of the drying process, to distribute humidity equally in the fruit and to develop the shape of the finished product. In South Korea, however, they are left to hang in a well-ventilated area without being kneaded (Sugiura and Taira, 2009; Hur et al., 2014).

González et al. (2021b) used the natural drying method without kneading on the persimmon variety *Rojo Brillante*, comparing the behavior of astringent and non-astringent fruits

(subjected to postharvest CO<sub>2</sub> treatment to remove astringency). After 20 days, there was a natural decrease in soluble tannin content; with astringent and non-astringent fruits having similar values (20–30 mg/100 g). Furthermore, the color of the astringent fruit flesh stayed orange, whereas a browning was observed in the non-astringent fruit. Thus, no deastringency treatment is required, and the authors suggested that using this natural drying technology, which has yet to be implemented in the *Rojo Brillante* persimmon industry, might be a good way to decrease the variety's surplus.

Vilhena et al. (2020) analyzed the physicochemical and microstructural changes during air drying of *Rojo Brillante* persimmons harvested in early maturity stage (S1) and last maturity stage (S2). Water loss caused shrinkage, which resulted in secondary epidermis creation and interior pulp gelling. Compared to the S2 fruits, the S1 fruits had a thicker epidermis, and a smaller gelled area volume inside, which resulted in a tougher fruit. Microstructural analysis demonstrated the parenchyma degradation after drying in both the secondary epidermis and pulp, with S1 showing a quicker rate of degradation than S2. Therefore, the dried persimmon characteristics depended on the maturity state upon harvest.



Besides natural drying, other drying techniques have been used. Because of their long shelf life and healthy nutritional value, combined with an attractive crispy taste, fruit snacks or chips have become increasingly popular among modern consumers (Jia et al., 2019). However, crispness of dried persimmon depends on the methods used for drying. Persimmon snacks obtained by hot-air drying are not brittle and hardly meet the needs of consumers willing to consume a crispy snack. Freeze drying creates a crunchy product rich in bioactive compounds (González et al., 2020). This technique preserves bioactive compounds better than other techniques, such as hot-air drying. However, freeze drying is a very time-consuming, energy-consuming, and costly process (Orak et al., 2012). Furthermore, a destringency treatment is necessary before freeze drying, because astringent samples retain a high content of soluble tannins and consequently have high astringency (González et al., 2022).

Because each drying process has inherent shortcomings, combining several methods is a practical strategy for manufacturing high-quality dried items that can overcome the present quality gap (Pu and Sun, 2017). Microwave drying is fast and highly efficient; however, the main issues are high running costs and process control difficulties caused by rapid and uneven heating, which results in thermal runaway and drying (Cheng et al., 2006; Koné et al., 2013).

Jia et al. (2019) investigated the effect of three methods of drying: hot-air drying, hot-air-microwave drying, and freeze drying on the properties of persimmon chips. Persimmon chips with good rehydration capacity, color, and textural qualities were obtained when microwave and hot-air drying were combined. Although freeze drying persimmon chips increased the rehydration potential, attractiveness, and retention of nutrients, the process had a low efficiency and high energy consumption. However, persimmon chips dried using a combination of hot-air and microwave drying were similar in color, texture, flavor, and general acceptability to the freeze-dried chips. According to the findings, a combination of hot-air and microwave drying can give high-quality persimmon snacks while saving energy and time. However, more research is needed to determine the ideal persimmon chip preservation parameters, such as the packaging material and the storage environment.

Kayacan et al. (2020) examined the effects of four drying methods on persimmon total bioactive compounds, and *in vitro* bioaccessibility of total phenolic content (TPC). Compared to fresh persimmons, the results showed that ultrasound-assisted vacuum drying, infrared drying (ID), and hot-air drying (HAD) increased TPC bioaccessibility. However, the bioaccessibility in freeze-dried samples was not substantially different from that of fresh persimmons. The increase in the bioaccessibility was because of the heat treatment used during drying, as bioactive compounds are released from food due to heat. Therefore, ID and HAD showed the highest bioaccessibility because they are the drying techniques with the highest heat load.

Soluble tannins are responsible for astringency in the persimmon fruit, and González et al. (2021c) reported that consumer perception of astringency correlates with the soluble tannin content of persimmon snacks. They studied the influence

of ripening stage and destringency treatment on the production of persimmon snacks via HAD. The snacks obtained from the astringent fruit, at the most advanced ripening stage, had similar soluble tannin content (10.5 g/100 g dry matter) to the samples obtained from non-astringent fruit, especially at 60°C (8.6 g/100 g dry matter). Although in the first ripening stage, consumers preferred the snacks obtained from non-astringent fruits; in the last ripening stage, snacks produced from astringent fruits were equally accepted as non-astringent.

## Persimmon Puree

Fruit puree quality is dictated by the sensory qualities, maturity and varietal traits of the fruit used. One of the most notable characteristics of persimmon fruits is their high level of dietary fiber and astringent polyphenols, which can often make their processing difficult. Fibers must be eliminated when preparing a puree; furthermore, the presence of seeds can affect the processing and the quality of the final products. Hafizov, (2022) prepared persimmon puree using *Gosho*, *Hachiya*, and *Hiakume* cultivars, they observed that using unseeded persimmon fruits improved the color and the production yield of the puree.

Persimmon puree is a paste with gel structure which tends to get stronger, forming aggregates and syneresis when heated and then cooled. To avoid gel formation, enzymatic incubation with Viscozyme L (a commercial enzyme) can be used, giving a more fluid persimmon puree, which can be submitted to thermal processing without gelation (Tárrega et al., 2013).

Rodríguez et al. (2020) used a high hydrostatic pressure (HHP)(technique to obtain persimmon purees, and recommended the less severe treatment (400 MPa for 1 min) to inhibit microorganisms without affecting the physicochemical properties, phenolic content, or antioxidant capacity of persimmon puree. When samples were treated at 500 and 600 MPa, the mechanical and rheological characteristics changed; nevertheless, these circumstances allowed the mechanical and rheological characteristics to be preserved during chilled storage.

According to De Ancos et al. (2000), HHP processing of *Rojo Brillante* persimmon puree at 300 MPa did not cause significant pigment changes and retained or even improved vitamin A levels and radical-scavenging ability.

## Persimmon Juice

Persimmon juice is emerging in the juice industry worldwide, as a new healthy commercial juice that may effectively supplement a healthy diet (Jiménez-Sánchez et al., 2015). However, persimmon juice is still scarce on the market because persimmon juice products contain significant amounts of tannins and pectin, which impairs fruit quality (Xu et al., 2021).

A high pectin content can cause low juice yield, which is one of the most common issues with persimmon juice processing. Adding exogenous enzymes, mainly pectinases, such as pectin methyl esterase or poly galacturonase, to boost fruit juice yield, clarify the juice, and increase membrane flow during ultrafiltration, is a classic technique to control this problem (Nighojkar et al., 2019).

Hu et al. (2022) investigated the application of microwave hydrothermal extraction (MHE) to prepare date plum persimmon juice and compared the juices obtained using this technique with those prepared by microwave (ME) and hydrothermal (HE) extractions. The process conditions of 131°C, 26 ml/g, 390 W, and 32 min yielded the maximum TPC in the juice. Compared to juices prepared with ME and HE, the MHE prepared juice had the highest amounts of total phenolics, total flavonoids, protein, and polysaccharides, as well as maximum antioxidant activity.

da Silva et al. (2021) examined the effect of ultrasound and freezing concentration in Fuyu persimmon juice. According to their studies, ultrasound treatment reduced microbiological loads (total and thermotolerant coliforms), resulting in a reduction in mild pasteurization time, which could represent significant savings for industry. Furthermore, the use of the ultrasound technique produced a homogeneous beverage that received excellent taste feedback while maintaining phenolic components and antioxidant capability. The juice prepared using freeze concentration had high quantities of sugar (glucose 58.76 g/100 ml and fructose 49.25 g/100 ml), malic acid (0.36 g/100 ml), phenolic compounds (1,454 mg/100 ml), and antioxidant activity (DPPH 3901 µmol Trolox/L, FRAP 6867 µmol Trolox/L).

## Persimmon Flours

Persimmon by-products can be processed to produce a stable fiber-rich flour that can be used in novel food processing to prepare foods such as meat products or pasta.

Regarding meat products, Lucas-González et al. (2019) observed that two concentrations (3% and 6%) of persimmon flour could be successfully used as a natural ingredient in pork liver pâté, improving general acceptance, and reducing lipid oxidation and residual nitrite levels. The use of flours prepared with micronized persimmon seeds, peels, and calyxes increased the concentration of phenolic (from 4.13 to 4.63 g/100 g) and flavonoid (from 0.78 to 1.56 g/100 g) components in persimmon flours, as well as their antioxidant activity, and reduced lipid oxidation in pork patties during storage (Ramachandiraiah and Chin, 2018).

For pasta prepared using persimmon flours, Lucas-González et al. (2021) reported that the total polyphenol content of durum wheat semolina increased in a dose-dependent way with the addition of persimmon flours (3% and 6%) and reported contents of gallic acid and coumaric acid-o-hexoxide, which were not present in the control spaghetti. The addition of persimmon flour to spaghetti did not increase the bioaccessibility of polyphenols. However, fortification of durum wheat pasta with persimmon powders decreased the kinetics of starch digestion when a concentration of 3% of persimmon flour was used. Therefore, spaghetti formulated with 3% of persimmon flour had a lower glycemic index than pasta with 6% of persimmon flour. The addition of 3% of persimmon flour (*Rojo Brillante* and *Triumph*) gave pasta with a higher polyphenol content and a reduced starch digestibility than the control spaghetti.

## Persimmon in Dairy Products

Different dairy products, such as yogurt and milkshakes, have been prepared using persimmon to enhance nutritional quality and texture perception. Yogurt consumption is expanding worldwide because of its nutritional benefits, medicinal effects, and functional qualities, which can be enhanced by adding fruits.

Karaman et al. (2014) reported that the addition of 24% of persimmon puree to ice cream improved its taste and color, and increased the TPC. Arslan and Bayrakçi, (2016) investigated the effects of two concentrations (10% and 12%) of persimmon marmalade and puree in yogurt production. The yogurt containing persimmon puree had less antioxidant activity (0.11 and 0.13 µmol Trolox/g for 10% and 12%, respectively) than the yogurt containing persimmon marmalade (0.19 and 0.18 µmol Trolox/g for 10% and 12%, respectively). The yogurt that contained 12% of persimmon marmalade scored the highest in the sensory attributes of appearance, sweetness, fruitiness, acidity, taste, flavor, and overall acceptability.

Hernández-Carrión et al. (2015) developed persimmon milkshakes with high nutritional value, and good acceptance varying the type of milk (whole and skimmed) and the treatment of the persimmon (untreated, high hydrostatic pressure-treated, and pasteurized). Persimmon milkshakes were perceived positively by consumers as a source of high antioxidants. Consumers preferred milkshakes made with HHP or untreated persimmons, and with whole milk.

Jokar and Azizi, (2022) investigated rheological, sensory, and physicochemical properties of a persimmon drink. Their studies showed that the most acceptable sensory scores for persimmon milk were obtained using 0.1% gum Arabic, 5% sugar and 10% persimmon. However, they reported that due to the hydrocolloid content in persimmons, a stable persimmon milk drink without gum can be obtained.

## Persimmon Vinegar

Persimmon vinegar, obtained from fermented persimmon fruit, is rich in polyphenols, such as gallic acid and catechins, which protect against hydrogen peroxide-induced cellular oxidative stress (Sakanaka and Ishihara, 2008; Zou et al., 2017, 2018). In recent studies, persimmon vinegar, with high potential in the health food market, has been proven to have anti-obesity and anti-inflammatory properties (Ahmed et al., 2016; Lee et al., 2016).

Sakanaka and Ishihara, (2008) compared the antioxidant properties of persimmon vinegar and other commercial vinegars (unpolished rice vinegar, polished rice vinegar, and apple vinegar) using radical-scavenging assays. The tested vinegars were effective antioxidants, and the persimmon vinegars made from the astringent persimmon (var. *Saijo*) showed the highest radical-scavenging activity.

Zou et al. (2017) studied the evolution of antioxidant capacity and phenolic compounds in persimmon during the course of alcoholic fermentation, acetification, and brief aging. When persimmon was converted from puree to vinegar, antioxidant activity increased 18.0% after 3 months; nevertheless, the total quantity of phenolic components remained steady. They showed gallic acid, the main phenolic compound, increased during

alcoholic fermentation (34.41 mg/L) but decreased during acetic fermentation (17.64 mg/L). Also, during alcoholic fermentation and acetification, the flavan-3-ol compounds increased. Furthermore, vanillyl alcohol, (-)-epigallocatechin, and p-coumaric acid, which were not found in persimmon puree, were found in persimmon vinegar. These findings suggest that alcoholic and acetic fermentation can boost persimmon fruit antioxidant activity.

In another study, Ubeda et al. (2011) evaluated the antioxidant activity and TP in persimmon vinegars produced by different processes. The results show that the persimmon vinegars had higher TP values than those obtained from white and red wine vinegars (32.4, 13.7, and 22.9 mg/100 g, respectively), indicating health-promoting qualities. However, the antioxidant activity was lower than reported by other authors because it was obtained from non-astringent persimmons (var. *Sharoni*).

Wang et al. (2022) studied the microbial diversity and flavor changes during spontaneous persimmon vinegar fermentation. Their study confirmed that the changes in the microbial community and metabolites during fermentation were responsible for the flavor of the persimmon vinegar.

## Persimmon Wine

The manufacture of persimmon wine is an appealing approach to employ surpluses and rejected fruits, reducing losses and improving this crop profitability. Persimmon has a higher sugar content (sucrose, glucose, and fructose) than other fruits, which gives copious carbon sources for brewing. Furthermore, during the winemaking process, persimmon bioactive compounds are released and can be easily absorbed by the human body (Shahidi, 2009).

Persimmon wine is made mainly by inoculating commercial yeast strains into the fermenting medium; such strains can maintain the quality stability of the persimmon wine, but they decrease its distinctiveness. Lu et al. (2021) compared the composition of microorganisms in the spontaneous and inoculated fermentation process of persimmon wine and studied the changes of microbial succession and volatile compounds. In another study, Lu et al. (2020) investigated changes in the physicochemical components, polyphenol profile, and flavor of persimmon wine during spontaneous and inoculated fermentation. When the two types of alcoholic fermentation were compared, they discovered that spontaneous persimmon wine fermentation (SPF) had lower bacterial community diversity and higher fungal community diversity than inoculated persimmon wine fermentation (IPF). SPF produced a wine with a more balanced and delicate body, but less brandy scent and bitterness than IPF. SPF boosted the total flavonoids and phenol content of persimmon wines; however, long fermentation times are needed to reach the same amount of ethanol; therefore, IPF would be more recommended for wine production. In this regard, the authors consider the idea of using indigenous aroma-producing bacteria as persimmon wine fermentation starters to enhance the wine's distinct features.

Persimmon wine quality is affected by the temperature at which the fermentation occurs. Liu et al. (2018) studied the effect of fermentation temperature on the phenolic content, volatil profile, and antioxidant activity of persimmon wine. Phenolic-

rich persimmon wine was characterized with high aroma concentration. Wine fermented at low temperature (15°C) had low ethanol concentration and high residual sugar content, indicating a slow fermentation. Most phenolic compounds increased as the temperature increased from 15 to 25°C (from 64.7 to 74.5 mg/L), and then decreased at 30°C (69.8 mg/L). However, the antioxidant activity of the wine increased with temperature. These findings suggest that a fermentation temperature between 25 and 30°C can be beneficial in persimmon winemaking, potentially paving the way for high-quality wine production conditions.

## CONCLUSION

In recent years, the exponential growth in persimmon production has been linked to a large amount of postharvest losses. The current challenge for the persimmon industry is the search for strategies that increase the value of the discarded fruit to generate opportunities and create a more sustainable system, contributing to the circular economy.

Using fruit surpluses or by-products rich in bioactive compounds to formulate foods is an emerging topic in food science research. The potential use of persimmon surpluses and by-products in developing new food products/foods has been proven through different studies compiled in this review. Persimmon can offer added value to food products because it is rich in nutrients and bioactive compounds (phenolic compounds, carotenoids, and dietary fiber) with bio-physiological functions, including antioxidant, hypolipidemic, and antidiabetic properties. Dried persimmon is the most investigated persimmon-derived food; different persimmon formats and drying techniques have been used to obtain products with good sensory and nutritional attributes. The current review has also surveyed the use of persimmon flour in pork liver pâté or pasta formulation, different research works related to ice cream and dairy products, such as milk and milkshakes formulated with persimmon, and persimmon vinegar and wine. Considering the works studied, developing new products with persimmon, thus improved nutritional properties, can increase the profitability and availability of this seasonal fruit, diversifying the offer to consumers.

## AUTHOR CONTRIBUTIONS

SH: Investigation, writing—original draft. CG: Investigation, writing—original draft. IH: Supervision, Conceptualization, writing—review and editing. GM: Supervision, Conceptualization, Writing—review and editing. All authors contributed to the article and approved the submitted version.

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