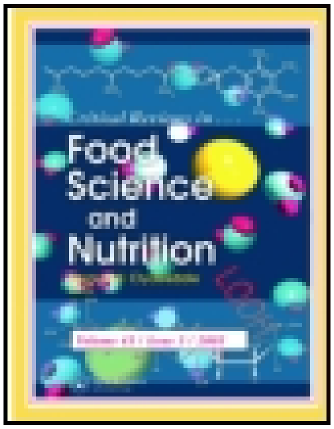

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A Review on the Effect of Drying on Antioxidant Potential of Fruits and Vegetables

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A review on the effect of drying on antioxidant potential of fruits and vegetables

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Abstract

The role of antioxidants in human nutrition has gained increased interest, especially due to their associated health beneficial effects for a number of chronic diseases, including cardiovascular diseases and certain types of cancer. Fruits and vegetables are perishable and difficult to preserve as fresh products. Dried fruits and vegetables can be easily stored, transported at relatively low cost, have reduced packing costs, and their low water content delays microbial spoilage. Air-, freeze-, microwave- and sun-drying are among the most thoroughly studied drying methods. This review provides an overview of recent findings on the effects of different drying techniques on major antioxidants of fruits and vegetables. In particular, changes in ascorbic acid, carotenoids, flavonoids, phenolic acids, total phenolics and antioxidant activity are discussed in detail.

Keywords: drying, fruits, vegetables, antioxidants, ascorbic acid, carotenoids, polyphenols

INTRODUCTION

Epidemiological studies have revealed a positive association between fruit and vegetable consumption and a reduced risk of certain degenerative diseases, such as cardiovascular diseases and certain types of cancer (Kaur and Kapoor, 2001; Stanner et al., 2004; Giampieri et al. 2014). In particular, phytochemicals with antioxidant potential are well-reported to play role in reducing the consequences of oxidative stress in disease development and the aging process, and thus contribute to the overall health-protective effects of fruits and vegetables (Kalt, 2005; Alvarez-Suarez et al., 2014).

Fresh fruits and vegetables, having moisture contents of > 80%, are classified as highly perishable commodities (Sagar and Kumar, 2010). Consequently, this fact gave rise to an expansion in the production and thereby consumption of processed foods with reduced moisture content values. Among them, dried fruits and vegetables attract much attention since they can be easily produced and stored, transported at relatively low cost, have reduced packing costs, and their low water content avoids the development of some microorganisms responsible for deterioration of fresh product (Santos and Silva, 2008). The market for dried fruits and vegetables is important for most countries worldwide. For instance, in Europe the market for dried vegetables was estimated to be worth US$ 260 million in early 1990s. Greece is the leading producer of raisins among European Union countries (Effie and Antonia, 2014). The world raisin production, mainly produced in the USA (297,557 tons) and Turkey (190,000 tons), was about 600,000 tons and valued at over US$ 125 million in 2000. This trend is expected to continue and even accelerate in all emerging economies of the world (Zhang et al., 2006).

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Among the various drying techniques, air-, freeze-, microwave- and sun-drying are the most thoroughly studied methods. Air-drying provides products that can have an extended shelf life of up to a year, whereas these conventionally dried products are generally in low quality compared to that of their fresh counterparts. In case of freeze-drying, the food materials are dried under vacuum and at very low temperatures -which prevents the deterioration and microbiological reactions- resulting in higher quality final products (Ratti, 2001). Microwave-drying offers opportunities to shorten the drying time, thereby improving quality of the final dried product (Zhang et al., 2006). Preservation of fruits and vegetables through sun-drying, which dates back many centuries, may result in poor quality and product contamination (Sagar and Kumar, 2010).

Hot-air drying is often used as it needs generally short drying times. However, due the high temperatures applied, higher losses in e.g. antioxidants can be expected. Conversely, drying at low temperatures, e.g. by freeze-drying, is more effective in preserving antioxidants. Moreover, retention of antioxidants may be further improved when a vacuum is used since the thermal and oxidative stress is reduced. Overall, the drying process changes the antioxidant potential of fruits and vegetables. This review provides an overview of recent findings on the effects of different drying techniques on major antioxidants of fruits and vegetables.

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Fruits and vegetables, which are rich sources of specific antioxidant groups such as ascorbic acid, carotenoids, flavonoids and phenolic acids, worth special consideration with a significant impact on promoting human health. In this section, the effects of various drying methods including hot-air/oven drying (Table 1), freeze-drying (Table 2), microwave-drying

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(Table 3), sun-drying (Table 4), and some other drying techniques (heat-pump, modified-atmosphere, refractance-window^{TM}, spouted-bed, and vacuum drying) (Table 5) on retention of these compounds will be discussed.

Ascorbic acid (Vitamin C)

Vitamin C, an essential compound found mainly in fruits and vegetables, not only prevents diseases like scurvy, but also plays a natural role as a biological antioxidant. During food processing, vitamin C can easily be degraded, depending on many variables such as pH, temperature, light, and the presence of enzymes, oxygen, and transition metal ion catalyzers. Thus, many studies on food processing methods, including the drying process, take vitamin C as a quality indicator (Santos and Silva, 2008).

Recent literature, which studied the effects of different drying techniques on ascorbic acid content of various fruit and vegetable products, indicated significant decreases; e.g. including the studies on hot-air/oven dried apple (Joshi et al., 2011), apricot (Garcia-Martinez et al., 2013), kale (Korus, 2011), sebuckthorn berry (Araya-Farias et al., 2011), sweet potato (Yang et al., 2010), and tomato (Gumusay et al., 2015) at 40-70°C for 5.5-36 h (Table 1); freeze-dried carrot (Yan et al., 2010), cherry, red bell pepper (Leong and Oey, 2012), kale (Korus, 2011), starfruit (Shofian et al., 2011), sweet potato (Yang et al., 2010), and tomato (Gumusay et al., 2015) at -50°C for 24-36 h (Table 2); microwave-dried apricot at 100 W (Garcia-Martinez et al., 2013) (Table 3); sun-dried tomato at 25-30°C for 3 days (Gumusay et al., 2015) (Table 4); modified atmosphere dried carrot (Liu et al., 2014); spouted-bed dried carrot; and vacuum dried carrot (Yan et al., 2010) and apple (Joshi et al., 2011) at 20-70°C (Table 5). On the other hand, vitamin C content of apricot, nectarine, plum (Leong and Oey, 2012), and mango (Shofian et al.,

2011) were not affected significantly as a result of freeze-drying for 48-72 h (Table 2). Furhermore, freeze-drying for 48-72 h resulted in < 3-fold increases in ascorbic acid content of carrot, muskmelon, peach (Leong and Oey, 2012), papaya and watermelon (Shofian et al., 2011) (Table 2). All these increases in vitamin C content as a result of drying can be explained by the inactivation of ascorbic acid oxidase leading to protection of ascorbic acid towards enzymatic oxidation (Leong and Oey, 2012).

The general loss of vitamin C during most of the drying methods applied could be attributed to the oxidation of ascorbic acid under high temperature drying conditions, as well as the depletion of this compound due to its utilization for protecting the oxidation of polyphenols during drying (Toor and Savage, 2006; Joshi et al., 2011). Certain drying procedures (e.g. tray drying) cause higher loss of ascorbic acid than other similar techniques, since a longer drying time facilitates faster oxidation of ascorbic acid (Nindo et al., 2003). In addition, certain pre-treatments, such as addition of sulphite, that are often used to reduce the rate of darkening of apricots during drying, may result in a complete loss of ascorbic acid. This situation could be related to the water-soluble character of ascorbic acid, which may cause its flow from the fruit into the sulphite solution during the immersion treatment (Garcia-Martinez et al., 2013). Furthermore, the reduction potential of most phenolic antioxidants, i.e. $E°_{red}$ of phenoxyl/phenol redox couple, are greater than the corresponding $E°_{red}$ of ascorbyl/ascorbate couple, rendering the regeneration of phenol from phenoxyl radical at the expense of oxidation of ascorbic acid to dehydroascorbic acid. On the other hand, blanching process, that is often applied as a pre-treatment to slow down or stop the enzyme and microbial activity causing undesirable changes in flavor and texture, helps to protect the vitamin content and color of the products (Korus, 2011).

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Carotenoids

Carotenoids exist as plant pigments, responsible for red, yellow and orange color, and have health-promoting effects. They are very important components of healthy human nutrition as they have pro-vitamin A activity, and their availability in processed food is an important issue (Regier et al., 2005). Alpha-carotene, β-carotene, β-cryptoxanthin, lutein, and lycopene are the main compounds that contribute to the total carotenoids present in fruits and vegetables (Leong and Oey, 2012).

Alpha-carotene has been identified as having antioxidant potential, anti-carcinogenic properties, and associations with reduced symptoms of diseases which may cause mortality (Kemp et al., 2013). In recent literature, there are only few studies which have investigated the effect of drying on α-carotene content of fruits and vegetables. Hot-air dried carrot (Zhao et al., 2014), guabiju, and red guava at 60-70°C (Table 1), freeze-dried guabiju, red guava (Nora et al., 2014), carrot, plum, and red bell pepper (Leong and Oey, 2012) (Table 2), microwave-dried carrots (Zhao et al., 2014) and jujube (Table 3) at 140-700 W, and sun-dried jujube (Gao et al., 2012) (Table 4) were found to contain significantly lower (6-100%) levels of α-carotene compared to their fresh products. On the other hand, freeze-drying for 48 h induced no change in α-carotene content of apricot, cherry, and nectarine, whereas the α-carotene content of peach was found to increase by 33% after freeze-drying (Leong and Oey, 2012) (Table 2). Similarly, 88% and 82% increases in α-carotene content of jujube were determined after oven-drying at 70°C for 8 h and freeze-drying at -50°C for 48 h, respectively (Gao et al., 2012) (Table 1 and 2).

Beta-carotene theoretically possesses 100% vitamin A activity and provides 80% of the vitamin A value of fruit and vegetables, while α-carotene possesses only 52% of vitamin A

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activity (Desobry et al., 1997). The demand for β-carotene has been increasing due to its high antioxidant potential -scavenging peroxyl radicals which occur as a result of oxidation reactions- especially at low oxygen tension (Hiranvarachat et al., 2008). However, degradation of β-carotene is often encountered in food processing. For instance, β-carotene content of hot-air/oven dried apricot (Ihns et al., 2011), carrot (Zhao et al., 2014), guabiju, red guava (Nora et al., 2014), murta berry (Rodriguez et al., 2014), papaya (Udomkun et al., 2015), paprika (Topuz et al., 2011), and sweet potato (Yang et al., 2010; Vimala et al., 2011) at 40-80°C for 4-24 h (Table 1); freeze-dried apricot, carrot, nectarine, plum, red bell pepper (Leong and Oey, 2012), guabiju, red guava (Nora et al., 2014), mango, papaya, starfruit, watermelon (Shofian et al., 2011), paprika (Topuz et al., 2011), and tomato (George et al., 2011) at -54-70°C for 48-72 h (Table 2); microwave-dried carrot (Arikan et al., 2012; Zhao et al., 2014), jujube (Gao et al., 2012), and sweet potato (Yang et al., 2010) (Table 3) at 700-900 W; sun-dried apricot (Turkyilmaz et al., 2014), fig (Yemis et al., 2012), jujube (Gao et al., 2012), and sweet potato (Vimala et al., 2011) (Table 4); refractance window^{TM} dried paprika at 94°C for 3 min (Topuz et al., 2011); and spouted-bed and vacuum-dried carrot at 5 kPa (Yan et al., 2010) (Table 5) were found to be lower than their fresh products (3-100%). On the other hand, while β-carotene in carrots (Yan et al., 2010), cherry (Leong and Oey, 2012), and sweet potato (Yang et al., 2010) were not affected significantly after freeze-drying at -40 to -50°C; surprisingly, jujube (Gao et al., 2012), muskmelon (Shofian et al., 2011), peach (Leong and Oey, 2012), and tomato (Jorge et al., 2014) were found to contained up to 9.1 fold higher β-carotene after this process (Table 2). Moreover, hot-air/oven drying at 45-70°C for 6-24 h was reported to provide a 25% to 3.9 fold increase in β-carotene content of broccoli, onion, red bell pepper (Mamatha et al., 2012), jujube (Gao et al., 2012), and tomato (Jorge et al., 2014) (Table 1). Possibly, the extractability of carotenoids has increased due to the drying processes, which may lead to a higher observed content.

Beta-cryptoxanthin plays an important role in the prevention and treatment of certain diseases, especially cancer (Ma et al., 2011). Studies investigating the effect of drying on β-cryptoxanthin revealed that drying generally reduces the β-cryptoxanthin content of fruit and vegetables. For example, hot-air/oven dried papaya (Udomkun et al., 2015), paprika (Topuz et al., 2011), guabiju, and red guava at 50-80°C (Table 1); freeze-dried guabiju, red guava (Nora et al., 2014), carrot, plum, red bell pepper (Leong and Oey, 2012), and paprika (Table 2); refractance window™ dried paprika at 94°C for 3 min (Topuz et al., 2011) (Table 5); and sun-dried fig (Yemis et al., 2012) (Table 4) contained 9-77% lower amounts of β-cryptoxanthin. Nevertheless, while no significant changes in β-cryptoxanthin content in apricot, cherry, and nectarine were observed after freeze-drying for 48 h; 33% increase was determined in case of peach (Leong and Oey, 2012) (Table 2).

Among the carotenoids, lutein has been shown to be one of the primary components in the human macula, which protects the retina from UV damage (Mamatha et al., 2012). Lutein was often reported to be degraded after drying of fruits and vegetables. Hot-air/oven dried guabiju, red guava (Nora et al., 2014), onion, and red bell pepper (Mamatha et al., 2012) at 45-80°C (Table 1); freeze-dried apricot, carrot, nectarine, plum, pepper (Leong and Oey, 2012), and guabiju (Nora et al., 2014) (Table 2); and sun-dried figs (Yemis et al., 2012) (Table 4) were found to contain 5-77% lower amounts of lutein. On the other hand, freeze-drying for 48 h resulted in no change in lutein content of cherry; whereas lutein contents of air-dried broccoli at

45°C for 6-8 h and freeze-dried peach and red guava at -54°C increased by 84, 33, and 65%, respectively (Leong and Oey, 2012; Mamatha et al., 2012; Nora et al., 2014) (Table 1 and 2).

Among all carotenoids, lycopene is not only the most abundant but also the most efficient singlet oxygen quencher with a capacity found to be more than twice that of β-carotene (Capanoglu et al., 2010). Processing conditions such as high temperature, light, and oxygen have been shown to have an effect on lycopene degradation. Degradation of lycopene not only affects the attractive color of the final products, but also their nutritional value (Muratore et al., 2008). In fact, studies have shown that hot-air dried papaya (Udomkun et al., 2015) and tomato (Kamiloglu et al., 2014a) at 50-80°C (Table 1), and freeze-dried apricot, carrot, cherry, nectarine, plum, red bell pepper (Leong and Oey, 2012), and tomato (George et al., 2011) (Table 2) contained 11-85% less or the same amount (in case of freeze-dried apricot, cherry and nectarine) of lycopene compared to their fresh counterparts. On the other hand, lycopene content of peach increased by 50% as a result of freeze-drying for 48 h (Leong and Oey, 2012) (Table 2). Similarly, up to a 10-fold increase in lycopene content of tomato was determined after oven-drying at 70°C for 24 h and freeze-drying at -54°C, 8.8×10^{-6} MPa for 48 h (Jorge et al., 2014) (Table 1 and 2). As discussed for β-carotene, this increase may relate to an improved extractability of carotenoids after drying.

Similar to the trends observed for individual carotenoids, total carotenoid content of fruit and vegetables is mostly found to decrease after various drying treatments. Total carotenoid content of apricot (Fratianni et al., 2013; Garcia-Martinez et al., 2013) after hot-air drying at 40-70°C (Table 1); bell pepper (Loizzo et al., 2013), fig (Yemis et al., 2012), and sweet potato (Vimala et al., 2011) after sun-drying for 2-14 days (Table 4); and carrot (Liu et al., 2014) after

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modified atmosphere drying at 40-70°C and 5-21% O_2 content (Table 5) were found to be reduced by 2-92%. Degradation of carotenoids during drying has been attributed to their high sensitivity to oxidation. Especially, since fruits and vegetables are directly exposed to the sunlight and heat during sun-drying, and the oxidation reactions are stimulated by light and heat -which activates the enzymes-, the major cause for carotenoid loss is most likely due to oxidation reactions. Moreover, compared to the other processing methods including heat treatment, drying leads to a higher degradation of carotenoids due to the increase in porosity (Turkyilmaz et al., 2014). When drying is conducted, the carotenoid inside the materials is concentrated and becomes vulnerable to the effects of processing conditions, such as heat and high oxygen tension, mainly because of oxidation and destruction of the conjugated double bonds in the carotenoid molecules. Conversely, reduced oxygen content during drying may improve the stability of carotenoids (Liu et al., 2014). In addition, the blanching process applied prior to drying also promoted the stability of β-carotene and lycopene during the drying process. This increase in the recorded lycopene and β-carotene contents after blanching treatment was linked to the fact that heating promotes the change from the cis to the trans conformation form, which intensifies the detection of these components (Jorge et al., 2014).

Flavonoids

Flavonoids constitute the largest group of plant phenolics, accounting for over half of the eight thousand naturally occurring phenolic compounds (Balasundram et al., 2006). Currently, there is an increasing interest in flavonoid research due to the possibility of improved public health through diet, where preventative health care can be promoted through the consumption of fruit and vegetables (Ignat et al., 2011). Fruits and vegetables rich in flavonoids can be consumed either as fresh or processed products. However, major flavonoids present in fruits and vegetables, including flavonols, flavones, flavanones, flavanols, and anthocyanins, may be affected by different processing methods including drying.

Among different flavonoid groups, flavonols, in fruits and vegetables, consist mainly of kaempferol and quercetin glycosides. Kaempferol and quercetin contents of air- and freeze-dried kale (Korus, 2011), and hot-air, freeze-, and microwave-dried raspberry (Mejia-Meza et al., 2010) were found to decrease by 2-92% compared to their fresh products (Table 1, 2 and 3). On the other hand, kaempferol-3-*O*-glucoside in oven- and sun-dried figs (Slatnar et al., 2011) and kaempferol-3-*O*-rutinoside in convective and microwave-dried sour cherry (Wojdylo et al., 2014) were found to increase approximately 2-24 fold and 2-37%, respectively (Table 1, 3 and 4). Moreover, while quercetin-3-*O*-galactoside present in apples was found to decrease by 20-43% after hot-air, oven-, and vacuum-drying (Joshi et al., 2011), quercetin-3-*O*-glucoside in oven- and sun-dried figs (Slatnar et al., 2011) and hot-air and microwave-dried sour cherry (Wojdylo et al., 2014) increased by 0.17 to 12 fold (Table 1, 3, 4 and 5). Additionally, both quercetin-3-*O*-rhamnoside in apple (Joshi et al., 2011) and quercetin-3-*O*-rutinoside (rutin) in apple (Joshi et al., 2011), jujube (Gao et al., 2012), plum (Miletic et al., 2013), sour cherry (Wojdylo et al., 2014), and tomato (Kamiloglu et al., 2014a) were decreased (8-92%) after hot-air/oven drying at 47-90°C for 7-36 h (Table 1). In addition, an 11-90% reduction in rutin content of freeze-, microwave- and sun-dried jujube was also reported (Gao et al., 2012) (Table 2, 3 and 4). In contrast, oven-drying at 62-64°C for 24 h and sun-drying at 31-34°C for 8 days caused 16% to 10 fold increases in rutin content of figs (Slatnar et al., 2011; Kamiloglu and Capanoglu, 2014) (Table 1 and 4), whereas 32-46% higher quercetin and total flavonol contents

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were determined in red onions as a result of freeze-drying at -70°C for 28 h (Perez-Gregorio et al., 2011) (Table 2).

Major flavones in fruits and vegetables include glycosides of apigenin and luteolin. Apigenin in bell pepper (Loizzo et al., 2013) and figs (Kamiloglu and Capanoglu, 2014) were found to decrease by 16-33% after sun-drying at 30-35°C for 8-14 days (Table 4). On the other hand, while luteolin-8-*C*-glucoside was not detected in fresh figs, oven- and sun-drying resulted in formation of this compound in the process (Slatnar et al., 2011) (Table 4).

One of the main flavanone aglycone present in fruits is naringenin. Hot-air, freeze- and microwave-drying varied the naringenin and naringin contents of raspberry, resulted in both increases and decreases (Mejia-Meza et al., 2010) (Table 1, 2 and 3). Complete loss of naringenin chalcone, as well as its conversion into naringenin was observed in tomatoes after hot-air drying at 70°C for 36 h (Kamiloglu et al., 2014a) (Table 1).

Catechin and epicatechin are the main flavanols in fruits and vegetables. The contents of catechin and epicatechin in hot-air and vacuum-dried apples (Joshi et al., 2011); oven-, freeze- and sun-dried jujubes (Gao et al., 2012); convective, freeze- and microwave-dried sour cherries (Wojdylo et al., 2014), and sun-dried figs (Kamiloglu and Capanoglu, 2014) were decreased, whereas hot-air dried figs at 62-64°C for 24 h (Slatnar et al., 2011) and microwave-dried jujube at 700 W for 4 min (Gao et al., 2012) were found to contain approximately 1.2-11 fold higher amounts of catechin and epicatechin (Tables 1, 2, 3, 4 and 5). Moreover, while oven drying at 70°C for 10 h and vacuum drying at 20-50°C for 24 h caused decreases in epigallocatechin content in apples (18-50%), air-drying at 47°C for 7 h resulted in an < 50% increase (Joshi et al., 2011) (Table 1 and 5).

The most widespread anthocyanidins are cyanidin, delphinidin, malvidin, pelargonidin, and peonidin, which are abundantly present as glycoconjugates in colored fruits. Air-drying at 70-90°C and freeze-drying at -54°C resulted in 51% to 100% loss of cyanidin in plum (Miletic et al., 2013), guabiju, and red guava (Nora et al., 2014) (Table 1 and 2). Moreover, both air-drying at 47°C for 7h and vacuum-drying at 20-50°C for 24 h caused 45-66% decreases in cyanidin-3-*O*-galactoside content in apples (Joshi et al., 2011), whereas hot-air dried grapes (Marquez et al., 2012); convective, freeze-, and microwave-dried sour cherry (Wojdylo et al., 2014); freeze-dried cherry, peach, and plum (Leong and Oey, 2012); and sun-dried fig (Kamiloglu and Capanoglu, 2014) contained up to 98% lower amounts of cyanidin-3-*O*-glucoside and cyanidin-3-*O*-rutinoside compared to their fresh products (Table 1, 2, 3, 4 and 5). Furthermore, the cyanidin-3-glucosylrutinoside and cyanidin-3-*O*-sophoroside content of sour cherries were also found to decrease (1-59%) as a result of convective, freeze-, and microwave-drying (Wojdylo et al., 2014) (Table 1, 2 and 3). On the other hand, freeze-dried apricot, nectarine (Leong and Oey, 2012), and guabiju (Nora et al., 2014) contained 0.22 to 3-fold higher cyanidin-3-*O*-glucoside compared to fresh fruits (Table 2). Delphinidin-3-*O*-glucoside content of grapes (Marquez et al., 2012) showed 37% decrease to 108% increase after air-drying at 40°C, while freeze-drying at -54°C caused 83% increase in delphinidin-3-β-D-glucoside content of guabiju (Nora et al., 2014) (Table 1 and 2). In addition, while malvidin-3-*O*-glucoside content of freeze-dried guabiju and red guava were found to decrease (Nora et al., 2014), grapes were found to contain 26-57% higher malvidin-3-*O*-glucoside after air-drying (Marquez et al., 2012) (Table 1 and 2). Peonidin-3-*O*-rutinoside content of sour cherries decreased by 21-60% as a result of hot-air, freeze- and, microwave-drying (Table 1, 2 and 3). Conversely, air-drying at 40°C resulted with an increase up to 74% in pelargonidin-3-*O*-glucoside, peonidin-3-*O*-glucoside, and petunidin-3-O-glucoside contents of grapes (Marquez et al., 2012) (Table 1). Various drying techniques induced reductions in total anthocyanin content of different fruits and vegetables, including blueberry (Sablani et al., 2011), fig (Kamiloglu and Capanoglu, 2014), mulberry (Chottamom et al., 2012), raspberry (Mejia-Meza et al., 2010; Sablani et al., 2011), red guava (Nora et al., 2014), and sweet potato (Liu et al., 2012) (Table 1, 2, 3, 4 and 5). On the contrary, the total anthocyanin contents of raspberry (Sablani et al., 2011) and red onion (Perez-Gregorio et al., 2011) were found to increase up to 26% (Table 2).

Total flavonoid content of fruits and vegetables is also affected during different drying treatments. While the total flavonoid content of air-dried murta berry (Rodriguez et al., 2014) and tomato (Kamiloglu et al., 2014a) at 40-80°C, and sun-dried bell pepper at 30-35°C (Loizzo et al., 2013) decreased (3-83%); air-drying at 90°C slightly increased the total flavonoid content of plum (≈%5) (Miletic et al., 2013) (Table 1 and 4). Moreover, while oven-drying at 60°C for 24 h increased the total flavonoid content of raw papaya (up to 105%), the same treatment decreased the flavonoid content of ripe papaya (≈67%). On the other hand, freeze-drying at -50°C for 24 h caused the opposite effect, leading to an increase in ripe papayas (up to 2 fold) and decrease in raw papayas (≈50%) (Annegowda et al., 2014) (Table 1 and 2). Similarly, total flavonoids in figs were measured to vary in content after sun-drying at 31-34°C for 8 days (Kamiloglu and Capanoglu, 2014) (Table 4). The use of high temperature during drying may affect the retention of flavonoids, which was reflected in the data presented here with hot-air dried fruits and vegetables, having lower retention of flavonoids compared to the other drying methods. The increase in the amount of total flavonoids as a result of drying can be explained by the break down of cell walls and/or release from sequestration, which may also end up with higher extractability of compounds from the samples (Capanoglu, 2014).

Phenolic acids

Among the phenolic compounds, phenolic acids have attracted considerable interest in the past few years due to their potential health benefits including antioxidant, antibacterial, antiviral, anticarcinogenic, anti-inflammatory, and vasodilatory actions (Babbar et al., 2015). Phenolic acids consist of two subgroups, including hydroxybenzoic and hydroxycinnamic acids, and are abundantly present in many fruits and vegetables.

Major hydroxybenzoic acids in fruits and vegetables include ellagic, gallic, *p*-hydroxybenzoic, protocatechuic, and vanillic acids. Ellagic acid content of hot-air dried murta berry (Rodriguez et al., 2014) and hot-air, freeze-, and microwave-dried pomegranate arils (Calin-Sanchez et al., 2013), and raspberry (Mejia-Meza et al., 2010) were reported to decrease by 3-87% (Table 1, 2, and 3); whereas a 50% higher amount of ellagic acid was measured in figs after sun-drying at 31-34°C for 8 days (Kamiloglu and Capanoglu, 2014) (Table 4). Moreover, while hot-air drying at 40-80°C for 300-1400 min induced a 49-63% reduction in gallic acid content of murta berry (Rodriguez et al., 2014); prunes were found to contain 3-3.5 fold higher amounts of gallic acid following hot-air drying at 90°C (Miletic et al., 2013) (Table 1). *p*-Hydroxybenzoic acid was either present in low quantities or not detected at all in oven-, freeze-, and microwave-dried jujubes; whereas sun-drying for 3 weeks resulted in a significant increase (2.6 fold) in the content of this compound (Gao et al., 2012) (Table 1, 2, 3 and 4). Furthermore, hot-air drying caused a 28-88% reduction in protocatechuic acid content of murta berry (Rodriguez et al., 2014) and plum (Miletic et al., 2013) (Table 1). Similarly, the protocatechuic acid content of jujubes decreased with oven-, freeze-, and sun-drying treatments (89-98%); whereas, 37% increase was observed with microwave treatment at 700 W for 4 min (Table 1, 2, 3 and 4). In addition, the amount of vanillic acid decreased (46-92%) in oven- and freeze-drying treatments compared to the fresh jujube, whereas sun-drying resulted in 1.5 fold increase in vanillic acid levels (Gao et al., 2012) (Table 1, 2, and 4).

Hydroxycinnamic acids are aromatic compounds, with caffeic, chlorogenic, cinnamic, *p*-coumaric, ferulic, and sinapic acids being the most common. Caffeic acid content of kale decreased (28-73%) as a result of air- and freeze-drying (Korus, 2011), whereas air-drying at 90°C increased the caffeic acid content of plum significantly (11-19%) (Miletic et al., 2013) (Table 1 and 2). Moreover, hot-air dried apple (Joshi et al., 2011) and tomato (Kamiloglu et al., 2014a); convective-, freeze-, and microwave-dried sour cherry (Wojdylo et al., 2014); and sun-dried fig (Kamiloglu and Capanoglu, 2014) were found to contain up to 87% lower levels of chlorogenic acid compared to their fresh product (Table 1, 2, 3 and 4). Conversely, oven- and sun-drying of figs resulted in a 3-11 fold higher chlorogenic acid content (Slatnar et al., 2011) (Table 1 and 4). While cinnamic acid content of jujubes decreased with oven-, freeze-, and sun-drying treatments (15-69%); hot-air dried murta berry at 40-80°C and microwave-dried jujube at 700 W for 4 min were determined to contain 8-35% higher amounts of cinnamic acid (Gao et al., 2012; Rodriguez et al., 2014) (Table 1, 2, 3 and 4). Furthermore, *p*-coumaric and ferulic acid contents of hot-air/oven- and freeze-dried kale (Korus, 2011) and jujube decreased by 33-100%, whereas the content of *p*-coumaric acid and ferulic acid contents of in sun-dried jujube increased up to 1.4 fold (Gao et al., 2012) (Table 1, 2 and 4). In addition, both neochlorogenic acid content of sour cherry (Wojdylo et al., 2014) and sinapic acid content of kale (Korus, 2011) decreased (7-56%) as a result of convective-drying at 50-70°C and freeze-drying at -50°C (Table 1 and 2).

Total phenolics and antioxidant capacity

In the literature, quantification of total phenolics in fruits and vegetables was generally performed using the Folin-Ciocalteu's method. For many years, this method has been used to measure total phenolic content in natural matrices but since its mechanism is an oxidation/reduction reaction, it may also be considered as an antioxidant method (Prior et al., 2005). Recently, there has been extensive research into the effect of processing on the total phenolic contents of various fruits and vegetables including the influence of drying. Total phenolic content of apple, mango, papaya, and pear after hot-air, microwave-, and heat-pump drying (Chong et al., 2013); jujube after oven-, microwave-, and sun-drying (Gao et al., 2012); kale after air- and freeze-drying (Korus, 2011); mulberry, murta berry, and sebuckthorn berry after hot-air drying (Araya-Farias et al., 2011; Chottamom et al., 2012; Rodriguez et al., 2014); pomegranate, raspberry, and sour cherry after hot-air, freeze-, and microwave-drying (Mejia-Meza et al., 2010; Calin-Sanchez et al., 2013; Wojdylo et al., 2014); tomato after oven-, freeze-, and sun-drying (Gumusay et al., 2015); mango, muskmelon, papaya, starfruit, and watermelon after freeze-drying (Shofian et al., 2011); and apricot, bell pepper, and fig (Turkyilmaz et al., 2012; Loizzo et al., 2013; Kamiloglu and Capanoglu, 2014) after sun-drying were all found to decrease (Table 1, 2, 3, 4 and 5). During the drying processes, activation of oxidative enzymes, such as polyphenoloxidase and peroxidase, may lead to the loss of phenolic compounds. In addition, binding of phenolic compounds to proteins, changes in chemical structures or low extraction efficiencies are other factors related to the loss in total phenolic content (Gumusay et al., 2015). On the other hand, various different drying methods resulted in up to a 10 fold increase in total phenolic content of apple (Joshi et al., 2011), blueberry (Sablani et al., 2011), fig (Slatnar et al., 2011), jujube (Gao et al., 2012), papaya (Annegowda et al., 2014) plum (Miletic et al., 2013), raspberry (Sablani et al., 2011), and sweet potato (Yang et al., 2010) (Table 1, 2, 3, 4 and 5). These increases in the total phenolic content can be explained by the release of phenolic compounds bound to the plant cell wall (Gumusay et al., 2015).

Different methodologies have been employed to evaluate the *in vitro* antioxidant capacity of fruits and vegetables. Assays such as 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), oxygen radical absorbance capacity (ORAC) and cupric ion reducing antioxidant capacity (CUPRAC) are simple, cost effective, easily interpreted and display either direct free radical inhibition (ABTS, DPPH) or reduction capacity (FRAP, CUPRAC) (Apak et al., 2007; Wootton-Beard et al., 2011; Kamiloglu et al., 2014b). It should be noted that such *in vitro* antioxidant measurement techniques are semi-quantitative and do not always show the capacity of antioxidation *in vivo* (Niki, 2011; Chiva-Blanch and Visioli, 2012). The antioxidant capacity of apple, mango, papaya (Chong et al., 2013), apricot (Turkyilmaz et al., 2014), fig (Kamiloglu and Capanoglu, 2014), jujube (Gao et al., 2012), mulberry (Chottamom et al., 2012), murta berry (Rodriguez et al., 2014), pomegranate (Calin-Sanchez et al., 2013), raspberry (Mejia-Meza et al., 2010), sebuckthorn berry (Araya-Farias et al., 2011), sour cherry (Wojdylo et al., 2014), starfruit (Shofian et al., 2011), and tomato (Kamiloglu et al., 2014a) were found to decrease after various drying treatments (Table 1, 2, 3, 4 and 5). The decrease in antioxidant activity as a result of drying is related to the degradation of biologically active compounds at high temperatures, due to chemical, enzymatic or thermal decomposition (Nicoli et al., 1999). However, certain drying treatments, especially freeze-drying, increased the total antioxidant capacity of dried fruits and vegetables, such as blueberry, raspberry (Sablani et al., 2011), guabiju, red guava (Nora et al., 2014), muskmelon, watermelon (Shofian et al., 2011), papaya (Annegowda et al., 2014), and sweet potato (Yang et al., 2010) (Table 2). Recent research suggested that the high antioxidant activity in fruits and vegetables after drying might be related to the fact that partially oxidized polyphenols have greater antioxidant activity than non-oxidized polyphenols (Nora et al., 2014). In addition, increases in antioxidant capacity after drying may be related to the Maillard reaction products (MRPs), which can be formed as a consequence of heat treatment or prolonged storage and, which generally exhibit strong antioxidant properties (Kamiloglu and Capanoglu, 2014).

CONCLUSION AND FUTURE PERSPECTIVES

This review presents the results observed through recent literature studies, where the influence of drying on antioxidant potential of fruits and vegetables has been described. In most cases, decreases of antioxidant content are observed, which can generally be attributed to oxidation processes or thermal degradation. However, in some cases spectacular increases (up to 20-fold) of the content of some antioxidants have been observed. While it is unlikely that antioxidants arise de novo during the drying processes, explanations for this phenomenon could be found in improved extractability of dried material, leading to an improved detection of the antioxidant compounds. In general, findings in the literature showed that freeze-drying is superior in comparison to the other drying methods, in terms of preserving the antioxidant compounds. During freeze-drying, low temperatures are used that could help to retain heat-sensitive antioxidants. Moreover, freeze-drying leads to higher extraction efficiencies of antioxidants with the formation of ice crystals within the plant matrix during freezing, that may result in a greater disruption of (sub)cellular structure, allowing for improved solvent infiltration into the matrix. On the other hand, other drying methods cause less cell damage, in addition to the negative effects of high temperatures, both of which favor antioxidant loss. However, current findings are still inconsistent. This may be attributed to the differences in the variety or ripeness of the fruits and vegetables that are used as raw materials, agricultural treatments, unknown external factors such as time, temperature, presence of oxygen, and/or light, and the method of drying, or it might just be a consequence of poor extraction of the antioxidants to be analyzed. Also, the ability to preserve antioxidant activity depends on the physical properties (texture, peel thickness, etc.) of fruits and vegetables. Another reason could be the application of various pre-treatments in different studies, e.g. pre-drying, blanching, freezing, sulphiting, and vacuuming, which can all have a strong influence on the recovery of bioactive compounds. In fact, it has been proven that sulphite treatment results in overestimation of the actual antioxidant activity and that sun-dried apricots retain more antioxidant power compared to sulphited-dried ones. Excessive sulphiting may also cause allergies and asthma (Guclu et al., 2006). Another reason that should be taken into consideration in observing different results in different studies is that in some studies, fruits and vegetables were obtained from local markets, thus the metadata regarding their history is unknown. However, it is well known that factors such as variety, age, treatment, etc. should also be considered while determining the antioxidant potential of fruits and vegetables. Furthermore, alterations in analytical methods and different ways used in expression of results (wet/dry basis) make the comparisons between studies rather difficult. Mathematical modeling is an important technology for optimization of drying parameters for fruit and vegetable preservation. Therefore, future studies may more and more include mathematical modeling to provide information on the optimum processing parameters (Sagar and Kumar, 2010). Although the traditional sun-drying method is still the most common way of preserving fruits and vegetables, there is limited information on the changes in antioxidant compounds of fruits and vegetables resulting from this method. Hence, further studies focusing on the effect of sun-drying on antioxidants of fruits and vegetables should be performed.

 ACCEPTED MANUSCRIPT

REFERENCES

Alvarez-Suarez, J.M., Giampieri, F., Tulipani, S., Casoli, T., Di Stefano, G., Gonzalez-Paramas, A.M., Santos-Buelga, C., Busco, F., Quiles J.L., Cordero, M.D., Bompadre, S., Mezzetti, B., and Battino, M. (2014). One-month strawberry-rich anthocyanin supplementation ameliorates cardiovascular risk, oxidative stress markers and platelet activation in humans. *J. Nutr. Biochem.* **25**: 289-294.

Annegowda, H.V., Bhat, R., Yeong, K.J., Liong, M.T., Karim, A.A., and Mansor, S.M. (2014). Influence of drying treatments on polyphenolic contents and antioxidant properties of raw and ripe papaya (*Carica papaya* L.). *Int. J. Food Prop*. **17**: 283-292.

Apak, R., Guclu, K., Demirata, B., Ozyurek, M., Celik, S. E., Bektasoglu, B., Berker, K.I., and Ozyurt, D. (2007). Comparative evaluation of various total antioxidant capacity assays applied to phenolic compounds with the CUPRAC assay. *Molecules*. **12**: 1496-1547.

Araya-Farias, M., Makhlouf, J., and Ratti, C. (2011). Drying of seabuckthorn (*Hippophae rhamnoides* L.) berry: Impact of dehydration methods on kinetics and quality. *Drying Technol*. **29**: 351-359.

Arikan, M.F., Ayhan, Z., Soysal, Y., and Esturk, O. (2012). Drying characteristics and quality parameters of microwave-dried grated carrots. *Food Bioprocess Tech*. **5**: 3217-3229.

Babbar, N., Oberoi, H.S., and Sandhu, S.K. (2015). Therapeutic and nutraceutical potential of bioactive compounds extracted from fruit residues. *Crit. Rev. Food Sci. Nutr*. **55**: 319-337.

Balasundram, N., Sundram, K., and Samman, S. (2006). Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. *Food Chem*. **99**: 191-203.

 ACCEPTED MANUSCRIPT

Calin-Sanchez, A., Figiel, A., Hernandez, F., Melgarejo, P., Lech, K., and Carbonell-Barrachina, A.A. (2013). Chemical composition, antioxidant capacity, and sensory quality of pomegranate (*Punica granatum* L.) arils and rind as affected by drying method. *Food Bioprocess Tech*. **6**: 1644-1654.

Capanoglu, E. (2014). Investigating the antioxidant potential of Turkish dried fruits. *Int. J. Food Prop*. **17**: 690-702.

Capanoglu, E., Beekwilder, J., Boyacioglu, D., De Vos, R.C., and Hall, R.D. (2010). The effect of industrial food processing on potentially health-beneficial tomato antioxidants. *Crit. Rev. Food Sci. Nutr*. **50**: 919-930.

Chiva-Blanch, G., and Visioli, F. (2012). Polyphenols and health: moving beyond antioxidants. *J. Berry Res.* **2**: 63-71.

Chong, C.H., Law, C.L., Figiel, A., Wojdylo, A., and Oziemblowski, M. (2013). Colour, phenolic content and antioxidant capacity of some fruits dehydrated by a combination of different methods. *Food Chem*. **141**: 3889-3896.

Chottamom, P., Kongmanee, R., Manklang, C., and Soponronnarit, S. (2012). Effect of osmotic treatment on drying kinetics and antioxidant properties of dried mulberry. *Drying Technol*. **30**: 80-87.

Desobry, S.A., Netto, F.M., and Labuza, T.P. (1997). Comparison of spray-drying, drum-drying and freeze-drying for β-carotene encapsulation and preservation. *J. Food Sci*. **62**: 1158-1162.

Effie, V., and Antonia, T. (2014). Greek raisins: A traditional nutritious delicacy. *J. Berry Res.* **4**: 117-125.

 ACCEPTED MANUSCRIPT

Fratianni, A., Albanese, D., Mignogna, R., Cinquanta, L., Panfili, G., and Di Matteo, M. (2013). Degradation of carotenoids in apricot (*Prunus armeniaca* L.) during drying process. *Plant Foods Hum. Nutr*. **68**: 241-246.

Gao, Q.H., Wu, C.S., Wang, M., Xu, B.N., and Du, L.J. (2012). Effect of drying of jujubes (*Ziziphus jujuba* Mill.) on the contents of sugars, organic acids, *α*-tocopherol, *β*-carotene, and phenolic compounds. *J. Agric. Food Chem*. **60**: 9642-9648.

Garcia-Martinez, E., Igual, M., Martín-Esparza, M.E., and Martinez-Navarrete, N. (2013). Assessment of the bioactive compounds, color, and mechanical properties of apricots as affected by drying treatment. *Food Bioprocess Tech*. **6**: 3247-3255.

George, S., Tourniaire, F., Gautier, H., Goupy, P., Rock, E., and Caris-Veyrat, C. (2011). Changes in the contents of carotenoids, phenolic compounds and vitamin C during technical processing and lyophilisation of red and yellow tomatoes. *Food Chem*. **124**: 1603-1611.

Giampieri, F., Alvarez-Suarez, J.M., and Battino, M. (2014). Strawberry and human health: Effects beyond antioxidant activity. *J. Agric. Food Chem.* **62**: 3867-3876.

Guclu, K., Altun, M., Ozyurek, M., Karademir, S. E., and Apak, R. (2006). Antioxidant capacity of fresh, sun- and sulphited- dried Malatya apricot (*Prunus armeniaca*) assayed by CUPRAC, ABTS/TEAC and folin methods. *Int. J. Food Sci. Technol.* **41**: 76-85.

Gumusay, O.A., Borazan, A.A., Ercal, N., and Demirkol, O. (2015). Drying effects on the antioxidant properties of tomatoes and ginger. *Food Chem*. **173**: 156-162.

Hiranvarachat, B., Suvarnakuta, P., and Devahastin, S. (2008). Isomerisation kinetics and antioxidant activities of β-carotene in carrots undergoing different drying techniques and conditions. *Food Chem*. **107**: 1538-1546.

Ignat, I., Volf, I., and Popa, V. I. (2011). A critical review of methods for characterisation of polyphenolic compounds in fruits and vegetables. *Food Chem*. **126**: 1821-1835.

Ihns, R., Diamante, L.M., Savage, G.P., and Vanhanen, L. (2011). Effect of temperature on the drying characteristics, colour, antioxidant and beta-carotene contents of two apricot varieties. *Int. J. Food Sci Technol*. **46**: 275-283.

Jorge, A., Almeida, D.M., Canteri, M.H.G., Sequinel, T., Kubaski, E.T., and Tebcherani, S.M. (2014). Evaluation of the chemical composition and colour in long-life tomatoes (*Lycopersicon esculentum* Mill) dehydrated by combined drying methods. *Int. J. Food Sci Technol*. **49**: 2001-2007.

Joshi, A.P.K., Rupasinghe, H.P.V., and Khanizadeh, S. (2011). Impact of drying processes on bioactıve phenolics, vitamin C and antioxidant capacity of red-fleshed apple slices. *J. Food Process. Preserv*. **35**: 453-457.

Kalt, W. (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *J. Food Sci*. **70**: R11-R19.

Kamiloglu, S., and Capanoglu, E. (2014). Polyphenol content in figs (*Ficus carica* L.): Effect of sun-drying. *Int. J. Food Prop*. doi:10.1080/10942912.2013.833522.

Kamiloglu, S., Demirci, M., Selen, S., Toydemir, G., Boyacioglu, D., and Capanoglu, E. (2014a). Home processing of tomatoes (*Solanum lycopersicum*): Effects on *in vitro* bioaccessibility of total lycopene, phenolics, flavonoids, and antioxidant capacity. *J. Sci. Food Agric*. **94**: 2225-2233.

Kamiloglu, S., Pasli, A.A., Ozcelik, B., and Capanoglu, E. (2014b). Evaluating the *in vitro* bioaccessibility of phenolics and antioxidant activity during consumption of dried fruits with nuts. *LWT-Food Sci. Technol.* **56**: 284-289.

Kaur, C., and Kapoor, H.C. (2001). Antioxidants in fruits and vegetables-the millennium's health. *Int. J. Food Sci Technol.* **36**: 703-725.

Kemp, M., Dever, J., Thompson, A., Metzger, B., and Barnes, D. (2013). Evaluation of pumpkins as a novel source for α-carotene. *FASEB J.* **27**: 1079.60.

Korus, A. (2011). Effect of preliminary processing, method of drying and storage temperature on the level of antioxidants in kale (*Brassica oleracea* L. var. *acephala*) leaves. *LWT-Food Sci. Technol.* **44**: 1711-1716.

Leong, S.Y., and Oey, I. (2012). Effects of processing on anthocyanins, carotenoids and vitamin C in summer fruits and vegetables. *Food Chem.* **133**: 1577-1587.

Liu, Y., Wu, J., Miao, S., Chong, C., and Sun, Y. (2014). Effect of a modified atmosphere on drying and quality characteristics of carrots. *Food Bioprocess Tech.* **7**: 2549-2559.

Liu, P., Zhang, M., and Mujumdar, A.S. (2012). Comparison of three microwave-assisted drying methods on the physiochemical, nutritional and sensory qualities of re-structured purple-fleshed sweet potato granules. *Int. J. Food Sci Technol.* **47**: 141-147.

Loizzo, M.R., Pugliese, A., Bonesi, M., De Luca, D., O'Brien, N., Menichini, F. and Tundis, R. (2013). Influence of drying and cooking process on the phytochemical content, antioxidant and hypoglycaemic properties of two bell *Capsicum annum* L. cultivars. *Food Chem. Toxicol.* **53**: 392-401.

Ma, G., Zhang, L., Kato, M., Yamawaki, K., Kiriiwa, Y., Yahata, M., Ikoma, Y. and Matsumoto, H. (2011). Effect of blue and red LED light irradiation on β-cryptoxanthin accumulation in the flavedo of citrus fruits. *J. Agric. Food Chem*. **60**: 197-201.

Mamatha, B.S., Arunkumar, R., and Baskaran, V. (2012). Effect of processing on major carotenoid levels in corn (*Zea mays*) and selected vegetables: Bioavailability of lutein and zeaxanthin from processed corn in mice. *Food Bioprocess Tech*. **5**: 1355-1363.

Marquez, A., Duenas, M., Serratosa, M.P., and Merida, J. (2012). Formation of vitisins and anthocyanin–flavanol adducts during red grape drying. *J. Agric. Food Chem*. **60**: 6866-6874.

Mejia-Meza, E.I., Yanez, J. A., Remsberg, C.M., Takemoto, J.K., Davies, N.M., Rasco, B. and Clary, C. (2010). Effect of dehydration on raspberries: polyphenol and anthocyanin retention, antioxidant capacity, and antiadipogenic activity. *J. Food Sci*. **75**: H5-H12.

Miletic, N., Mitrovic, O., Popovic, B., Nedovic, V., Zlatkovic, B., and Kandic, M. (2013). Polyphenolic content and antioxidant capacity in fruits of plum (*Prunus domestica* L.) cultivars "Valjevka" and "Mildora" as influenced by air drying. *J. Food Qual*. **36**: 229-237.

Muratore, G., Rizzo, V., Licciardello, F., and Maccarone, E. (2008). Partial dehydration of cherry tomato at different temperature, and nutritional quality of the products. *Food Chem*. **111**: 887-891.

Nicoli, M.C., Anese, M., and Parpinel, M. (1999). Influence of processing on the antioxidant properties of fruit and vegetables. *Trends Food Sci. Technol*. **10**: 94-100.

Niki, E. (2011). Antioxidant capacity: which capacity and how to assess it?. *J. Berry Res*. **1**: 169-176.

Nindo, C., Sun, T., Wang, S. W., Tang, J., and Powers, J. R. (2003). Evaluation of drying technologies for retention of physical quality and antioxidants in asparagus (*Asparagus officinalis* L.). *LWT-Food Sci. Technol*. **36**: 507-516.

Nora, C.D., Muller, C.D.R., de Bona, G.S., Rios, A.D.O., Hertz, P.F., Jablonski, A., de Jong, and Flores, S.H. (2014). Effect of processing on the stability of bioactive compounds from red guava (*Psidium cattleyanum* Sabine) and guabiju (*Myrcianthes pungens*). *J. Food Composit. Anal*. **34**: 18-25.

Perez-Gregorio, M. R., Regueiro, J., Gonzalez-Barreiro, C., Rial-Otero, R., and Simal-Gandara, J. (2011). Changes in antioxidant flavonoids during freeze-drying of red onions and subsequent storage. *Food Control*. **22**: 1108-1113.

Prior, R.L., Wu, X., and Schaich, K. (2005). Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. *J. Agric. Food Chem*. **53**: 4290-4302.

Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. *J. Food Eng*. **49**: 311-319.

Regier, M., Mayer-Miebach, E., Behsnilian, D., Neff, E., and Schuchmann, H.P. (2005). Influences of drying and storage of lycopene-rich carrots on the carotenoid content. *Drying Technol*. **23**: 989-998.

Rodriguez, K., Ah-Hen, K., Vega-Galvez, A., Lopez, J., Quispe-Fuentes, I., Lemus-Mondaca, and Galvez-Ranilla, L. (2014). Changes in bioactive compounds and antioxidant activity during convective drying of murta (*Ugni molinae* T.) berries. *Int. J. Food Sci Technol.* **49**: 990-1000.

Sablani, S.S., Andrews, P.K., Davies, N.M., Walters, T., Saez, H., and Bastarrachea, L. (2011). Effects of air and freeze drying on phytochemical content of conventional and organic berries. *Drying Technol*. **29**: 205-216.

Sagar, V.R., and Kumar, P.S. (2010). Recent advances in drying and dehydration of fruits and vegetables: a review. *J. Food Sci. Technol*. **47**: 15-26.

Santos, P.H.S., and Silva, M. A. (2008). Retention of vitamin C in drying processes of fruits and vegetables-A review. *Drying Technol*. **26**: 1421-1437.

Shofian, N.M., Hamid, A.A., Osman, A., Saari, N., Anwar, F., Pak Dek, M.S., and Hairuddin, M.R. (2011). Effect of freeze-drying on the antioxidant compounds and antioxidant activity of selected tropical fruits. *Int. J. Mol. Sci*. **12**: 4678-4692.

Slatnar, A., Klancar, U., Stampar, F., and Veberic, R. (2011). Effect of drying of figs (*Ficus carica* L.) on the contents of sugars, organic acids, and phenolic compounds. *J. Agric. Food Chem*. **59**: 11696-11702.

Stanner, S.A., Hughes, J., Kelly, C.N.M., and Buttriss, J. (2004). A review of the epidemiological evidence for the 'antioxidant hypothesis'. *Public Health Nutr*. **7**: 407-422.

Toor, R.K., and Savage, G.P. (2006). Effect of semi-drying on the antioxidant components of tomatoes. *Food Chem*. **94**: 90-97.

Topuz, A., Dincer, C., Ozdemir, K.S., Feng, H., and Kushad, M. (2011). Influence of different drying methods on carotenoids and capsaicinoids of paprika (Cv., Jalapeno). *Food Chem*. **129**: 860-865.

Turkyilmaz, M., Ozkan, M., and Guzel, N. (2014). Loss of sulfur dioxide and changes in some chemical properties of Malatya apricots (*Prunus armeniaca* L.) during sulfuring and drying. *J. Sci. Food Agric*. **94**: 2488-2496.

Udomkun, P., Nagle, M., Mahayothee, B., Nohr, D., Koza, A., and Muller, J. (2015). Influence of air drying properties on non-enzymatic browning, major bio-active compounds and antioxidant capacity of osmotically pretreated papaya. *LWT-Food Sci. Technol*. **60**: 914-922.

Vimala, B., Nambisan, B., and Hariprakash, B. (2011). Retention of carotenoids in orange-fleshed sweet potato during processing. *J. Food Sci. Technol*. **48**: 520-524.

Wojdylo, A., Figiel, A., Lech, K., Nowicka, P., and Oszmianski, J. (2014). Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. *Food Bioprocess Tech*. **7**: 829-841.

Wootton-Beard, P.C., Moran, A., and Ryan, L. (2011). Stability of the total antioxidant capacity and total polyphenol content of 23 commercially available vegetable juices before and after *in vitro* digestion measured by FRAP, DPPH, ABTS and Folin-Ciocalteu methods. *Food Research Int*. **44**: 217-224.

Yan, W.Q., Zhang, M., Huang, L.L., Tang, J., Mujumdar, A.S., and Sun, J. C. (2010). Studies on different combined microwave drying of carrot pieces. *Int. J. Food Sci Technol*. **45**: 2141-2148.

Yang, J., Chen, J.F., Zhao, Y.Y., and Mao, L.C. (2010). Effects of drying processes on the antioxidant properties in sweet potatoes. *Agric. Sci. China*. **9**: 1522-1529.

Yemis, O., Bakkalbasi, E., and Artik, N. (2012). Changes in pigment profile and surface colour of fig (*Ficus carica* L.) during drying. *Int. J. Food Sci Technol*. **47**: 1710-1719.

Zhang, M., Tang, J., Mujumdar, A.S., and Wang, S. (2006). Trends in microwave-related drying of fruits and vegetables. *Trends Food Sci. Technol*. **17**: 524-534.

Zhao, D., An, K., Ding, S., Liu, L., Xu, Z., and Wang, Z. (2014). Two-stage intermittent microwave coupled with hot-air drying of carrot slices: Drying kinetics and physical quality. *Food Bioprocess Tech*. **7**: 2308-2318.

Table 1. Changes in antioxidant compounds of fruits and vegetables subjected to hot-air/oven drying

Product	Treatment	Pre-treatment	Compound	Result	Reference
Apple	47±2°C, 7 h, 0.7±0.1 m/s air velocity	None	Vitamin C Quercetin-3-*O*-galactoside Quercetin-3-*O*-glucoside Quercetin-3-*O*-rhamnoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Epigallocatechin Cyanidin-3-*O*-galactoside Chlorogenic acid Total phenolics Antioxidant capacity	51%↓(dw)* 27%↓(dw) 2%↑(dw) 15%↓(dw) 11%↓(dw) 31%↓(dw)* 23%↓(dw)* 50%↑(dw) 53%↓(dw) 3%↓(dw) 6%↑(dw) 4%↓, 33%↑(dw)	Joshi et al., 2011

			(FRAP, ORAC)		
	70±2°C, 10 h	None	Vitamin C Quercetin-3-*O*-galactoside Quercetin-3-*O*-glucoside Quercetin-3-*O*-rhamnoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Epigallocatechin Cyanidin-3-*O*-galactoside Chlorogenic acid Total phenolics Antioxidant capacity (FRAP, ORAC)	30%↓(dw)* 43%↓(dw)* 35%↓(dw) 21%↓(dw)* 72%↑(dw) 17%↓(dw) 22%↓(dw)* 50%↓(dw) 66%↓(dw)* 18%↓(dw) 9%↑(dw) 72%↓, 6%↑(dw)	Joshi et al., 2011
	53.94±0.03°C	Cold-air drying	Total phenolics Antioxidant capacity	46%↓ 67%↓	Chong et al., 2013

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			(DPPH)		
Apricot	60-70°C, 240-990 min, 0.2 m/s air velocity	None	β-carotene Antioxidant capacity (ORAC)	32-76%↓(dw)* 70%↓ to 61%↑(dw)*	Ihns et al., 2011
	60-70°C, 2-21 h, 2.3 m/s air velocity	None	Total carotenoids	≈0-40%↓*	Fratianni et al., 2013
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Apricot	40-60°C	None	Ascorbic acid Total carotenoids	68-72%↓(dw)* 5-9%↓(dw)*	Garcia-Martinez et al., 2013
	40-60°C	Sulphiting	Ascorbic acid Total carotenoids	100%↓(dw)* 11-16↓(dw)*	Garcia-Martinez et al., 2013
Blueberry	65°C, 5 m/s air velocity, 11.2%RH	None	Total anthocyanins Total phenolics Antioxidant capacity (ABTS)	42-81%↓(dw)* 18%↓ to 80%↑(dw)* 38%↓ to	Sablani et al., 2011

				43%↑(dw)*	
	65°C, 5 m/s air velocity, 11.2%RH	Blanching	Total anthocyanins Total phenolics Antioxidant capacity (ABTS)	44-54%↓(dw)* 5%↓ to 17%↑(dw) 27%↓ to 25%↑(dw)	Sablani et al., 2011
Broccoli	45±5°C, 6-8 h	Blanching	β-carotene Lutein	93%↑(dw)* 84%↑(dw)*	Mamatha et al., 2012
Carrot	60°C, 5 m/s air velocity, 37%RH	None	α-carotene β-carotene	14%↓(dw)* 15%↓(dw)*	Zhao et al., 2014
	60°C, 5 m/s air velocity, 37%RH	Microwave drying	α-carotene β-carotene	31%↓(dw)* 15%↓(dw)*	Zhao et al., 2014
Fig	62-64°C, 24 h	None	Kaempferol-3-*O*-glucoside Quercetin-3-*O*-glucoside Rutin Catechin	≈2-24 fold↑* ≈1.5-12 fold↑* ≈3-11 fold↑* ≈4-11 fold↑* ≈2-4 fold↑*	Slatnar et al., 2011

			Epicatechin Cyanidin-3-*O*-rutinoside Chlorogenic acid Total phenolics Antioxidant capacity (DPPH)	26-61%↓* ≈3-11 fold↑* ≈6-10 fold↑* ≈2 fold↑*	
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Grape	40°C, 20%RH	None	Cyanidin-3-*O*-glucoside Delphinidin-3-*O*-glucoside Malvidin 3-*O*-glucoside Pelargonidin 3-*O*-glucoside Peonidin-3-*O*-glucoside Petunidin-3-*O*-glucoside	13-33%↓* 37%↓ to 108%↑* 26-57%↑* 6-74%↑* 12-35%↑* 2%↓ to 58%↑*	Marquez et al., 2012

Guabiju	70°C, 0.72 m/s air velocity	Freezing	α-carotene β-carotene β-cryptoxanthin Lutein Total carotenoids Cyanidin chloride Cyanidin-3-*O*-glucoside Delphinidin 3-β-D-glucoside Malvidin chloride Malvidin-3-*O*-glucoside Peonidin chloride Antioxidant capacity (ABTS)	56%↓(dw)* 51%↓(dw)* 57%↓(dw)* 71%↓(dw)* 57%↓(dw)* 90%↓(dw)* 48%↓(dw)* 95%↓(dw)* 88%↓(dw)* 95%↓(dw)* 87%↓(dw)* 27%↑(dw)	Nora et al., 2014
Jujube	70°C, 8 h	None	α-carotene β-carotene Rutin Catechin Epicatechin	88%↑(dw)* 89%↑(dw)* 92%↓(dw)* 88%↓(dw)* 96%↓(dw)*	Gao et al., 2012

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			p-Hydroxybenzoic acid Protocatechuic acid Vanillic acid Cinnamic acid *p*-Coumaric acid Ferulic acid Total phenolics Antioxidant capacity (ABTS)	88%↓(dw)* 98%↓(dw)* 92%↓(dw)* 69%↓(dw)* 94%↓(dw)* 89%↓(dw)* 30%↓(dw)* 56%↓(dw)*	
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Kale	55°C, 5.5 h	None	Vitamin C Kaempferol Quercetin Caffeic acid *p*-Coumaric acid Ferulic acid Sinapic acid Total phenolics	31%↓ 51%↓ 50%↓ 73%↓ 51%↓ 63%↓ 56%↓ 60%↓	Korus, 2011
	55°C, 5.5 h	Blanching	Vitamin C	35%↓	Korus,

			Kaempferol Quercetin Caffeic acid *p*-Coumaric acid Ferulic acid Sinapic acid Total phenolics	60%↓ 58%↓ 56%↓ 68%↓ 72%↓ 51%↓ 65%↓	2011
Mango	53.94±0.03°C	Cold-air drying	Total phenolics Antioxidant capacity (DPPH)	46%↓* 55%↓*	Chong et al., 2013
Mulberry	60°C, 1 m/s air velocity	None	Total anthocyanins Total phenolics Antioxidant capacity (FRAP)	≈80%↓(dw)* ≈65%↓(dw)* ≈80%↓(dw)*	Chottamom et al., 2012
	60°C, 1 m/s air velocity	Osmotic treatment	Total anthocyanins Total phenolics Antioxidant capacity (FRAP)	≈75-90%↓(dw)* ≈65-80%↓(dw)* ≈70-80%↓(dw)*	Chottamom et al., 2012
Product	**Treatment**	**Pre-**	**Compound**	**Result**	**Reference**

		treatment			
Murta berry	40-80°C, 300-1400 min, 2.0±0.1 m/s air velocity	None	β-carotene Total flavonoids Ellagic acid Gallic acid Protocatechuic acid Cinnamic acid *p*-Coumaric acid Total phenolics Antioxidant capacity (DPPH, ORAC)	20- 45%↓(dw)* 76- 83%↓(dw)* 51-63%↓(dw) 49-63%↓(dw) 79-88%↓(dw) 19-35%↑(dw) 18- 200%↑(dw) ≈75- 90%↓(dw)* ≈0- 80%↓(dw)*	Rodriguez et al., 2014
Onion	45±5°C, 6-8 h	Blanching	β-carotene Lutein	25%↑(dw)* 5%↓(dw)	Mamatha et al., 2012
Papaya	53.94±0.03°C	Cold-air drying	Total phenolics Antioxidant capacity	7%↓ 22%↓*	Chong et al., 2013
	60°C, 24 h	None	Total flavonoids Total phenolics	67%↓ to 105%↑*	Annegowda et al.,

			Antioxidant capacity (ABTS, DPPH, Phosphomolybdenum assay)	68%↓ to 176%↑* 51%↓ to 105%↑*	2014
	50-80°C, 0.2-0.7 m/s air velocity, 10-25 g water/kg dry air	Osmotic treatment	β-carotene β-cryptoxanthin Lycopene	6-75%↓(dw) 22-77%↓(dw) 35-76%↓(dw)	Udomkun et al., 2015
Paprika	60°C, 7±0.5 h, 0.76 m/s air velocity	None	β-carotene β-cryptoxanthin	25%↓(dw)* 23%↓(dw)*	Topuz et al., 2011
Pear	53.94±0.03°C	Cold-air drying	Total phenolics Antioxidant capacity	33%↓* 75%↑*	Chong et al., 2013
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Plum	90°C, 1 m/s air velocity	None	Rutin Cyanidin Total anthocyanins Total flavonoids	32-51%↓(dw)* 100%↓(dw)* 92%↓ to	Miletic et al., 2013

			Gallic acid Protocatechuic acid Caffeic acid Chlorogenic acid Neochlorogenic acid Total phenolics Antioxidant capacity (ABTS)	≈200%↑(dw) * ≈0-5%↑(dw)* 3-3.5 fold↑(dw)* 28-36%↓(dw)* 11-19%↑(dw)* 29%↓* to 5%↑(dw) 13-25%↓(dw)* ≈10-40%↑(dw)* ≈35-60%↑(dw)*	
Pomegranate	50-70°C, 0.8 m/s air velocity	None	Ellagic acid Total phenolics Antioxidant capacity (DPPH)	38-80%↓(dw)*** 73-74%↓*** 42-46%↓***	Calin-Sanchez et al., 2013

Raspberry	76.6°C, 4.5 h	None	Kaempferol Quercetin Naringenin Naringin Total anthocyanins Ellagic acid Total phenolics Antioxidant capacity (ABTS)	41-92%↓(dw)* 37-81%↓(dw)* 92%↓* to 24%↑(dw)* 86%↓* to 53%↑(dw)* ≈75-90%↓(dw)* 87%↓(dw)* ≈70-90%↓(dw)* ≈60-85%↓(dw)*	Mejia-Meza et al., 2010
	65°C, 5 m/s air velocity, 11.2%RH	None	Total anthocyanins Total phenolics Antioxidant capacity (ABTS)	20-29%↓(dw)* 13-41%↑(dw)* 13%↓ to 33%↑(dw)*	Sablani et al., 2011
	65°C, 5 m/s	Blanching	Total anthocyanins	16%↓ to	Sablani et

	air velocity, 11.2%RH		Total phenolics Antioxidant capacity (ABTS)	3%↑(dw)* 43-60%↑(dw)* 15%↓ to 43%↑(dw)*	al., 2011
Red bell pepper	45±5°C, 6-8 h	Blanching	β-carotene Lutein	28%↑(dw) 33%↓(dw)*	Mamatha et al., 2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Red guava	70°C, 0.72 m/s air velocity	Freezing	α-carotene β-carotene β-cryptoxanthin Lutein Total carotenoids Cyanidin chloride Cyanidin-3-*O*-glucoside Malvidin-3-*O*-glucoside Total anthocyanins Antioxidant capacity	73%↓(dw)* 72%↓(dw)* 56%↓(dw)* 66%↓(dw)* 61%↓(dw)* 100%↓(dw)* 97%↓(dw)* 100%↓(dw)* 98%↓(dw)* 66%↑(dw)*	Nora et al., 2014

			(ABTS)		
Sebuckthorn berry	50-60°C, 15 h, 1 m/s air velocity	None	Vitamin C Total carotenoids Total phenolics	33-39%↓ 55-64%↓ 11-14%↓	Araya-Farias et al., 2011
Sour cherry	50-70°C, 1 m/s air velocity	None	Kaempferol-3-*O*-rutinoside Quercetin-3-*O*-glucoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Cyanidin-3-*O*-glucoside Cyanidin-3-glucosylrutinoside Cyanidin-3-*O*-rutinoside Cyanidin-3-*O*-sophoroside Peonidin-3-*O*-	2-13%↑(dw)* 0-17%↑(dw)* 8-13%↓(dw)* 84-89%↓(dw)* 90-100%↓(dw)* 27-38%↓(dw)* 41-43%↓(dw)* 27-28%↓(dw)* 46-59%↓(dw)* 21-43%↓(dw)*	Wojdylo et al., 2014

			rutinoside Chlorogenic acid *p*-Coumaric acid Neochlorogenic acid Total phenolics	14- 23%🡻(dw)* 11- 36%🡻(dw)* 9-28%🡻(dw)* 34-38%🡻(dw)	
Sweet potato	65°C, 9h	Steaming	Ascorbic acid β-carotene Total phenolics Antioxidant capacity (FRAP)	18%🡻(dw) ≈50%🡻(dw) 116%🡹(dw) ≈40%🡹 (dw)	Yang et al., 2010
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Sweet potato	50-60°C, 24-48 h	None	β-carotene Total carotenoids	4-11%🡻 4-10%🡻	Vimala et al., 2011
Tomato	70±2°C, 24 h	None	β-carotene Lycopene	≈3.5 fold🡹 ≈3.8 fold🡹	Jorge et al., 2014
	70±2°C, 24 h	Blanching	β-carotene Lycopene	≈3.6 fold🡹 ≈3.9 fold🡹	Jorge et al., 2014
	70°C, 36 h	None	Lycopene Rutin	85%🡻(dw)* 25%🡻(dw)	Kamiloglu et al.,

			Rutin apioside Naringenin chalcone Total flavonoids Chlorogenic acid Total phenolics Antioxidant capacity (ABTS, DPPH, FRAP, CUPRAC)	56%↓(dw)* 100%↓(dw)* 43%↓(dw) 38%↓(dw) 43%↓(dw) 47-95%↓(dw)*	2014a
	60°C, 36 h	None	Ascorbic acid Total phenolics	98%↓(dw) 56%↓(dw)	Gumusay et al., 2015
	60°C, 36 h	Vaccuming	Ascorbic acid Total phenolics	94%↓(dw) 55%↓(dw)	Gumusay et al., 2015

RH: Relative humidity; ABTS: 2, 2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid; CUPRAC: Cupric ion reducing antioxidant capacity; DPPH: 2,2-Diphenyl-1-picrylhydrazyl; FRAP: Ferric ion reducing antioxidant capacity; ORAC: Oxygen radical absorbance capacity; ↑increase; ↓:decrease; dw: dry weight; *:$p<0.05$; ***:$p<0.001$.

Table 2. Changes in antioxidant compounds of fruits and vegetables subjected to freeze-drying

Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Apricot	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin Lutein Lycopene Cyanidin-3-*O*-glucoside Cyanidin-3-*O*-rutinoside	0%↓(dw) 0%↓(dw) 11%↓(dw) 0%↓(dw) 10%↓(dw) 0%↓(dw) ≈3 fold↑(dw) 57%↓(dw)	Leong and Oey, 2012
Blueberry	-60°C, 48 h, 20 Pa	Freezing	Total anthocyanins Total phenolics Antioxidant capacity (ABTS)	32%↓ to 15%↑(dw)* 19-25%↑(dw)* 1-27%↑(dw)*	Sablani et al., 2011
Carrot	-40°C, 100 Pa	Microwave drying	Vitamin C β-carotene	≈10%↓* ≈0%↓	Yan et al., 2010

	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin Lutein Lycopene	125%↑(dw) 10%↓(dw) 11%↓(dw) 9%↓(dw) 12%↓(dw) 11%↓(dw)	Leong and Oey, 2012
Cherry	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin Lutein Lycopene Cyanidin-3-*O*-glucoside Cyanidin-3-*O*-rutinoside	33%↓(dw) 0%↓(dw) 0%↓(dw) 0%↓(dw) 0%↓(dw) 0%↓(dw) 12%↓(dw) 15%↓(dw)	Leong and Oey, 2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Guabiju	-54°C	Freezing	α-carotene β-carotene β-cryptoxanthin	6%↓(dw) 4%↓(dw) 12%↓(dw)	Nora et al., 2014

			Lutein Total carotenoids Cyanidin Cyanidin-3-*O*-glucoside Delphinidin 3-β-D-glucoside Malvidin Malvidin-3-*O*-glucoside Peonidin Antioxidant capacity (ABTS)	11%↓(dw)* 8%↓(dw) 46%↓(dw) 22%↑(dw) 83%↑(dw)* 39%↓(dw) 0.2%↓(dw) 39%↓(dw) 38%↑(dw)	
Jujube	-50°C, 48 h	None	α-carotene β-carotene Rutin Catechin Epicatechin *p*-Hydroxybenzoic acid Protocatechuic acid	82%↑(dw)* 2.4 fold↑(dw)* 90%↓(dw)* 65%↓(dw)* 74%↓(dw)* 100%↓(dw) *	Gao et al., 2012

			Vanillic acid Cinnamic acid *p*-Coumaric acid Ferulic acid Total phenolics Antioxidant capacity (ABTS)	94%↓(dw)* 88%↓(dw)* 69%↓(dw)* 100%↓(dw) * 96%↓(dw)* 36%↑(dw)* 18%↓(dw)	
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Kale	-50°C, 48 h	None	Vitamin C Kaempferol Quercetin Caffeic acid *p*-Coumaric acid Ferulic acid Sinapic acid Total phenolics	25%↓ 5%↓ 33%↓ 28%↓ 33%↓ 60%↓ 37%↓ 49%↓	Korus, 2011
		Blanching	Vitamin C Kaempferol Quercetin	28%↓ 54%↓ 50%↓	Korus, 2011

			Caffeic acid *p*-Coumaric acid Ferulic acid Sinapic acid Total phenolics	54%🡻 36%🡻 56%🡻 31%🡻 51%🡻	
Mango	3 days	Freezing	Vitamin C β-carotene Total phenolics Antioxidant capacity (DPPH, FRAP)	0%🡻 26%🡻* 23%🡻* ≈2-50%🡻	Shofian et al., 2011
Muskmelon	3 days	Freezing	Vitamin C β-carotene Total phenolics Antioxidant capacity (DPPH, FRAP)	23%🡹 3%🡹 10%🡻 ≈20%🡻 to 40%🡹	Shofian et al., 2011
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Nectarine	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin	0%🡻(dw) 0%🡻(dw) 11%🡻(dw) 0%🡻(dw)	Leong and Oey, 2012

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			Lutein Lycopene Cyanidin-3-*O*-glucoside Cyanidin-3-*O*-rutinoside	10%↓(dw) 0%↓(dw) ≈3 fold↑(dw) 57%↓(dw)	
Papaya	3 days	Freezing	Vitamin C β-carotene Total phenolics Antioxidant capacity (DPPH, FRAP)	2%↑ 8%↓ 40%↓* ≈10%↓ to 80%↑	Shofian et al., 2011
	-50°C, 24 h, 0.12 Torr	None	Total flavonoids Total phenolics Antioxidant capacity (ABTS, DPPH, Phosphomolybdenum assay)	50%↓ to ≈200%↑* ≈0.6-3.2 fold↑* 9-102%↑*	Annegowda et al., 2014
Paprika	-70°C	None	β-carotene β-cryptoxanthin	28%↓(dw)* 29%↓(dw)*	Topuz et al., 2011
Peach	48 h	Freezing	Vitamin C	≈3	Leong and Oey,

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			α-carotene β-carotene β-cryptoxanthin Lutein Lycopene Cyanidin-3-*O*-glucoside Cyanidin-3-*O*-rutinoside	fold↑(dw) 33%↑(dw) 33%↑(dw) 33%↑(dw) 33%↑(dw) 50%↑(dw) 25%↓(dw) 11%↓(dw)	2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Plum	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin Lutein Lycopene Cyanidin-3-*O*-glucoside Cyanidin-3-*O*-rutinoside	0%↓(dw) 33%↓(dw) 25%↓(dw) 25%↓(dw) 50%↓(dw) 50%↓(dw) 49%↓(dw) 42%↓(dw)	Leong and Oey, 2012

Pomegranate	-60°C, 48 h, 65 Pa	None	Ellagic acid Total phenolics Antioxidant capacity (DPPH)	48%↓(dw)*** 74%↓*** 48%↓***	Calin-Sanchez et al., 2013
Raspberry	-60°C, 48 h, 20 militorr	Freezing	Kaempferol Quercetin Naringenin Naringin Total anthocyanins Ellagic acid Total phenolics Antioxidant capacity	47-50%↓(dw)* 73-88%↓(dw)* 51-98%↓(dw)* ≈46-400%↑(dw)* ≈35-90%↓(dw)* 74%↓(dw)* ≈80-90%↓(dw)* ≈50-85%↓(dw)*	Mejia-Meza et al., 2010
	-60°C, 48 h,	Freezing	Total anthocyanins	6-	Sablani et al.,

	20 Pa		Total phenolics Antioxidant capacity (ABTS)	26%↑(dw)* 19-34%↑(dw) 13-82%↑(dw)*	2011
Red bell pepper	48 h	Freezing	Vitamin C α-carotene β-carotene β-cryptoxanthin Lutein Lycopene	12%↓(dw) 6%↓(dw) 14%↓(dw) 13%↓(dw) 10%↓(dw) 13%↓(dw)	Leong and Oey, 2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Red guava	-54°C	Freezing	α-carotene β-carotene β-cryptoxanthin Lutein Total carotenoids Cyanidin Cyanidin-3-*O*-glucoside	13%↓(dw) 3%↓(dw) 23%↓(dw)* 65%↑(dw)* 6%↑(dw) 51%↓(dw) 71%↓(dw)* 32%↓(dw)*	Nora et al., 2014

			Malvidin-3-*O*-glucoside Total anthocyanins Antioxidant capacity (ABTS)	55%↓(dw)* 29%↑(dw)	
Red onion	-70°C, 28 h, 4.2 Pa	Freezing	Quercetin Total flavonols Total anthocyanins	46%↑ 32%↑ 25%↑	Perez-Gregorio et al., 2011
Sebuckthorn berry	20-50°C, 15 h	None	Total carotenoids Vitamin C Total phenolics	21-22↓ 10-19%↓ 1-4%↓	Araya-Farias et al., 2011
Sour cherry	-60°C, 24 h, 0.960 kPa	None	Kaempferol-3-*O*-rutinoside Quercetin-3-*O*-glucoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Cyanidin-3-*O*-glucoside	15%↓(dw)* 11%↓(dw)* 8%↓(dw)* 41%↓(dw)* 79%↓(dw)* 13%↓(dw)* 9%↓(dw)* 11%↓(dw)* 10%↓(dw)* 23%↓(dw)*	Wojdylo et al., 2014

			Cyanidin-3-glucosylrutinoside Cyanidin-3-*O*-rutinoside Cyanidin-3-*O*-sophoroside Peonidin-3-*O*-rutinoside Chlorogenic acid *p*-Coumaric acid Neochlorogenic acid Total phenolics	1%↓(dw)* 14%↓(dw)* 7%↓(dw)* 17%↓(dw)	
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Starfruit	3 days	Freezing	Vitamin C β-carotene Total phenolics Antioxidant capacity (DPPH, FRAP)	6%↓ 16%↓ 24%↓* ≈10-80%↓*	Shofian et al., 2011
Sweet potato	-50°C, 0.006 mbar,	Steaming	Ascorbic acid β-carotene	16%↓(dw) 0%↓(dw)	Yang et al., 2010

	36 h		Total phenolics Antioxidant capacity (FRAP)	≈1.5 fold🡅(dw) ≈100%🡅(dw)	
	-38°C	Microwave drying	Total anthocyanins	25%🡇	Liu et al., 2012
Tomato	10°C, 0.1-0.5 mbar	Freezing	Vitamin C β-carotene Lycopene Total phenolics	5%🡇 to 11%🡅(dw) 11-14%🡇(dw)***** 47%🡇(dw)***** 0-30%🡇(dw)*****	George et al., 2011
	-56±4°C, $8.8x10^{-6}$ MPa, 48 h	None	β-carotene Lycopene	≈6 fold🡅 ≈5.2 fold🡅	Jorge et al., 2014
		Blanching	β-carotene Lycopene	≈6.8 fold🡅 ≈7.3 fold🡅	

		Hot air drying	β-carotene Lycopene	≈4.6-8.0 fold↑ ≈6.2-8.1 fold↑	
		Hot air drying+blanching	β-carotene Lycopene	≈6.8-9.1 fold↑ ≈7.2-9.8 fold↑	
	-50°C, 0.133 mbar, 24 h	None	Ascorbic acid Total phenolics	79%↓(dw) 17%↓(dw)	Gumusay et al., 2015
Watermelon	3 days	Freezing	Vitamin C β-carotene Total phenolics Antioxidant capacity (DPPH, FRAP)	36%↑ 43%↓* 48%↓* 0-40%↑*	Shofian et al., 2011

ABTS: 2, 2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid; DPPH: 2,2-Diphenyl-1-picrylhydrazyl; FRAP: Ferric ion reducing antioxidant capacity; ↑increase; ↓:decrease; dw: dry weight; *:$p<0.05$; ***:$p<0.001$; *****:$p<0.00001$.

Table 3. Changes in antioxidant compounds of fruits and vegetables subjected to microwave drying

Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Apple	240 W	Hot-air drying+ vacuuming	Total phenolics Antioxidant capacity	39%🡻* 90%🡻*	Chong et al., 2013
	240 W	Heat pump drying+ vacuuming	Total phenolics Antioxidant capacity	9%🡻* 28%🡻*	Chong et al., 2013
Apricot	60-70°C, 2-18 h, 2 kW, 2.4 GHz	None	Total carotenoids	≈10-50%🡻*	Fratianni et al., 2013
	100 W	None	Ascorbic acid Total carotenoids	27%🡻(dw)* 14%🡻(dw)*	Garcia-Martinez et al., 2013
	100 W	Sulphiting	Ascorbic acid Total carotenoids	100%🡻(dw)* 5%🡻(dw)	Garcia-Martinez et al., 2013
	100 W	Hot air drying	Ascorbic acid Total carotenoids	38%🡻(dw)* 19%🡻(dw)*	Garcia-Martinez et

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					al., 2013
	100 W	Sulphiting+hot air drying	Ascorbic acid Total carotenoids	100%↓(dw)* 2%↓(dw)	Garcia-Martinez et al., 2013
Carrot	900 W, 2450 MHz	None	β-carotene	30-70%↓(dw)*	Arikan et al., 2012
	140-175 W	None	α-carotene β-carotene	26%↓(dw)* 29%↓(dw)*	Zhao et al., 2014
Jujube	700 W, 4 min	None	α-carotene β-carotene Rutin Catechin Epicatechin *p*-Hydroxybenzoic acid Protocatechuic acid Vanillic acid Cinnamic acid *p*-Coumaric acid	100%↓(dw)* 61%↓(dw)* 11%↓(dw)* 117%↑(dw)* 158%↑(dw)* 100%↓(dw)* 37%↑(dw)* 46%↓(dw) 8%↑(dw) 100%↓(dw)* 63%↓(dw)* 5%↓(dw) 17%↓(dw)	Gao et al., 2012

			Ferulic acid Total phenolics Antioxidant capacity (ABTS)		
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Mango	240 W	Hot-air drying+ vacuuming	Total phenolics Antioxidant capacity	71%↓* 79%↓*	Chong et al., 2013
	240 W	Heat pump drying+ vacuuming	Total phenolics Antioxidant capacity	7%↓* 21%↓*	Chong et al., 2013
Papaya	360 W	Hot-air drying+ vacuuming	Total phenolics Antioxidant capacity	37%↓* 49%↓*	Chong et al., 2013
	360 W	Heat pump drying+ vacuuming	Total phenolics Antioxidant capacity	13%↓* 60%↓*	Chong et al., 2013
Pear	240 W	Hot-air drying+ vacuuming	Total phenolics Antioxidant capacity	63%↓* 85%↓*	Chong et al., 2013

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	240 W	Heat pump drying+ vacuuming	Total phenolics Antioxidant capacity	13%↓* 45%↓*	Chong et al., 2013
Pomegranate	240-480 W	Vacuuming	Ellagic acid Total phenolics Antioxidant capacity (DPPH)	3-31%↓(dw)*** 67-79%↓*** 38-53%↓***	Calin-Sanchez et al., 2013
	360 W	Air drying+ Vacuuming	Ellagic acid Total phenolics Antioxidant capacity (DPPH)	21%↓(dw)*** 74-75%↓*** 40-43%↓***	Calin-Sanchez et al., 2013
Raspberry	65.5°C, 90 min, 3000 W	Freezing	Kaempferol Quercetin Naringenin Naringin Total anthocyanins Ellagic acid Total phenolics Antioxidant capacity	33%↓ to 35%↑(dw)* 53-82%↓(dw)* 100%↓(dw)* 45%↓ to 31%↑(dw)* 50-90%↓(dw)* 15%↓(dw)	Mejia-Meza et al., 2010

				≈70-90%↓(dw)* ≈75-85%↓(dw)*	
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Raspberry	71.1°C, 60 min, 3000 W	Hot-air drying	Kaempferol Quercetin Naringenin Naringin Total anthocyanins Ellagic acid Total phenolics Antioxidant capacity	2-78%↓(dw)* 10-25%↓(dw)* 94%↓ to 61%↑(dw)* 64%↓ to ≈200%↑(dw)* ≈80-90%↓(dw)* 23%↑(dw) ≈60-70%↓(dw)* ≈75-85%↓(dw)*	Mejia-Meza et al., 2010
Sour cherry	120-480 W	Vacuuming	Kaempferol-3-*O*-	20-	Wojdylo et

			rutinoside Quercetin-3-*O*-glucoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Cyanidin-3-*O*-glucoside Cyanidin-3-glucosylrutinoside Cyanidin-3-*O*-rutinoside Cyanidin-3-*O*-sophoroside Peonidin-3-*O*-rutinoside Chlorogenic acid *p*-Coumaric acid Neochlorogenic acid	37%↑(dw)* 17-46%↑(dw)* 4%↓ to 8%↑(dw)* 26-78%↓(dw)* 9-77%↓(dw)* 0-38%↓(dw)* 1-30%↓(dw)* 23%↓ to 9↑(dw)* 4-38%↓(dw)* 60%↓ to 32↑(dw)* 0-12%↓(dw)* 4%↓ to 5↑(dw)* 0-14%↓(dw)* 4-22%↓(dw)	al., 2014

			Total phenolics		
Sweet potato	800 W, 50 Hz	Steaming	β-carotene Ascorbic acid Total phenolics Antioxidant capacity (FRAP)	≈65%🡻(dw) 42%%🡻(dw) ≈2 fold🡹(dw) ≈2 fold🡹(dw)	Yang et al., 2010

RH: Relative humidity; ABTS: 2, 2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid; DPPH: 2,2-Diphenyl-1-picrylhydrazyl; FRAP: Ferric ion reducing antioxidant capacity; 🡹increase; 🡻:decrease; dw: dry weight; *:p<0.05; ***:p<0.001.

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Table 4. Changes in antioxidant compounds of fruits and vegetables subjected to sun drying

Product	Treatment	Pre-treatment	Compound	Result	Reference
Apricot	6 days	Sulphiting	β-carotene Total phenolics Antioxidant activity (ABTS)	6–21%↓(dw)* ≈10-25%↓(dw)* ≈10-20%↓*	Turkyilmaz et al., 2014
Bell pepper	30-35°C, 2 weeks	None	Total carotenoids Apigenin Total flavonoids Total phenolics Antioxidant capacity (ABTS, DPPH)	20-92%↓ 16-33%↓ 3-24%↓ 8-13%↓ 5%↓ to 430%↑	Loizzo et al., 2013
Fig	7 days	None	Kaempferol-3-*O*-glucoside Quercetin-3-*O*-glucoside Rutin Catechin Epicatechin	≈2-10 fold↑* ≈0.4-12 fold↑* ≈0.5-10 fold↑* ≈1.2-7	Slatnar et al., 2011

			Cyanidin-3-*O*-rutinoside Chlorogenic acid Total phenolics Antioxidant capacity (DPPH)	fold↑* ≈0.5-2 fold↑* 79%↓* to 24%↑* ≈30%↓* to 600%↑* ≈3-6 fold↑* ≈2 fold↑*	
	7 days	None	β-carotene β-cryptoxanthin Lutein Total carotenoids	68%↓(dw)* 46-52%↓(dw)* 74-77%↓(dw)* 83-85%↓(dw)*	Yemis et al., 2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Fig	31-34°C, 8 days	None	Kaempferol-rutinoside Quercetin-3-*O*-	33%↓ to 200%↑(dw) 33-	Kamiloglu and Capanoglu, 2014

			glucoside Rutin Apigenin Catechin Epicatechin Cyanidin-3-*O*- glucoside Cyanidin-3-*O*- rutinoside Total anthocyanins Total flavonoids Chlorogenic acid *p*-Coumaric acid Ellagic acid Gallic acid Total phenolics Antioxidant capacity (ABTS, DPPH, FRAP, CUPRAC)	42%↓(dw) 24%↓ to 16%↑(dw) 17%↓ to 47%↑(dw)* 35- 81%↓(dw)* 45- 68%↓(dw)* 98%↓(dw)* 96%↓(dw)* 83- 98%↓(dw)* 21%↓ to 75%↑(dw)* 58- 87%↓(dw)* 34- 59%↓(dw)* 0-50%↑(dw) 66%↓ to 66%↑(dw)	

Product	Treatment	Pre-treatment	Compound	Result	Reference
				8-15%↓(dw) 13-59%↓(dw)*	
Jujube	3 weeks	None	α-carotene β-carotene Rutin Catechin Epicatechin *p*-Hydroxybenzoic acid Protocatechuic acid Vanillic acid Cinnamic acid *p*-Coumaric acid Ferulic acid Total phenolics Antioxidant capacity (ABTS)	100%↓(dw)* 100%↓(dw)* 53%↓(dw)* 100%↓(dw)* 100%↓(dw)* 2.6 fold↑(dw)* 89%↓(dw)* 1.5 fold↑(dw)* 15%↓(dw) 1.4 fold↑(dw)* 48%↑(dw)* 77%↓(dw)* 65%↓(dw)*	Gao et al., 2012

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Sweet potato	48 h	None	β-carotene Total carotenoids	27-37%↓ 27-37%↓	Vimala et al., 2011
Tomato	25-30°C, 3 days	None	Ascorbic acid Total phenolics	92%↓(dw) 60%↓(dw)	Gumusay et al., 2015

ABTS: 2, 2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid; CUPRAC: Cupric ion reducing antioxidant capacity; DPPH: 2,2-Diphenyl-1-picrylhydrazyl; FRAP: Ferric ion reducing antioxidant capacity; ↑increase; ↓:decrease; dw: dry weight; *:$p<0.05$.

Table 5. Changes in antioxidant compounds of fruits and vegetables subjected to other drying methods

Product	Treatment	Pre-treatment	Compound	Result	Reference
			Heat pump drying		
Apple	35°C, 20%RH	None	Total phenolics Antioxidant capacity	63%🡻* 77%🡻*	Chong et al., 2013
Mango	35°C, 20%RH	None	Total phenolics Antioxidant capacity	71%🡻* 73%🡻*	Chong et al., 2013
Papaya	35°C, 20%RH	None	Total phenolics Antioxidant capacity	69%🡻* 77%🡻*	Chong et al., 2013
Pear	35°C, 20%RH	None	Total phenolics Antioxidant capacity	65%🡻* 72%🡻*	Chong et al., 2013
			Modified atmosphere drying		
Carrot	40-70°C, 5-21% O_2	None	Ascorbic acid Total carotenoids	≈26-65%🡻 ≈20-67%🡻	Liu et al., 2014
			Refractance window™ drying		
Paprika	94°C, 3 min, 0.45-0.58 m/min belt	None	β-carotene β-cryptoxanthin	23%🡻(dw)* 17%🡻(dw)*	Topuz et al., 2011

	velocity				
Spouted bed drying					
Carrot	50°C	Microwave drying	Vitamin C β-carotene	≈40%↓* ≈30%↓*	Yan et al., 2010
Sweet potato	80°C	Microwave drying	Total anthocyanins	46%↓	Liu et al., 2012
Product	**Treatment**	**Pre-treatment**	**Compound**	**Result**	**Reference**
Vacuum drying					
Apple	20-50°C, 24h	None	Vitamin C Quercitin-3-*O*-galactoside Quercitin-3-*O*-glucoside Quercitin-3-*O*-rhamnoside Quercetin-3-*O*-rutinoside Catechin Epicatechin Epigallocatechin	1-53%↓(dw)* 20-22%↓(dw) 13%↓ to 52%↑(dw) 17%↓ to 13%↑(dw) 0%↓(dw) 0-15%↓(dw) 3-	Joshi et al., 2011

			Cyanidin-3-*O*- galactoside Chlorogenic acid Total phenolics Antioxidant capacity (FRAP, ORAC)	18%↓(dw) 18- 50%↓(dw) 45- 58%↓(dw)* 3%↓to 1%↑(dw) 9%↑(dw) 4- 42%↑(dw)	
Carrot	5 kPa	Microwave drying	Vitamin C β-carotene	≈40%↓* ≈30%↓*	Yan et al., 2010
Sweet potato	4.5 kPa	Microwave drying	Total anthocyanins	29%↓	Liu et al., 2012

RH: Relative humidity; FRAP: Ferric ion reducing antioxidant capacity; ORAC: Oxygen radical absorbance capacity; ↑:increase; ↓:decrease; dw: dry weight; *:p<0.05.