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Impact of Post-harvest Treatments on The Antioxidant Content of Fruits and Vegetables

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FRUITS are one of the most important natural sources of antioxidant compounds such as phenolics (anthocyanin and flavonoids), vitamins, carotenoids, and tannins. These compounds have essential role in fruit quality, also, are very necessary in maintaining human health. Fruits are exposed to many pre and postharvest conditions as well as operations that affect their quality.

This review focused on the effects of the most common postharvest conditions and practices such as, ripening stage, harvest time, chemical treatments, ultraviolet irradiation, ozone treatment, coatings, storage period, storage temperature, controlled and modified atmosphere, in addition processing conditions on the antioxidant compounds of fruits. Further, to underline the best practices which maintain fruits quality and their nutritional value for human health.

Presented review suggested that antioxidant contents in fruits and vegetables are varied significantly with changes in all mentioned postharvest conditions. So, it is important to determine the optimum treatments for each kind of fruits to achieve the highest benefit for human health and obtain attractive fruits for consumers, in the same time.

Keywords: Postharvest Treatment, Antioxidant, Phenolics, Anthocyanin, Flavonoids, Vitamins, Carotenoids, Tannins, Human Health.

Introduction

Antioxidants are a group of compounds necessary for protecting living cells by inhibiting the chemical reactions that produce free radicals (Wang et al., 2011). Free radicals participate in a chain of reactions that can finally lead to cell damage. Thus, antioxidants have an effective pharmacological usage in improving human health as well as decreasing the incidence of different disorders and diseases like: aging, cancer, diabetes, liver diseases and inflammations (Sánchez-Moreno et al., 2003, Wootton-Beard and Ryan, 2011, Neha et al., 2019)

Antioxidants group includes phenolic compounds such as anthocyanin, flavonoids, vitamins (A,B,C,D,E and F), carotenoids and tannins (Grabek-Lejko, 2015). These compounds are important because these not only contribute to fruit quality such as color and flavor, but also improve their antioxidant capacities as well. Fruits such as blackberry, raspberry, cherry, strawberry, soursop, pome fruits, peach, apricot, grapes, citrus, pecan, walnuts etc., are very rich in antioxidant compounds. They are considered as a good natural source of antioxidant compounds to human body. These compounds mainly differ in fruits depending on their genotypes (Leccese et al., 2012, Abou-Farrag et al., 2013, Grabek-Lejko, 2015 and Andrade-Cuvi et al., 2017), growing conditions and management practices such as climate, soil type, mulching, application of plant growth regulators, nutrients, water (quality and quantity), in addition to biotic and abiotic stresses, etc. (Mallik & Hamilton, 2017 and Wang, 2006).

Many postharvest treatments have been used to maintain fruits quality and increase their shelflife (Yahia, 2011). These treatments during handling, storage, transportation, and marketing have a clear effect on antioxidants content (Abou-Farrag et

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al., 2013, Cantin & Echeverría, 2014,Westerheide et al., 2016 and Hailemariam & Wudineh, 2020). Nowadays, consumers are becoming more conscious of the nutritional value in their food. Therefore, this review will focus on the main postharvest conditions and treatments suchas fruit ripening stage, harvest time, chemical treatments, ultraviolet radiation, ozone treatment, coatings, storage period, storage temperature, controlled and modified atmosphere and food processing, and their effects on antioxidants content in perishable fruits (Table 1).

Fruit ripening stage and harvest time

Fruits pass during their life through many stages, until reaching the ripening stage. During growth and development of the fruits, many complex biochemical and physiological changes occur, which include changes in color, flavor and firmness (Yahia, 2011) that make them edible and attractive for consumers. Maturity stage can also affect antioxidants content in harvested fruits. For example, Kyriacou et al. (2021) noticed that total phenolic content, condensed tannins, hydrolysable tannins, catechins and flavonol glycosides in carob fruit declined with ripening, mainly during the transition from the half brown to brown stage. Furthermore, in Malay cherry fruits, the antioxidants content decreased, as the total polyphenols decreased upon ripening, while seventeen anthocyanins uniquely appeared in the ripe fruit (Zhang et al., 2019). In pomegranate, Mohamed et al. (2015) reported same results, where vitamin C concentration increased gradually from full bloom to maturity stage (165 days from full bloom). The total phenolics and hydrolysable tannin content in fruit peel and juice started to raise, and then declined gradually till minimal level at maturity. Total anthocyanin content of pomegranate arils and peel began low for the three studied cultivars and gradually increased till the end of fruit development.

Ledesma-Escobar et al. (2019) identified bioactive compounds in Persian lime after fruit set till maturity. Citric and malic acids (the main identified carboxylic acids), reached a maximum concentration at commercial maturity (14 weeks of flowering). In addition, the concentration of flavanones (i.e. hesperidin, neoeriocitr in or naringin) and flavones (i.e. rhoifolin, diosmetin glucoside or luteolinrutinoside) increased during fruit growth and reached their maximum values around week 12, whereas flavanols such as quercetin derivatives reached their maximum concentration during the first 5 weeks and then decreased at the end of maturation. During ripening of Cordia and Carissa, Kachhwaha and Gehlot (2015) observed significant decreases in total phenols, associated with increase in lycopene (only in red color Carissa fruit) and ascorbic acid content. In guava, ascorbic acid content increased from immature stage up to turning stage then declined at ripening stage (Mondal et al., 2009).

Harvest time also effects antioxidants level. Overripe wild blueberry harvested late in the season had higher total phenols, anthocyanin contents and antioxidant levels (Mallik and Hamilton, 2017). This increase may be attributed to the decrease in water content of late harvested fruits. Al Juhaimiet et al. (2020) reported that in prickly pear, the highest total phenolic content was found in fruit harvested at the early season, followed by that harvested at late season. Moreover, Bhandari et al. (2016) reported that in fully matured red pepper that harvested six times during the season, the content of total phenols, total flavonoid, ß-carotene, vitamin C and antioxidant activity had higher values in the initial and final harvests, while vitamin E content was relatively stable during the harvest season. These differences were probably due to the prevailing weather conditions such as temperature, day length, day light, and humidity.

Summing up, collected data suggests that the most preferable stage to consumers must not always have the greatest health benefit and highest antioxidant content. So, it is useful to determine the optimum harvesting date to achieve highest benefit. Generally, unripe fruits are good sources of phenolic compounds and tannins, while ascorbic acid and the components associated with fruit color as anthocyanin and lycopene increase with ripening.

Chemical treatments

The effects of many postharvest chemical treatments to maintain fruit quality during storage and shelf life were investigated by many researchers. For example, 1-methylcyclopropene (1-MCP) has been used commercially to delay processes related to ripening by inhibiting ethylene action (Yahia, 2011). 1-MCP treatment increased total antioxidants and flavonoids concentrations in apple fruits through inhibition of catabolism of flavonoids by its effect on the transcription of two flavonoid biosynthetic enzymes (phenylalanine ammonialyase and chalcone synthase), flavonoid transport (glutathione 5-transferase) and ethylene perception (MacLean, 2007) thus it is important to understand how postharvest practices affect the phytochemical content of these fruits. Recently, the ethylene antagonist 1-methylcyclopropene (1-MCP. Abd El-Khalek (2018) noted that combinations of 1-MCP (0.5 or 1 ppm) and salicylic acid (0.5 or 1 mM) were more effective than 1-MCP or salicylic acid alone on Canino apricot fruits, as these delayed the deterioration rate of ascorbic acid and fruit color development. Furthermore, they increased total phenolic contents.

The effects of several other chemical treatments on maintaining fruit quality and enhancing storage life have been investigated. Salicylic acid treatments increased total phenolics and antioxidant activity of apple fruits at the earlier stages of storage (Hadian-Deljou et al., 2017). Chitosan and putrescine treatments delayed ascorbic acid degradation, and caused small increases in phenolic compounds content and antioxidant activity at the end of the storage period (Marjan et al., 2018). While, polyamines can maintain ascorbic acid content in stored guava fruits(Abd El-Khalek, 2018). Baltazari et al. (2020) reported that dipped orange fruits in Hexanal (0.02% v/v for 5 min) increased total flavonoids and vitamin C contents However, before using these chemicals, further investigations are required to understand their mechanisms and their effect on antioxidant capacity.

Summing up, the data available literature indicate that all treatments that delay fruit ripening, maintain fruit quality and increase fruit life also increase antioxidant capacity, ascorbic acid, phenolics, tannins and flavonoids contents and decrease compounds associated with fruit color such as anthocyanins, carotenoids and lycopene.

Ultraviolet irradiation

Postharvest application of ultraviolet (UV) irradiations, either UV-C or UV-B, is an alternative non-chemical technique used to maintain fruit quality. UV-C radiation slows down loss of antioxidant capacity during storage of "Mortino" and "Uvilla" berries (Andrade-Cuvi et al., 2017). Moreover, Maharaj et al. (2014) observed that total phenols increased one week earlier in tomato fruits exposed to different doses of UV-C (3.7 and 24.4 kJ/m^2) compared to the control. However, UV-C irradiation decreased ascorbic acid content. These observations demonstrate the role of UV-C in delaying fruit ripening.

In addition, daily postharvest treatment of mature green tomato fruits, with UV-B radiation (1 h, 6.08 kJ/m^2 day) (Castagna et al., 2014) or exposure to (20 or 40 kJ/m^2) and storage in the dark at 14°C, 95% RH (Liu et al., 2011) enhanced the concentration of flavonoids, flavonols, phenolics and increased antioxidant capacity. On the other hand, UV-B irradiation reduced ascorbic acid content. However,, the higher dose (80 kJ/m^2) resulted in negative effects on antioxidants capacity (Liu et al., 2011).

The obtained data suggested that UV-C and UV-B treatments may be useful techniques to maintain antioxidant capacity. However, it is necessary to determine the optimum dose and frequency needed for each kind of fruit to achieve the highest benefit.

Ozone treatment

Ozone has been widely used in the storage of agricultural products, as it has a strong oxidant activity with anti-bactericidal properties and no residues, and it can help to maintain fruit quality during storage. Shalluf (2010) found that the effect of ozone on fruits differed according to its dose. Low doses of ozone delayed color development in tomato, while higher doses caused black spots on the surface. Ozone did not affect the ascorbic acid content, but treated fruits had higher ß-carotene and lycopene compared to the control.

Zhang et al. (2020) reported that postharvest ozone treatment of strawberries improved the accumulation of ascorbic acid and glutathione and enhanced antioxidant capacity. This effect was probably due to enhanced activity of antioxidant enzymes and increased the expression of antioxidant proteins related to the ascorbic acid–glutathione cycle.

Coatings

Maina et al. (2019)variety "ngowe" harvested at mature green stage were subjected to two waxing treatments, namely Shellac or Decco wax™. The waxes were applied by dipping the fruits in wax for five seconds followed by air drying. The waxed fruits were then packed in carton boxes and stored either at ambient room temperature (25°C found that waxing treatments of mango fruits delayed the development of β-carotene compared to untreated fruits. This was probably due to delayed synthesis and accumulation of β-carotene because of lowering O_2 and increasing CO_2 concentrations. On the other hand, the total phenolics and vitamin C contents were increased in soursop fruits coated with roselle mucilage (2%) and stored at 15°C for eight days (De los Santos-Santos et al., 2020). The role of different coatings on antioxidant capacity is related to their effect on delaying fruit ripening and extending their shelf life.

Table 1. Effects of postharvest treatments on antioxidant components in edible fruits and vegetables

Postharvest conditions	Effects on antioxidant compounds	References
• Changes associated with maturity	↓ Antioxidant capacities, total phenolic content, tannins, catechins and flavonol glycosides ↑ Vitamin C, total anthocyanin, lycopene	Mondal *et al.*, 2009; Mohamed *et al.*, 2015; Ledesma-Escobar *et al.*, 2019; Zhang *et al.*, 2019; Kyriacou *et al.*, 2021
• Harvest time	Total phenols, total flavonoid, ß-carotene anthocyanin, vitamin C and antioxidant levels increase in early and late season Vitamin E was relatively stable during the harvest season.	Bhandari *et al.*, 2016; Mallik and Hamilton, 2017; Al Juhaimi*et al.*, 2020
• Chemical treatments ▪ (1-MCP) ▪ Salicylic acid ▪ Chitosan and putrescine ▪ Polyamines ▪ Hexanal	↑ Total antioxidant, flavonoid, vitamin C and phenolic compound	MacLean, 2007;Yahia, 2011; Hadian-Deljou *et al.*, 2017; Abd El-Khalek, 2018; Marjan *et al.*, 2018; Baltazari *et al.*,2020
• Ultraviolet irradiation	↑ Antioxidant capacity, total phenols ↓ Vitamin C	Liu *et al.*, 2011;Castagna *et al.*, 2014;Andrade-Cuvi *et al.*, 2017
• Ozone treatment	↑ Antioxidant capacity	Zhang *et al.*, 2020
• Coatings	↑ Total phenolic content and vitamin C ↓ Beta carotene	De los Santos-Santos *et al.*, 2020
• Storage period	↓ Vitamin C, phenolic content, tannins and anthocyanins	Zee *et al.*, 1991; Hanafy-Ahmed *et al.*, 2008; Abou-Farrag *et al.*, 2013; Vieites *et al.*, 2012;Baltazari *et al.*, 2020
• Cold Storage	↑ Vitamin C ↓ Total phenols and anthocyanin	Hanafy-Ahmed *et al.*, 2008; Mallik and Hamilton, 2017; Baltazari *et al.*, 2020
• Controlled and modified atmosphere	↑ Antioxidant capacity ↓ Anthocyanins content	Holcroft *et al.*, 1998; Khorshidi *et al.*, 2011
• Processing ▪ Drying ▪ Cooking	↓ Ascorbic acid, phenolic content, anthocyanins and antioxidant capacity. ↓ Vitamin C	Khan *et al.*, 2018:Vidinamo *et al.*, 2020; Hiwilepo-van Hal *et al.*, 2012

Storage period

Fruits are stored to extend their marketing period, extend their ability exportation or maintain their quality for processing. Many studies have been conducted to evaluate changes in fruits antioxidants content during storage. It was found that prolonged storage period decreased the content of vitamin C in many fruits and vegetables stored at ambient and cold temperatures (Zee et al., 1991). Vitamin C decreased in navel oranges stored at 2 and 8°C (Hanafy-Ahmed et al., 2008), dried figs at room temperature (Abou-Farrag et al., 2013), orange fruits at ambient (28±2°C) and reduced (18±٢°C) temperatures (Baltazari et al., 2020). Zee et al.(1991) added that the delayed vitamin C degradation during first few days of storage is due to the increases of vitamin C as a result of fruit continuing endogenous metabolism. While, Davey et al. (2000) found that loss of ascorbic acid content in guavas during cold storage was due to rapid conversion of L-ascorbic acid into dehydroascorbic acid in the presence of oxidizing enzymes like ascorbic acid oxidase and ascorbate peroxidase.

Concerning the changes in phenolics content during storage, literature indicated that phenolics content decreased with storage duration of dried figs (Abou-Farrag et al., 2013). In “Om El-Frakh” dates stored at 5°C, it sharply decreased with storage period from 0 to 14 days then sharply increased after 21 days in an opposite trend to total sugars content (El-Hadidy et al., 2015). Vieites et al. (2012)soluble solids (SS added that total phenolics content decreased after the breathing peak in avocado fruits stored at room temperature (24ºC) and in refrigerator (10ºC). Lattanzio et al. (2001) found that in Golden Delicious apples, the concentration of total phenolics increased during the first 60 days of cold storage (2°C), then it began to decrease to reach the initial concentration after 200 days of storage. Whereas, total phenolics content in three studied genotypes of blueberry increased up to 90 days in cold storage (2ºC) or freezing (Mallik and Hamilton, 2017). Total tannins in dates decreased with increasing duration of storage (El-Hadidy et al., 2015).

Anthocyanin content increased in stored apples during cold storage (0°C)in the first 60 days and then decreased right afterwards till 193 days of storage (Hadian-Deljou et al., 2017). Also, anthocyanins content decreased in dried figs with storage duration (Abou-Farrag et al., 2013).

In general, by increasing the storage period, antioxidants content decreases due to the decreases in phenolics content, vitamin C, tannins and anthocyanins in stored fruits.

Storage temperature

Cold storage is a common procedure used to increase fruit storability and decrease postharvest losses. The effects of storage temperatures on antioxidants were investigated by several researchers. They reported that lower temperatures maintained vitamin C content, while it decreased with increasing storage temperature. According to Baltazari et al. (2020) investigation, storage at ambient (28±2°C) and low (18±2°C) temperature had no impact on vitamin C content and total flavonoids of sweet oranges. While, Hanafy-Ahmed et al. (2008) indicated that navel oranges stored at 2ºC had higher concentration of ascorbic acid than those stored at 8ºC.

In contrast, total phenols concentration in orange peel and flesh were higher at 8ºC compared to 2ºC (Hanafy-Ahmed et al., 2008). Same trend was obtained in blueberry stored at higher temperature (2ºC) and freezing storage (-15ºC) (Mallik and Hamilton, 2017). The decline in phenolics content at low temperature may be due to the decrease in the respiratory metabolism at lower temperature (Kalt et al., 1999), which lead to a decrease in available energy for antioxidants synthesis. Also the decelerated in production of reactive oxygen species (ROS) decreased the need for antioxidants synthesis (Mittler et al., 2004).

Concerning the effect of cold storage on anthocyanins content, Mallik and Hamilton, (2017)reported that changes in anthocyanins content of blueberry during cold storage at (2ºC) and freezing at (-15ºC) temperatures were genotype-dependent. At refrigerator temperature, total anthocyanins content of *Vaccinium myrtilloides* increased (about 24%) after 90 days of storage, while insignificant changes occurred in other genotypes (*V. angustifolium* and *V. angustifolium* var. *nigrum*).

Controlled and modified atmosphere storage

Controlled atmosphere storage and modified atmosphere packaging usually refer to the storage environment with elevated CO_2 and/or reduced O_2 concentration. Wang et al. (2021) indicated that storing fresh-cut pears at 10% CO_2 inhibited the generation of ROS due to inducing effects of genes and enzymes related to antioxidant capacity, which finally alleviated oxidative damage. Modified atmosphere also retarded the decrease in anthocyanins content of strawberrys (Khorshidi et al., 2011). In contrast,Holcroft et al.(1998)indicated that increases in CO_2 levels decreased anthocyanins content in pomegranates either by inhibiting their synthesis or by lowering their stability.

Processing

Various processes have been used recently to convert fruits to other forms and maintain their characteristics and quality. These processes can either increase or decrease the antioxidants contents depending on the process type. For example, drying process is the most common and easiest way to preserve fruits outside refrigerators up to many years. Abou-Farrag et al. (2013) observed that both air and microwave drying methods of figs decreased ascorbic acid, phenolics and anthocyanins contents, and reduced the antioxidant capacity. While, Vidinamo et al. (2020) reported that freeze-drying can preserve the antioxidant compounds in comparison to air-, microwave- and sun-drying. In addition, increases in antioxidant capacity after drying may be related to the reaction products that can be formed as a consequence of heat treatment or prolonged storage (Kamiloglu and Capanoglu, 2015).

Regarding cooking and heat treatments, Hiwilepo-van Hal et al.(2012) reported that processing through heat treatments (from 80 to 150 °C) of marula, mango and guava pulp caused degradation of vitamin C. The ascorbic acid in marula pulp was about 15-fold more stable to heat than the ascorbic acid in mango and guava pulp at temperatures lower than 125 °C. Hailemariam and Wudineh (2020)locally called Ye'abesha Gomen, and cabbage (Brassica oleracea added that the pressure cooking method minimizes the loss of ascorbic acid in green leafy vegetables, as it required shorter cooking period, compared to open pan cooking. On the other hand, exposure to high pressure during process (400 MPa and 40°C for 1 minute) reduced approximately 30% of the total carotenoid content of mandarin juice (Cilla et al., 2020). Contrary to that, total carotenoid increased 54% in sweet orange juice after a treatment of 400 MPa/40°C for 1 min (Sánchez-Moreno et al., 2005). The variable effects of the high pressure treatment on the carotenoid content in mandarin juices and sweet orange may be related not only to their specific carotenoid composition (mandarin is rich in β-cryptoxanthin while sweet oranges are rich in epoxy-xanthophylls) but also to the juicing method used (Cilla et al., 2020).

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Conflicts of Interest

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تأثير معاملات ما بعد الحصاد على محتوى مضادات الأكسدة فى الفاكهة والخضر

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تعتبر الفاكهة من أهم المصادر الطبيعية لمركبات مضادات الأكسدة مثل الفينولات (الأنثوسيانين والفلافونويد) والفيتامينات والكاروتينات والتأنينات. هذه المركبات لها دور أساسي في جودة الثمار و أيضا تعد ضرورية جدا في الحفاظ على صحة الإنسان. تتعرض الثمار للعديد من الظروف قبل وبعد الحصاد بالإضافة إلى بعض العمليات التي قد تؤثر على جودتها.

تناولت هذه المراجعة تأثير الظروف والمعاملات التى تتعرض لها الثمار بعد الحصاد مثل مرحلة النضج، ووقت الحصاد، والمعاملات الكيميائية، والإشعة فوق البنفسجية، والمعاملة بالأوزون، والتغليف، وطول وفترة التخزين، ودرجة حرارة التخزين، والجو المتحكم فيه اوالمعدّل ، بالإضافة إلى ظروف التصنيع على محتوى الثمار من مضادات الاكسدة. علاوة على ذلك ، للتأكيد على أفضل الممارسات التي تحافظ على جودة الفاكهة وقيمتها الغذائية لصحة الإنسان.

اوضحت المراجع المقدمة إلى أن محتوي الفاكهة والخضر من مضادات الأكسدة تختلف بشكل معنوى مع حدوث تغيرات في جميع ظروف ما بعد الحصاد المذكورة. لذلك، فمن المهم تحديد المعاملات المثلى لكل نوع من انواع الفاكهة لتحقيق أعلى فائدة لصحة الإنسان وفي نفس الوقت الحصول على ثمار جذابة للمستهلك.