The Pharma Innovation Journal 2022; 11(6): 1769-1775

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(6): 1769-1775

www.thepharmajournal.com
Received: 01-04-2022
Accepted: 09-05-2022

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Effect of ultraviolet-c irradiation on biochemical properties of horticulture produce

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Abstract

Ultraviolet irradiation is one of the popular minimal processing techniques which offers improved shelf life with better preservation of sensorial and biochemical properties of food. Ultraviolet-C irradiation has higher energy compared to UV-A and UV-B, hence having a comparative higher germicidal effect. Various studies have highlighted the benefits of UV-C irradiation on physicochemical properties along with the germicidal effect. This review paper presents brief information about UV-C irradiation and its effect on nutritional (Total soluble solid, total phenol, titratable acidity, ascorbic acid and antioxidant activity) properties of horticulture produce. UV irradiation enhances plant defence by increasing the production of defence hormones such as phenylalanine ammonia-lyase and peroxidase. The literature evidence showed a positive effect of treatment on total phenol, total soluble solid and antioxidant activity of horticulture produce. UV-C treatment also showed potential in maintaining titratable acidity during storage. Its application showed promising results in reducing respiration and ethylene production. The reduced ethylene production delays ripening hence delayed senescence of commodity. Research efforts on the effect of intensity and harvest maturity on the biochemical composition of horticulture produce on UV-C treatment are required to be explored.

Keywords: Ultraviolet, irradiation, phenol, horticulture, phenylalanine ammonia-lyase, peroxidase

Introduction

Agriculture is considered a major event in human evolution. The demand for the preservation of food products started soon after cultivation. Through the course of history and advancement of technology, the processing techniques being adopted for preservation kept on refining. The conventional technologies relied on heat application and reduction in the water activity of the food. The preserved food so achieved comes at a cost of declined quality of sensorial and nutritional parameters [1]. With the advancement of technologies, the use of additives was also practiced. However, their use is also limited due to the possibility of adverse effects on the human body. There is also a surge in the customer demand for more natural flavor and lesser use of additives in processed food. The minimal processing techniques are making their mark with their potential of preserving the food products and fulfilling the current demand of customers. These processing techniques use minimal processing conditions to preserve the food which allows the better retention of sensorial and nutritional characteristics of food. These advantages are luring the scientific community towards minimum processing techniques such as cold plasma, sonication, ozonation, pulsed electric field, high hydrostatic pressure and irradiation [2].

In food processing, irradiation stands for the application of radiation on food products. Irradiation is generally related to gamma irradiation in food processing. But there are other irradiation techniques also such as X-ray and ultraviolet irradiation. In contrast to the latter, the gamma irradiation facilities require sophisticated facilities for processing and also demand for high fortune. However Ultraviolet irradiation (UV) is comparatively easy to use and requires a simple facility with better control over the processing conditions. It is among the emerging minimal processing techniques with promising results of enhanced shelf life and better maintenance of nutritional properties of the product with minimal processing conditions. This technique is also environmentally friendly and cost-effective [3]. In contrast to ionizing gamma irradiation, it is non-ionizing germicidal radiation which has comparatively lower penetration. The germicidal surface decontamination property of UV offers a vast opportunity for controlling microbial growth in food processing [4]. Among ultraviolet electromagnetic spectra, ultraviolet-c radiation is acknowledged for its germicidal property.

The lower penetration depth restricts its use on the food surface, clear liquids and juices with turbulence systems & thin layers.

Horticulture products are more perishable compared to other food commodities. UV irradiation has shown the potential in increasing the shelf life of horticulture produce. Various literature also reports better maintenance of nutritional composition of horticulture produce. This review paper will highlight brief information about ultraviolet-C irradiation and its effect on the biochemical characteristics of horticulture products.

Ultraviolet Irradiation

Ultraviolet light has a wavelength between 10-400 nm and lies between X-rays and visible electromagnetic spectra. UV is further divided into UV-A, UV-B, UV-C and vacuum UV (with a wavelength of 100-200nm and exists in a vacuum only). The photon energy of different UV is given in Table 1. As it can be seen that the UV-C has higher energy compared to others leaving vacuum UV. Vacuum UV is not generally used in food processing as it makes the irradiation facility sophisticated. UV-A doesn't have enough energy to achieve disinfection [5]. To inactivate E. coli using UV-A a dose of 70 mW cm^{-2} was required which requires higher fluency and treatment time which makes the use of UV-A alone for disinfection obsolete. Comparative to UV-A, UV-B has more energy and is responsible for skin tanning. UV-B irradiation has the potential to improve the nutritional characteristics of horticulture produce [6]. It has the potential in improving chlorophyll content, delaying yellowing, maintaining sensory qualities and improve antioxidant qualities [7]. However, UV-C with the highest energy has the potential in sterilizing the food products compared to UV-B [8]. The UV-C radiations have germicidal properties and are extensively used in the food industry. U.S.FDA permitted the use of UV in juice processing in 2001, which improved the commercial use of ultraviolet radiation in the food industry [9]. Several kinds of literature compare the effect of different UV spectra on food nutrition and microbial characteristic. It was reported that the antioxidant activity and total phenol content were found highest in UV-C treated grapes compared to UV-B and combined (UV-C and UV-B) treatment [8]. Similarly was reported that UV-C preserved peach fruit exhibited enhanced physic-chemical and sensory characteristics compared to UV-B treated fruits [10]. The concerning point in the application of any processing technique is its effect on the sensorial and nutritional composition of the product. The current review focuses on the effect of UV-C treatment on the biochemical characteristics of horticulture produce.

Ultraviolet light has similar properties as both wave and particle nature and carries energy in packets known as photons. The photochemical changes occur in food products when UV photons are absorbed by molecules [11]. The photons increase the energy of the electron which leads to the orbital jump of electrons in higher orbits at a highly unstable excited state with a duration of 10^{-10} to 10^{-8} seconds. However, this duration is enough for the molecules to undergo a photochemical reaction to achieve a stable state. Hence the photochemical reaction can be commenced if the UV light of required energy gets absorbed by the food molecules [9]. The UV light works on two principles in food processing. Firstly the germicidal effect involves the absorption of photons by DNA molecules. In germicidal affect the absorbed energy results in the crosslinking between neighboring thymine and cytosine of the same DNA strand. The mutation of DNA due to intra-cross linking results in the disruption of hydrogen bonds to the opposite strand of DNA. The breaking of the hydrogen bond results in disruption of DNA structure which halts the transcription and replication. This directly affects the cellular functioning of molecules and leads to cell death [12-13]. The DNA of microbial populations such as bacteria, viruses, moulds and protozoa highly absorb UV-C radiation which leads to disruption of DNA and halts their reproduction [11]. In contrast, UV-C has the least effect on the protein content and doesn't produce any byproducts [14]. The second working principle of UV light is the hormesis effect. The stimulation by application of low doses of harmful agents is known as hormesis [15]. The application of low doses of UV-C can create positive effect homeostasis of a plant [16]. UV-C light stimulates the production of phenylalanine ammonia-lyase (PAL) which enhances the biosynthesis of phytoalexins such as scopoletin and scoparone. The stimulation of these compounds increases the resistance of plant tissue to spoilage-causing factors [3, 17]. The application of UV-C stimulates the production of certain beneficial biochemical parameters which mimics the compounds released by plants under abiotic stresses [18]. The hormesis effect also maintains the nutritional parameters of food products.

Table 1: Different UV compositions and their relative photon energy [19].

Type	Wavelength (nm)	Photon energy (eV)
UV-A	Long (320-400)	3.10-3.94
UV-B	Medium (280-320)	3.94-4.43
UV-C	Short (200-280)	4.43-12.4
UV- Vacuum	Very short (100-200)	12.4-120

Effect of uv-c on biochemical properties

UV-C irradiation had shown promising results in maintaining the quality of products with the combined effect of germicidal, hormesis and minimal effect on the biochemical properties of food [20].

Total Soluble Solid

Fruit maturity and final consuming quality are related to total soluble solids (TSS) content or TSS to starch ratio is indexed by the maturity and ripening of fruit [21]. UV-C irradiation can alter the TSS content throughout its storage, whether increased or decreased. The effect of UV-C (0.5-1 kJ m^{-2}) on shelf life and the quality of strawberries harvested at 80-85% of their maturity was investigated [22]. At the end of storage (day 9), the fruit treated with 1 kJ m^{-2} showed significantly higher (7.5^0 Brix) TSS content compared to any other treatment. The control sample showed the lowest (5^0 Brix) TSS content. The increase in TSS was attributed to an increase in sugar accumulation which might result from UV-C stress. The stress leads to an increase in sucrose synthase activity and inhibition of degradation enzyme-like phosphorylase or invertase [23]. TSS was maintained only in untreated and UV-C treated samples, in contrast, other treatments (Combined treatment of UV-C and freezing) suffered a significant decline [24]. The authors attributed the increase in TSS in the post-harvest period was because of the loss of water from fruit sap, which resulted in a higher concentration. The increase in TSS was attributed to the increased activity of starch hydrolysis enzymes [25-26]. UV-C didn't affect the TSS of liquid foods, such as apple, orange, mango and pomegranate juice [27-28-29-30].

Titratable Acidity

The titratable acidity (TA) of fruits and vegetables reduces with ripening and decides the maturity. The major organic acid is malic acid, which usually gets converted into sugar with ripening. An increase in TA with storage time in both treated (UV-C, freezing and combined treatment) as well as control dates [24]. The increase in TA was reported to be lowest in UV-C irradiation, followed by freezing. The increase in TA was correlated with the increase in microbial load, UV-C treatments showed the lowest microbial load hence the minimum increase in TA. The increase in microbial loads lead to an increase in acidity and a drop in pH [31]. In another study UV- treated tomato and strawberry fruit showed lower acidity than control [32]. The fruit treated with higher intensity showed lower TA compared to the low intensity irradiated fruit.

Total Phenol

Phenolic compounds are one of the most abundant classes of secondary metabolites which are synthesized via the shikimate pathway in the plant kingdom [33]. The total phenolic count of the plant kingdom increases on exposure to external stresses such as pathogen attack, wounding and radiation [34]. Phenols play an important role in plant defense by increasing PAL enzyme activity [35].

An increase in the total phenol content of the mangosteen pericarp was reported in UV-C treated samples compared to control. The total phenol content peaked after 6 days, and reached 1.06 mg g^{-1} for treated fruit and 0.92 mg g^{-1} for control [3]. A significant dose-dependent increase in the phenolic compound of UV-C treated (exposure time 20, 30 and 40 min) bitter gourd fruit with the highest value on the 16th day. Close findings were observed in different cultivars of blueberry which displayed elevated total phenol content on UV-C irradiation [36]. The effect of UV-C dose of 2.3 kJ m^{-2} or 4.6 kJ m^{-2} on blueberry of three cultivars *viz.* Legacy, Brigitta, and Bluegold was evaluated [37]. In response, UV-C treated Blue-gold resulted in the highest TPC levels when treated with the higher dose of 4.6 kJ m^{-2}. Alike effect of dose was observed on other cultivars. Apart from enhancing the total phenol content of fruits and vegetables, UV-C treatment also showed promising results in maintaining the TPC level during longer storage time [38]. In another study the influence of UV-C application (0.1-2 kJ m^{-2}) on peeled garlic was examined. A significant increase in total phenols in garlic treated with a dose of 1 and 2 kJ m^{-2} by 5.73 and 11.3%, respectively was reported during storage for 15 days at 0^{0}C [39]. Although the effect of low doses on the phenol content of garlic was insignificant. Similar findings of an increased phenolic content were observed in tomatoes on UV-C irradiation [40]. Similarly the TPC count was significantly increased on treatment with UV-C. The increased TPC count was attributed to the effect of biotic and abiotic stresses acting on the product, which ultimately affects the biosynthesis and metabolism of phenolic compounds [2]. In concomitance to the above findings a dose-dependent increase in TPC compared to untreated samples of tomato juice. The untreated sample contained 27.90 GAE/g whereas an increase of a maximum of up to 36.22 GAE/g in TPC was observed in treated samples. The increased TPC was attributed to the increase in PAL and polyphenol oxidase activity due to increased enzyme concentration resulting from the dissolution of polysaccharides in the cell wall [41]. The TPC rise might also be a response to light and temperature [42]. UV-C irradiation can also maintain the TPC content during study. A decreasing trend in the TPC content of date in all treatments (UV-C, freezing and their combined treatment). Although, combined treatment of UV-C and freezing was able to reduce the TPC level decline compared to other treatments. The decline in TPC content of date fruit was attributed to the oxidation of antioxidant to brown pigment as phenols are considered antioxidants [24].

Antioxidant Activity

Antioxidants are compounds that protect human body cells by reducing harmful free radicals. Antioxidants have a beneficial effect on several chronic diseases. Fruits and vegetables are an indispensable part of a healthy diet and are rich in antioxidants [43]. Antioxidants also prevent oxidative damage to plant cells [44]. The UV-C irradiation had shown a dichotomy effect on the antioxidant activity (AA) of food products. A dose-dependent increase in DPPH inhibition of bitter gourd with a maximum being in 40 minutes of treatment and a minimum being in control. After 16 days of storage, the treated samples (40 min) showed a 69% elevated DPPH inhibition ability compared to control [36]. Similarly in another study a 75% increase in AA content of sweet cherry on UV-C dose of 6 kJ m^{-2} [45]. The increase in AA is attributed to an increase in secondary metabolites on UV-C irradiation [46]. As discussed earlier, UV-C induces stresses which lead to an increase in the concentration of secondary metabolites [47]. Similarly a strong correlation between secondary metabolites and AA [48]. Though, higher doses also result in a decline in antioxidant activity due to excess stress, which results in injury. A marked decrease in DPPH radical scavenging ability was reported in fresh-cut baby corn at higher doses (6 kJ m^{-2}). Whereas lower doses (4 kJ m^{-2}) showed higher DPPH scavenging ability throughout the storage period [49]. Similarly a decline in antioxidant activity was reported at higher doses in strawberry and blueberry [50-51]. Similar findings were obtained on UV irradiation of tomato. The samples treated with 4 kJ m^{-2} resulted in the highest AA value of 92.83% trailed by 8 kJ with 92.69% AA [52].

In contrast to the trend of increase in antioxidant activity of solid food, UV-C resulted in a dichotomy of antioxidant activity of liquid foods. The increase or decrease in AA in fruit juices depends upon more than one factor, such as raw material, maturity, dose and exposure time. An increase in the DPPH scavenging ability of star fruit juice was reported [53]. Similarly a significant increase in DPPH inhibition at higher doses (60min) was reported in tomato juice compared to control. On UV-C irradiation of tomato juices with an exposure time of 15, 30 and 60 minutes, DPPH radical scavenging activities of 53.48%, 53.05% and 60.45% respectively compared to 50.33% of control were observed [41]. In contrast, an antioxidant capacity loss of 54.3 ± 10.0% on UV-C irradiation in white grape juice was also reported [54].

Ascorbic Acid

Ascorbic acid (AsA) is an important constituent of vitamin C. Major processing techniques have a potential negative impact on the ascorbic acid content of food products. UV-C irradiation has a dichotomy effect on ascorbic acid content. A higher AsA content in control compared to treated fruit was reported. Higher doses resulted in higher losses of ascorbic. A 7% decrease in AsA compared to untreated was found in 40 minutes of treatment, which increased up to 24% at the storage end [36]. Similar result of decline in the AsA content on UV irradiation was also observed in broccoli [55]. The decrease in ascorbic acid was attributed to the enhanced oxidation reaction during storage time because of UV-C irradiation [56]. The decrease might be related to the decreased activity of the ascorbic acid catabolic enzyme and ascorbate oxidase on UV-C irradiation [57].

In fresh-cut fruits, the UV-C application showed the potential to maintain the AsA content during storage. On irradiation of fresh-cut baby corn with UV-C (2.2, 4.4, and 6.6 $kJ.m^{-2}$) 4.4 $kJ.m^{-2}$ resulted in better retention of AsA compared to other treatments and control at the end of the storage (7 days). Whereas, every treatment and control displayed a decrease in AsA content during its storage [49]. Similar results of inhibition in the decline of ascorbic acid on UV-C application were reported in watermelon, yellow pepper and kiwi fruit [20-58-59].

In contrast to the above findings, an increase in vitamin C in cabbage on UV-C application was reported [60]. However, the increased vitamin content only remained up to 2 days of storage. Similar results were reported on UV-C irradiation of tomatoes [61]. The increase in ascorbic acid might result in the interactions between film components and vegetable tissues. Whereas the decline of ascorbic acid with storage period was attributed to energy requirement in metabolism and reduction in tissue deterioration [62]. Similarly a significant increase in AsA in different varieties, such as Balzamoth, Lorenzo, Trust, Clermont and Makari of tomato with different extent based on their harvesting maturity (10% ripe and fully ripe harvest) was also reported. It was stated that the increase of AsA was more in fruits that were harvested at 10% ripe maturity [63]. The maturity at which treatment is given significantly affects the response of fruit [64-65].

Effect of Uv-C on respiration and Ethylene production

Agriculture commodities are living entities and remain metabolically active even after harvesting. To continue their life cycle, the storage reservoir is used to produce energy and release CO_2, which is usually referred as respiration. In fruits and vegetables along with carbon dioxide, ethylene production takes place that enhances the ripening process, ultimately leading to the early senescence of fruit, which is not desirable from the food processing perspective [66]. UV-C has shown potential in reducing the respiration rate and ethylene production. The response of jinxing yellow peaches on UV-C (4 $kJ\ m^{-2}$) irradiation was investigated and was concluded that UV-C significantly inhibited the ethylene production rate and reduced the peak ethylene production. However, it doesn't delay the peak ethylene production time [67]. Similarly a lower peak respiration rate compared to untreated mangosteen fruit. The peak respiration rate of the control fruit was 44.32 $mg\ kg^{-1}\ h^{-1}$ whereas treated fruit showed 36.67 $mg\ kg^{-1}\ h^{-1}$ [3]. In concomitance to the above results, respiration rate of sweet cherry reduced significantly with an increase in UV-C dose was also reported. On exposure to sweet cherry fruit with UV-C dose, a decline of 5, 8 and 14% respiration rate was observed on 1.2, 3.0 and 6.0 $kJ\ m^{-2}$ dose respectively [45]. Similar results of reduction in respiration rate of shallots were reported UV-C irradiated samples (30, 60 and 90 minutes) compared to control [68]. Similar findings were observed in persimmon, tomatoes *and* strawberries [69-32]. The decline in respiration rate might be a result of inhibition of several steps involved in the mitochondrial electron transport chain and Krebs cycle [70]. The decrease in the activity of respiratory enzymes such as cytochrome C oxidase and succinic dehydrogenase reduces the respiration rate of ripening peach. UV-C can stimulate ethylene production in fruits by the hormesis phenomenon. On irradiation with UV-C, stresses develop inside the plant due to oxidative reactions. In response, the plant induces scavenging enzymes and antioxidant synthesis enzymes. The beneficial enzymes protect cells against any incoming stresses [69].

Conclusion

Based on literature evidence UV-C irradiation had a lethal effect on microbial DNA, which reduces the microbial load on horticulture produce. The germicidal effect of UV-C results in food products free from disease-causing micro-organisms. UV-C induced hormesis effect increases the production of plant defence enzymes which increases the activity of PAL and POD. The increased activity of these enzymes decreases the incidence of diseases. The combined effect of germicidal and hormesis effects enhances the shelf life of the product. The application of UV-C irradiation on horticulture produce had shown the potential of enhancing the total phenol, total soluble solids and total antioxidant content. Ascorbic acid is the most affected biochemical parameter in heat processing. UV-C irradiation showed the potential to maintain the ascorbic acid content in many horticulture produce however its phenomenon is not clear. Hence more studies on the effect of UV irradiation on ascorbic acid are required. The major problem of horticulture production is respiration and ethylene production rate. UV-C had shown potential in decreasing the respiration and ethylene production rate, which can delay the ripening, and ultimately senescence of the horticulture produce. There is a lack of literature evidence for justifying the effect of radiation intensity and harvest maturity on biochemical characteristics of the horticulture produce. To increase the application of UV-C irradiation, enhanced research is required to optimize the UV-C dose for better retention of biochemical parameters of horticulture produce.

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