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Ultraviolet light treatment of fresh fruits and vegetables surface: A review

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Abstract

Fresh fruits and vegetable are highly susceptible to microbial spoilage. This can be avoided with the application of surface treatments. The treatment of surface has to be as gentle as possible for keeping the integrity and the freshness of fruits and vegetables. Minimal processing techniques such as ultraviolet (UV) light treatment meet these requirements. The use of UV light treatment proved to be effective at reducing microbial loads of pathogens on fresh fruits and vegetables. This paper aims to review the available literature data and provide a general review of the application of UV light treatment on fresh fruits and vegetables surface for decontamination, preventing diseased and enhancing their shelf life and quality.

Keywords: ultraviolet light, germicidal, decontamination, decay, bacteria, mould, food pathogen, fruit, vegetable

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1. Introduction

Fruits and vegetables are important components of a healthy and balanced diet. Their sufficient daily consumption could help prevent major diseases such as cardiovascular diseases and certain cancers [1]. According to World Health Organisation / Food and Agriculture Organisation (WHO/FAO) report published in 2004, a minimum of 400 g of fruits and vegetables per day, excluding potatoes and other starchy tubers, are recommended for the prevention of chronic diseases such as heart disease, cancer, diabetes and obesity, as well as for the prevention and release of several micronutrient deficiencies [1].

Whether eaten fresh or cooked fruits and vegetables should be sound, clean and as free as possible of pesticides and microorganisms. However, major outbreaks involving fresh fruits and vegetables have been associated with common foodborne pathogens such as *Salmonella*, *Shigella* spp., *Campylobacter*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Staphylococcus aureus*, *Clostridium* spp., *Bacillus cereus* [2-4].

The risk involved with the consumption of fresh fruits and vegetables could be minimised either reducing or eliminating external surface contamination [3, 5]. Because simply washing of fresh fruits and vegetables with water may not remove pathogens and other spoilage microorganisms [6], other alternative processes were researched. The simple washing of raw fruits and vegetables in hot water or water containing disinfectants removes a portion of the pathogenic and spoilage microorganisms, reductions of 10-fold to 100-fold could sometimes be achieved [2, 7-10]. Traditional disinfectants (chlorine, chlorine dioxide, bromine, iodine, trisodium phosphate, sodium chlorite, sodium hypochlorite, quaternary ammonium compounds, acids, hydrogen peroxide, ozone, permanganate salts etc.) are partially effective in removing pathogens, each type of disinfectant varying in efficiency and in allowable maximum concentration [2, 3, 10, 11].

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Other attempts in reducing the number of microorganisms on the surface of fresh fruits and vegetables and extending the shelf life were modified atmosphere packaging [12-17], low temperature storage [17-19] and the use of edible films [20-24]. These treatments are selective in reducing the number of pathogens on the surface of fresh fruits and vegetables. Therefore, the use of nonselective treatments for the destruction of pathogens on the surface of fresh fruits and vegetables would be a better option. Such alternative processes are the irradiation of food and the use of germicidal ultraviolet light (UV-C).

The aim of this paper was to review the available literature data and provide a general review of the application of UV light treatment for the decontamination of fresh fruits and vegetables surface.

2. Ultraviolet spectrum

Plants use sunlight for photosynthesis and, as a consequence, are exposed to the ultraviolet (UV) radiation that is present in sunlight. UV radiation is divided into three segments: UV-A, UV-B and UV-C. The UV-C (λ = 200-280 nm) radiation is absorbed by ozone in the upper and middle parts of atmosphere and, thus, is not present in sunlight at the earth's surface [25, p. 2].

UV radiation promotes photo-oxidative reactions in plants producing reactive oxygen species (ROS). The major ROS are singlet oxygen, hydrogen peroxide and hydroxyl radicals [26]. The free radicals generated from UV radiation can target cell membranes, nucleic acids, cell walls and enzymes, inducing the acceleration of senescence [27, 28].

The effect of UV-C is directly lethal to microorganisms, hence the term "germicidal". However, the germicidal action of UV light is strongly dependent on the natural resistance to UV-C of the microorganisms. Shama (2005) has shown that microorganisms differ greatly in the UV doses required for inactivation [29]. Another important factor of survival is the surface on which microorganisms are attached. Gardner and Shama (2000) have shown that surface "topography" plays a major role in determining survival following exposure to UV-C. Microorganisms present on a surface that may be considered smooth are more susceptible to the effects of UV than the microorganisms present on a surface containing crevices inside which they might be shielded from the lethal effects of UV-C. The germicidal effect occurs over relatively short time that is essentially limited to the time of exposure of the microorganism to the UV source. The exposure times typically range from fractions of a second to perhaps tens of seconds [30].

3. Ultraviolet light treatment of fruits and vegetables surface

During the last two decades, the exposure of horticultural crops to non-ionizing artificial UV-C light (180-280 nm with maximum at λ = 254 nm) has been considered as an alternative to chemical fungicide in order to control postharvest diseases [31]. Furthermore, researches were shown that UV-C is able to induce resistance of fruits and vegetables to postharvest storage rots [32-37] and to delay the ripening process extending the shelf life of fruits and vegetables [38-41]. Moreover, when used at optimum level, UV-C light induces an accumulation of phytoalexins that play an important role in the resistance to disease of many plant systems [31, 42-44] and activates genes encoding pathogenesis-related proteins [28].

Treatment with UV-C light offers several advantages to food processors as it does not leave any residue in treated food, is easy to use and lethal to most types of microorganisms [45], and does not require extensive safety equipment to be implemented [3]. However, more research is needed to optimize UV light use [46].

3.1. Decontamination of fresh fruits and vegetables with UV light

The use of non-ionizing, germicidal UV-C light could be effective for the decontamination of fruits and vegetables as a whole or as fresh cut products. UV-C affects several physiological processes in plant tissues and damages microbial DNA [47, 25, p. 69-71]. Lado and Yousef (2002) reported that UV-C light inhibited microbial growth through a very simple way: radiation generates hydroxyl radicals from water, which remove hydrogen atoms form DNA components, sugar and bases. UV light at 254 nm induces the formation of pyrimidine dimmers which alter the DNA helix and block microbial cell replication. All cells which cannot repair damaged DNA die [48].

The efficiency of UV-C light has been demonstrated by a number of *in vitro* studies [30, 49, 50].

The effect of UV light was also evaluated on the microbial population and quality of fruits and vegetables as a whole and fresh cut [35, 51-53].

Erkan et al. (2001) showed that the exposure of zucchini squash slices to UV light for 10 and 20 min. reduced microbial activity and deterioration during subsequent storage at 5 or 10°C. Moreover, the respiration rate of the slices was stimulated while ethylene production and the degree of chilling injury at 5°C were unaffected [51].

Similar results were obtained for bell peppers [54], lettuce [3, 52, 53], apples [3], pear [55] strawberry [41, 56], broccoli [57], tomato fruits [58, 59], spinach [37], oyster mushrooms [60, 61] and many other fruits and vegetables.

Yaun et al. (2004) innoculated Red Delicious apples, leaf lettuce and tomatoes with cultures of *Salmonella* spp. or *Escherichia coli* O157:H7 for investigating the bactericidal effect of UV-C light (253.7 nm) with doses ranging from 1.5 to 24 mW/cm^2. They obtained different log reductions of microbial populations on the surface of fresh products varying from 2.19 logs for tomatoes inoculated with *Salmonella* spp. to 3.3 logs for apples inoculated with *E. coli* O157:H7 at the highest dose of UV-C light of 24 mW/cm^2. The difference may be due to bacteria shielding from the UV light by the wax applied on the tomatoes surface. There was no significant difference in the use of UV-C for inactivating equivalent populations of *Salmonella* spp. (2.65 logs) or *E. coli* O157:H7 (2.79 logs) on the surface of green lettuce [3].

Other study compared the effect of processing cantaloupe melon under UV radiation on storage properties of the cut fruit with post-cut UV-C fruit treatment [39]. The results indicated that fresh-cut pieces of melon than treated with UV light had lower populations of aerobic mesophilic and lactic acid bacteria compared to control and post-cut-treated pieces. Moreover, post-cut application of UV radiation improved shelf life, while cutting fruit under UV light further improved the quality of the product [39].

Fonseca and Rushing (2006) reported the influence of UV-C light (1.40-13.70 kJ/m^2 at 254 nm) on the quality of fresh-cut watermelon. They showed that exposing packaged watermelon cubes to UV light at 4.1 kJ/m^2 produced more than a 1-log reduction in microbial populations without affecting juice leakage, colour, and overall visual quality [62].

Schenk *et al*. (2008) investigated the microbicidal effect of UV-C light (λ = 253.7 nm, dose range between 0 and 87 kJ/m^2) on pear slices with and without peel against *Listeria innocua* ATCC 33090, *Listeria monocytogenes* ATCC 19114 D, *Escherichia coli* ATCC 11229, and *Zygosaccharomyces bailli* NRRL 7256 used as individual strains. Then strain cocktails of *Listeria*: *L. innocua* ATCC 33090, *L. innocua* CIP 8011, *L. welshimeri* BE 313/01, *L. monocytogenes* (ATCC 19114, ATCC 33090), and yeasts: *Z. bailli* NRRL 7256, *Zygosaccharomyces rouxii* ATCC 52519, and *Debaryomyces hansenii* NRRL 7268 were used for inoculation. Inoculated pear slices were treated with UV-C then log reductions of microbial populations were determined. Overall, as the UV dose was increased by increasing the time of exposure, better inactivation was obtained for all microbial species. Great log reductions rated were obtained at UV-C doses smaller than 15 kJ/m^2. The UV-C treatment was more effective for pear slices without peel. Thus, the inactivation ranges between 2.6 and 3.4 log cycles for these samples and 1.8 and 2.5 log cycles for pear slices with peel after treatments lasting 20 min, corresponding to 87 kJ/m^2 UV-C dose [55].

3.2. UV light used to control fungal decay

A number of studies showed that the pre-storage exposure of fruits and vegetables to UV light was effective in reducing the development of postharvest diseases: citrus fruits [42], kumquat [31], carrots [44, 63], apple [64], strawberry [35, 65-67], sweet cherry [35], mandarin [68], bell peppers [36], mango [69, 70], blueberry [71], grapes [72], persimmom fruit [73].

For instance, Baka et al. (1999) investigated the effect of pre-storage exposure to shortwave ultraviolet (UV-C) light on the decay and quality of fresh strawberries. They exposed fresh strawberries to UV-C at doses of 0.25 and 1.0 kJ/m^2. UV-treated fruits were randomly placed in plastic mesh baskets and stored in the dark at 4°C or 13°C. The storehouse atmosphere was maintained at about 95% relative humidity by continuous ventilation with humidified air. The decay caused by *Botrytis cinerea* at both temperatures was controlled through UV-C treatment and the shelf-life of the fruits was extended by 4 to 5 d. UV-treated fruits had a lower respiration rate, higher titratable acidity and anthocyanin content, and were firmer than the untreated fruits.

The authors observed that the percentage of free sugars increased faster in UV treated fruits at the beginning of the storage period. Fruits treated with 0.25 kJ/m^2 had a slower rate of senescence compared to the control. The maximum used dose of UV-C of 1.0 kJ/m^2 produced damage to the fruits. Overall, UV treatment at a 0.25 kJ/m^2 dose appeared to slow down the ripening and senescence of strawberry fruits stored at 4 °C [74].

However, López-Rubira et al. (2005) found inconsistent results regarding the effect of UV-C on microbial growth in fresh cut pomegranate arils stored up to 15 d at 5°C, only some UV doses reducing mesophilic, psychrotropic, lactic acid bacteria and enterobacteriaceae counts [46]. The combined use of modified atmosphere packaging (MAP) and UV-C treatment has been efficient for lowering psychrotropic bacteria, coloform and yeast growth in fresh cut lettuce without adversely affect sensory quality [53].

More examples of the effect of UV light on the reduction of microbial population counts on fruits and vegetables surface, preventing disease spreading, improving shelf live and maintaining products quality are presented in Table 1 for fruits and in Table 2 for vegetables, in alphabetical order.

Table 1. Summary of the study results related to postharvest UV treatment of fruits surface

Fruit (Cultivar)	**UV light conditions**	**Results**	**References**
Apple (*Malus domestica*, cv. Red Delicious)	UV-C λ = 254 nm 7.5 kJ/m^2	– The earliest application of UV treatment (96 hours) before inoculating with *Penicillium expansum* provided the best defence against disease.	De Capdeville et al., 2002
Apple (*Malus domestica*, cv. Red Delicious)	UV-C λ = 253.7 nm 1.5-24 mW/cm^2	– Reduction of *E. coli* O157:H7 with 3.30-log CFU/cm^2	Yaun et al., 2004
Bluberry fruit (*Vaccinium corymbosum* L. cvs. Collins, Bluecrop)	UV-C 0-4 kJ/m^2 Storage 7 d at 5°C plus 2 d at 20°C	– Weight loss and firmness were not affected by light treatment – Decay incidence from ripe rot (*Colletotrichum acutatum*, syn. *C. gloeosporioides*) on fruit was decreased by 10% with 1-4 kJ/m^2 UV-C light – Antioxidants (measured by total anthocyanin), total phenolics, and ferric reducing antioxidant power (FRAP) increased with treatment intensity	Perkins-Veazie et al., 2008
Blueberry fruit (*Vaccinium corymbosum* L. cv. Duke)	UV-C λ = 254 nm 0.43, 2.15, 4.30 and 6.45 kJ/m^2 Frozen in liquid nitrogen at –80°C	– Increased levels of flavonoids in blueberries after UV-C treatment – Significantly higher antioxidant capacity was detected in fruit treated with 2.15, 4.30, or 6.45 kJ/m^2	Wang et al., 2009
Cantaloupe melon (*Cucumis melo* L. var. reticulatus) sliced	UV 15 and 60 min	– Fruit exposure to UV light decreased the concentrations of most of the aliphatic esters by over 60% of the amounts present in the corresponding fresh cut fruit	Lamikanra et al., 2002
Cantaloupe melon (*Cucumis melo* L.) - fresh cut	UV-C Storage at 10°C	– Fruit processed under UV-C radiation had the lowest esterase activity throughout the storage period. – Lipase activity was higher in post-cut treated fruit than fruit processed under UV-C light and the control fruit. – UV-C was effective in reducing yeast, mould and *Pseudomonas* spp. populations	Lamikanra *et al.*, 2005
Grapefruit (*Citrus paradisi*, cv. Star Ruby)	UV-C λ = 254 nm 0.5-3.0 kJ/m^2	– Quality and disease resistance determined after storage at 7°C for 4 weeks followed by 1 week at 20° C. – Scoparone and scopoletin levels were increased at all UV doses. – Rind browning and tissue necrosis occurred at UV doses > 1.5 kJ/m^2.	D'hallewin et al., 2000

Grapes (*Vitis vinifera* L. cv. Italia)	UV-C $\lambda = 254$ nm 0.125-4 kJ/m^2	– Grapes irradiated 24-48 hours before inoculating with *Botrytis cinerea* showed a lower disease incidence than those inoculated immediately before irradiation. – Doses above 1.0 kJ/m^2 resulted in skin discolouration. – Treatment within the optimum range did not significantly reduce the numbers of epiphytic yeasts that showed antagonism towards pathogenic moulds.	Nigro et al., 1998
Grapes (Vitis vinifera L.) - table grapes cvs. Thompson Seedless, Autumn Black, Emperor - green grape selection B36-55	UV-C 0.36 J/cm^2, 5 min	– Reduction of gray mould incidence (*Botrytis cinerea*) – UV-C light induced catechin in cv. Autumn Black berries and trans-resveratrol in both cv. Autumn Black and selection B36-55	Romanazzi et al., 2006
Kumquat (*Citrus japonica*, cv. Nagami)	UV-C, $\lambda = 254$ nm 0.2-12 kJ/m^2	– Inactivation of *Penicillium digitatum* inoculated after UV treatment – UV-treated fruit showed signs of damage after 2 weeks of storage at 17°C – Damage was absent when fruits were stored at lower temperatures	Rodov et al., 1992
Mandarin (*Citrus unshiu* Marc.) Satsuma	UV-C 10 min	– UV light treatments reduced green mold, but caused some injury to the fruit. The disease incidence was very low among fruit that were held at 30 °C with high humidity (90–95%) for 72 h.	Kinay et al., 2005
Mango (*Mangifera indica* cv. Tommy Atkins)	UV-C, $\lambda = 254$ nm 4.9 and 9.9 kJ/m^2	– Quality and disease resistance determined after storage at 5° C for 14 days followed by 7 days at 20° C. – Treatment at 4.9 kJ/m^2 resulted in improved fruit appearance and texture. – The higher dose induced senescence.	Gonzales-Aguilar et al., 2001
Mango (*Mangifera indica* cv. Haden)	UV-C, $\lambda = 254$ nm 2.46 and 4.93 J/m2 Stored 18 d at 25°C	– UV-C maintained better overall appearance, lower decay percentage and increased shelf life of fruit.	Gonzales-Aguilar et al., 2007
Oranges (*Citrus sinensis* cv. Biondo Comune, Washington Navel, Tarocco, Valencia Late)	UV-C, $\lambda = 254$ nm 0.5-3.0 kJ/m^2	– Quality and disease resistance determined after storage at 7°C for 4 weeks followed by 1 week at 20° C – Peel quality was affected in all cultivars with the exception of Valencia L. – Percentage of damaged fruit at the higher dosages decreased as the season progressed. – UV irradiation at 0.5 kJ/m^2 was effective in reducing decay development. – The higher dose of 1.5 kJ/m^2 was more effective but only in early harvested fruit.	D'hallewin et al., 1999
Peach (*Prunus persica*, cv. Elberta)	UV-C, $\lambda = 254$ nm 0.4-40 kJ/m^2	– Exposure to UV delayed ripening, suppressed ethylene production and increased phenylalanine ammonia-lyase (PAL) activity – inactivation of *Monilinia fructicola* inoculated after UV treatment – Doses of 40 kJ/m^2 increased susceptibility to brown rot – Increased number of the antagonist yeast *Debaryomyces hansenii* on the surface of the fruit	Stevens et al., 1998
Peach (*Prunus persica* L. Batsch cv. Loring)	UV-C $\lambda = 254$ nm 7.6 kJ/m^2 10 min	– UV-C light caused a rapid induction of enzymes activities: chitinase, β-1,3-glucanase, and phenylalanine ammonia lyase (PAL) starting 6 h after treatment and reaching maximum levels at 96 h after treatment	El Ghaough et al., 2003

Pear (*Pyrus communis* L.) Fresh-cut pear – slices without peel	UV-C λ = 253.7 nm Time = 0–20 min Dose = 0–87 kJ/m^2	– Reduction of different strains (*L. innocua* ATCC 33090, *L. monocytogenes* ATCC 19114 D, *E. coli* ATCC 11229, *Z. bailli* NRRL 7256) with 2.6-3.4-log	Schenk et al., 2008
Pear (*Pyrus communis* L.) Fresh-cut pear – slices with peel	UV-C λ = 253.7 nm Time = 0–20 min Dose = 0–87 kJ/m^2	– Reductions with 1.8-2.5-log of cocktail strains of: *Listeria*, *L. innocua* ATCC 33090, *L. innocua* CIP 8011, *L. welshimeri* BE 313/01, *L. monocytogenes* (ATCC 19114, ATCC 33090), and yeasts: *Z. bailli* NRRL 7256, *Z. rouxii* ATCC 52519, *D. hansenii* NRRL 7268	Schenk et al., 2008
Persimmom fruit (*Diospyros kaki* Thunb. cv. Karaj)	UV-C 1.5 and 3 kJ/m2 Storage 0-4 month at 1°C	– UV-C reduced the postharvest disease incidence without important effect on fruit attributes (firmness, ethylene production and skin colour)	Khademi et al., 2013
Pineapple (*Ananas comosus* L.) - fresh cut	UV-C for 15 min Storage 24 h at 4°C	– UV produced a considerable decrease in the esters concentration and increase in the relative amount of copaene	Lamikanra & Richard, 2004
Pomegranate (*Punica granatum* cv. Mollar of Elche) Fresh cut arils	UV-C 0.56-13.62 kJ/m^2 Up to 15 d at 5°C	− Respiration rate was not affected − Reduction of mesophilic, psychrotrophic, LAB and enterobacteriaceae counts − Yeasts and moulds were unaffected	López-Rubira et al., 2005
Strawberries (*Fragraria ananassa* cv. Kent)	UV-C, λ = 254 nm 0.25 and 1 kJ/m^2 Storage at 4°C and 13°C	– UV treatment controlled the decay caused by *Botrytis cinerea* at both temperatures and extended the shelf-life of the fruits by 4 to 5 d – Fruits treated at the lower UV dose showed a lower rate of senescence. – UV-treated fruits had a lower respiration rate, higher titratable acidity and anthocyanin content, and were firmer than the untreated fruits – Some evidence obtained that damage caused at the highest dose tested.	Baka et al., 1999
Strawberries (*Fragraria ananassa*)	UV-C λ = 254 nm 0.025, 0.05 and 0.10 J/cm^2 10, 20 and 40 s	– Conidia of *Botrytis cinerea* and *Monilia fructigena*	Marquenie et al., 2002 Marquenie et al., 2003a, b
Strawberry (*Fragraria ananassa* cv. Elsanta) sepals	UV-C λ = 254 nm 0.05, 0.50, 1.00 and 1.50 J/cm^2	– Inhibition of growth od *Botrytis cinerea* MUCL 18864 was significant starting from a dose of 0.05 J/cm^2	Lammertyn et al., 2003
Strawberries (*Fragraria ananassa*, *Duch.*)	UV-C λ = 254 nm 0.43, 2,15 and 4.30 kJ/m^2 1, 5 and 10 min Storage at 10°C	– Enhanced antioxidant capacity after storage for 15 days – Best decay inhibition with 5 and 10 min UV-C treatment	Erkan et al., 2008
Strawberries (*Fragraria ananassa*, *Duch.* cv Kurdistan)	UV-C λ = 254 nm 0.25 and 0.5 J/cm^2 Stored up to 7 d at 1...5°C	– All UV-C doses decreased growth of yeast – Fruits treated with the highest doses (0.5 J/m^2) are significantly firmer on day 7 and this dose improved the sensory quality of the product	Darvishi et al., 2012
Sweet cherries (*Prunus avium*)	UV-C λ = 254 nm 0.5-15.0 J/cm^2	– UV treatment had no affect either on fungal development (conidia of *Botrytis cinerea* and *Monilia fructigena*) or fruit quality	Marquenie et al., 2002

Table 2. Summary of the study results related to postharvest UV treatment of vegetables surface

Vegetable (cultivar)	UV light conditions	Results	References
Asparagus, white (*Asparagus officinalis* L.)	UV-C, λ = 254 nm 1 kJ/m^2, 8 min Aqueous ozone Combined treatments	− Slight reduction of respiration in white asparagus spears, but increase in spear tissue toughness − Total cell wall compounds were only tendentiously reduced after 4 d of shelf-life at 20°C by application of aqueous ozone and UV-C	Huyskens-Keil *et al*., 2011
Asparagus, white (*Asparagus officinalis* L.)	UV-C, λ = 254 nm 1 kJ/m^2 Storage 4 d at 20°C Wash with ozonated water	− Washing the spears of asparagus with ozonated water (3 or 4.5 ppm) and treating them with UV-C radiation did not systematically and significantly affect the microbial loads during storage.	Hassenberg et al., 2012
Bell peppers (*Capsicum annuum* L. var. *annuum*, Grossum Group cvs, 'Delphin' or 'Bell Boy')	UV-C 0.22, 0.44, 0.88 and 2.20 kJ/m^2 Storage at 13°C and 20°C	− Reduction in the number of natural infections occurring during storage at 13 °C − Fruit exposed to UV-C 24 hours before inoculation with *B. cinerea* had a lower percentage of infections	Mercier et al., 2001
Bell peppers (*Capsicum annuum* L.), whole	UV-C 2.27kJ/m^2 21 d at °C	− Reduced decay caused by *Botrytis cinerea*	Artés *et al*., 2006
Broccoli heads (*Brassica oleracea* cv. Italica Group)	UV-C 4–14 kJ/m^2	− Delayed yellowing and chlorophyll degradation at 20°C − Displayed lower respiration rate − Increased total phenols and flavonoids, along with higher antioxidant capacity	Costa et al., 2006
Carrots (*Daucus carota* L.)	UV-C, λ = 254 nm 0.88 kJ/m^2	– Inhibition of *Botrytis cinerea* found in both UV-treated and preinoculated roots	Mercier et al., 2000
Chinese kale (*Brassica oleracea* var. *alboglabra*)	UV-C, λ = 254 nm 1.8, 3.6, 5.4 and 7.2 kJ/m^2 Storage at 20°C	− UV-C dose of 3.6 and 5.4 kJ/m2 delayed leaf yellowing − UV-C delayed the decrease in activities of antioxidant enzymes, particularly peroxidase (POD) and superoxide dismutase (SOD) − UV-C reduced ethylene production and respiration rates	Chairat et al., 2013
Cress / garden cress (*Lepidium sativum* L.)	UV-C lamp 60 W 10, 20 and 30 min Storage 7 d at 5°C and 95% RH.	− UV-C treatment was prevented leaf yellowing of garden cress, increased chlorophyll content and prevented chlorophyll degradation but increased electrolyte leakage due to tissue damage	Kasım and Kasım, 2012
Lettuce (*Lactuca sativa* L. cv. 'Lollo rosso') - fresh cut	UV-C, λ = 254 nm 0.4, 0.81, 2.44, 4.07 and 8.14 kJ/m^2 Stored up to 9-10 d at 5°C	− Decreased psychrotrophic and coliform bacteria, and yeast growth − Growth of LAB seemed to be stimulated by UV-C radiation, probably due to reduced growth of competitive flora	Allende and Artés, 2003a

Table 2. Summary of the study results related to postharvest UV treatment of vegetables surface (*continuous*)

Vegetable (cultivar)	UV light conditions	Results	References
Lettuce (*Lactuca sativa* L. cv. 'Red Oak Leaf') - fresh cut	UV-C, λ = 254 nm 0.4, 0.81, 2.44, 4.07 and 8.14 kJ/m^2 MAP (2-10 kPa O_2 and 5-12 kPa CO2) Storage 10 d, 5°C	− Combination of UV-C radiation and MAP was effective for reducing psychrotrophic bacteria, coliform, and yeast growth. − Sensory quality of lettuce was not adversely affected	Allende and Artés, 2003b
Leaf lettuce	UV-C λ = 253.7 nm 1.5 – 24 mW/cm^2	− *Salmonella* spp. 2.65 log − *E. coli* O157:H7 2.79-log	Yaun et al., 2004
Lettuce (*Lactuca sativa* L. cv. 'Red Oak Leaf') - fresh cut	Two sided UV 1.18, 2.37 kJ/m^2 Passive MAP - up to 10 d at 5°C	− Reduction of natural microbiota (20 bacterial strains) − All UV-C treatments extended the shelf-life of the product	Allende et al., 2006
	7.11 kJ/m^2 7 d at 5°C	− The 7.11 kJ/m^2 dose induced tissue softening and browning	
Oyster mushroom (*Pleurotus ostreatus*)	UV-C 6, 96, 216, 360 and 504 mWs/cm^2 combined with ethanol, H_2O_2 and NaClO	− The combined sanitizers / UV-C treatments resulted in greater reductions in bacterial counts (*B. cereus* and *S. aureus*) than either treatment alone	Ha et al., 2011a, b
Onion (*Allium cepa* L.) Walla Walla	0.44×10^4, 1.32×10^4, 3.52×10^4, 7.33×10^4 and 19.1×10^4 erg/mm ± of UV	– Reduction in postharvest rots – Not significant effect on pH	Lu et al., 1987
Onion (*Allium cepa* L.), green	UV-C UV lamp 30 W 3, 5, 10 and 15 min Stored 15 d at 5°C	– UV-C controlled pathogen growth – Antioxidant activity of fresh-cut green onion was enhanced with higher UV-C – UV-C for 15 min produced noticeable yellowing of green onion – Electrolyte leakage of fresh-cut green onions was getting high with the higher doses of UV-C – The lower dosed were recommended for pathogen control both for lower electrolyte leakage and lower decay	Kasım and Kasım, 2010
Potatoes (*Solanum tuberosum* L.)	UV-C, λ = 254 nm 15.0 kJ/m^2	– completely suppression of dry rot (conidia of *Fusarium solani*) and of soft rot (cells of *Ervinia cartovora*)	Rangana et al., 1997
Spinach (*SPinacia oleracea* L.)	UV-C 2.4, 7.2, 12.0 and 24.9 kJ/m2 13 and 14 d at 5°C	– All UV-C doses were effective in reducing bacterial growth (pathogens *L. monocatogenes* and *S. enterica*; spoilage bacteria *Pseudomonas marginalis*)	Escalona et al., 2010
Sweet potatoes (*Ipomea batatas* L.)	UV-C, λ = 254 nm 3.6 kJ/m^2	– increased resistance of sweet potato roots to *Fusarium solani* – failing to develop lesions after 10 d – maximum phenylalanine ammonia-lyase (PAL) activity at 3.6 kJ/m^2	Stevens et al., 1999
Tomatoes (*Lycopersicon esculentum* Mill.)	UV-C 1.3 – 40 kJ/m^2	− inhibition of black and gray mould formation − delayed ripening − extended shelf life	Liu et al., 1993

Tomatoes (*Lycopersicon esculentum* L.)	UV-C, λ = 254 nm 3.7 kJ/m^2 (37 s and 100 J/m^2·s) Stored in dark at 16°C for 25 d	− UV-C delays fruits ripening inducing reactive oxygen species (ROS) which trigger the activation of ROS-scavenging enzymes − the cell-wall-degrading enzymes are inhibited by the UV-C	Barka, 2001
Tomatoes	UV-C λ = 253.7 nm 1.5 – 24 mW/cm^2	− Reduction of *Salmonella* spp. with 2.19-log	Yaun et al., 2004
Tomatoes (*Lycopersicon esculentum* L.) for fresh cut	UV-C 4 kJ/m^2 pretreatment + Storage under 5 kPa O_2 + 1 kPa CO_2 at 12°C for 21 d	− Retarded ripening − Maintained better firmness and sensory attributes than air storage	Robles et al., 2007
Tomato fruit (*Solanum lycopersicum cv*. Zhenfen 202)	UV-C 2.0, 4.0, 8.0, and 16.0 kJ/m^2 Stored 14°C	− UV-C significantly increased total phenolic content and antioxidant activity	Liu et al., 2012
Tomato fruit (*Lycopersicon esculentum* L.)	UV-C 3.7 kJ/m^2	− Phenylalanine ammonia-lyase which improves antioxidant capacity – resistance to *Botrytis cinerea*	Charles *et al*., 2008 Charles *et al*., 2009
Zucchini squash (*Cucurbita pepo* L., cv. Tigress) slices	UV-C 10 and 20 min 5 or 10°C	− Significant reduced microbial activity and deterioration during subsequent storage at 5 or 10°C − Higher respiration rates − Ethylene production was not affected − Chilling injury: dried sunken brown spots on the surface of cortex tissue – only after 20 days of storage at 5°C − No consistent effect of UV-C on sugar or malic acid concentrations	Erkan et al., 2001

4. Conclusion

Fresh fruits and vegetable are highly susceptible to microbial spoilage. This can be avoided with the application of surface treatments. The treatment of their surface has to be as gentle as possible for keeping the integrity and the freshness of fruits and vegetables. Minimal processing techniques such as ultraviolet (UV) light treatment meet these requirements. The use of UV-C light treatment proved to be effective at reducing microbial loads of pathogens on fresh fruits and vegetables. This paper aims to review the available literature data and provide a general review of the application of UV light treatment on fresh fruits and vegetables surface for decontamination, preventing diseased and enhancing their shelf life and quality.

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Compliance with Ethics Requirements

Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human and/or animal subjects (if exists) respect the specific regulations and standards.

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