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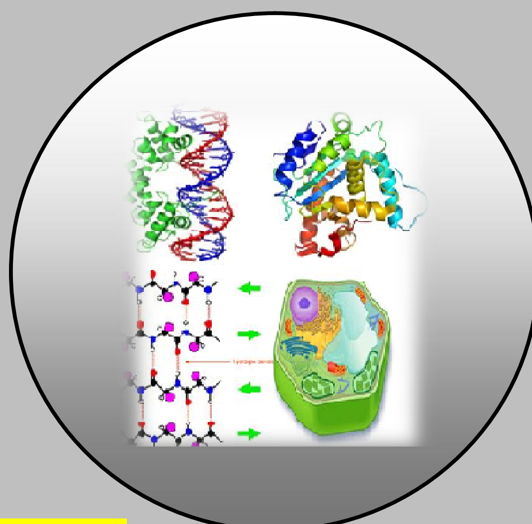

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RESEARCH PAPER

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UV-C Light as an Effective Physical Method to Control Post Harvest Diseases

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ABSTRACT

The earliest application of UV irradiation in the field of post-harvest technology of fresh fruits and vegetables in the eighties has been emphasized mainly to control post-harvest pathogens. Later towards the end of the previous decade, the survey of literature reveals shift in the focus to study the effect of UV on ripening. Today, consumer interest is not just to find wholesomeness of the product intact but also to have enhanced quality. In the past 3-4 years, very limited studies have examined the relevance of UV irradiation on quality aspects of treated produce during storage and possible influence on functional quality.
Keywords: UV-C Light, Post-Harvest Diseases, Pathogen, Physical control.

INTRODUCTION

Economic losses caused by postharvest disease are more considerably than are often realized because fruits and vegetables increase manifold in unit value while passing from the field at harvested to the consumer. The data collected from the some studies carried out in India on postharvest diseases of fruits and vegetables put the average loss at 20-30%. The national committee appointed by the Government of India has estimated food grain losses during the postharvest period to be 9.3% and part of it due to fungal deterioration. Post-harvest process include the integrated function of harvesting, cleaning, grading, cooling, storing, packaging, transporting and marketing. Post-harvest handling involve the practical application of engineering principles and knowledge of fruits and vegetables physiology to solve problems utilizing improvement post-harvest practices often results in reduced food losses. Controlling post-harvest diseases, therefore, becomes essential for the maintenance of production quality.

Traditionally, powerful fungicides have been used effectively to ensure high quality fruit over extended periods of time. However, due to increased global chemophobia, producers have been forced to evaluate alternative approaches to ensure delivery of fruits and vegetables with the highest quality. Several approaches such as soft fungicides, natural chemicals, disinfectants, calcium applications, growth regulators, chemical elicitors to induce natural host defenses, biological control, integrated control, hypobaric pressure, physical means such as ultraviolet illumination, radiation, hot water or heat shock treatments, modified atmosphere storage and packaging, genetic modification of plants represent some of the approaches more recently evaluated to ensure top fruit quality.

Ionizing radiation has been studied extensively since 1950 and has been used successfully in many countries on several different crops to extend shelf life and prevent decay. Recently, low doses of ultraviolet light especially UV-C hormosis have emerged as alternative technology to avoid chemical fungicides. Pre-storage treatment of several postharvest commodities with low doses of UV-C has been shown to reduce disease development. UV-C treatment controlled natural infection in Walla onions, sweet potato, and tomato, and apple, peach and citrus fruit. Optimum doses of UV-C for the control of postharvest decay in various commodities occur in a rather narrow range and appear to vary depending upon the commodity, the type of cultivar and physiological status of tissue. Optimum dose for vegetables, pome, stone and citrus fruit were reported to be in the range 2-10× 10^4erg/mm^2 caused skin blemishes and increased the susceptibility of the tissue to decay (Liu et al., 1993). The decontaminating properties of UV-C light are well known, but the potential of ultraviolet light for surface disinfection of fruits and vegetables has been studied only recently (Stevens *et al*., 1998a). In addition to its lethal effect on the fungal pathogen (Nigro *et al*., 1998) low doses of UV-C were also reported to induce physiological reaction in the exposed product, inhibiting the fungal development (Stevens *et al*., 1998a). There are evidences that enzymes in host, namely phenylalanine ammonia-lyase, peroxidase and antifungal hydrolases plays important role in induction of defensive responses in fruits UV-C light has already been tested in many fruits mainly to control post harvests diseases and delay some ripening associated processes. Brown *et al.* (2001) reported low doses of UV-C seed treatment in cabbage to control black rot. Erkan *et al*. (2001) reported that UV-C irradiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue. More recently application of low doses of ultraviolet light irradiation (UV-C) reduced post-harvest decay and retained the quality of the peppers (Vicente *et al.,* 2005). Low dose UV-C hormesis was shown to reduce resistance in post-harvest commodities to harvest decay and to extend shelf life of fruits by delaying the ripening and senescence process (Sharma and Alderson, 2005). Recently under *in vitro* conditions UV-C treatment has been reported to be effective in inactivation of *P. expansum* and *A.niger* spores (Sharma *et al.,* 2005). Sharma and Tripathi, (2008) reported that dose of 4.96 KJ m-^{2} was sufficient to reduce the population of *Fusarium* significantly.

Gamma radiation has been studied for controlling decay, disinfestations, and extending the storage and shelf-life of fresh fruits and vegetables. Commercial application of gamma radiation is limited due to the cost and size of equipment needed for the treatment and to uncertainty about the acceptability of irradiated foods to the consumer. Gamma irradiation may be used more in the future once methyl bromide is no longer available to control insect infestation in stored products. All uses of methyl bromide are being phased out to avoid any further damage to the protective layer of ozone surrounding the earth.

This article describes the results of several years of studies and implications for the control of post-harvest decay of fresh commodities and explanation of how UV-C control post-harvest decay and the advantages of UV-C

1. Photo biological effects of UV-C irradiation. Ultraviolet radiation is a non-ionizing radiation ranges between X-ray and visible light of the electromagnetic wave spectrum. The UV light present in the sunlight is generally designated UV-C (short wavelength, below 280 nm), UV-B (middle wavelength, 280-320 nm), and UV-A (large wavelength, 320-390 nm).Although low in energy and lacking in penetrating power affects a wide range of biological processes, and has been reported to stimulate numerous plant responses (Mau *et al*., 1998; Kasim *et al*., 2008; Ait Barka *et al*., 2000; Ben-Yehosua, 2003). There are following approaches to study the photobiological effects of UV-C-

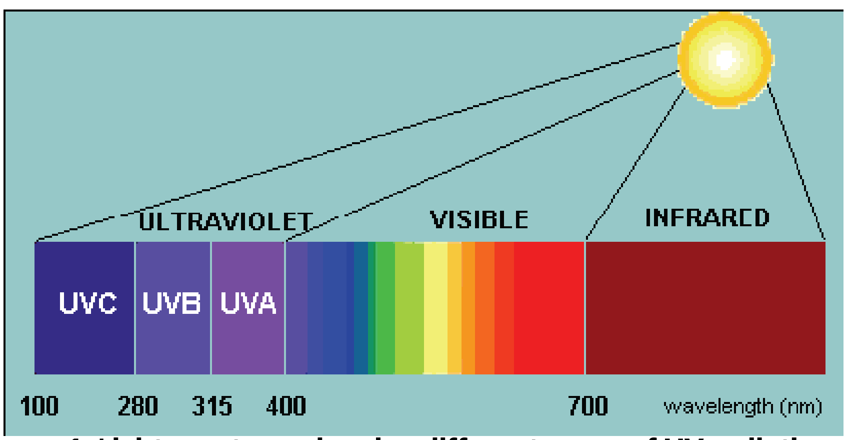

Figure 1. Light spectrum showing different range of UV radiation.

(Photo: http://www.arpansa.gov.au/is_sunys.htm)

a) Use of UV-C light for surface sterilization: - The portion of UV spectrum between 200-300nm is considered to germicidal with a maximum effect at 260 nm. The light intensity is powerful enough to break the outer protective covering of the microorganism and penetrate through the nucleus and deactivate the DNA of the pathogen.

To be more specific, the UV-C light forms covalent bonds between adjacent bases in DNA. The bonds prevent the DNA from being unzipped for cell replication; therefore the pathogen is unable to reproduce. UV treatment brings some benefits to the fresh cut industry as its use is approved by the code of Food and Drug Administration (FDA) in the USA (Rhim *et al*., 1999) on food products to control surface micro-organisms, does not leave a residue, and does not require extensive safety equipment (Yaun *et al.,* 2004).Several in vitro studies have demonstrated the efficiency of UV-C radiation on microbial inhibition (Gardner and Shama, 2000). Yaun *et al.* (2004) observed that five *Salmonella* and *Escherichia coli* O157:H7 strains inoculated in lettuce showed similar logarithmic reductions when treated with the same doses of UV-C radiation. Additionally, many researchers showed that UV-C radiation was effective in inhibiting growth of different micro-organisms commonly present in food products (Bintsis *et al.,* 2000; Sommer *et al.,* 2000) and some of them demonstrated the efficacy of UV-C radiation for reducing microbial growth in fruit and vegetables (Marquenie *et al.,* 2003; Stevens *et al.,* 1998; Vicente *et al.,* 2005) of special interest is the development of an UV-C apparatus, which delivered low-dose UV-C light to the surface of fruit on a processing line (Wilson *et al.,* 1997).

b) Effect of UV-C light on the morphogenesis of plant development: -Theeffect of UV-C light on the morphogenesis of plant development has been studied in many crops (Iriti *et al.,* 2007).

c)Effect of UV-C light on phytoalexin induction: - UV-C irradiation is a useful inducer technique to induce the accumulation of phytoalexin to inhibitory levels against pathogens. Ben-Yehosua *et al,* (2003) showed that low dose UV-C irradiation reduced lemon fruit susceptibility to *P. digitatum*. Increased UV-C dose lead to higher concentrations of the phytoalexin scoparone induced in flavedo tissue. Similar phytoalexin-mediated responses and associated increases in postharvest natural disease resistance have been observed in other citrus fruit, carrot and tomato. (Mercier *et al.,* 1993),

d) Effect of UV-C hormesis:- low dose UV light (UV-C, 254 nm) hormesis was shown to induce resistance in commodities to postharvest decay (Arul *et al.,* 2001) and extended shelf life of fruits by delaying the ripening process (Stevens *et al*. 2004; Charles *et. al.* 2005).

2) UV Hormesis: Hormesis is the application of potentially harmful agents at low doses to living organisms in order to induce stress responses (Shama and Alderson, 2005).Hormetic effects can be induced by both ionizing and non-ionising radiation (e.g. UV).The UV portion of the electromagnetic spectrum ranges from approximately 100 to 400 nm; however, the phenomenon of hormesis is concerned with effects induced by UV-C, i.e. wavelengths in the range 100–280 nm.The mechanism for hormesis proposed by Luckey (1980) suggested that low doses of UV could inflict repairable damage to DNA and this slight trauma would activate repair mechanisms for radiation induced DNA damage. This suggests that sublethal radiation may stimulate vital processes inside the cells and create a positive change in the homeostasis of the plant.

Upon exposure of fruits to low doses of UV, a number of changes are induced including the production of antifungal agents and delays in ripening (Shama and Alderson, 2005). Application of low dose(s) UV-C light reduced the development of postharvest decay in bulb (onion), tropical root (sweet potato), pome (apple), stone fruit (peach), citrus fruits (grapefruit, kumquat, tangerine, and lemon), solanaceous vegetable fruits (bell pepper and tomato), temperate rots to 10-44% compared with 100% decay for the non-irradiated control depending on the type of commodities and decay pathogens (Stevens *et al.,* 2004; Marina *et al*, 2009; Hemmaty *et al.,*2007).usually 0 to20 or 40 KJ/m^2 doses of UV-C were initially applied when testing a commodity to determine the optimum dose(s) for inducing resistance in the host to a certain decay and the optimum dose of UV-C that improve storage ability with minimum blemishes or damages to any harvested commodity. Three types of dose decay response relationship were found for the various harvested commodity that have been reported-

1. When a commodity was UV-C treated, it showed an increase resistance to decay when compared with the control. The effect of UV-C on the percent infection would be quadratic, meaning that the effectiveness of the UV-C treatment declined beyond a certain optimum as shown by a V-shaped dose response curve when UV-C dose versus percent decay were plotted. (Stevens *et al.,* 1996). The second degree polynomial regression analysis of the data from dose response plot was shown to curvilinear and statistically significant (Stevens *et al.,* 1996). The following are examples of incidence of postharvest decay in commodities showing a quadratic dose decay response relationship: several varieties of sweet potatoes that were irradiated with UV-C, showed an effective decrease in percent *Fusarium* surface and storage root rots(*Fusarium solani*) and Rhizopus soft rot (*Rhizopus stolonifer*). The optimum doses were 3.6- 4.8 KJ/m^2 for naturally infected storage rots. When artificially inoculated sweet potatoes were used, the optimum UV-C dose for control of both diseases were 3.6 KJ/m^2.Grapefruits, artificially inoculated with *Penicillium digitatum* following UV-C treatment, exhibited a reduced disease incidence. The disease incidence of green mold on grapefruits was 14% and 90% for the optimum UV-C dose (3.2 KJ/m^2) and the non-irradiated control, respectively
2. This dose decay response relationship was observed for green mold rot of tangerine naturally infected with *Penicillium digitatum* where two optimum UV-C levels showed a sinuate dose decay response, where 1.3 and 20 KJ/m^2 gave the best control.
3. Third type of dose decay response relationship showed a linear response between all doses used and incidence of decay for example, the application of UV-C was effective in controlling Alternaria rot (*Alternaria citri*) and sour rot (*Geotrichum candidum*) of tangerines the optimum dose starting from 1.3- 20 KJ/m^2.

4) Effect of harvest time onUV-C dose response

Tree fruits harvested at various times during the growing season, such as peaches showed a stable UV-C dose respond for controlling brown rot.

It was found that early peach varieties were harvested during late May and early June and late season varieties during late July, only optimum dose of 7.5 KJ/m^2 controlled brown rot of peaches (Stevens's unpublished data). However, grapefruit harvested at various times growing season required a UV-C dose of 4.8 KJ/m^2 in November for maximum response. This response decline to 1.6 and 3.2 KJ/m^2 for fruits harvested in December and January, respectively and increased to 8 KJ/m^2 for fruits harvested in February.

5) Effect ofUV-C irradiation on induced resistance

The UV-C induced resistance of commodities was reversed by fluorescent light but not by darkness. This suggests that UV-C induced changes in commodities may involve DNA damage mediated by dimerization of thymine and other pyrimidines and the damages are repaired in the presence of light. Luckey (1980) indicated that UV-C radiation penetrate very poorly in the host. UV-C light act as a secondary intermediary process resulting in the host of induce resistance. There are numerous biochemical physiological host defense responses that explain induce resistance in harvested commodities. The treatment of fruit with low UV doses results in the synthesis in the fruit of a number of anti-fungal compounds. Synthesis is initiated by UV treatment but continues to occur for periods measured in days after the irradiation event. Shama and Alderson, (2005) after reviewing considerable literature, state that synthesis of such compounds occurs throughout the entire fruit. Of the pathogenesis related proteins (antifungal enzymes) produced by plants, chitinases, glucanases and lysozymes have the ability to hydrolyse insoluble polysaccharides from the cell walls of fungi and bacteria. Glucanases and chitinases inhibit fungi while lysozymes and some chitinases also inhibit bacteria (Shama and Alderson, 2005). Ultra-structural studies in tomato indicated that UV treatment induces accumulation of phenolic compounds and formation of lignin and suberin in few layers of cells near the surface. Tomatoes treated with UV-C at green mature stage and stored at 13oC, 95% RH witnessed a greater accumulation of 'rishitin', a phytoalexin (Charles *et al.,* 2003).Defense against *Botrytis cinerea* in grapes occurs maximally 24–48 h after UV treatment and the protective effect was attributed to a number of possible factors including PAL and peroxidase activity as well as the induction of 'stilbene-like phytoalexins' such as resveratrol (3,5,40-trihydroxystilbene) (Nigro *et al.,* 1998). Higher levels of polyamines in mango fruits treated with UV for 10 min was suggested to be related to the suppression of decay and softening caused by microbial growth (Gonzalez-Aguilar *et al.,* 2001). It was proposed that UV irradiation induced and activated decay-resistance mechanisms, such as increase in anti-fungal compounds in the fruit peel.Hormic doses of UV-C light to elicit beneficial response in biological systems such as fresh fruits and vegetables (Arul *et al.,* 2001). Research work so far carried out in this direction demonstrates the beneficial effect of UV as two-fold. First, it has been shown to induce the production of antifungal compounds thus fortifying the produce against post-harvest diseases (Mercier *et al,* 1993;; Stevens *et al.,* 1998a; Arul, *et al.,* 2001.

Gonzalez-Aguilar *et al.,* 2001; Charles *et al.,* 2003). On the other hand, UV delays ripening and senescence of treated produce in comparison to control (Liu *et al.* 1993; Barka *et al.,* 2000; Stevens *et al.* 2004; Charles *et al*., 2005).

6) "Nutraceutical" effect of UV-C hormesis

UV-C hormesis is also alleged, similarly with other abiotic stressors, to alter the chemistry of plant organs and, in some cases, to enhance their "nutraceutical" (Cisneros-Zevallos, 2003) or "bioactive" potential. A **"***Nutraceutical* is a product isolated or purified from foods that is generally sold in medicinal forms not usually associated with food". A Nutraceutical is demonstrated to have a physiological benefit or provide protection against chronic disease.The use of UV hormesis to enhance the nutraceutical properties of fresh fruit and vegetable is relatively recent. In strawberries, UV treatment has resulted in the enhancement of anthocyanin levels phenolic content, and the antioxidant capacity (Erkan *et al.* 2008). Mau *et al.* (1998) reported that UV irradiation increased the vitamin D2 content of edible mushrooms, UV-B having greater enhancing ability than UV-C. UV-C irradiation has been found to increase phenolic stilbenes in grape berries (Cantos *et al.* 2000), which led to the application of this treatment to develop"functional table grapes" (Cantos *et al.* 2001) and "stilbeneenriched red wines" and grape juice (González-Barrio *et al.* 2009) with higher resveratrol concentration. Recently, a study by Liu *et al.* (2009) has reported on an increase in the lycopene content of UV-Ctreated tomato.

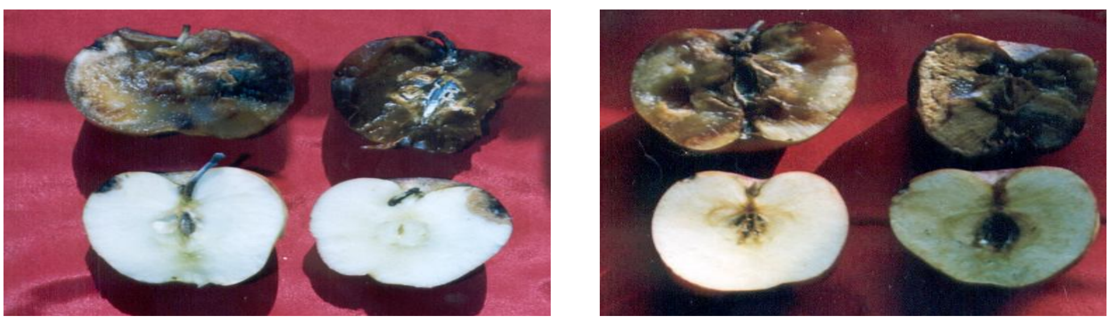

Fig 2. Effect of UV-C treatment to control blue and gray mold of apple.

Fig 3. Physical control as shown by UV-C treatment in different fruits. Treated fruits with UV-C treatment are in the *upper line* while infected fruits can be seen on the *bottom side.*

Table1. Examples of postharvest UV-C treatment in reducing storage diseases in horticultural produce.

Species and cultivar	Optimum UV-C dose (kJ m-2)	Targeted pathogen
A. deliciosa (kiwifruit) cv. Hayward	0.5	*B. cinerea*
Allium cepa (onion) cv. Walla Walla		
Capsicum annuum (bell pepper) cvs. Bell Boy and Delphin	3.58-7.33	Not specified
Citrus aurantifolia (lime) cv. Tahiti	0.88	*B. cinerea*
Citrus cinensis (orange) cvs. Biondo Comune and Washington Navel		
cvs. Tarocco and Valencia Late	5.0	*P. digitatum*
cvs. Shamouti and Valencia		
Citrus limon (lemon) cv. Eureka	0.5-3.0	Not specified
C. paradisi (grapefruit) cv. Marsh Seedless		
cv. Star Ruby	0.5-1.5	As above
Citrus reticulata (tangerine) cv. Dancy	5.0	*P. digitatum*
Cucurbita pepo (zucchini squash) cv.	5.0	*P. digitatum*
Tigress *Daucus carota* (carrot) cv. Caropak	5.0	*P. digitutum*
	1.6-8.0	
Ipomea batatas (sweet potato) cv. Jewel	2.2	As above
and Carver	0.5	As above
cv. Georgia Jet	0.84	As above
cv. Jewel	3.6	*Alternaria*
Fortunella margarita (kumquat) cv.		*citriGeotrichum*
Nagami	1.3	*candidum*
F. ananassa (strawberry) cv. Pajaro	4.93-9.86	*P. digitatum*
cv. Kent		Not specified
cv. Elsanta	4.4-8.8	
Lycopersicon esculentum (tomato) cv.		*B. cinerea*
Tuskegee 80--130	4.8	
		Fusarium spp. and *Rhizopus* spp

Table2. Some other examples of postharvest UV-C treatment in reducing storage diseases in horticultural produce.

Species and cultivar	Optimum UV-C dose (kJ m-2)	Targeted pathogen
Malus domestica (apple) cv. Golden	3.6	As above
Delicious	3.6	*Fusarium solani*
	5.0	*P. digitatum*
	1.5	As above
cv. Empire	0.5-1.0	*B. cinerea*
M. indica (mango) cv. Tommy Atkins	0.25	As above
Prunus persica (peach) cv. Loring	0.5-15.0	*B.cinereaAlternaria*
cv. Elberta	7.5	*alternataB. cinerea* and
cv. Loring and Elberta		*Erwinia* spp *Rhizopus*
cv. Loring	7.5	*stoloniferB.cinereaAlternaria*
Vitis vinifera (table grape) cv. Italia	3.6	*sp*. and *Monilinia* sp.
	3.7	As above
	7.5	*.gloeosporioidesB. cinerea* and
		P. digitatum
	4.8	Not specified
	7.5	
	1.38	*Monilinia fructicola*
	Not defined	As above
		As above
	20	*B. cinerea*
		B. cinerea
	4.8-20	
	4.8-7.5	
	7.6	
	0.125-0.5	

All fruits and vegetables are not alike but they are diversified in terms of the tissue composition, biochemical constitution and the metabolism. The diversity is not limited to the genera or the species but it is evident even between the varieties of the same kind of a fruit or vegetable. There are several advantages in using UV-C radiation to control postharvest decay in harvested commodities which include:

A) No radioactivity or toxic accumulation of chemical residues
B) Unlike gamma rays, UV-C dose does not cause softening of fruits and vegetables
C) UV-C is easier and safer to operate than ionizing radiation such as gamma rays
D) UV-C at selective low hermetic doses does not stimulate postharvest decay
E) Lower investment cost when compared with other radiation systems

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