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Use of irradiation in postharvest disease management: problems and solutions

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Abstract

Purpose of review: The elevated incidence of disease is a postharvest problem in fruits during storage, transport and commercialisation. This article reviews the effects of gamma and UV-C radiations on the control of postharvest diseases on a wide variety of fruits, as well as the possibility that these treatments promote physical-chemical changes during the postharvest phase.
Findings: Gamma and UV-C irradiations are physical treatments that can be used for the control of postharvest diseases. Irradiation has been used to delay ripening-associated processes and control pathogens and insects, and different types of radiation have been tested for fruits. The primary mode of action of many physical treatments is disinfection of the commodity. Thus, fungal spores and mycelial infections on and in the outer cell layers of fruits or vegetables are removed or destroyed. However, physical stress can lead to induced resistance against future infection in some species.
Directions for future research: The data accumulated so far indicate that UV-C and ionising energy has some potential applications for fresh fruits. These applications have real potential amongst physical methods for controlling postharvest diseases and can also extend the postharvest life of fruits by delaying ripening. Besides economic and logistic factors, and opposition based on psychological discernment problems due to lack of public knowledge on wholesomeness of irradiated food, physical-chemical changes frequently constitute a dose limitation. Proper information about the safety and benefits of irradiated foods could increase the level of understanding and acceptance of irradiated products by consumers.

Keywords: gamma radiation; UV-C light; rots; control; resistance induction; quality

Abbreviations

ASP	Alkali Soluble Pectin
CSP	Chelator Soluble Pectin
UV-C	Ultraviolet-C
WSP	Water Soluble Pectin

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Introduction

The problems caused by diseases have been amplified by the development of pathogen resistance to fungicides and by the withdrawal of some products from the market. Furthermore, consumers are looking for fruit free of chemical residues. Consequently, alternative control strategies, ie, antagonists, natural compounds and physical treatments have attracted attention. Gamma and UV-C irradiations are physical treatments that can be used for the control of postharvest diseases [1]. Irradiation has been used to delay ripening-associated processes and control pathogens and insects [2], and different types of radiation have been tested for fruits (Tables 1 and 2). The primary mode of action of many physical treatments is disinfection of the commodity. Thus, fungal spores and mycelial infections on and in the outer cell layers of fruits or vegetables are removed or destroyed. However, physical stress can lead to induced resistance against future infection in some species [3**].

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Table 1. Potential applications of gamma irradiation on the postharvest control of diseases in fruits.

Fruit	Gamma dose (kGy)	Pathogen	Reference
‘Golden’ papaya	0.75–1.00	*C. gloeosporioides*	[1]
‘Clemenules’ clementine mandarins	0.51–0.87	*P. digitatum and P. italicum*	[10]
‘Nagpur’ mandarin	≤1.50	*Penicillium, Botryodiplodia theobromae, Alternaria citri*	[11]
‘Keitt’ mango	0.50–0.75	*C. gloeosporioides*	[13]

Table 2. Potential applications of UV-C irradiation on the postharvest control of diseases in fruits.

Fruit	UV-C dose (kJ/m^2)	Pathogen	Reference
‘Pajaro’ strawberry	0.50–1.00	*B. cinerea*	[28]
‘Italia’ table grape	0.125–4.0	*B. cinerea*	[27]
'Elberta' peach	7.5	*M. fructicola*	[23]
‘Golden Delicious’ apple	7.5	*C. gloeosporioides*	[30]
‘Elberta peach	7.5	*M. fructicola*	[30]
‘Dancy’ tangerine	1.3	*P. digitatum*	[30]
Grapefruit	1.6–8.0	*P. digitatum*	[24]
‘Golden’ papaya	0.2–2.4	*C. gloeoporioides*	[1]
‘Tommy Atkins’ mango	4.9 and 9.9	Not specified	[32]
Tomato	1.3–40.0	*A. alternata, B. cinerea, R. stolonifer*	[26]

Fruit fly infestation is a global problem with devastating effects on more than 100 fruit species, thus restricting fruit distribution among countries and even within a country. The common quarantine treatment for most fruits against fruit flies is methyl bromide fumigation. However, methyl bromide is scheduled to be phased out by 2015 as it is toxic to humans and harmful to the ozone layer. In recent years, much effort has been directed towards developing alternative methods to methyl bromide fumigation [4, 5]. Irradiation is very promising, since low doses exhibit insecticidal effects on fruit flies. In addition, the storage period for fruits can be extended when associated with thermal treatments for disease control. Gamma radiation is effective on all stages of the life cycle of a pest such as a fruit fly and it is ready to be used as an efficacious quarantine treatment method [6]. However, the greatest obstacle in the use of irradiation for postharvest treatment is the high cost and prejudice by consumers in relation to irradiated foods.

The data accumulated so far indicate that ionising energy has some potential applications for fresh fruits, vegetables, and ornamentals, but also has many limitations. Thus, this technology will not solve all the problems of postharvest deterioration of fresh produce. Several factors related to the characteristics of each commodity or to irradiation procedures influence the response of fresh fruits and vegetables to ionising treatments. The commodity factors are related to type of commodity and cultivar, production area and season, maturity at harvest, initial quality, and postharvest handling procedures. In addition, irradiation procedures can also influence the response of the commodity to treatment, ie dose, dose rate, and environment conditions during irradiation (temperature and atmospheric condition) [7**].

Proper information about the safety and benefits of irradiated fruits could increase the level of understanding and acceptance of gamma irradiated products by consumers. Besides the fact that radiation shows potential for controlling postharvest diseases, it is important to investigate whether the required level of irradiation necessary for controlling diseases can cause acute injury or other detrimental effects.

Non-ionising radiation has real potential amongst physical methods for controlling postharvest diseases [8]. When fruits are exposed to low doses of UV radiation a number of changes are induced including the production of anti-fungal compounds and delays in ripening. Both of these responses could be exploited by the horticultural sector to reduce postharvest losses. Low doses of short-wave ultraviolet light (UV-C, 190–280 nm wavelengths) can control many storage rots of fruits and vegetables. UV-C irradiation at low doses (0.25–8.0 kJ/m^2) target the DNA of micro-organisms. For this reason UV-C treatment has been used as a germicidal or mutagenic agent. In addition to this direct germicidal activity, UV-C irradiation can modulate induced defence in plants [3**, 9**]. Although UV-C radiation has potential for controlling postharvest diseases, it can cause physiological damage, characterised by skin browning, regardless of dose used. This damage can contribute to increasing fruit susceptibility to disease. This article reviews the effects of gamma and UV-C radiation on the control of postharvest diseases on a wide variety of fruits, as well as the possibility that these treatments promote physical-chemical changes during storage.

Gamma radiation

The possible use of ionising energy for insect disinfestations is one of its most promising applications. Irradiation at doses below 1 kGy is an effective insect-disinfestation treatment against various insect species of quarantine significance in marketing fresh fruits and vegetables [7**]. It is advisable to quarantine fresh foods to prevent the migration of insects and other organisms to new areas. Traditional quarantine treatment involves chemical treatments (fumigation) or the use of high or low temperatures. Food irradiation for insect and micro-organism decontamination has been studied for more than 40 years. Doses lower than 1.0 kGy effectively control a large number of insects [5] and have already been used in many countries. Furthermore, radiation has been also investigated for controlling postharvest diseases. The potential use of ionising radiation to control postharvest diseases depends on the radiation sensitivity of the micro-organism relative to the ability of the host to withstand the required radiation level with little or no acute injury or other detrimental effects. The effectiveness of irradiation as a fungicidal or fungistatic treatment depends on the pathogen, its stage of growth, and the number of viable fungal cells on or within the tissue [7**]. It is well established that irradiation disinfestations requires lower ionising radiation doses than the decontamination of food, which might call for higher doses. Gamma irradiation at 0.75 and 1 kGy inhibited conidial germination, and mycelial growth *in vitro* of *Colletotrichum gloeosporioides*. Doses of 0.75 and 1 kGy reduced anthracnose incidence and severity in ‘Golden’ papaya fruits [1].

The integration of sodium carbonate (dips at 20°C for 150 s in aqueous 3% sodium carbonate solutions) treatments and X-ray irradiation (at doses of 510 and 875 Gy) was evaluated on artificially inoculated ‘Clemenules’ clementine mandarins for the control of postharvest green and blue moulds, caused by *Penicillium digitatum* and *Penicillium italicum*, respectively. Although significant, the reduction of both disease incidence and severity on fruits either incubated at 20°C for 7 days or cold-stored at 5°C for 21 days was not sufficient for satisfactory disease control under hypothetical commercial conditions [10]. The effects of irradiation dose and refrigerated storage conditions on ‘Nagpur’ mandarin, ‘Mosambi’ sweet orange and ‘Kagzi’ acid lime were investigated. The authors stated that in ‘Nagpur’ mandarin, radiation dose up to 1.5 kGy did not cause any rind disorder. Radiation treatments did not reduce the extent of decay. *Penicillium* rot was delayed in fruits treated with 1.5 kGy, while it appeared early in those fruits treated with 0 kGy. Irradiation doses were ineffective in controlling rots due to *Botryodiplodia theobromae* and *Alternaria citri* [11]. UV-C and gamma rays reduced storage rot and delayed ripening of peach fruits, but the combination of UV and gamma radiation showed no advantage over the use of UV or gamma treatments alone [12]. Anthracnose severity on ‘Keitt’ mango fruits was reduced by doses equal to or above 0.5 kGy and rot incidence reduced by a 0.75 kGy dose [13].

The potential usefulness of ionising radiation for retarding ripening will depend on its cost/benefit evaluation relative to other treatments that elicit the same response, such as controlled/modified atmosphere and ethylene-removal methods [7**]. It is necessary to adjust the doses applied to each fruit to prevent undesirable reactions such as softening or skin browning [1]. Similar to other techniques of food processing, irradiation can induce certain alterations that can modify both the chemical composition and the nutritional value of foods. These changes depend on the food composition, the irradiation dose and factors such as temperature and presence or absence of oxygen in the irradiating environment. The sensitivity of vitamins to radiation is unpredictable and food vitamin losses during the irradiation are often substantial [14*]. However, the literature shows that not enough information is available on the effect of irradiation on chemical characteristics of some stored fruits.

Several studies have been presented regarding definition of the maturation stage of papaya at the moment of irradiation, since its efficiency in delaying the ripening process will depend on the maturation stage [15–17]. Papaya can tolerate up to 1 kGy before surface scald occurs [15] and fruits irradiated at 0.5–1 kGy retained their firmness for 2 days longer than the non-irradiated control [16]. Moderate doses of irradiation delayed ripening in papaya fruits depending on maturity at treatment time [15]. In papaya, cell wall-degrading enzymes during fruit ripening have been investigated. The enzymes reported include polygalacturonase, pectinmethylesterase, xylanase and cellulase [18]. There is a close relationship between polygalacturonase and xylanase and the rise in respiration, ethylene evolution and softening of papayas [19]. Irradiation at 0.5–1 kGy when papaya fruits were 25–30% yellow appeared to reduce further depolymerisation of pectic substances, resulting in a firmer texture at the full ripe stage that stayed firmer about 2 days longer than the non-irradiated control [16]. Afterward, it was observed that the firmness of irradiated fruits (0.5 kGy) was retained at least 2 days longer than in non-irradiated fruits and these fruits also had a slower rate of softening. They concluded that irradiation had no direct effect on firmness of papayas but it acted by altering the ripening induced synthesis of cell wall enzymes, mainly pectinmethylesterase [20].

Papaya var. Sunset at three initial ripeness stages were irradiated with 0.25, 0.5, 0.75, 1.0 or 1.5 kGy gamma-irradiation and pectin changes during ripening determined. A significant linear relationship was found between irradiation dose and firmness immediately after irradiation. Irradiation had no effect on fruit skin or flesh colour of papaya fruits irradiated at the 5 to 30% yellow stage and allowed to ripen. Papaya irradiated when 5 to 30% yellow showed no significant changes in pectin methylesterase activity when ripe. Immediately after irradiation, the pectin in 10 to 30% yellow papaya showed depolymerisation and demethoxylation, though no effect on pectin methylesterase activity was detected. There was an increase in water soluble pectin (WSP), while chelator soluble pectin (CSP) and alkali soluble pectin (ASP) decreased, with a significant decline in the methanol content of the ASP fraction. After the 25 to 30% yellow ripeness stage, fruits irradiated at 0.50 to 1.0 kGy had less pectic depolymerisation, and had a firmer texture when ripe than non-irradiated ones. A lower level of WSP and higher levels of CSP and ASP were found in ripe fruits that had been irradiated at 0.5 to 1.0 kGy when 25 to 30% yellow skin with a significant quadratic relationship between irradiation dose and the three pectin fractions [16].

Papaya fruits treated with 250 Gy of gamma irradiation frequently softened more uniformly than non-irradiated fruits. Fruits with less than 25% of their surface coloured yellow placed immediately into storage at 10°C after irradiation developed skin scald. This was prevented by delaying storage by 12 h. Fruits that were irradiated when 30% of the skin was yellowed softened at a slower rate than non-irradiated fruits. There was no difference in softening rate between irradiated and non-irradiated fruits at the mature green stage. Fruits stored for 14 days at 10°C before returning to 25°C had a slightly slower rate of softening than fruits allowed to ripen at 25°C without storage. Premature flesh softening occurred occasionally in fruits that had between 8 and 18% of the skin yellow and 70–90% flesh colouring when irradiated. Premature softening occurred in the tests run on fruits that were harvested during the warmer months; fruits harvested during the cooler months did not show the condition [16].

Treating dates with relatively high doses of irradiation (> 0.6 kGy) induced significant changes in pectic substances. Post-irradiation storage resulted in a decrease in some chemical characteristics. However, it has been demonstrated that irradiation up to a dose of 1.8 kGy is safe for the main chemical properties of 'Boufeggous' dates. It is, therefore, recommended that doses up to 0.6 kGy would effectively control many losses associated with insects, without resulting in any adverse effect on chemical properties of dates [21].

Applying gamma radiation to citrus fruits at the pasteurisation dose level could be the means of extending the shelf life of these commodities. Problems are related to physiological response of the citrus fruits being irradiated and the dose required to achieve their disinfection. The dose level for disinfection can be intolerable to some citrus fruits and can result in disorders. The feasibility of the treatments depends upon the sensibility of the host tissues. Findings indicated that gamma irradiation exhibit limited promise in extending the storage life of 'Nagpur' mandarin, 'Mosambi' orange and 'Kagzi' acid lime. Fruit tolerance to irradiation is species dependent. Mature orange-coloured 'Nagpur' mandarin appears to have tolerance to a dose up to 1.5 kGy. 'Mosambi' orange is not so tolerant to gamma radiation since pitting develops on rind after 75 days under refrigerated storage conditions. Mature yellow acid limes are also not tolerant to doses of 1 and 1.5 kGy since the pulp texture and other quality parameters were adversely affected. Deteriorative effects of higher doses are apparent after prolonged storage. The benefit of irradiation may be in terms of delaying *Penicillium* rots during short-term storage (1 to 1.5 months) and thus avoiding chemical residues of fungicides, which are presently being used. In the case of 'Mosambi' sweet orange, higher doses and long-term storage cannot be combined due to cumulative adverse effects. In the case of mature yellow 'Kagzi' acid limes, irradiation is not a promising treatment, since it will further deteriorate quality [11]. The authors reported that doses up to 1.5 kGy did not cause any significant effect on fruit firmness and juice content; however, total soluble solids increased while acidity and vitamin C content decreased.

Although studies have reported the effect of low dose irradiation on grapefruit quality parameters such as soluble solids, acidity and appearance, very little information is available on the effect of low dose irradiation on health promoting compounds in grapefruit such as flavanones (naringin and narirutin), limonin, carotenoids, lycopene and Vitamin C. Patil *et al.* [5] evaluated flavanones, terpenoids (limonin 17-β-D-glycopyranoside, β-carotene and lycopene) and quality (ascorbic acid content, soluble solids, and titratable acidity) immediately following irradiation treatment and storage. Results demonstrated that the response of fruit to irradiation depended on harvest time. Lower doses (at or below 200 Gy) of irradiation coupled with 35 days of storage were useful in enhancing health promoting compounds in early season grapefruit. Higher doses of irradiation (400 and 700 Gy) and 35 days of storage had detrimental effects on the quality of early season grapefruit; however, no significant effect was observed on the quality of the late season fruits [5].

UV-C radiation

Non-ionising radiation has real potential amongst physical methods for controlling postharvest diseases [8]. Low doses of short-wave ultraviolet light (UV-C, 190–280 nm wavelengths) can control many storage rots of fruits [3**]. Although hormetic effects can be induced by both ionising and non-ionising radiation (eg, UV), it is effects caused by the latter that will be examined here. The UV portion of the electromagnetic spectrum ranges from approximately 10 to 400 nm; however, the phenomena described here are concerned with effects induced by UV-C light, ie, wavelengths in the range 100–280 nm [9**]. A mechanism for hormesis was proposed in which the author suggested that low doses of UV radiation could inflict repairable damage to DNA, and that this slight trauma would activate repair mechanisms for radiation-induced DNA damage [22]. This suggests that sublethal radiation may stimulate vital processes inside the cells and create a positive change in the homeostasis of a plant [9**].

Reduction of rots by UV-C treatment may be due to the germicidal effect on the pathogen or resistance induction in the plant tissue [23*]. The effect of UV radiation in reducing green mould in grapefruit is mediated through the host response, rather than being merely the result of the germicidal action of the UV treatment [24*]. Later, an increase in grapefruit resistance to *P. digitatum* was attributed to chitinase and β-1,3- endoglucanase induction in the fruit skin [25]. The UV-C treatment can also extend the postharvest life of fruits by delaying ripening. The occurrence of *Alternaria alternata*, *Botrytis cinerea*, and *Rhizopus stolonifer* in tomato fruits was reduced with different UV-C dosages, and fruits were firmer in texture and less red in colour than those used as controls [26].

Single 'Itália' table grape berries were irradiated with ultraviolet-C doses ranging from 0.125 to 4 kJ/m^2 and inoculated with *B. cinerea*. Results showed that significantly lower numbers of infected berries and lesion diameter were found in berries treated with UV-C doses ranging from 0.125 to 0.5 kJ/m^2. There was also a significantly lower level of disease in berries inoculated after 24–48 h than in those inoculated just after (10–15 min) the UV-C treatment. Thus, pretreatment with low UV-C doses followed by artificial inoculation with *B. cinerea* reduced postharvest grey mould of table grapes, suggesting induced resistance to the disease, both in berries wounded before and after irradiation. The microbial epiphytic population on UV-C-treated berries was also monitored. Results showed a significantly higher increase in the population of yeasts (including yeast-like fungi) and bacteria on berries irradiated with 0.25 and 0.5 kJ/m^2 than on unirradiated control berries [27].

UV-C doses at 0.50 and 1.00 kJ/m^2 significantly reduced botrytis storage rot in 'Pajaro' strawberries arising from both artificial inoculations and natural infections in comparison with the unirradiated control. The doses shown to reduce botrytis rot produced an increase in phenylalanine ammonia-lyase activity 12 h after irradiation; this result indicates the activation of metabolic a pathway related to the biosynthesis of phenolic compounds, which are usually characterised by antifungal activity. The overall results from these investigations indicate that treatment with low UV-C doses produced a reduction in postharvest decay of strawberries related to induce resistance mechanisms. Moreover, a germicidal effect of reducing external contaminating pathogens cannot be excluded [28].

The application of ultraviolet light-C doses (254 nm) was used to determine the germicidal and hormetic effects on reducing brown rot of 'Elberta' peaches which were naturally and artificially inoculated with *Monilinia fructicola*. The results showed that a negative relationship existed between UV-C doses, colony forming units of the fungus, and the number of brown rot lesions. In addition, the results of this study showed that the hormetic (beneficial) effect of low UV-C dose of 7.5 kJ/m^2 induced host resistance by controlling latent brown rot infection. The hormetic effects of UV-C treatment on peaches was photoreversed with visible light and resulted in the reduction of host resistance to brown rot. Furthermore, the results indicated that UV-C doses increased phenylalanine ammonia-lyase activity, delayed ripening and suppressed ethylene production [23*]. In another study, results showed that the treatment of peach fruits with UV-C light caused a rapid induction of chitinase, β-1,3-glucanase, and PAL activities starting 6 h after treatment and reaching maximum levels at 96 h after treatment. By 96 h after UV-C treatment, chitinase, β-1,3-glucanase, and PAL activities in UV-C-treated fruits were over twofold above the levels observed for the control. In nontreated control fruits, no apparent increase in chitinase and β-1,3-glucanase activities was detected but a minor increase in PAL activity was seen. Thus, the response of peach fruits to elicitor treatment is similar to that seen in other plant–elicitors interactions and suggests the involvement of peach biochemical defence responses in UV-C-mediated disease resistance [29].

The possibility of inducing resistance to bitter rot (*C. gloeosporioides*), brown rot (*M. fructicola*), and green mould (*P. digitatum*) in apples, peaches, and tangerines, respectively, by treating them with ultraviolet light-C at the stem end in a stationary position without rotation was investigated by Stevens *et al.* [30]. This approach was compared with the conventional procedure where fruits were rotated four times, thereby exposing the entire surface area to the full effects of the UV-C light. Results revealed that when the stem ends of apples, peaches and tangerines were exposed in a stationary position to dosages of 7.5, 7.5 and 1.3 kJ/m^2 of UV-C light, respectively, induced host resistance to postharvest decay which was equal to, or slightly better than when fruits were rotated four different times. When fruits were rotated, exposing only one or two different sides to UV-C light, the percent infection appeared to increase, compared to treating only the stem ends or when fruits were rotated four times [30*].

The effect of UV irradiation on the levels of the flavanone, naringin, and the polymethoxyflavone, tangeretin, in the peel of *Citrus aurantium* fruits was described, as changes in the synthesis or accumulation of these compounds after infection with *P. digitatum*. The growth of *P. digitatum* on previously irradiated fruits was reduced by up to 45%. Changes in flavonoid levels were detected, associated with inhibition of fungus growth, the naringin content falling by 69% and tangeretin levels increasing by 70% [31].

Exposure to UV-C radiation can delay fruit softening, one of the main factors determining fruit postharvest life. Ripe ‘Tommy Atkins’ mangoes exposed to UV-C irradiation for 10 and 20 min, prior to storage for 14 days at 5 or 20°C and a shelf-life period of 7 days at 20°C. UV-C-treated fruits maintained better visual appearance than unirradiated controls. UV-C irradiation for 10 min was the most effective treatment in suppressing decay symptoms and maintaining firmness during storage at 5 or 20°C. Such fruits (treated with UV-C for 10 min) showed greater levels of putrescine and spermidine after cold storage than controls and those treated with UV-C for 20 min. Higher levels of sugars and lower levels of organic acids were observed in mangoes treated with UV-C for 20 min. No UV-damage was observed on treated fruits after storage. These results indicate that UV-C irradiation could be used as an effective and rapid method to preserve the postharvest life of ripe mangoes without adversely affecting certain quality attributes [32].

UV-C treatment of ‘Aroma’ strawberries delayed fruit softening, and treated fruits showed higher firmness than controls even 96 h after irradiation. The irradiation modified the expression of the genes and the activity of assayed enzymes (polygalacturonases, endoglucanases and pectin-methylesterases). In general, the expression of analysed genes was reduced a few hours after irradiation, while it increased afterwards to reach similar as the controls or higher. Therefore, the effect of UV-C irradiation on strawberry fruit softening could be related to the decrease of the transcription of a set of genes involved in cell wall degradation, during the first hours after treatment [33].

In the skin of cv. Napoleon table grapes, the anthocyanins malvidin 3-glucoside (and its acetyl and p-coumaroyl derivatives), cyanidin 3-glucoside, peonidin 3-glucoside, cyanidin 3-glucoside, petunidin 3-glucoside, and delphinidin 3-glucoside were identified by HPLC-DAD-MS. In addition, quercetin 3-glucoside and 3-glucuronide, caffeoyltartaric, piceid, and resveratrol were also detected. The content of most phenolics remained quite constant during postharvest refrigerated storage (10 days at 0°C) while the resveratrol derivatives increased 2-fold. Postharvest treatments of grapes with UV-C and UV-B light induced a large increase in resveratrol derivatives (3- and 2-fold, respectively). This means that a serving of mature Napoleon grapes (200 g) provides ≈1 mg of resveratrol, which is in the range of the amount supplied by a glass of red wine. This can be increased to 2 or 3 mg of resveratrol per serving in grapes that have been irradiated with UV-B or UV-C, respectively. These results show that refrigerated storage and UV irradiation of table grapes can be beneficial in terms of increasing the content of potentially health-promoting phenolics [34].

Conclusion

It is clear from the available literature that fruit irradiation is a promising preservation method with certain advantages. The data accumulate so far indicate that UV-C and ionising energy has some potential applications to fresh fruits. There is real potential amongst physical methods for controlling postharvest diseases and can also extend the postharvest life of fruit by delaying ripening. Besides economic and logistic factors, and opposition based on psychological perception problems due to lack of public knowledge on wholesomeness of irradiated food, sensory and physical-chemical changes frequently constitute a dose limitation [35*]. Proper information about the safety and benefits of irradiated foods could increase the level of understanding and acceptance of irradiated products by consumers. The benefits of irradiation should never be considered as an excuse for poor quality or for poor handling and storage conditions, ie, as a substitute for good management practices. Furthermore, finding the best conditions, doses, and combination treatments for different hurdle technologies is considered another challenge that irradiation studies face.

References

Papers of interest have been highlighted as:
*Marginal importance
**Essential reading

1 Cia P, Pascholati SF, Benato EA, Camili EC and Santos CA. Effects of gamma and UV-C irradiation on the postharvest control of papaya anthracnose. Postharvest Biology and Technology 2007: 43:366–373.

2 Vicente AR, Civello PM, Martínez GA, Powell ALT, Labavitch JM and Chaves AR. Control of postharvest spoilage in soft fruit. Stewart Postharvest Review 2005: 4:1–11.

3 **Terry LA and Joyce DC. Elicitors of induced disease resistance in postharvest horticultural crops: a brief review. Postharvest Biology and Technology 2004: 32:1–13.

4 Vanamala J, Cobb G, Loaiza J, Yoo K, Pike LM and Patil BS. Ionizing radiation and marketing simulation on bioactive compounds and quality of grapefruit (*Citrus paradisi* c.v. Rio Red). Food Chemistry 2007: 105:1404–1411.

5 Patil BS, Vanamala J and Hallman G. Irradiation and storage influence on bioactive components and quality of early and late season ‘Rio Red’ grapefruit (*Citrus paradisi* Macf.). Postharvest Biology and Technology 2004: 34:53–64.

6 Moy JH and Wong L. Efficacy of gamma–radiation as a quarantine treatment of fruits, herbs, and ornamentals for Hawaii. Radiation Physics and Chemistry 1996: 48:373–374.

7 **Kader AA. Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. Food Technology 1986: 40:117–121.

8 Wilson CL, El Ghaouth A, Upchurch B, Stevens C, Khan V, Droby S and Chalutz E. Using an on-line apparatus to treat harvest fruit for controlling postharvest decay. HortTechnology 1997: 7:278–282.

9 **Shama G and Alderson P. UV hormesis in fruits: a concept ripe for commercialization. Trends in Food Science and Technology 2005: 16:128–136.

10 Palou L, Marcilla A, Rojas-Argudo C, Alonso M, Jacas JA and del Río MA. Effects of X-ray irradiation and sodium carbonate treatments on postharvest Penicillium decay and quality attributes of clementine mandarins. Postharvest Biology and Technology 2007: 46:252–261.

11 Ladaniya MS, Singha S and Wadhawan AK. Response of ‘Nagpur’ mandarin, ‘Mosambi’ sweet orange and ‘Kagzi’ acid lime to gamma radiation. Radiation Physics and Chemistry 2003: 67:665–675.

12 Lu JY, Lukombo SM, Stevens C, Khan VA, Wilson CL, Pusey PL and Chaultz E. Low dose UV and gamma radiation on storage rot and physicochemical changes in peaches. J. Food Qual. 1993: 16:301–309.

13 Spalding DH and vonWindeguth DL. Quality and decay of irradiated mangos. HortScience 1988: 23:187–189.

14 *Dionísio AP, Gomes RT and Oetterer M. Ionizing Radiation Effects on Food Vitamins – A Review. Brazilian Archives of Biology and Technology 2009: 52:1267–1278.

15 Paull RE. Ripening behavior of papaya (*Carica papaya* L.) exposed to gamma radiation. Postharvest Biology and Technology 1996: 7:359–370.

16 Zhao M Moy J and Paull RE. Effect of gamma-irradiation on ripening papaya pectin. Postharvest Biology and Technology 1996: 8:209–222.

17 Miller WR and McDonald RE. Irradiation, stage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. HortScience 1999: 34:1112–1115.

18 Paull RE, Gross K and Qiu Y. Changes in papaya cell walls during fruit ripening. Postharvest Biology and Technology 1999: 16:79–89.

19 Paull RE and Chen NJ. Postharvest variation in cell wall-degrading enzymes of papaya (*Carica papaya* L.) during fruit ripening. Plant Physiol. 1983: 72:382–385.

20 D'Innocenzo M and Lajolo FM. Effect of gamma irradiation on softening changes and enzyme activities during ripening of papaya fruit. J. Food Biochem. 2001: 25:425–438.

21 Azelmat K, El Garrouj D, Mouhib M and Sayah F. Irradiation of 'Boufeggous' dates: Effects on chemical composition during storage. Postharvest Biology and Technology 2006: 39:217–222.

22 Luckey TD. Hormesis with Ionizing Radiation. CRC Press, Boca Raton, FL. 1980.

23 *Stevens C, Khan VA, Lu JY, Wilson CL, Pusey PL, Kabwe MK, Igwegbe ECK, Chalutz E and Droby S. The germicidal and hormetic effects of UV-C light on reducing brown rot disease and yeast microflora of peaches. Crop Protection 1998: 17:75–84.

24 *Droby S, Chalutz E, Horev B, Cohen L, Gaba V, Wilson CL and Wisniewski M. Factors affecting UV-induced resistance in grapefruit against the green mould decay caused by *Penicillium digitatum*. Plant Pathology 1993: 42:418–424.

25 Porat R, Lers A, Dori S, Cohen L, Weiss B, Daus A, Wilson CL and Droby S. Induction of chitinase and β-1,3-endoglucanase proteins by UV irradiation and wounding in grapefruit peel tissue. Phytoparasitica 1999: 27:233–238.

26 Liu J, Stevens C, Khan VA, Lu JY, Wilson CL, Adeyeye O, Kabwe MK, Pusey PL, Chalutz E, Sultana T and Droby S. Application of ultraviolet-C light on storage rots and ripening of tomatoes. J. Food Prot. 1993: 56:868–872.

27 Nigro F, Ippolito A and Lima G. Use of UV-C light to reduce Botrytis storage rot of table grapes. Postharvest Biology and Technology 1998: 13:171–181.

28 Nigro F, Ippolito A, Lattanzio V, Di Venere D and Salerno M. Effect of ultraviolet-c light on postharvest decay of strawberry. Journal of Plant Pathology 2000: 82:29–37.

29 El Ghaouth A, Wilson CL and Callahan AM. Induction of chitinase, β-1,3-Glucanase, and phenylalanine ammonia lyase in peach fruit by UV-C treatment. Phytopathology 2003: 93:349–355.

30 *Stevens C, Khana VA, Wilson CL, Lu JY, Chalutz E and Droby S. The effect of fruit orientation of postharvest commodities following low dose ultraviolet light-C treatment on host induced resistance to decay. Crop Protection 2005: 24:756-759.

31 Arcas MC, Botía JM, Ortuño AM and Del Río JA. UV irradiation alters the levels of flavonoids involved in the defence mechanism of *Citrus aurantium* fruits against *Penicillium digitatum*. European Journal of Plant Pathology 2000: 106:617–622.

32 González-Aguilar GA, Wang CY, Buta JG and Krizek DT. Use of UV-C irradiation to prevent decay and maintain postharvest quality of ripe `Tommy Atkins' mangoes. International Journal of Food Science and Technology 2001: 36:767–773.

33 Pombo MA, Dotto MC, Martínez GA and Civello PM. UV-C irradiation delays strawberry fruit softening and modifies the expression of genes involved in cell wall degradation. Postharvest Biology and Technology 2009: 51:141–148.

34 Cantos E, García-Viguera C, Pascual-Teresa S and Tomás-Barberán FA. Effect of Postharvest ultraviolet irradiation on resveratrol and other phenolics of cv. Napoleon table grapes. J. Agric. Food Chem. 2000: 48:4606–4612.

35 *Farkas J. Irradiation as a method for decontaminating food: a review. International Journal of Food Microbiology 1998: 44:189–204.