Journal of Scientific & Industrial Research
Vol. 83, November 2024, pp. 1206-1213
DOI: 10.56042/jsir.v83i11.6365

# Does UV-C Irradiation Help in Suppression of Anthracnose and Maintain Quality of Stored Papaya Fruit?

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*Received 23 October 2023; revised 09 September 2024; accepted 24 September 2024*

Papaya, a climacteric fruit, undergoes rapid ripening and softening, resulting in a shortened shelf life, notable quality deterioration and vulnerability to post-harvest diseases. UV-C irradiation is an environmentally conscious approach towards sustainable postharvest fruit preservation. The *in vitro* and *in vivo* effectiveness of UV-C against anthracnose and its impact on the quality of cold-stored papaya fruit were investigated. For the qualitative study, papaya fruits were subjected to UV-C irradiation at varying doses (1.2, 1.6, 2.0 kJ·m$^{-2}$) and subsequently stored at 13 ± 1°C for 20 days. Potent *in vitro* germicidal effects on anthracnose were demonstrated by UV-C doses (> 2.0 kJ·m$^{-2}$) doses during 7 days of incubation. However, complete prevention of in vivo disease incidence was not achieved, as UV-C light induced scalding and damage to the peel, causing latex to ooze out and creating a conducive environment for fungal colonization. The peel damage following UV-C exposure was attributed to the enhanced accumulation of MDA and $H_2O_2$ in the fruit peel. Conversely, lower doses (1.2 kJ·m$^{-2}$) of UV-C irradiation were effective in reducing weight loss and respiration rate, retaining higher firmness, and maintaining better phenols and antioxidant activity. However, a loss of glossiness and patchy discoloration on the fruit peel were observed, which reduced its visual appeal. Severe stress caused by UV-C light, even at the lower dose, led to higher oxidative damage, and thus least practical utility is found for UV-C in postharvest disease management and quality retention of stored papaya fruit.

**Keywords:** *Colletotrichum*, *In vitro* assay, Peel damage, Postharvest disease, Sensory quality

## Introduction

Papaya (*Carica papaya* L.) is regarded as a delicious and economically valuable fruit, owing to its exceptional nutritional content and health benefits around the world. India holds the top position globally in both area under cultivation and production, with 0.142 Mha and 5.78 MT, respectively. This impressive output is noted to constitute a substantial 44.05% of the world's total production.[1,2] Due to its climacteric nature, papayas experience swift ripening and softening, typically occurring within a span of 6 to 8 days at room temperature.[3] This limited shelf life, coupled with significant quality deterioration and vulnerability to post-harvest diseases, presents a major challenge for the global papaya industry. The issue is exacerbated by papaya's high water transpiration rate, respiratory metabolism, chilling injury, perishable nature, and susceptibility to microbes during transportation and storage processes.[4] According to a study by Nabard Consultancy Services Private Limited (NABCONS) in 2022[(5)], papaya suffered a 6.59% loss after harvest throughout all stages of production and distribution. Specifically, the major post-harvest diseases like anthracnose, stem end rot and rhizopus rot are responsible for the reduction of shelf life and postharvest losses of papaya.[6] Among these, anthracnose (*Colletotrichum gloeosporioides*) is the most prevalent disease affecting ripe fruits in various papaya-producing regions of India. This renders them unsuitable for both commercial purposes and consumption. Remarkably, anthracnose can infect fruits while they are still in the field, staying dormant without showing any visible symptoms. It only becomes active and develops fully when favorable conditions arise.[7] For years, chemical fungicides have been the primary choice for preventing anthracnose diseases due to their cost-effectiveness and convenience. However, concerns about their environmental impact and

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potential harm to human health from residual chemicals persist, compounded by the development of fungicide resistance.[8] This underscores the need for an eco-friendly approach to disease control in postharvest fruit. Ultraviolet-C (UV-C) treatment is an affordable, eco-friendly, and residue-free preservation technique gaining widespread acceptance as an alternative to chemical methods across various fresh food products.[9] Non ionizing UV-C radiation, within the 200–280 nm range, is esteemed for its potent germicidal properties, presenting a viable option for reducing initial microbial contamination.[10] Studies have shown that applying a low dose of postharvest UV-C exposure yields positive effects on crucial quality indicators of fresh fruits and vegetables.[8,10–12] This includes elevate plant defence, alleviate the proliferation of pathogenic microorganisms, enhancing secondary metabolites biosynthesis, and improving both nutritional content and storage longevity.[11,12] Cia *et al.*[13] observed that UV-C irradiation reduced anthracnose sporulation in papaya when inoculated 48 h after treatment, though it caused browning and scalding on fruit surface. In contrast, Rivera-Pastrana *et al.*[14] reported that UV-C exposure enhanced the antioxidant system in papaya fruit without causing any visible damage. However, a comprehensive study assessing the effectiveness of UV-C light on physicochemical quality, along with sensory evaluation and anthracnose disease suppression of stored papaya fruit, remains conspicuously absent. This research gap prompted the present study, which was aimed at addressing this lacuna by evaluating the impact of UV-C irradiation, both *in vitro* and *in vivo*, on disease suppression in 'Red Lady' papaya fruit. Additionally, the influence of UV-C treatment on the overall quality of papaya fruit under cold storage conditions was explored.

## Material and Methods

### Pathogen

The fungal pathogen *C. gloeosporioides* (Culture No. 6979) was obtained from the Indian Type Culture Collection (ITCC), Plant Pathology Division, ICAR-IARI, New Delhi. The pure culture was preserved in PDA media at 4°C and was pre-cultured at 25°C to facilitate growth prior to experimentation.

### Inoculation and Fruit Treatment

#### *In vitro Efficacy of UV-C Against C. gloeosporioides*

The *in vitro* efficacy of incremental doses of UV-C irradiation was retrieved against the mycelial growth of *C. gloeosporioides* through the method illustrated by Terao *et al.*[12] The *C. gloeosporioides* spore suspension ($10^5$ spores·mL$^{-1}$) was spread in an open petri dish and subjected to incremental doses of UV-C irradiation (0.8 to 2.8 kJ·m$^{-2}$) using a prototype irradiator fitted with a germicidal tube (UV 25 W/ T8, 254 nm, Philips, Poland). The radiation exposure time was determined using the equation: T (s) = D (mJ·cm$^{-2}$) / I (mW·cm$^{-2}$), where T represents the exposure time, D represents the dose being evaluated, and I signifies the UV-C lamp intensity. The light intensity was measured directly by using a radiometer (Lutron UVC-254). After the treatment, 5 µL of each suspension was pipetted onto 3 mm wells on PDA plates. A control group with only the pathogen was included. Plates were then incubated at 25 ± 1°C, and colony diameters were measured on days 3, 5, and 7. Mycelial growth inhibition was calculated using Bhan *et al.*[15]

#### *In vivo Efficacy of UV-C Against C. gloeosporioides*

The *in vivo* efficacy of UV-C irradiated was assessed on papaya against anthracnose disease incidence following the procedure described by Ong and Ali.[16] Uniform 'Red lady' papaya fruits, free from visual blemishes and at maturity index 2 (10–15% epidermic yellowing), were selected for the *in vivo* test. The papaya fruits were first washed with tap water and then surface-sterilized using a 0.1% NaOCl solution for one minute and then rinse with sterile water. After air-drying at room temperature, the fruits were injured using a sterile cork borer and subsequently inoculated with mycelium plugs (Ø 3 mm) of *C. gloeosporioides*. Following this, the fruits were placed in an incubator for 24 hours. Then, they were exposed to UV-C light at varying doses (1.2, 1.6, 2.0 kJ·m$^{-2}$) from a distance of 15 cm from the lamp. The control group consisted of untreated fruits. Lesion diameter was quantified on days 3, 5, and 7 by measuring the average of both horizontal and vertical diameters. Disease incidence was recorded as the percentage of fruits in each treatment displaying specific disease symptoms.

### Quality Parameters

Physiological Loss in Weight (PLW) in papaya was assessed by computing the variance between the initial weight and the ultimate weight at the time of measurement. This variation was then expressed as a percentage. Firmness was evaluated following the method described by Dhami *et al.*[17] using a texture analyser (Stable Microsystems, UK), with firmness recorded as the maximum peak force measured in

Newtons (N). The respiration rate was estimated using an autogas analyser (Checkmate 9900 $O_2/CO_2$, Dansensor PBI, Denmark).[18] The results were presented in units of mL $CO_2$ $kg^{-1}{\cdot}h^{-1}$.

Total Phenolic Content (TPC) and Antioxidant (AOX) activity in fruit samples were estimated using the Folin-Ciocalteu reagent[19] and DPPH method[20] respectively. The findings were reported in mg GAE 100 $g^{-1}$ FW for TPC and percentage for AOX. The total carotenoid content was determined by first homogenizing the pulp in acetone and then separating it through petroleum ether for pigment extraction.[21] The carotenoid content was then indicated as mg·100 $g^{-1}$ FW. Malondialdehyde (MDA) and hydrogen peroxide ($H_2O_2$) accumulation in the peal sample was estimated by thiobarbituric acid[18] and trichloroacetic acid method[22] respectively and indicated as $\mu M{\cdot}g^{-1}$ FW.

#### Sensory Analysis

Sensory characteristics of the treated papaya fruits were evaluated using a 5-point Hedonic scale. A trained ten-panel assessed the fruits for taste, flavor, texture, visual appearance and overall acceptability. Individual perceptions were used to evaluate each attribute and assign a corresponding score.[23]

#### Statistical Analysis

The study adopted a completely randomized design, employing three replications, each consisting of fifteen fruits. Over a span of 20 days, the fruits underwent assessment for various physicochemical parameters at 5-day intervals during their storage at 13 ± 1°C and 80–90% RH. The percentage of mycelial growth, along with its inhibition percentage (presented in parentheses), underwent transformation using the square root of the arcsine. Subsequently, a two-way ANOVA was executed, followed by the Tukey's HSD test at a 5% significance level. Any significant disparities were denoted by distinct letters. The data underwent analysis through PROC CORR in SAS 9.4 software.

## Results and Discussion

#### *In vitro* Efficacy of UV-C Irradiation in Controlling *C. gloeosporioides*

The UV-C irradiation proved a significant ($p \leq 0.05$) inhibitory effect against the test pathogen. Table 1 shows a rapid decrease in mycelial growth as the UV-C dose increases (0–2.8 $kJ{\cdot}m^{-2}$). The doses of 2.0, 2.4 and 2.8 $kJ{\cdot}m^{-2}$ had a complete inhibition activity (100%) against the *in vitro C. gloeosporioides* during 7 days of incubation (Table 1), whereas, the dose of 1.6 $kJ{\cdot}m^{-2}$ (33 mm) significantly reduced the mycelial growth. The assessed UV-C doses were highly effective in inhibiting the mycelial growth of postharvest anthracnose disease in papaya under *in vitro* conditions. UV-C irradiation chiefly impairs pathogens' genetic material (DNA and RNA), leading to the formation of DNA photoproducts known as pyrimidine dimers. Consequently, vital processes like transcription and replication are disrupted, ultimately causing the death of the pathogen.[6] Our findings align

Table 1 — The efficacy of UV-C irradiation on the mycelial growth and inhibition of *C. gloeosporioides* under *in vitro* conditions

| *Treatments* | Mycelial growth (mm) | | |
|---|---|---|---|
| | Storage days | | |
| | 3 | 5 | 7 |
| Control | 27.67 ± 1.5 (31.51) | 55.67 ± 0.7 (48.25) | 79 ± 0.3 (62.26) |
| 0.8 $kJ{\cdot}m^{-2}$ | 19.67 ± 1.2 (26.08) | 46 ± 0.6 (42.71) | 76 ± 0.6 (60.67) |
| 1.2 $kJ{\cdot}m^{-2}$ | 11.33 ± 0.9 (19.36) | 26.33 ± 0.9 (30.87) | 64 ± 1.7 (53.73) |
| 1.6 $kJ{\cdot}m^{-2}$ | 6.67 ± 0.3 (14.95) | 15.67 ± 0.7 (23.31) | 33 ± 0.9 (35.26) |
| 2.0 $kJ{\cdot}m^{-2}$ | 0 ± 0 (0.63) | 0 ± 0 (0.63) | 0 ± 0 (0.63) |
| 2.4 $kJ{\cdot}m^{-2}$ | 0 ± 0 (0.63) | 0 ± 0 (0.63) | 0 ± 0 (0.63) |
| 2.8 $kJ{\cdot}m^{-2}$ | 0 ± 0 (0.63) | 0 ± 0 (0.63) | 0 ± 0 (0.63) |
| | | Inhibition (%) | |
| Control | 0 ± 0 (0.63) | 0 ± 0 (0.63) | 0 ± 0 (0.63) |
| 0.8 $kJ{\cdot}m^{-2}$ | 28.05 ± 8.4 (32.35) | 17.32 ± 1.9 (24.53) | 2.98 ± 0.9 (9.68) |
| 1.2 $kJ{\cdot}m^{-2}$ | 58.75 ± 4 (50.53) | 52.65 ± 2 (46.52) | 17.01 ± 1.1 (24.34) |
| 1.6 $kJ{\cdot}m^{-2}$ | 75.89 ± 0.5 (60.41) | 71.83±1.4 (57.96) | 57.44 ± 1.2 (49.28) |
| 2.0 $kJ{\cdot}m^{-2}$ | 100 ± 0 (89.38) | 100 ± 0 (89.38) | 100 ± 0 (89.38) |
| 2.4 $kJ{\cdot}m^{-2}$ | 100 ± 0 (89.38) | 100 ± 0 (89.38) | 100 ± 0 (89.38) |
| 2.8 $kJ{\cdot}m^{-2}$ | 100 ± 0 (89.38) | 100 ± 0 (89.38) | 100 ± 0 (89.38) |

The results are expressed as the average of three replicates (n = 3), along with their corresponding standard deviations. Values in parentheses represent arc sine-transformed data ($p < 0.05$; Tukey's HSD test).

with the earlier research conducted by Terao *et al.*[12], which demonstrated the effectiveness of UV-C (2.5 kJ·m$^{-2}$) in deactivating *Botryosphaeria dothidea*. Likewise, Terao *et al.*[24] reported similar results in the inhibition of *Penicillium digitatum*.

**In Vivo Efficacy of UV-C Irradiation in Controlling *C. gloeosporioides***

The papaya irradiated with all the doses of UV-C, alleviated lesion diameter and disease incidence at the site of *C. gloeosporioides* inoculation than the control during the entire storage, with the best result at 2 kJ·m$^{-2}$ (Figs. 1a & b). On day 7, compared to the control fruit, the UV-C treated fruit exhibited a 65.32% reduction in lesion diameter and a 26.7% decrease in disease incidence. However, it was not effective in preventing fruit infection, as the UV-C irradiation induced scalding and damage to the peel at the proximal end, causing latex to ooze out. This condition favored secondary fungus colonization, ultimately accelerating disease incidence towards the end of storage. Despite demonstrating potent germicidal effects on *C. gloeosporioides in vitro* (Table 1), UV-C light was not entirely effective in preventing fruit infection. A parallel phenomenon was noted in postharvest nectarines, as an *in vivo* study demonstrated that UV-C treatment at 6 kJ·m$^{-2}$ actually hastened the onset of brown rot.[8] Likewise, in melons and mangoes, damage to the peel was observed at doses exceeding 2.5 kJ·m$^{-2}$, leading to elevated levels of fusarium rot and anthracnose, respectively.[12,25]

**Impact of UV-C Irradiation on Physicochemical Parameters**

***PLW***

The loss of weight in fresh horticultural produce primarily arises from water evaporation during storage, driven by metabolic activities like transpiration and respiration.[15] The findings from this study clearly demonstrate that the weight loss of papaya fruits notably increased as the storage progressed (Fig. 2a). Significantly, UV-C treatments demonstrated a small reduction in postharvest weight loss compared to the control ($p < 0.05$). By the end of the storage (20$^{th}$ day), the 1.2 kJ·m$^{-2}$ UV-C treatment exhibited the lowest PLW at 5.10%, while the control group recorded the highest at 6.19%. UV irradiation's effectiveness in preventing weight loss could be linked to its capacity to slow down the respiration rate (Fig. 2c) and transpiration, resulting in reduced water loss in the treated fruits.[26] Moreover, the slightly higher PLW observed in higher dosages of UV-C-treated fruit could be linked to the damage to the fruit peel and inhibition of cell membrane dysfunctions.[10] Our findings align with previous studies which have also demonstrated that low dose of UV-C irradiation leads to a reduction in weight loss in peach and strawberry.[26,27]

***Firmness***

Flesh firmness in all treatment groups exhibited a linear decline during the storage (Fig. 2b). Nevertheless, the rate of softening in treated fruits was notably slower than that observed in the control group. Notably, the 1.2 kJ·m$^{-2}$ UV-C treatment effectively maintained fruit firmness at 8.62 N. In contrast, the control fruits had a firmness of 3.85 N by the end of storage. UV-C radiation has been demonstrated to effectively inhibit ethylene synthesis and impede the action of enzymes responsible for fruit softening, consequently reducing the rate of respiration. These combined effects contribute to the preservation of fruit firmness.[10] Additionally, UV-C treatment has been found to down regulate the genes and hinder the accumulation of transcripts related to cell wall degrading enzymes

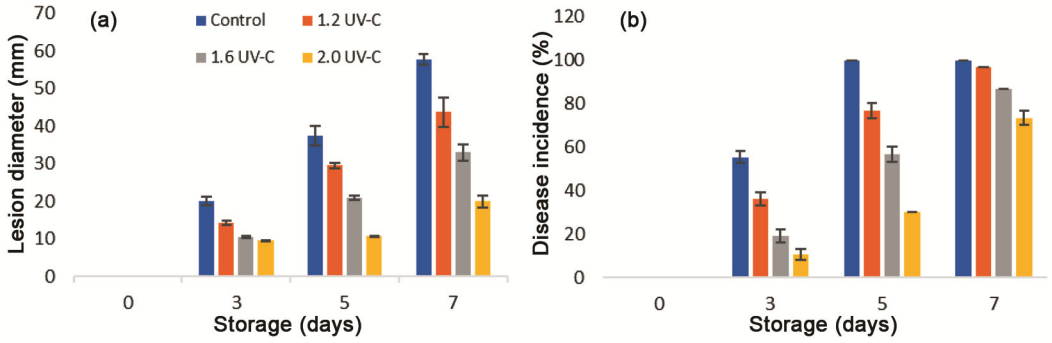


Fig. 1 — The efficacy of UV-C irradiation against lesion diameter (a) and disease incidence (b) of *C. gloeosporioides* on papaya fruit. Error bars represent the standard deviation, while distinct letters indicate statistically significant differences between the values ($p < 0.05$; Tukey's HSD test)

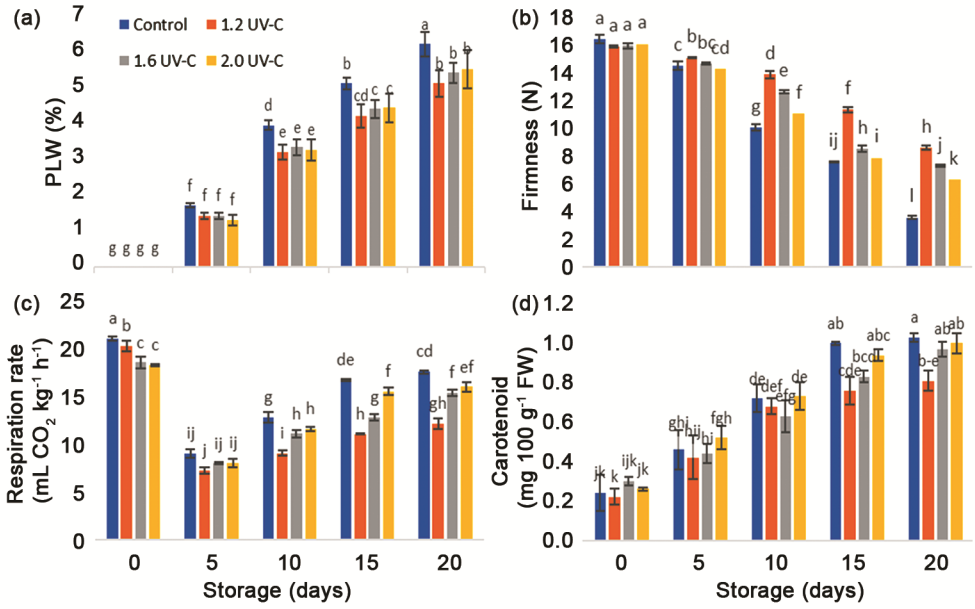


Fig. 2 — (a) PLW, (b) firmness, (c) respiration rate and (d) carotenoid content in control and UV-C irradiated papaya fruit during cold storage. Error bars represent the standard deviation, while distinct letters indicate statistically significant differences between the values ($p < 0.05$; Tukey's HSD test)

such as PME2.1 (pectin methylesterase), Cel1 (cellulase), PGcat (polygalacturonase), and Exp1 (expansin). This inhibition aligns with the delayed softening due to UV-C observed in papaya fruits.[11,28] Numerous research reports have indicated that low dose of UV-C irradiation is effective in mitigating firmness loss during storage.[10,27,29]

***Respiration Rate***

The respiration rate stands as a crucial indicator, offering insights into nutrient utilization and the aging process of fruit during storage.[17] As illustrated in Fig. 2c, the respiration rate of papaya in all treatments gradually increased with extended storage time. Remarkably, papaya treated with 1.2 kJ·m$^{-2}$ UV-C exhibited a significantly lower respiration rate (11.10 mL $CO_2$ kg$^{-1}$·h$^{-1}$) than the controls (16.79 mL $CO_2$ kg$^{-1}$·h$^{-1}$) after cold storage ($p < 0.05$). As it is evident from the research conducted by Yang *et al.*[30], UV-C treatment has the capacity to suppress the respiration rate by diminishing the activity of succinic dehydrogenase and cytochrome C oxidase. However, exposing the fruit to higher doses of UV-C (1.6 and 2.0 kJ·m$^{-2}$) led to damage in the fruit peel and consequently, an increased respiration rate. This finding is consistent with prior studies on strawberries[29] and mangoes[12], affirming that appropriate doses of UV-C can effectively impede respiration rates.

***Total Carotenoid Content***

The total carotenoid content displayed a rising trend during the cold storage (Fig. 2d). However, UV-C exhibited a dose-dependent reduction in carotenoid accumulation in the pulp. The control and 2.0 kJ·m$^{-2}$UV-C treated fruits exhibited the highest total carotenoid concentrations on the 20$^{th}$ day of storage (1.03 mg·100g$^{-1}$ FW and 1.0 mg·100g$^{-1}$ FW, respectively), while the 1.2 kJ·m$^{-2}$ UV-C treated fruit showed the lowest concentration (0.81 mg·100g$^{-1}$ FW). This aligns with the findings by Ma *et al.*[28], who reported that UV-C treatment suppressed enzymes related to carotenoid biosynthesis. The increase in carotenoid content with higher UV-C dosage may be attributed to UV-C acting as a stress inducer, prompting the plant to enhance carotenoid production as a protective mechanism against stress-induced damage.[31] Similar decreases in carotenoid content due to UV-C irradiation have been observed in bitter gourd and peach fruit.[11,28]

***Total Phenol Content***

The TPC in all treatments initially rose and then consistently declined over the storage period, reaching its lowest level in the control samples on the 20$^{th}$ day (Fig. 3a). However, this decline was less pronounced in the UV-C-treated fruits in a dose-dependent manner compared to the control group. Significantly,

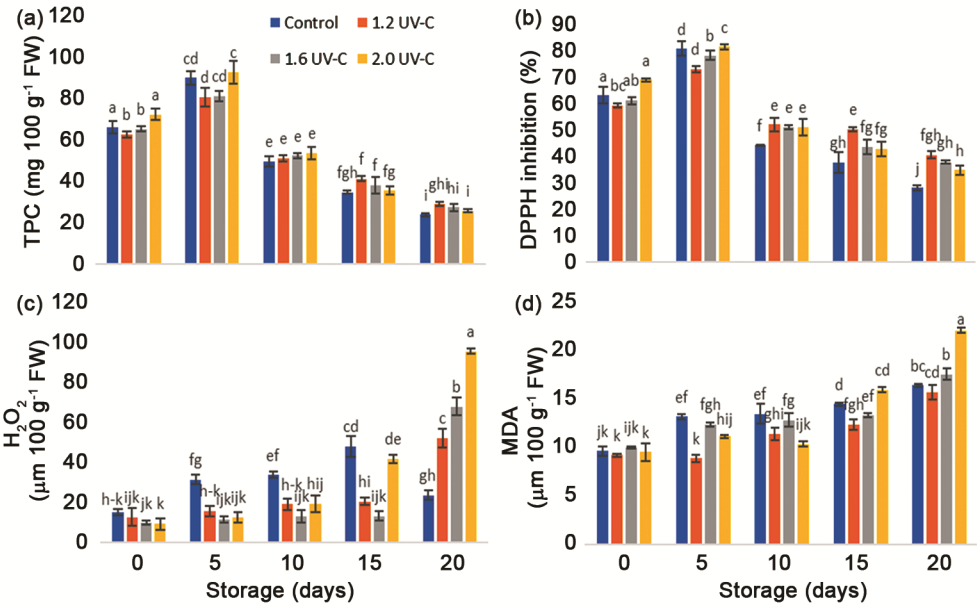


Fig. 3 — Content of different constituents in control and UV-C irradiated papaya fruit during cold storage: (a) Total phenols content, (b) antioxidant activity, (c) hydrogen peroxide, and (d) malondialdehyde; Error bars represent the standard deviation, while distinct letters indicate statistically significant differences between the values ($p < 0.05$; Tukey's HSD test)

fruit treated with 1.2 kJ·m$^{-2}$ UV-C exhibited a lower reduction in TPC (64.43%) compared to the control (73.63%) by the end of cold storage ($p < 0.05$). This preservation of TPC can be attributed to the heightened activity of phenylalanine ammonia-lyase[9], an enzyme involved in phenol synthesis in fruits. This trend in TPC was similarly reported in UV-irradiated nectarines[8], and peach.[26,32]

***Antioxidant Activity***

The AOX capacity in papaya fruits initially increased and then gradually declined during storage. However, UV-C treatments demonstrated a dose-dependent inhibition of this reduction (Fig. 3b). For instance, fruits treated with 1.2 kJ·m$^{-2}$ UV-C exhibited notable retention of AOX capacity (40.55%) compared to the control (28.18%) towards the end of storage ($p < 0.05$). The reduced AOX loss in UV-treated fruits may also be linked to the amplified levels of secondary metabolites, as well as the fact that UV-C treatment prompted the upregulation of various antioxidant-related genes, including peroxidase (POD) and superoxide dismutase (SOD), as observed in peach fruit.[11] Similar instances of UV-induced reduction in AOX loss have been previously noted in sweet cherry[10], and bitter gourd[31], respectively.

***MDA and $H_2O_2$***

Lipid peroxidation and the generation of reactive oxygen species (ROS) serve as inherent indicators of fruit ripening and aging. At the outset, there was no notable distinction in MDA and $H_2O_2$ levels between the UV-C irradiated and control groups. (Figs. 3c & d). As postharvest storage progressed, both groups exhibited an increase in MDA and $H_2O_2$ content, indicating an escalation in cellular oxidative damage over time. Notably, the accumulation of MDA in samples treated with 1.2 kJ·m$^{-2}$ UV-C was significantly ($p < 0.05$) lower (15.67 µM·g$^{-1}$) than in the 2.0 kJ·m$^{-2}$ UV-C (22.04 µM·g$^{-1}$ FW). A lower content of $H_2O_2$ was detected in UV-C irradiated fruit on all storage days, except on day 20. Kan *et al.*[11] noted a downregulation of genes encoding lipoxygenase in peach fruit following UV-C treatment. The initial low level of $H_2O_2$ suggests that UV-C significantly boosted antioxidant enzymes activity like SOD, ascorbate peroxidase, and catalase, contributing to the scavenging of $H_2O_2$.[(11)] The elevated level on the 20$^{th}$ day may be attributed to peel damage and fungal disease infection at the damaged part of the fruit, causing increased stress. Maintaining intracellular ROS homeostasis is crucial for the disease resistance of postharvest fruit. Uncontrolled ROS production can lead to oxidative damage in cell tissues, resulting in a range of metabolic disorders, including enhanced disease incidence.[33] Similar observations of UV-induced reduction in MDA and $H_2O_2$ accumulation have been documented in peaches.[11,30]

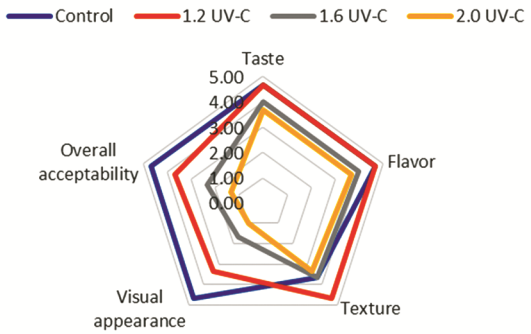


Fig. 4 — Influence of UV-C irradiation on the sensory qualities of papaya fruit during cold storage

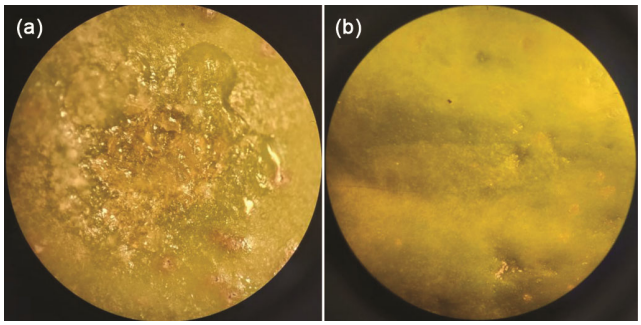


Fig. 5 — Microscopic images of the papaya fruit peel surface, taken after: (a) UV-C irradiation, and (b) control

### Sensory Analysis

Consumer acceptance testing was utilized to gauge the influence of UV-C irradiation on papaya fruit quality. Noticeable changes in the appearance and colour of the papayas were observed, with significant variations ($p < 0.05$) detected between the UV-C-exposed and control papayas after 20 days of storage (Fig. 4). The lower UV-C dose (1.2 kJ·m$^{-2}$) preserved the taste, flavor, and texture of the fruits; however, a reduction in visual appeal occurred due to a loss of glossiness and patchy discoloration on the fruit peel, resulting in a lower overall score compared to the control. In contrast, higher UV-C doses (1.6 and 2.0 kJ·m$^{-2}$) received very low acceptability scores, as they caused damage to the peel, particularly at the proximal end, leading to latex oozing and an undesirable visual appearance (Fig. 5). These results are consistent with those reported for nectarines[8] and sweet cherries.[34]

## Conclusion

In conclusion, UV-C light demonstrated potent *in vitro* germicidal effects on anthracnose mycelial growth suppression. Under *in vivo* conditions, higher doses (> 1.6 kJ·m$^{-2}$) resulted in a noticeable increase in UV-C-induced papaya peel damage, likely due to the enhanced accumulation of MDA and $H_2O_2$. Conversely, lower doses (1.2 kJ·m$^{-2}$) maintained physicochemical integrity, albeit with a loss of glossiness and patchy discoloration, which affected sensory appeal. The findings suggest that the sole application of UV-C does not yield desirable effects on the overall quality of papaya and needs to be synergized with other suitable physical or biochemical elicitors. The prospect of enhancing papaya postharvest disease suppression through judicious UV-C application holds immense promise for the horticulture industry, potentially mitigating post-harvest losses and ensuring a more sustainable supply chain.

## Conflict of Interest

The authors confirm that they have no financial interests or personal connections that could have influenced the content of this paper.

## Acknowledgement

This research work was supported by, Indian ICAR - Indian Agricultural Research Institute (IARI), New Delhi, India.

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