EFFECT OF ULTRAVIOLET-C LIGHT ON POSTHARVEST DECAY OF STRAWBERRY

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SUMMARY

The effect of ultraviolet-C light (u.v.-C) at low doses on postharvest decay of strawberries caused by *Botrytis cinerea* and other pathogens was investigated. Phenylalanine ammonia-lyase (PAL) activity and ethylene production, as influenced by ultraviolet-C irradiation, were also determined. Strawberries (cv. 'Pajaro') from plants that had been treated with chemicals against grey mould were irradiated with u.v.-C doses ranging from 0.25 to 4.00 kJ m^{-2} and inoculated with *B. cinerea* at different times (0, 12, 24 and 48 hours) after irradiation. To assess the effect of u.v.-C light on the naturally occurring postharvest decay, organically grown strawberries were also used. After treatment the strawberries were stored at 20±1°C or at 3°C. u.v.-C doses at 0.50 and 1.00 kJ m^{-2} significantly reduced botrytis storage rot 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 PAL activity 12 h after irradiation; this result indicates the activation of metabolic a pathway related to the biosynthesis of phenolic compounds, which are usually characterized by antifungal activity. In addition, u.v.-C irradiation caused an increase in ethylene production proportional to the doses applied, reaching the highest value 6 h after treatment. The overall results from these investigations indicate that treatment with low u.v.-C doses produces a reduction in postharvest decay of strawberries related to induced resistance mechanisms. Moreover, a germicidal effect of reducing external contaminating pathogens cannot be excluded.

Key words: *Fragaria* x *ananassa*, *Botrytis cinerea*, storage rot, induced resistance, PAL activity, ethylene.

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INTRODUCTION

Grey mould, caused by *Botrytis cinerea* Pers. (ex Fr.), is the most severe postharvest disease of strawberries. An important role in the development of the disease playing the infections contracted during flowering, that remain quiescent and then develop at harvest and during storage (Bristow *et al.*, 1986); furthermore, consideration must be given to infections caused by lesions incurred during harvesting and due to external contamination with pathogens such as *Rhizopus stolonifer* (Ehrenb. ex Fr.) Vuill and *Mucor* sp. At present, the control of postharvest decay and Botrytis rot, in particular, is based mainly on the use of suitable preharvest chemical treatments (Salgarollo and Tesi, 1982) and on storage technologies, such as pre-refrigeration and controlled atmospheres (Li and Kader, 1989; Pratella, 1993). The use of fungicides is restricted in most countries, and there are problems due to the negative effects they may have on the wholesomeness of the products and on the selection of fungicide-resistant strains of the pathogen. Consequently, the search for alternative methods, retarding ripening and senescence processes and/or increasing natural defence mechanisms, could be useful in the control of storage decay of strawberries.

The possibility of inducing resistance to pathogens in commodities after harvest has only been investigated recently. Prestorage treatments of different fruits and vegetables with biotic (Wilson *et al.*, 1994) and abiotic agents (El-Ghaouth and Arul, 1992; Saks *et al.*, 1996; Ippolito *et al.*, 1997) resulted in a reduction in storage rots associated with induced resistance. In the list of abiotic agents which induce resistance is ultraviolet radiation at short wavelengths (u.v.-C, 190-280 nm). u.v.-C irradiation of plant tissues at suitable doses brings about weak stress responses, often associated with inducible pathogen resistance. The wavelength at 254 nm is reported to be among the most effective with regard to elicitation of substances related to resistance mechanisms (Fritzenheimer *et al.*, 1983; Sarig *et al.*, 1996). Moreover, recent attempts to use u.v.-C light, alone or integrated with other biologically based technologies, have shown a reduction in postharvest decay for several

fruits and vegetables (Stevens *et al.*, 1996; Nigro *et al.*, 1997, 1998).

Therefore, considering the promising results obtained with other fruits and vegetables, the aim of our research was to investigate the effect of different u.v.-C doses at 253.7 nm on postharvest decay caused by *B. cinerea* and other pathogens on strawberry. Some biochemical parameters, such as ethylene production and phenylalanine ammonia-lyase (PAL) activity, as influenced by u.v.-C treatment, were also determined.

MATERIALS AND METHODS

Strawberries. Trials were carried out on strawberries (*Fragaria* x *ananassa*, Duch. cv. 'Pajaro') taken from commercial groves located in Southern Italy at Torre a Mare (Province of Bari) and cultivated by the methods usually utilised in these areas. In particular, to protect against grey mould vinclozolin, iprodione or procymidone, were used beginning at the onset of flowering and spaced out according to the weather conditions. Furthermore, tests were made on chemically untreated strawberries taken from commercial groves in the Ionian Metaponto area that were not subjected to any phytosanitary treatments (organic farming), except for sporadic spraying with colloidal sulphur.

The strawberries were harvested when they had achieved orange/red coloration of 2/3 of the surface area. This degree of ripeness is considered the best for fruit which is to be transported a long way and for medium to long storage periods (8-10 days) (Rosati and Cantoni, 1993). Once in the laboratory the strawberries were selected for uniformity in size and absence of defects and processed the same day of harvest.

u.v.-C irradiation. Strawberries were irradiated using three germicidal, low-pressure vapor lamps (Osram HNS OFR) as previously described (Nigro *et al.*, 1998). In particular, each lamp (2.5 cm tube diameter; 88 cm length) had a nominal power output of 30 watts and a peak wavelength emission of 253.7 nm. u.v.-C irradiance was measured using a UVX digital radiometer (Ultraviolet Products Inc., San Gabriel, California, USA) equipped with a UV-X 25 254 nm sensor. Strawberries, arranged in plastic trays in a single layer, were placed 25 cm from the light source and treated with u.v. light at various doses. These ranged from 0.25 to 4.00 kJ m^{-2} and were varied by altering the duration of irradiation at a fixed distance and flux density, the latter averaging 1.33 mV cm^{-2} in the u.v.-C field area. During irradiation the strawberries were rotated on their major axis in such a way that each side received full amount of irradiation.

Effect of u.v.-C doses on postharvest storage rots. In order to assess u.v.-C inducible resistance, chemically treated strawberries were inoculated with *B. cinerea* (isolated from naturally infected strawberries) after irradiation. This was carried out by placing 25 µl of a conidial suspension (10^4 conidia ml^{-1}) of the pathogen in the equatorial zone of the fruit. The pathogen was inoculated 10-15 min after u.v.-C irradiation (defined as 0 h) and 12, 24, and 48 h later. During the period between u.v.-C treatment and inoculation, the strawberries were kept at 15°C in the dark, with high RH (95-97%). Chemically untreated strawberries (organic farming) were not inoculated. The u.v.-C doses at 0.25, 0.50, 1.00, 2.50, and 4.00 kJ m^{-2} were tested. Unirradiated strawberries were used as a control.

Storage and data recording. After irradiation and inoculation, the strawberries were stored in the dark for either 4-6 days at 20±1°C or at 3°C for 8-10 days (RH = 95-97%), followed by 3-4 days shelf life at room temperature. During storage and shelf life the number of rotted strawberries caused by *B. cinerea* and other pathogens (*i.e. R. stolonifer* and *Mucor* sp.) were recorded. In addition, the extent of Botrytis rot was evaluated by using an empirical scale covering 9 degrees: 0 = healthy strawberry; 1 = less than 10% of fruit surface rotten; 2 = 11-20 %; 3 = 21-30%; 4 = 31-40%; 5 = 41-50%; 6 = 51-65%; 7 = 66-80%; 8 = more than 80% fruit surface rotten; from this the average disease severity of the infected fruits was computed.

Effect of u.v.-C on ethylene production. The effect of u.v.-C irradiation at 0.50-1.00-2.50 and 4.00 kJ m^{-2} on ethylene production was determined just at the end of the irradiation and 4-6-12-24 and 48 h later, on strawberries kept in the dark, at 15°C, high RH (95-97%); unirradiated fruits served as a control. To measure ethylene production, three replicates of twenty strawberries were weighed and placed in 1 litre jars, sealed for 1 h before each determination, and the headspace gas withdrawn using a syringe through a rubber septum. Ethylene was measured by a gas chromatograph (Varian 3400, Walnut Creek, California) equipped with a flame ionization detector. The stainless steel column (120 cm x 2 mm internal diameter) was packed with Porapak N 80/100 (Varian). The operating conditions were: oven temperature 50°C; injection port and detector temperature 135°C; air flow 300 ml min^{-1}; hydrogen flow 40 ml min^{-1}; nitrogen flow 50 ml min^{-1}. The results obtained were expressed as µl of ethylene Kg^{-1} h^{-1}.

Extraction and quantification of phenylalanine ammonia-lyase (PAL) activity in u.v.-C treated strawberries. In the first set of trials the effect of u.v.-C irradiation on PAL activity was determined just at the end of the irradiation at 0.50 and 2.50 kJ m^{-2} and 12, 24, and 48 h later; in the second set of trials PAL activity was determined 12 h after irradiation at 0.25-0.50-1.00 and 2.50 kJ m^{-2}. After treatment the fruits were kept in the dark, at 15°C and high RH (95-97%) until the PAL assay. Unirradiated fruits served as a control. PAL activity was determined on acetone powder prepared from a 2-3 mm layer of superficial tissue of fruits. It was homogenized in a blender for 10 min with cold (-15 °C) acetone (2.5 ml g^{-1} fresh wt). The suspension was filtered through a Büchner funnel on a Whatmann no. 1 paper disk; the residue was then homogenised twice with cold acetone. Acetone powder was dried under vacuum and extracted for 2 h at 4°C with 0.1 M borate buffer, pH 8.8 (5 ml g^{-1} fresh wt). The suspension was centrifuged at 20,000 *g* for 10 min giving a supernatant crude extract. Enzyme activity was assayed by using HPLC to measure the cinnamic acid production after a 12 h incubation period at 30°C of an appropriate amount of crude extract with 0.01 M phenylalanine (Lattanzio *et al.*, 1989). The protein concentration was determined according to Bradford (1976), by using Bio-Rad protein assay.

Experimental design and statistics. Trials were arranged in a completely randomized design. Each treatment consisted of five replications and each replicate consisted of 18 strawberries. The trials in which *B. cinerea* was inoculated at different times after irradiation were arranged in a bifactorial randomized design. The factors were u.v.-C dose and inoculation time and the replications were the same as those already stated.

Each experiment was repeated at least twice throughout three different harvest seasons, by using fruits from different field populations; however, the reported results are from representative experiments for each harvest season. The data were submitted to analysis of variance and the mean values compared using Duncan's Multiple Range Test (DMRT) or Least Significant Difference test (LSD). Percentage data were transformed using values from a standardize arcsin percentage transformation table to stabilize variances before analysis. The data obtained from chemically untreated strawberries were subjected to 1st and 2nd degree polynomial regression analysis, where appropriate (Snedecor and Cochran, 1980).

RESULTS

Effect of u.v.-C on botrytis storage rot in artificially inoculated strawberries. The results of the tests performed on strawberries artificially inoculated with *B. cinerea* after irradiation and stored at 20°C are shown in Fig. 1. Irradiation in doses of 0.25 to 2.50 kJ m^{-2} produced significant ($P \leq 0.01$) reductions in the percentage of infected strawberries in comparison to the dose of 4.00 kJ m^{-2} and the unirradiated control (Fig. 1A); however, significantly lower symptom severity was only found in berries irradiated at 0.25 and 0.50 kJ m^{-2} (Fig. 1B). In the tests carried out on strawberries stored at 3°C the percentage of infected fruits and the disease severity were significantly lower ($P \leq 0.01$) in the berries irradiated with 0.50 kJ m^{-2} in comparison with the control. The other doses tested, while producing disease reductions statistically different from the control, were not differentiated amongst each other (Fig. 2).
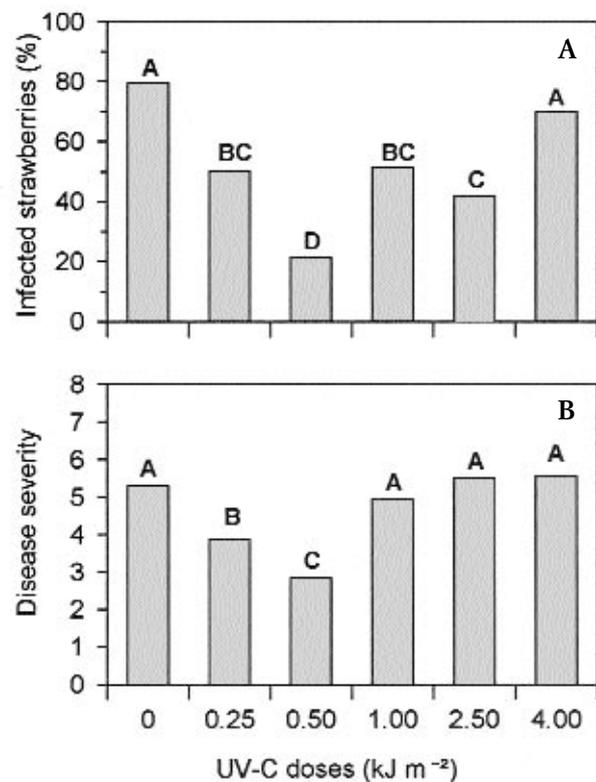

Fig. 1. Effect of u.v.-C dose on *Botrytis* infection (**A**) and disease severity (**B**) of strawberries (cv. 'Pajaro') artificially inoculated with the pathogen after u.v. irradiation. The strawberries were stored at 20±1°C for 5 days. Values marked with the same letter are not statistically different at the 1% level, according to DMRT.
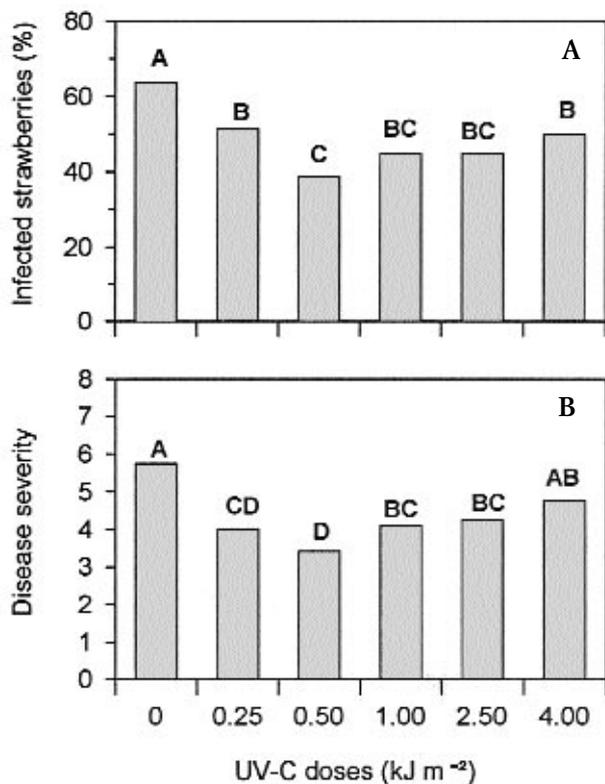
Fig. 2. Effect of u.v.-C dose on *Botrytis* infection (**A**) and disease severity (**B**) of strawberries (cv. 'Pajaro') artificially inoculated with the pathogen after u.v. irradiation. The strawberries were stored at 3°C for 10 days, followed by 4 days shelf life at room temperature. Values marked with the same letter are not statistically different at the 1% level, according to DMRT.

Irradiation at 4.00 kJ m^{-2} induced phytotoxic effects on strawberries stored both at 3 and 20°C. The symptoms consisted of loss of colour brightness and surface dehydration.

The results of the tests set up according to a bifactorial design in order to evaluate the combined effect of the u.v.-C dose and the inoculation time of the pathogen are shown in Fig. 3. A significantly ($P \leq 0.05$) lower infection percentage was found in strawberries irradiated with 0.50 and 1.00 kJ m^{-2} and inoculated 12 hours later, in comparison with both the control inoculated soon after irradiation and the other combinations. Longer time lapses between irradiation and inoculation produced an increased percentage of infected berries (Fig. 3). Similar results were obtained in trials performed at 3°C (data not shown) although not always statistically significant.
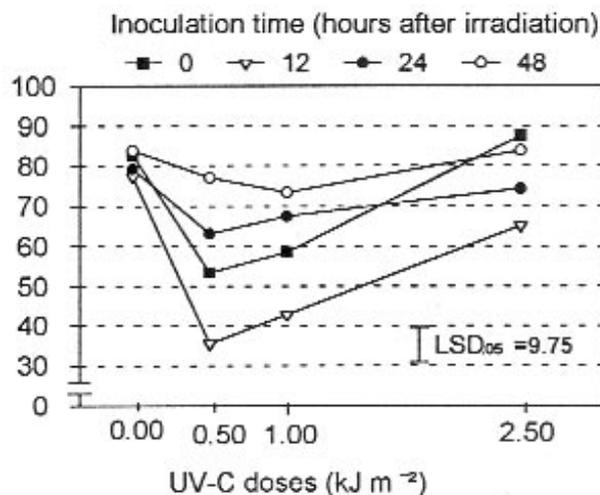

Fig. 3. Combined effect of u.v.-C dose and inoculation time on *Botrytis* infection of strawberries (cv. 'Pajaro') artificially inoculated with the pathogen. The strawberries were stored 8 days at 3°C followed by 3 days shelf life at room temperature.

Effect of u.v.-C irradiation on naturally occurring storage rots. The results of the trials carried out on organically grown strawberries are shown in Tables 1 and 2, for the tests at 20°C and 3°C respectively. With strawberries stored at 20°C for five days the percentage of total rots (due to *B. cinerea, R. stolonifer*, and to a lesser extent to *Mucor* sp.) significantly decreased as u.v.-C doses increased from 0.25 to 2.50 kJ m^{-2}, in comparison with the control. Botrytis rot was significantly reduced at doses of 0.50 and 1.00 kJ m^{-2}; Rhizopus rot showed a generally decreasing trend as the u.v.-C doses increased up to 2.50 kJ m^{-2} (Table 1). Total rot and Botrytis rot incidence were correlated to the u.v.-C dose in a quadratic equation with regression coefficients significant at $P \leq 0.01$; the data obtained for Rhizopus rot were less clear as they were not correlated at all, or hardly correlated to the u.v.-C dose (Table 1).

The results of the tests carried out on strawberries stored at 3°C (Table 2) show significant reductions in Botrytis rot and in disease severity with the increase of dose to 0.50-1.00 kJ m^{-2} in comparison with the unirradiated control. As in the tests conducted on strawberries stored at 20°C, a positive correlation was found between the u.v.-C dose and percentage of infected fruits ($r^2 = 0.92$ in the best of cases), expressed as a quadratic equation with regression coefficients significant at $P \leq 0.01$ (Table 2). Rots caused by *R. stolonifer* and *Mucor* sp. were negligible, although showing decreasing percentages as the dose was increased to 2.50 kJ m^{-2} (data not shown).

Table 1. Effect of u.v.-C dose on the control of naturally occurring storage rots of strawberry (cv. 'Pajaro') stored at 20°C. Data of representative tests conducted over a two year period are reported.

| U.v.-C doses (kJ m^{-2}) | Storage rots (%)[a] | | | | | |
| | 1st year[b] | | | 2nd year[c] | | |
	Total[a] rots	Grey mould	Rhizopus rot	Total rots	Grey mould	Rhizopus rot
0.00	98.8	90.8	48.3	90.3	56.1	65.2
0.25	80.5	19.7	42.6	36.6	23.0	28.2
0.50	58.4	11.3	12.6	29.8	17.0	13.5
1.00	56.7	10.2	23.9	23.0	16.8	17.8
2.50	48.9	46.6	18.8	23.5	28.4	20.0

[a] The percentage of storage rots was determined 6 days after the u.v.-C irradiation. Total rots include grey mould, Rhizopus rot and, to a lesser extent, rots caused by *Mucor* sp.
[b] Quadratic regression equation of u.v.-C doses (x) on total rots (y) was $y = 71.99-37.64x+10.70x^2$, $r^2 = 0.79$; on grey mould (y) was: $y = 59.62-81.24x+30.04x^2$, $r^2 = 0.72$; Rhizopus rot resulted uncorrelated.
[c] Quadratic regression equation of u.v.-C doses (x) on total rots (y) was $y = 62.73-62.51x+21.71x^2$, $r^2 = 0.73$; on grey mould (y) was: $y = 43.11-36.5x+12.94x^2$, $r^2 = 0.72$; on Rhizopus rot (y) $y = 47.31-43.57x+14.23x^2$, $r^2 = 0.57$.
Regression coefficients were significant at $P \leq 0.01$ for all equations.

Table 2. Effect of u.v.-C doses on the control of naturally occurring botrytis storage rot of strawberry (cv. 'Pajaro') stored at 3°C. Data of representative tests conducted over a three year period are reported.

| U.v.-C doses (kJ m^{-2}) | Disease incidence[a] | | | | | |
| | 1st year[b] | | 2nd year[c] | | 3rd year[d] | |
	Infected fruits (%)	Disease severity	Infected fruits (%)	Disease severity	Infected fruits (%)	Disease severity
0.00	86.3	6.31	83.7	5.88	84.4	7.50
0.25	72.7	5.06	60.0	4.90	63.9	5.02
0.50	55.9	4.01	39.8	3.75	41.0	4.11
1.00	43.0	4.43	45.0	4.77	53.9	4.80
2.50	54.1	5.43	56.7	5.74	68.9	6.74

[a] The percentage of infected fruits and disease severity were determined after 8 days of cold storage at 3°C (RH = 95-97%) followed by 4 days shelf life at room temperature.
[b] Quadratic regression equation of u.v.-C doses (x) on the percentage of infected fruits (y) was: $y = 67.49-39.86x+12.45x^2$, $r^2 = 0.86$; on disease severity (y) was: $y = 5.28-1.82x+0.75x^2$, $r^2 = 0.70$.
[c] Quadratic regression equation of u.v.-C doses (x) on the percentage of infected fruits (y) was: $y = 61.90-38.59x+13.44x^2$, $r^2 = 0.64$; on disease severity (y) was: $y = 5.49-2.27x+0.96x^2$, $r^2 = 0.56$.
[d] Quadratic regression equation of u.v.-C doses (x) on the percentage of infected fruits (y) was: $y = 61.60-22.20x+7.78x^2$, $r^2 = 0.92$; on disease severity (y) was: $y = 6-2.94x+1.15x^2$, $r^2 = 0.83$.
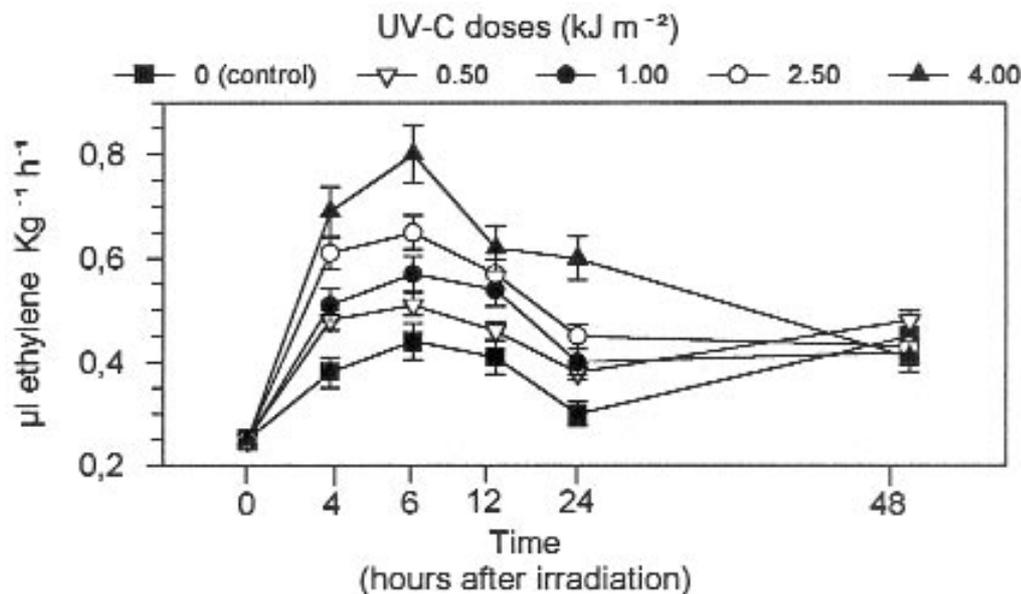Regression coefficients were significant at $P \leq 0.01$ for all equations.

Fig. 4. Variation with time of ethylene production in strawberries (cv. 'Pajaro') irradiated with different u.v.-C doses. Values represent the average of two independent experiments; bars indicate the SE ($n = 3$).

Effect of u.v.-C on ethylene production. Four and six hours after irradiation the ethylene production showed an increasing trend as the u.v.-C dose increased up to 4.00 kJ m^{-2} (Fig. 4). In a subsequent determination ethylene production progressively decreased, although remaining higher up to 24 h after irradiation in strawberries treated with 4.00 kJ m^{-2} than the other doses.

Effect of u.v.-C on PAL activity. The results of the tests aimed at evaluating variation with time of PAL activity are reported in Fig. 5A. Strawberries irradiated at 0.50 and 2.50 kJ m^{-2} showed a higher increase in PAL activity 12 h after treatment than the unirradiated control. With determinations at 24 and 48 h after irradiation, PAL activity decreased and no differences were found between u.v.-C-treated and untreated strawberries. In the second set of tests a larger range of u.v-C dose was tested and PAL was evaluated 12 h after irradiation. Doses at 0.50-1.00 and 2.50 kJ m^{-2} induced a higher PAL activity than both the unirradiated control and the dose at 0.25 kJ m^{-2}; the highest PAL activity value was found at 0.50 kJ m^{-2} (Fig. 5B).

DISCUSSION

Under the experimental conditions of the trials, u.v.-C irradiation reduced the incidence of postharvest decay of strawberries. The best doses for the reduction of decay caused by *B. cinerea*, whether artificially inoculated or naturally occurring, were relatively low (0.50-1.00 kJ m^{-2}). Total decay, including grey mould, Rhizopus rot and Mucor rot, showed a decreasing trend as doses were increased to 2.50 kJ m^{-2}. Rhizopus rot was not clearly affected by irradiation, although showing a reduction as doses were increased. Overall, the best doses resulting from the present tests were within the range of useful values reported in the literature. The doses of 0.50, 0.44 and 0.88 kJ m^{-2} were best for the control of Botrytis rot of artificially inoculated carrots and table grape berries (Mercier *et al.,* 1993; Nigro *et al.*, 1998) and for decay of pepper caused by different naturally occurring pathogens (Wilson *et al.,* 1994).

The reductions in Botrytis rot obtained in the trials involving artificial inoculation of the pathogen can be attributed to induced resistance rather than to the germicidal effects of u.v.-C irradiation, considering that the pathogen was inoculated after irradiation. Lower disease severity was constantly found in strawberries irradiated with 0.50 kJ m^{-2} than the other doses; these results could be attributed to a slower disease progression in the host tissue. The results of the trials in which *B. cinerea* was inoculated at different times after irradiation further confirm the existence of inducible resistance and show that the response of the host is gradual over time, as previously reported for u.v.-C-treated table grape berries (Nigro *et al.*, 1998). Furthermore, the significant interaction between u.v.-C dose and inoculation time, obtained in the tests conducted at 20°C, indicates that induced resistance is greatest 12 hours after irradiation with 0.50-1.00 kJ m^{-2}.
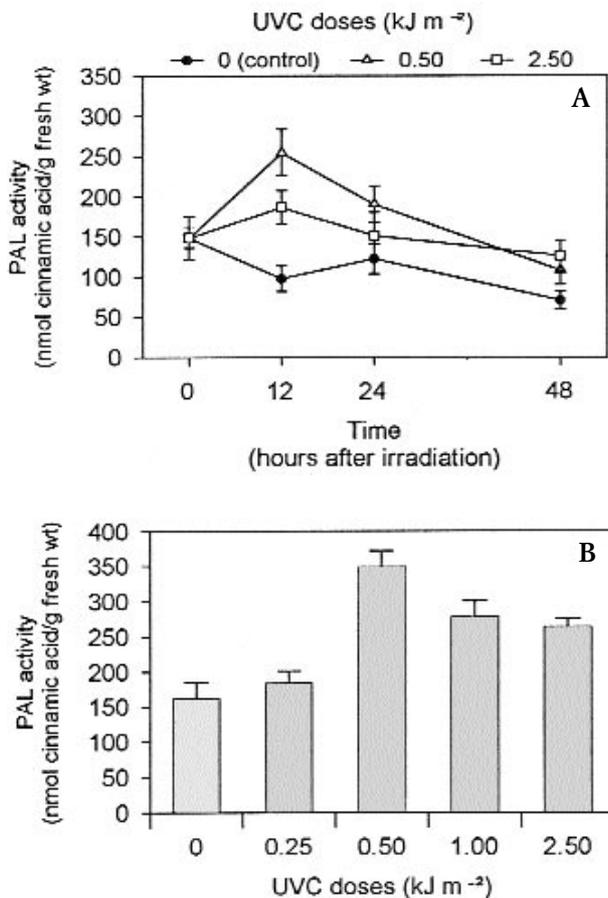
Fig. 5. Variation with time of PAL activity (**A**) and PAL activity values 12 h after the irradiation (**B**) in strawberries (cv. 'Pajaro') treated with different u.v.-C doses. Values represent the average of triplicate sampling; bars indicate the SE (*n* = 3).

There are different mechanisms by which u.v.-C can induce resistance. In fact, it is known that it stimulates the activity of phenylalanine ammonia-lyase (PAL) (Hadwiger and Schwochau, 1971; Ensminger, 1993), a key enzyme in the biosynthesis of phenolic compounds which are usually characterized by antifungal activity (Chappel and Hahlbrock, 1984). Similarly to what has been reported for other species of fruit and vegetables (Stevens *et al.*, 1990; Droby *et al.*, 1993) our results also indicate increased PAL activity in the strawberries irradiated with doses shown to be useful in the reduction of postharvest decay. In particular, the reduction of Botrytis rot incidence on strawberries inoculated with the pathogen 12 h after the irradiation at 0.50 kJ m^{-2} was associated with PAL activity value twice as high as that of the unirradiated control. Furthermore, a possible role played by phytoalexin in the observed induced resistance should not be excluded, considering that

u.v.-C irradiation is reported to be efficient in eliciting such substances in different fruit and vegetables (Fritzheimer *et al.*, 1983; Ben-Yehoshua *et al.*, 1992; Mercier *et al.*, 1993a).

Ethylene production for non-climateric fruit, such as the strawberry, was also reported; it was considered a stress response induced by wounds, temperature variation and water potential (Knee *et al.*, 1977; Couture *et al.*, 1990). Our results indicate that the increase in ethylene production is proportional to the u.v.-C dose and it is highest 6 h after irradiation at 4.00 kJ m^{-2}. Therefore, the higher the u.v.-C dose the most severe the stress. On the basis of these results it could be hypothesized that ethylene production is a measure of the stress caused by u.v.-C irradiation. Low ethylene production was also found in unirradiated strawberries and it may be caused by a stress response due to harvest, handling or temperature variations. In addition, ethylene is known to stimulate PAL synthesis in different fruit and vegetables (Hyodo and Yang, 1971; Camm and Towers, 1973; Wade *et al.*, 1993); therefore, a correlation between ethylene production and PAL increase could not be excluded, at least with the lower and the most effective u.v.-C doses that induced ethylene production before enhancing PAL activity. Our results cannot establish if enhanced PAL activity is attributable to *de novo* synthesis or induction of a pre-existing enzyme. It seems, therefore, possible to speculate that cellular PAL was triggered by increased ethylene levels produced in fruit tissues following u.v.-C irradiation (Figs 4 and 5A). The concentrations of ethylene that affect levels of PAL activity vary in different plants (Camm and Towers 1973; Jones 1984). Our experiments show that an increase in ethylene after the irradiation at 0.5 kJ m^{-2}, induces the highest PAL activity 12 h after the treatment.

The reductions in grey mould storage rot of strawberries taken from organic farms can also be attributed to induced resistance, considering that most of this decay derives from quiescent infections contracted at the flowering stage (Lima *et al.*, 1997). However, a certain germicidal effect cannot be excluded, as demonstrated by the results on total rot obtained in the trials carried out at 20°C (Table 1); from these a decreasing trend in decay can be inferred along with the increase of u.v.-C dose up to 2.50 kJ m^{-2}, the highest among those tested. Therefore, it is likely that germicidal activity mostly affected external contaminating pathogens such as *R. stolonifer* and *Mucor* spp. The low incidence of Rhizopus rot recorded on strawberries stored at 3°C did not give clear indications on the effect of u.v.-C irradiation; however, the observed decreasing trend sustain the hypothesis that the reduction is mainly due to a germicidal effect.

The regression of the u.v.-C doses versus the incidence of postharvest grey mould was quadratic, with the optimum dose being 0.50 kJ m^{-2}. These results indicate that the effect of u.v.-C irradiation tends to diminish beyond a threshold dose, as reported by others for different fruit and vegetables (Mercier *et al.,* 1993; Stevens *et al.,* 1996). In the case of strawberries, the threshold dose resulted 2.50 kJ m^{-2}; in fact, the berries treated with 4.00 kJ m^{-2} showed a higher incidence of Botrytis rot, particularly in the tests carried out at 20°C (Fig. 1). In the tests at 3°C, however, the dose of 4.00 kJ m^{-2} produced disease levels still significantly lower than in the control (Fig. 2). It is likely that at 20°C the stress induced by a dose of 4.00 kJ m^{-2} was such as to weaken the host, while at 3°C such an effect was attenuated by slowed metabolism. The results obtained, however, indicate that the response of the host to u.v.-C is influenced by storage temperature, as reported for citrus fruits (Droby *et al.,* 1993).

Damage caused by u.v.-C light was also observed in strawberry, like that reported in other fruit and vegetables (Liu *et al.,* 1993; Nigro *et al.,* 1998). Doses starting from 4.00 kJ m^{-2} caused browning of the calyx and loss of colour brightness. The phytotoxic effects of u.v.-C on plants has been known for some time; they consist of necrosis of surface tissues associated with the deposition of melanin pigments (Freytag, 1933). Dehydration of surface cell layers, as reported for several citrus species (D'Hallewin *et al.*, 1992; Ben-Yehoshua *et al.,* 1992), could be responsible for the loss of colour brightness.

The overall results from these investigations indicate that treatment with ultraviolet light at 254 nm produces a reduction in postharvest decay of strawberries. The reduction in Botrytis storage rot can be attributed to induced resistance, while a germicidal effect would seem to account for the reduction of Rhizopus rot and Mucor rot.

ACKNOWLEDGEMENTS

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