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Using an On-line UV-C Apparatus to Treat Harvested Fruit for Controlling Postharvest Decay

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ADDITIONAL INDEX WORDS. radiation, ultraviolet light, induced disease resistance

SUMMARY. An apparatus was designed to deliver low-dose UV-C light to the surface of fruit on a processing line and tested for its control of postharvest decay. It consisted of a row of UV-C emitting lamps mounted on a frame above a conveyor belt that transported the fruit. The dosage of the UV-C light delivered to the fruit surface was regulated by varying the speed of the conveyor belt. Postharvest decay after 28 days storage of 'Empire' apples was reduced 52% relative to the untreated checks when the fruit were conveyed at 6.2 m·min⁻¹ (1.38 kJ·m⁻² dose) under the UV-C apparatus. Factors affecting the practical application of UV-C irradiation of fruit for controlling postharvest decay are discussed.

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In the past we have relied heavily on synthetic fungicides for controlling postharvest decay, which causes about a 25% loss of fruits and vegetables in the United States (USDA, 1965). In developing countries these losses can exceed 50% (Coursey and Booth, 1972). Fungicide residues on harvested fruit and vegetables have been found to pose a potential health threat to the consumer, particularly children (National Research Council, 1987, 1993).

When microorganisms are exposed to UV-C light (254 nm), its energy targets the chromophore DNA. For this reason UV-C has proven to be a good germicidal or mutagenic agent. Because of their germicidal activity, UV-C lamps have been used in microbiological hoods for sterilization and in water treatment apparatuses for disinfection. It has also been discovered that UV light can elicit biological responses in plant tissue (Luckey, 1980).

In a cooperative research effort among scientists at the USDA-ARS Appalachian Fruit Research Station, Kearneysville, W.Va; Tuskegee Univ., Tuskegee, Ala.; The Volcani Center, Bet Dagan, Israel; and Laval Univ., Quebec, Canada, it has been demonstrated that low-dose UV-C light (254 nm wavelength) will elicit disease resistance in harvested fruit and vegetables and extend their shelf life (Wilson et al., 1994). Such treatments elicited resistance to rots in sweetpotatoes (Stevens et al., 1990), onions (Lu et al., 1987), peaches (Stevens et al., 1991, 1996), apples (Stevens et al., 1991, 1996), citrus (Chalutz et al., 1992; Droby et al., 1993), carrots (Mercier et al., 1993a, 1993b), and tomato (Liu et al., 1993).

It became apparent in our studies that protecting fruit and vegetables against postharvest decay by low-dose UV-C does not occur solely from its germicidal activity. First, we found that tissue inoculated after UV-treatment was more resistant to pathogen invasion (Wilson et al., 1994). Also, the UV effect was not correlated with increased UV dosage. Optimum UV-C doses for induced resistance in the

Fig. 1. (a) Fruit processing line including on-line UV-C treatment apparatus. (b) Close-up of UV-C treatment apparatus with Plexiglas covering. (c) Close-up of UV-C lamps above conveyor.

various commodities occur in a narrow range specific for each commodity. The maximum protection provided by UV treatments occurs at varying periods after the treatment and depends on the commodity. Maximum tissue resistance in peaches against *Monilinia fructicola* (Stevens et al., 1991, 1996) and in tomatoes against *Rhizopus stolonifer* was observed 48 to 72 h after treatment (Liu et al., 1993). In sweet potatoes, maximum protection against Java black rot (*Diplodia tubericola*) occurred 1-7 d after treatment (Stevens et al., 1990).

If UV-C treatment of harvested commodities is to be used commercially, a procedure must be devised to administer UV-C irradiation to harvested fruit and vegetables during pro-

cessing. Administering UV-C will require a treatment station on the processing line that can deliver a sufficient dosage of UV-C light to the fruit surface in a defined period of time. This paper describes an apparatus developed at the USDA-ARS Appalachian Fruit Station designed to irradiate fruit on line during processing. Also, results demonstrating the effectiveness of this apparatus in delivering UV-C light to the surfaces of apples are presented.

Materials and methods

THE UV-C TREATMENT APPARATUS.

Ten stainless-steel reflectors with UV-C emitting lamps (model UF-36-SR; American Ultra Violet Co.) (15.8 UV W emitting 90% quasi-monochromatic

UV radiation at 254 nm) were mounted 2 cm apart over a conveyor belt on a cast iron frame extending to the floor (Fig. 1 A and C). The legs of the frame were adjusted to position the UV-C lamps at a desirable height with the reflector edge 9.8 cm above the processing line (Fig. 2). The processing line beneath the UV-C lamps (44 cm in width) (Michigan Orchard Supply, South Haven, Mich.) consisted of rollers on a conveyor belt that rotates the fruit as it progresses (Fig. 1 A and B). The speed of the conveyor belt was adjusted by changing the speed of the motor that propelled it.

A five-sided 0.5-cm-thick Plexiglas box enclosure (101 cm wide and 126 cm long) was constructed to fit over the UV-C lamps and reflectors and treatment area. It was supported by the processing line (Fig. 1 B). Two sides of the box were 126 × 85 cm and two sides were 126 × 55 cm. This allowed the Plexiglas box to rest on the processing line and provided additional UV protection below it. The Plexiglas allowed observation of the fruit during UV-C treatment while protecting the operator from UV irradiation.

DETERMINING UV-C DOSE. UV-C light emitted by the lamps was measured 11 cm below the lamp surface with a UVX radiometer (UVP, Inc., San Gabriel, Calif.). Ten readings made randomly along the conveyor path under the UV-C lamps showed little variation (data not shown). With the conveyor speed at 2.5 m·min⁻¹, the UV lamps delivered 3.3 kJ·m⁻²; at 6.2 m·min⁻¹ 1.38 kJ·m⁻², and at 12.4 m·min⁻¹ 0.70 kJ·m⁻². Over time the intensity of the lamps will decrease, which will require bulb replacement regularly.

APPLES. Commercially mature 'Empire' apples were harvested at the Appalachian Fruit Research Station between 13 and 19 Sept. 1995 and sorted to remove any fruit with apparent injuries or infections. Selected apples were stored at 4 °C for 24 h before treatment. Following treatment, fruit were stored at 18 °C.

TREATING APPLES WITH THE UV-C APPARATUS. The UV-C lamp suspension frame was adjusted to allow 9.8 cm clearance between the edge of the

* American Ultra Violet Co. Model UF-36-SR

Fig. 2. (a) Dimensions of the UV-C lamps in relation to the conveyor. (b) Dimensions of the UV-C lamp reflectors.

reflectors and the conveyor belt (Figs. 1B and 2). Readings on the conveyor roller surface with a UV-C dosimeter showed that this distance resulted in an even distribution of UV-C radiation over the treatment area (data not shown). The apples were taken out of storage, placed on the processing line, and conveyed under the UV-C treatment apparatus at three speeds (2.5 m·min⁻¹, 6.2 m·min⁻¹, and 12.4 m·min⁻¹) by varying the rpm speed of the conveyor belt motor. For each treatment, five replications of 56 fruit were arranged in a randomized complete block and the treated fruit were stored at 18 °C. Fruit were evaluated daily for symptoms of decay over 28 d and diseased fruit were discarded at each inspection. The data were analyzed by an anova followed by Duncan's multiple range test to separate means.

Results

TREATING APPLES WITH THE UV-C APPARATUS. Each of the three doses of UV-C administered to the apples significantly reduced decay (caused primarily by *Botrytis cinerea* and *Penicillium expansum*) after 14 and 28 d of storage at 18 °C (Fig. 3). Untreated checks had 73% decay after 28 d of storage, whereas the UV-treated apples had 45%, 21%, or 30% when the fruit were exposed to 0.70, 1.38, or 3.31 kJ·m⁻² of UV-C, respectively (Fig. 3). Decay after exposure to 3.31 kJ·m⁻² of UV-C (2.5 m·min⁻¹) was significantly less than after exposure to 1.38 kJ·m⁻² (6.2 m·min⁻¹) or 0.70 kJ·m⁻² (12.4 m·min⁻¹) (Fig. 3).

No UV-C induced injury was detectable to the fruit treated at the three dosages of UV-C.

Discussion

Our studies indicate that it is feasible to treat apples on line during processing with UV-C light for controlling postharvest decay. Additional studies will be required to determine the optimum UV-C exposure required to protect 'Empire' apples from decay. Conveyors average about 16 to 24 m·min⁻¹ on commercial processing lines for apples. Adequate UV-C exposure with increased processing line speed can be accomplished by adding lamps to the UV-C apparatus.

A number of problems will have to be addressed before the practical application of UV-C light to fruit on line will be realized. The effectiveness of UV-C light for controlling postharvest decay can vary with the commodity, its maturity, and the harvest season (Droby et al., 1993). These factors will have to be evaluated when attempting to use this procedure commercially. Also, the resistance provided by UV-C treatments is temporal, reaching its maximum protective effect between 24 and 70 h after the treatment and decreasing thereafter (El Ghaouth, 1994).

Besides eliciting resistance responses in apples (Stevens et al., 1996), UV-C is germicidal. At a dose of 0.13 kJ·m⁻², UV-C is germicidal against *Penicillium expansum* (IES Lighting Handbook, 1981). The Public Health Service dose requirement for disinfection

Fig. 3. Effect of different UV doses on decay of 'Empire' apples stored at 18 °C. Apples were exposed to three UV-C doses using a UV chamber built on the processing line. Percent-age of decay was based on five replications of 56 fruit each. Columns with the same letter within the same time interval are not significantly different according to Duncan's multiple range test, $P = 0.05$.

tation is 0.16 kJ·m⁻². We did not determine the relative impact of the germicidal activity of the UV-C treatment and its elicitation of resistance. It is assumed that both played a role in the reduced decay.

Biologically based alternatives to synthetic fungicides are emerging for controlling postharvest diseases (Wilson and Wisniewski, 1995). These involve antagonistic microorganisms, natural plant- and animal-derived fungicides, and a variety of elicitors of host resistance including UV-C light. Often these biological treatments, when used alone, fall short of the level of control obtained with synthetic fungicides. We recommend that future research involve combinations of these methodologies into a multifaceted control strategy (Wilson and El Ghaouth, 1993). Our preliminary tests combining UV-treatments with antagonistic microorganisms and natural fungicides have been encouraging. In fact, certain combinations have resulted in synergistic control of postharvest decay (Wilson and El Ghaouth, 1993).

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Using Ultra-high Carbon Dioxide Levels Enhances Plantlet Growth In Vitro

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ADDITIONAL INDEX WORDS. CO₂ enrichment, sugar free medium, sucrose, photoautotrophic growth, photomixotrophic growth, heterotrophic growth, lettuce

SUMMARY. A continuous CO₂ flow system was used to study the growth of carrot (*Daucus carota* L.), citrus (*Citrus macrophylla* L.), kale (*Brassica oleracea* L.), lettuce (*Lactuca sativa* L.), radish (*Raphanus sativus* L.), and tomato (*Lycopersicon esculentum* L.) cultures in vitro under photoautotrophic, photomixotrophic, and heterotrophic conditions. Lettuce plantlets were grown on Murashige and Skoog medium with 0%, 0.3%, 1%, and 3% sucrose within flow chambers containing 350, 750, 1500, 3000, 10,000, 30,000, and 50,000 $\mu\text{L}\cdot\text{L}^{-1}$ CO₂. Increasing the levels of CO₂, especially at the ultra-high levels (i.e., $\geq 3,000 \mu\text{L}\cdot\text{L}^{-1}$ CO₂), increased fresh weight, shoot length, leaf number, leaf length, leaf width, root number, and root length for plantlets grown regardless of sucrose levels tested compared to plantlets grown at normal atmospheric CO₂ levels, i.e.,

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