Gray Mold in and Quality of Strawberry Fruit following Postharvest Heat Treatment

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Abstract. **Strawberries (*Fragaria ×ananassa* Duch. 'Tudla') were inoculated with gray mold conidia (*Botrytis cinerea* Pers.) and were subjected to postharvest heat treatment by dipping in water at various temperatures for 15 min. Heat treatment delayed *Botrytis* proliferation, but using dips at ≥48C caused fruit to soften and develop an atypical pink pigmentation. Fruit treated at 44 or 46C showed the best retention of firmness and maintained initial quality, developing neither an off-color nor an off-flavor.**

Botrytis cinerea is a ubiquitous, fungal, plant pathogen that causes economic losses in a wide range of fruit, vegetables, and ornamentals in the field and during transport and storage. Strawberry fruit are highly susceptible to its action. Control of *Botrytis* during storage can be achieved by physical and chemical methods. Increasing CO_2 concentrations and decreasing temperatures were effective in reducing the mycelial development of this fungus (Brown, 1922; Reyes and Smith, 1986). However, high CO_2 concentrations could cause an off-flavor in strawberries (Ke et al., 1994; Li and Kader, 1989). Although significantly reducing *Botrytis* growth, using low temperatures alone is not 100% effective in *Botrytis* control. Chemical methods of controlling decay also have been studied (Smith and Worthington, 1965), but there is increased concern among consumers about the potentially harmful health effects of chemical treatments (Klein and Lurie, 1991). Postharvest heat treatments are nonpolluting physical procedures for insect disinfestation and disease control in fresh horticultural products. They were used in the 1920s (Fawcett, 1922), but with the development of effective fungicides and insecticides with persistent pesticidal activity, interest in them waned. Nevertheless, with the increase in the chemical treatment restrictions, studies on applying heat treatment to fresh produce have revived. Recent contributions in this field have been summarized (Barkai-Golan and Phillips, 1991; Coates and Johnson, 1993; Couey, 1989; Klein and Lurie, 1991; Paull, 1990). Couey and Follstad (1966) effectively controlled postharvest decay of five California strawberry cultivars by heat pasteurization using moist air at 44C for 40 min, and they observed no effect on flavor or texture. Hot-water dips allow a more homogeneous heating of the product, and it has been used successfully to prevent decay in a variety of fruit species (Akamine and Arisumi, 1953; Paull and Chen, 1990; Spalding and Reeder, 1986; Teitel et al., 1989).

The start of infection in harvested strawberries appears mainly in fruit previously infected in the green stage; however, the fungi from these fruit subsequently can invade the healthy and ripe neighbors. We used a mycelial suspension of *Botrytis* applied to ripe strawberries as a model system to test the effect of postharvest hot-water treatment on *B. cinerea* growth in 'Tudla' strawberry fruit, the most frequently cultivated Spanish cultivar.

Materials and Methods

'Tudla' strawberries (*Fragaria×ananassa*) were harvested early in the morning and transported to the laboratory where undamaged fruit at the same ripening stage (80% of the skin red) was selected and distributed randomly among seven treatments of 300 fruit (≈5 kg) each. A 20-µl droplet containing 1.94×10^5 conidia of *B. cinerea*/ml water was placed on the surface of each fruit. Three 100-strawberry replicates for each treatment were inoculated. The conidia were obtained by washing mycelia from a pure culture grown on potato dextrose agar (PDA) with a 1% Triton-X100 solution. After filtering and centrifuging at 6500 *g* for 5 min, the pellet was resuspended in water. The conidia were counted using a Bürker camera (Superior Gmbh, Bad-Mergentheim, Germany), and the final concentration was adjusted by dilution. One hour after the inoculation, six of the seven groups of inoculated strawberries were submerged for 15 min at 40, 42, 44, 46, 48, and 50C in thermostatically controlled water baths for heat treatments. Afterwards, the fruit were dried, using a dry air stream at 50C for 5 min, and were placed in a room at 18C. Using an air stream for drying the fruit after the hot-water dip only affected the internal temperature of the fruit slightly because the energy supplied was used to evaporate the water located on the fruit's surface. The seventh group was placed directly in the 18C room without heat treatment. At the same time, further control was provided by another seven groups with the same number of noninoculated strawberries, which were subjected to the same treatments. The experiment was performed in two consecutive seasons under the same conditions.

The number of fruit in the various treatments with visible mycelial growth of *Botrytis* was monitored daily for 4 days. Ten noninoculated healthy fruit were taken at random from

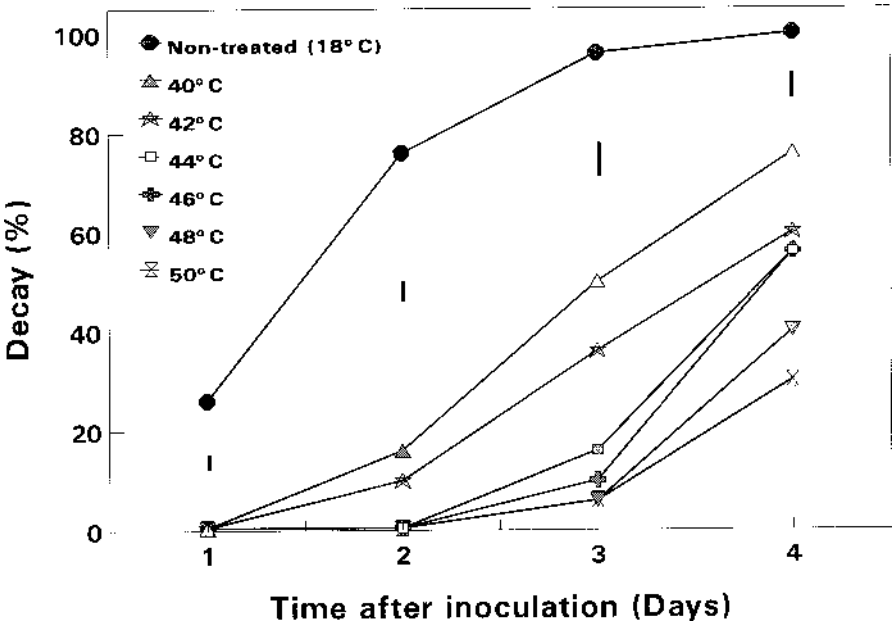

Fig. 1. Decay in strawberry fruit inoculated with *Botrytis cinerea* conidia and later treated with 15-min water dips at various temperatures. Vertical bar represents least significant difference at $P \leq 0.05$.

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each treatment daily for measuring fruit firmness using a densimeter (model 3300; Zwick Gmbh & Co., Ulm, Germany) with a 5-mm disk. (The force required to depress the disk 2.4 mm into the fruit was determined. Data are expressed in newton per square centimeter of probe surface). Samples of 24 noninoculated healthy fruit were taken daily at the same hour from each treatment and were tested organoleptically in a sun-illuminated room by an analytical panel of 12 tasters using the simplified procedure of multiple comparisons (Mahoney et al., 1957). Nonheated fruit were used as a reference sample. The possible occurrence of off-flavors or off-colors as a consequence of heat treatment was especially examined.

Analysis of variance was performed on all the data. Least significant difference at $P \leq 0.05$ was used to establish differences among the means obtained in the treatments.

Results and Discussion

For inoculated fruit, the extent of fungal growth was inversely related to the temperature used in the heat treatment (Fig. 1). Thus, fruit treated at 50C needed 4 days to achieve the same percentage of mycelial development as the nontreated fruit on the first day after inoculation. The fruit treated at 40 and 42C were intermediate in behavior with significantly less mycelial development than nontreated fruit but more than the other heat-treated fruit. Three days after inoculation, there was no statistically significant difference in mycelial growth between fruit treated at 44 or 46C and between fruit treated at 48 or 50C. Four days after inoculation, decay of 48 and 50C fruit was significantly ($P \leq 0.05$) less than in fruit from all other treatments. As was the case with low temperature and high CO_2 concentrations (Agar et al., 1990), hot-water dips significantly delayed gray mold development but did not prevent it.

Heat treatments also were effective in controlling postharvest decay in the noninoculated fruit (Fig. 2). After 3 days at 18C, >15% of the nontreated fruit had decayed, while <5% of the heated fruit showed decay. Treatments at 40 and 48C were less effective after 4 days at 18C. However, berries treated at 44C had a lower, but not statistically significant, incidence of decay at 4 days than the other berries. These data agree with the decay control obtained by Couey and Follstad (1966) using moist air at the same temperature.

Treatments at 48 or 50C injured fruit quality. Strawberry fruit treated at these temperatures showed a significantly greater loss of fruit firmness than fruit subjected to other treatments (Fig. 3). This softening was accompanied by the development of an atypical pink pigmentation on the fruit (data not shown) like that of boiled strawberries, which made the fruit unmarketable. Fruit treated at 44 or 46C retained firmness best, maintaining ≈90% of the initial value even 4 days after heat treatment. Nontreated fruit and fruit heated at 40 and 42C showed an intermediate behavior, losing a mean of 25% of the initial value of

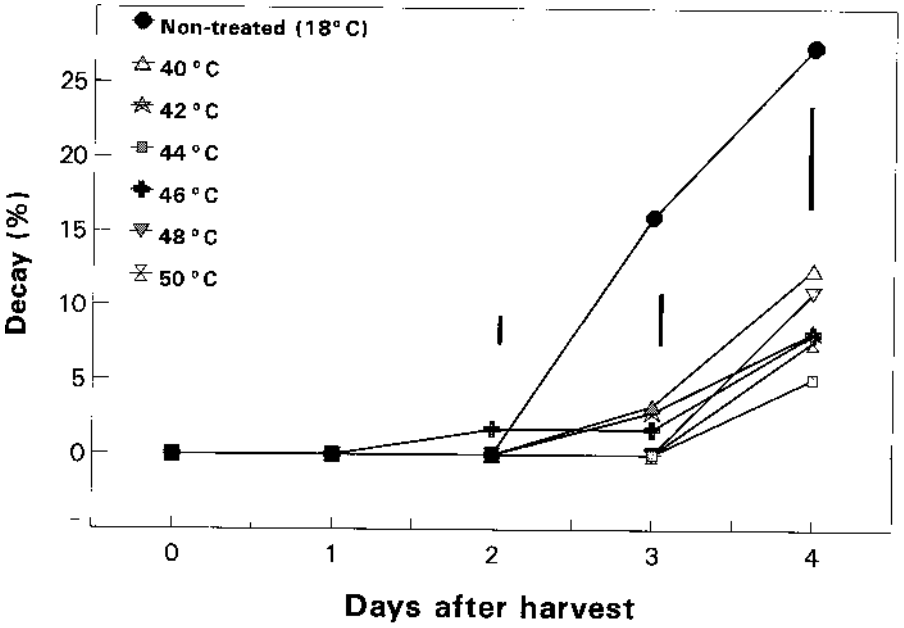

Fig. 2. Decay in noninoculated strawberry fruit treated with 15-min water dips at various temperatures. Vertical bar represents least significant difference at $P \leq 0.05$.

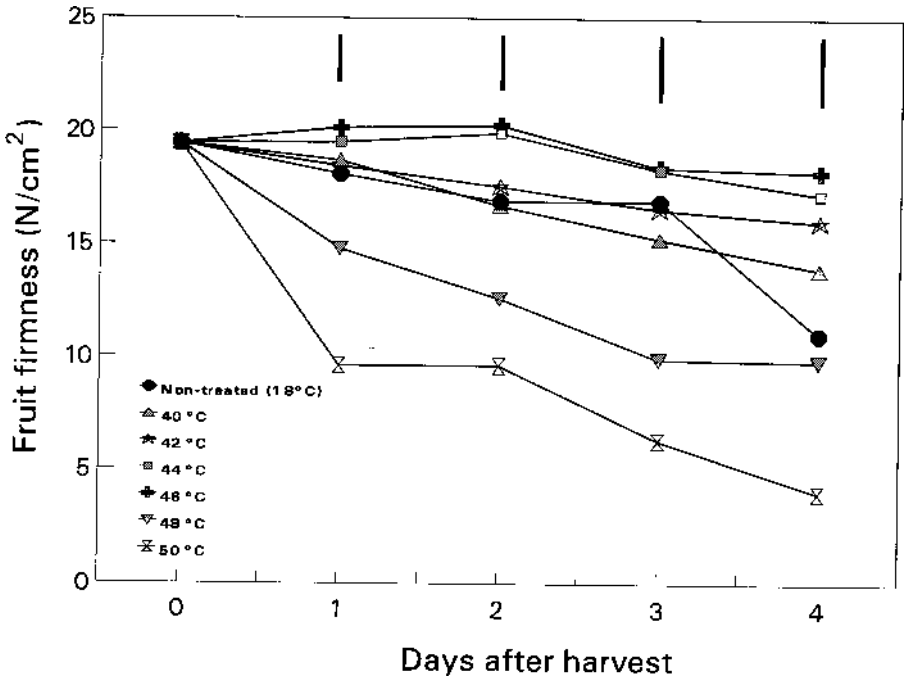

Fig. 3. Decrease in firmness (newtons per square centimeter) of strawberry fruit treated with 15-min water dips at various temperatures. Vertical bar represents least significant difference at $P \leq 0.05$.

fruit firmness. Biggs et al. (1988), Eaks (1978), and Klein and Lurie (1991) found firmness to be retained after heating of various fruit.

Sensory analysis did not find any negative effect of heat treatments at <48C on fruit quality. These fruit maintained their initial quality for 4 days after heat treatment, developing neither the atypical pink nor an off-flavor. The appearance and the softening of fruit treated at ≥48C gave them a repulsive flavor, and they were rejected.

Immersion in water at 44 or 46C allowed the best control of *Botrytis* development without affecting sensory quality of fruit. Heat treatments could be especially suitable in practice for strawberries with a foreseeable high postharvest decay, such as fruit harvested after rain. Studies on the compatibility of these heat treatments with storage at low temperature and high CO_2 are needed.

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