# Use of Heat Treatments to Control Postharvest Pathogens on Tomatoes and Melons

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There is an increasing interest and need to evaluate potential alternatives to postharvest fungicide treatments. This interest exists for both the organic and conventional markets, and for both the domestic and international markets. Melons and tomatoes are the two major-volume fresh-market vegetables in California that receive postharvest chemical treatments in packinghouse situations. They are both currently treated with the fungicide SOPP in wax in conventional postharvest handling.

The use of heat is an especially attractive alternative for decay control, since such treatments can control pathogens on and below the surface of the product, providing potentially greater decay control than contact sanitizers and fungicides. Other potential benefits of the use of short-term heat treatments include (1) modifying ripening and storage behavior by reducing the activity of certain enzymes associated with deterioration; (2) possible applicability as a quarantine treatment; and (3) providing a clean, economical, relatively easy-to-apply treatment that is compatible with current postharvest handling, regardless of the scale of operation.

The efficacy of hot-water and, more recently, hot forced-air treatments to control postharvest pathogens and insects has been demonstrated by several researchers on a range of horticultural products, including mango, pear, cantaloupe, tamarillo, papaya, peach, and sweet potato, among others (see reference list).

The objective of this work was to evaluate a range of hot-water and forced-air time-and-temperature regimes on decay control efficacy, fruit quality, and commercial potential for postharvest handling of melons and tomatoes.

## METHODOLOGY

Tomato fruits (mature-green and vine-ripe) and cantaloupe melons (commercial maturity) were inoculated with spore suspensions of different fungi (usually *Botrytis* for tomatoes and *Fusarium* for melons), using 100 nongerminated spores per 10 µl per wound. Since fungal spores are more difficult to kill with heat than germinated spores, fruits were all treated within a few hours of inoculation before germination occurred. Fruits were subjected to a range of hot-water (circulating hot-water bath) and nonhumidified forced hot air treatments (drying cabinets for plant materials).

For melons, hot-water regimes of 40° to 70°C (104° to 158°F) for from less than 1 minute to 90 minutes immersion, and forced-air treatments of 40° to 65°C (104° to 150°F) for 1 to 12 hours were tested. For tomatoes, hot-water treatments from 40° to 65°C for less than 1 minute to 30 minutes, and forced-air treatments of 40° to 65°C (104° to 150°F) for periods of 0.5 to 16 hours were tested. After treatment, fruits were cooled by air to the temperature of storage or ripening. Tomatoes were routinely evaluated at 15° or 20°C and melons were placed in polyethylene bags at 7.5° or 10°C (45° or 50°F), both conditions designed to favor pathogen development.

Fruits were evaluated periodically for decay development (incidence and severity of decayed area), and results were expressed by a rating scale (1 = no decay, 2 = slight, 3 = moderate, 4 = moderately severe, and 5 = severe decay [about 30% of fruit surface with decay]) or as a relative decay percentage (decay of inoculated and treated fruits as a percentage of the decay development of inoculated nontreated fruits). Quality measurements on heat-treated tomatoes included firmness (mm compression by a 500 g weight), color (L, a, b values using a portable color difference meter and visual scoring of color development), composition (percentage soluble solids, pH, and percentage titratable acidity), and sensory testing (difference tests). Melons were evaluted for fruit firmness, weight loss, and soluble solids content. The effect of selected heat treatments on the ripening physiology (respiration and ethylene production rates) of tomato and melon fruits was also evaluated.

## RESULTS

### Heat treatment regimes that are visibly noninjurious to tomato and cantaloupe fruits

Treatment regimes must not only be effective for pathogen control, but must also be nondamaging to the product. Figure 1 summarizes the tolerance limits of time and temperature for heat treatments of tomatoes and cantaloupes. For hot-water, temperature and time must be precisely controlled to avoid injury. Hot-water is a relatively rapid treatment, and more study is needed to evaluate higher temperatures for shorter periods of time so that this treatment could be of greater commercial interest. Although hot forced-air treatments require longer periods for effective treatment, these treatments also require more time for injury to occur to the fruits. Symptoms of heat injury on tomato fruits included blistering of the skin and irregular color development during ripening. If the heat treatment is too severe on cantaloupe, the fruit surface below the net becomes brown and discolored.

## Hot-water treatment of different varieties of tomato fruits

Several time-and-temperature regimes of hot-water were found effective in controlling *Botrytis* on tomato fruit of different cultivars (table 1). From the many different regimes tested, the three most effective regimes were 53°C for 7 to 10 minutes, 55°C for 5 to 7 minutes, and 58°C for 2.5 to 3 minutes. There may be some variation in heat damage to different cultivars, although none of the fruits of the cultivars listed in table 1 were damaged under the heat treatment regimes reported here. Efficacy of the hot-water treatments was similar among the cultivars tested.

## Use of hot-water to control fungi other than *Botrytis* on tomatoes

Conditions that favor the killing of *Botrytis* spores also permit control of other common postharvest fungi (table 2). It is important to note that *Rhizopus* was quite effectively controlled, although *in vitro* results showed that it was more heat tolerant than *Botrytis*. Inoculation of fruits with a mixed fungal culture resulted in decay control comparable to that achieved with *Botrytis cinerea* inoculation alone.

## Quality of hot-water-treated tomato fruits

Tables 3 and 4 show typical results for firmness and compositional evaluations of tomatoes treated with effective decay-controlling hot-water regimes. Shorter time treatments usually had no significant effect on firmness, composition, or sensory quality. Longer-term treatments sometimes decreased fruit firmness if fruit was treated when ripening. After some heat treatments, color development was accelerated. Further evaluation of the quality of heat-treated tomatoes is needed (volatile profiles and more results from sensory evalua-

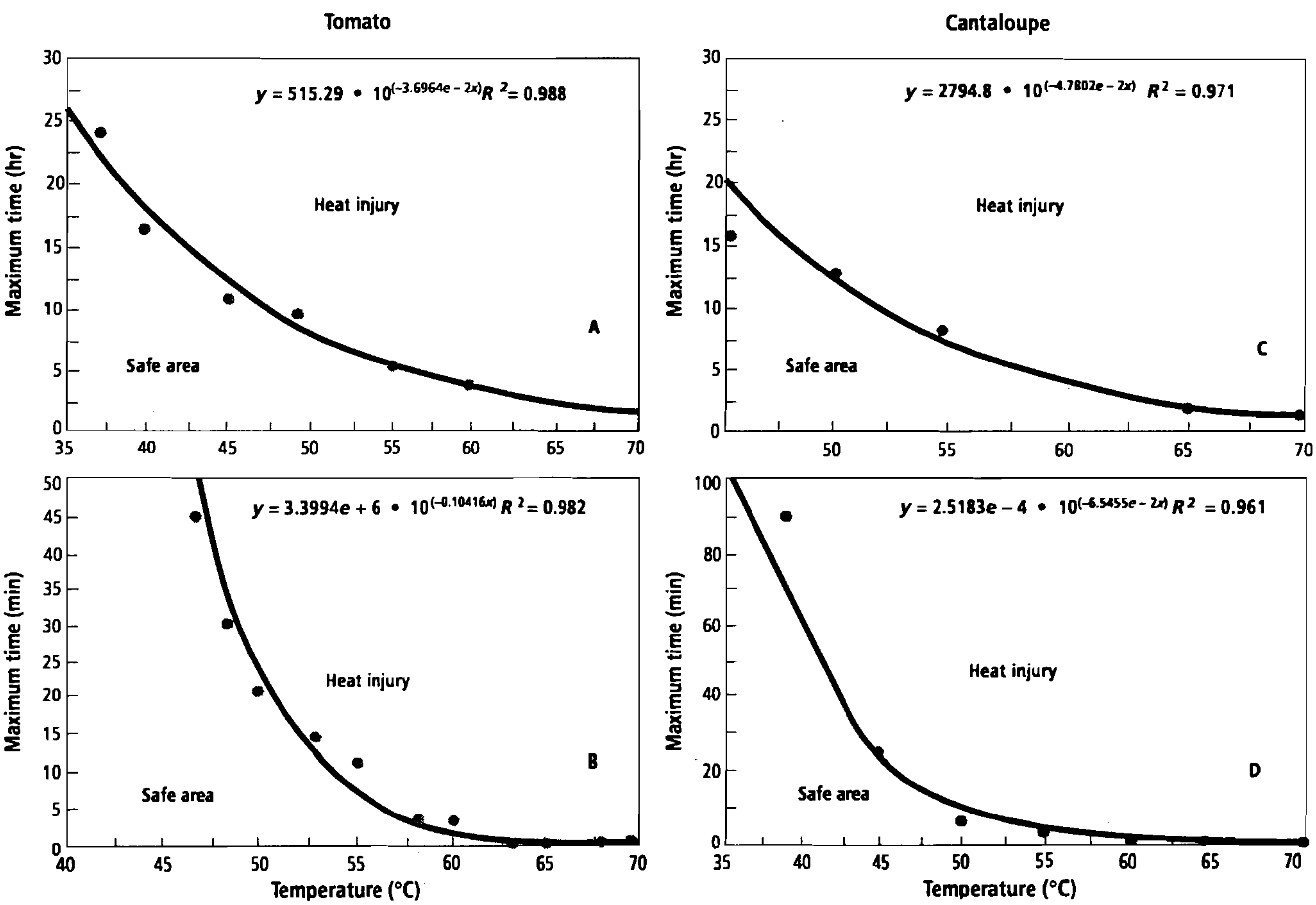



**Figure 1. The "safe area" for heat treatment of tomatoes (A: hot air; B: hot water) and cantaloupes (C: hot air; D: hot water). The time-and-temperature parameters of any point within the safe area can be used for heat treatment without causing visible damage to the fruit surface**

Table 1. Decay development on tomato fruits of 12 cultivars (fruits were treated with one of three hot-water regimes within 10 hours of inoculation with *Botrytis cinerea*, then ethylene-treated and held at 20°C to ripen)

| Variables | Decay score after storage at 20°C* | | | | | |
|---|---|---|---|---|---|---|
| | 3 days | 6 days | 9 days | 12 days | 15 days | 18 days |
| Cultivars | | | | | | |
| XPH5621 | 1.00† | 1.23b | 1.51d | 1.71c | 1.99d | 2.18d |
| XPH5741 | 1.00a | 1.07a | 1.34bcd | 1.53bc | 1.64bcd | 1.76bc |
| XPH5752 | 1.00a | 1.08a | 1.24abc | 1.37abc | 1.54abcd | 1.80bc |
| UC5 | 1.00a | 1.00a | 1.00a | 1.04a | 1.08a | 1.12a |
| Keno | 1.00a | 1.03a | 1.09ab | 1.23ab | 1.25ab | 1.30ab |
| UCN 28 | 1.00a | 1.08a | 1.38cd | 1.71c | 1.77cd | 1.88bc |
| Sweepstakes | 1.00a | 1.03a | 1.19abc | 1.43bc | 1.54abcd | 2.06d |
| Celebrity | 1.00a | 1.01a | 1.13abc | 1.28ab | 1.35abc | 1.50abc |
| Olympic | 1.00a | 1.00a | 1.15abc | 1.61bc | 1.78cd | 1.93cd |
| Merced | 1.00a | 1.09a | 1.33bcd | 1.56bc | 1.89d | 2.01d |
| Jackpot | 1.00a | 1.06a | 1.21abc | 1.42bc | 1.57abcd | 1.67abc |
| Royal Flush | 1.00a | 1.07a | 1.37cd | 1.70c | 1.99d | 2.08d |
| Treatments | | | | | | |
| Untreated | 2.95b‡ | 4.97c | 5.00d | 5.00d | 5.00d | 5.00c |
| 53°C/7 min | 1.00a | 1.02a | 1.10a | 1.24a | 1.35a | 1.74a |
| 55°C/5 min | 1.00a | 1.08b | 1.23b | 1.45b | 1.61b | 1.17a |
| 58°C/2.5 min | 1.00a | 1.09b | 1.40c | 1.70c | 1.88c | 2.01b |

*Decay score: 1 = No decay; 2 = Slight; 3 = Moderate; 4 = Moderately severe; 5 = Severe decay. Severe indicates approximately one-third of fruit surface shows decay.

†Each value is the average of the three hot-water treatments, based on 4 replications, 10 fruits per replication. Mean separation in a column by LSD at 5% level.

‡Each value is the average of results from the 12 cultivars tested. Mean separation by LSD at 5% level.

tion tests), although results to date indicate that firmness is one of the fruit quality parameters most sensitive to heat treatment. Therefore, if heat treatments are screened for their lack of impact on fruit firmness, it is probable that effects on other quality parameters would also be minimal.

## Heat treatment of cantaloupe melons

As with tomato fruits, several forced hot air and hot-water treatment regimes were found effective in controlling decay on melon fruits. Stem-end decay (due to inoculation with *Fusarium*) was evaluated separately (table 5) from surface decay (table 6), which was due mostly to naturally occurring *Rhizopus*. For melons, it appears that longer-duration treatments were more effective than the short-term treatments. Such long-term treatment regimes are commercially impractical, and improvement in the efficacy of the high-temperature, short-term regimes needs to be investigated.

## Quality and ripening physiology of heat-treated melon fruits

Melon quality was generally less affected by heat treatment than tomato quality. There were no significant differences in melon firmness or soluble solids content among control and fruits treated under the regimes described in tables 5 and 6. Figure 2 illustrates the effect of heat treatments on the physiology of the fruit when stored before and after heat treatment at 7.5°C (45°F). The heat-treated fruits showed temporary increases in respiration and ethylene production rates. Longer-duration treatments generally had more effect on physiology, firmness, and other quality attributes (flavor) than the shorter-duration treatments. One day after heat treatment, all melon fruits had returned to normal rates of respiration and ethylene production (fig. 2).

## Future work

We are expanding the range of time-and-temperature regimes for hot-water and forced-air treatment of melons and tomatoes to include conditions that will be more practical for incorporation into current commercial postharvest operations (i.e., shorter treatment periods). Further documentation of the effects of the heat treatments on quality, physiology, and sensory properties of the fruits needs to be compiled. Preliminary tests have shown the efficacy of heat treatments to control *Rhizopus* on sweet potatoes and *Botrytis* on onions. Heat

Table 2. Decay development on tomato fruits (cv. Castlemart) after inoculation with one of seven fungi at mature-green stage (fruits were heat-treated, and then ethylene-treated and ripened at 20°C)

| Variable | Decay score after storage at 20°C* 3 days | 6 days | 9 days | 12 days |
|---|---|---|---|---|
| Fungus | | | | |
| *Botrytis cinerea* | 1.14c† | 1.54c | 2.18c | 2.53b |
| *Rhizopus stolonifer* | 1.00a | 1.04a | 2.04bc | 2.04b |
| *Fusarium solani* | 1.10bc | 1.22b | 1.40b | 2.09b |
| *Fusarium roseum* | 1.07b | 1.18b | 1.60b | 1.78ab |
| *Alternaria solani* | 1.00a | 1.00a | 1.31b | 1.41ab |
| *Alternaria alternata* | 1.00a | 1.00a | 1.31b | 1.41ab |
| *Geotrichum candidum* | 1.01a | 1.20b | 2.29c | 2.33b |
| Treatment | | | | |
| Untreated | 2.30c‡ | 2.99c | 3.61c | 3.87b |
| 58°C/3 min | 1.14b | 1.49b | 2.10b | 2.41a |
| 55°C/7 min | 1.00a | 1.17a | 1.53a | 1.62a |
| 53°C/10 min | 1.00a | 1.22a | 1.45a | 2.21a |

*Decay score: 1 = No decay; 2 = Slight; 3 = Moderate; 4 = Moderately severe; 5 = Severe decay. Severe indicates approximately one-third of fruit surface shows decay.
†Each value is the average of the three hot-water treatments, based on 4 replications, 10 fruits per replication. Mean separation in a column by LSD at 5% level.
‡Each value is the average from results of fruits with one of seven fungi.

Table 3. Effect of hot-water treatment at the mature-green stage on the firmness at the table-ripe stage (fruits were ethylene-treated and ripened at 20°C)

| Variable | Deformation (mm) Table-ripe | Table-ripe + 8 days |
|---|---|---|
| Treatment | | |
| Untreated | 0.97a* | 1.26a |
| 53°C/8 min | 1.09b | 1.39b |
| 58°C/2.5 min | 1.02a | 1.29a |
| Cultivar | | |
| EX-18 | 1.28c | 1.65c |
| L-19 | 1.06b | 1.36b |
| L-31 | 0.76a | 0.99a |

*Mean separation within a column for a given variable by LSD at 5% level.

Table 4. The composition and firmness of ripe tomatoes (cv. Castlemart) after hot-water treatment at the mature-green stage (fruits were ethylene-treated and ripened at 15°C)

| | Composition | | | Firmness (mm deformation) | |
|---|---|---|---|---|---|
| Treatment | % SS | pH | %Titratable acidity | Table-ripe | Table-ripe + 8 days |
| Untreated | 3.97a* | 4.26a | 0.357a | 1.79b | 2.13a |
| 53°C/8 min | 4.02a | 4.32b | 0.314a | 1.63ab | 2.09a |
| 58°C/2.5 min | 4.36a | 4.33b | 0.331a | 1.52a | 1.93a |

*Mean separation within a column by LSD at 5% level.

Table 5. Decay development on the stem end of cantaloupe melons after hot-water treatment of *Fusarium*-inoculated fruits and storage in polybags at 10°C

| | % Relative decay after storage at 10°C* | | |
|---|---|---|---|
| Treatment | 12 days | 15 days | 18 days |
| 40°C/90 min | 0.00a† | 0.00b | 17.00b |
| 45°C/30 min | 0.00a | 0.00b | 20.00b |
| 50°C/10 min | 0.00a | 11.67a | 40.00a |
| 55°C/ 5 min | 0.00a | 9.17ab | 21.33b |
| 60°C/ 3 min | 2.67a | 10.00a | 30.67ab |

* % Relative decay = percentage decay on treated fruits ÷ percentage decay on control fruits × 100.

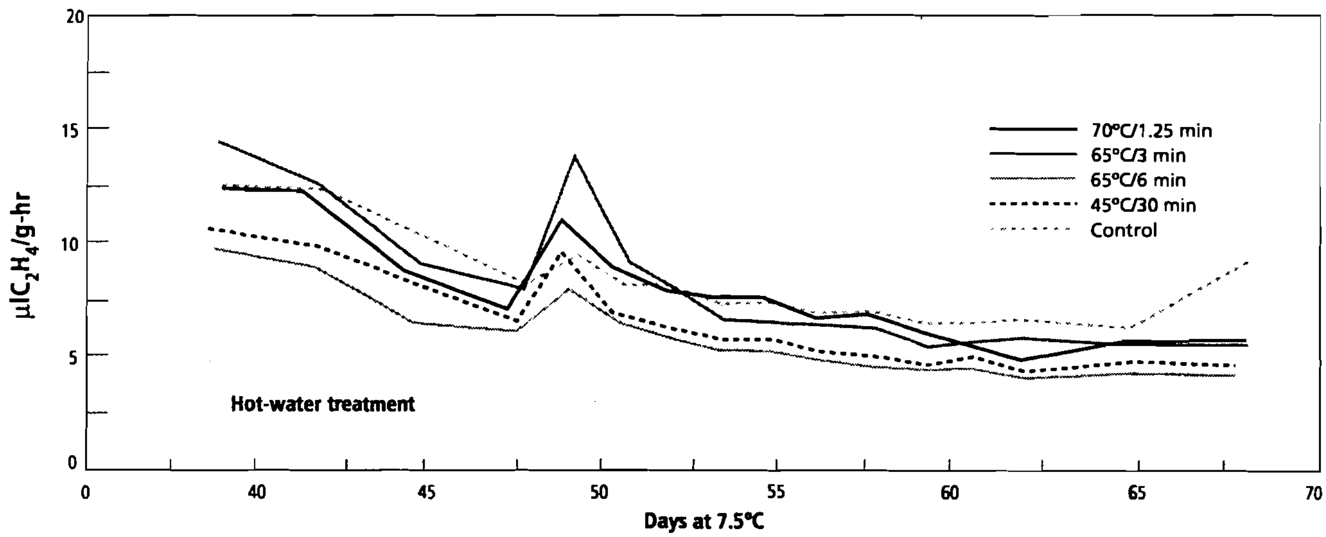
† Each value is based on 6 replications, 5 fruits per replication. Mean separation within a column by LSD at 5% level.

Table 6. Development of surface mold on cantaloupe fruit after hot-water treatment and storage in polybags at 10°C

| | % Relative decay* | | |
|---|---|---|---|
| Treatment | 12 days | 15 days | 18 days |
| 40°C/90 min | 0.00a† | 0.00c | 2.00b |
| 45°C/30 mi | 0.00a | 0.00c | 2.50b |
| 50°C/10 min. | 0.00a | 9.00abc | 10.00b |
| 55°C/5 min | 0.00a | 3.00bc | 8.75b |
| 60°C/3 min | 2.00a | 6.75abc | 12.50b |
| 65°C/2 min | 3.75a | 11.00ab | 35.25a |
| 70°C/1 min | 0.00a | 13.00b | 45.75a |

* % Relative decay = percentage decay on treated fruits ÷ percentage decay on control fruits × 100.

† Each value is based on 6 replications, 5 fruits per replication. Mean separation within a column by Duncan's Multiple Range Test at 5% level.



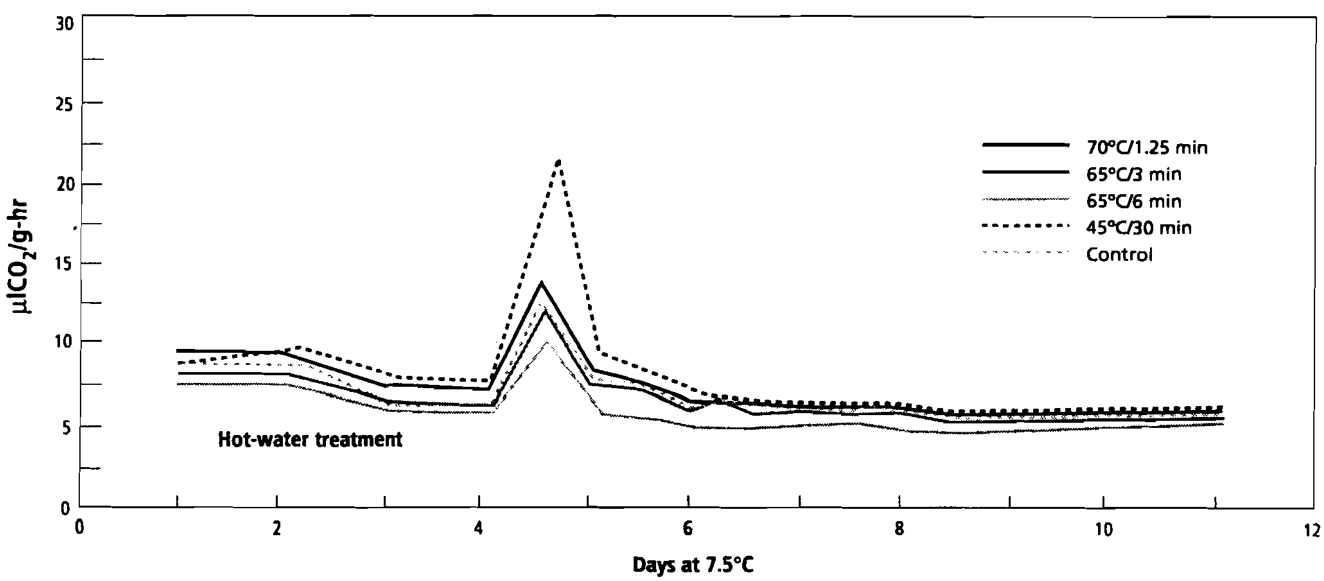




**Figure 2. Respiration and ethylene production rates**

treatment of sweet potatoes will be pursued, since it is a viable alternative treatment with potential to be easily incorporated into current handling operations, and because of the imminent loss of registration for the postharvest fungicide Botran.

## SUMMARY

We have studied the efficacy of a range of heat treatment conditions on fresh-market tomatoes and cantaloupe melons as alternatives to application of postharvest fungicides. Tomatoes (mature-green and vine-ripe) were inoculated with nongerminated spores of several fungi, although *Botrytis* was the most commonly used organism. Cantaloupes were inoculated on the stem end with *Fusarium*, and surface decay due to natural *Rhizopus* contamination was also evaluated. Several hot air and hot-water treatment regimes provided effective pathogen control for both fruits without causing visible fruit injury. Only a few treatment regimes, however, resulted in fruit equal in quality to untreated fruit. Generally, the higher the temperature and the shorter the duration of the heat treatment, the less was the impact on fruit quality.

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