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Combined High Temperature and Ultraviolet Radiation Injury of Red Raspberry Fruit

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Abstract. **A disorder of red raspberry (*Rubus idaeus* L.) in an area exposed to high temperature and solar radiation has been identified as a form of solar injury. Specific fruit maturity stages were defined and susceptibility to injury was found to rapidly increase as fruit matured from the "green" to the "white" to the "pink" stage. Appreciable injury (more than two unpigmented drupelets per fruit) only occurred at 42C and higher with 4 or more hours of UV radiation at the fluence level used. While the injury at 42C was proportional to UV exposure, the radiation environment in the laboratory was not designed to simulate solar radiation. Therefore, no quantitative function relating injury to fruit temperature and UV radiation is presented. The results indicated that attenuating UV absorption alone, without lowering temperature, is likely to protect raspberries in the field.**

Red raspberry fruit are prone to a disorder that has been identified as a form of solar injury. The condition, observed most often in areas with high temperature and solar radiation, is characterized by drupelets that enlarge but fail to turn red. Symptoms are greatly reduced by artificial shading (Renquist et al., 1987). The economic impact of the disorder for growers is due to added labor costs for sorting fruit and to cullage rates as high as 40%. Damaged fruit is usable for processing, but its value is considerably less than that of fresh fruit.

Sunscald, a term that has been applied to all types of solar injury to plants, includes both heat injury and ultraviolet radiation damage (Barber and Sharpe, 1971). In most cases, there is tissue browning or desiccation. This symptom does not occur in this raspberry disorder. The apparent blockage of pigment synthesis may be a type of photodynamic sunscald (Barber and Sharpe, 1971; Teramura, 1983), which includes chemical lesions. It may also have similarities to photobleaching, the loss of chlorophyll following UV stress (Smillie and Hetherington, 1983). The involvement of UV radiation in solar injury has been implicated in other instances by use of UV-B- (280–315 nm) attenuating filters (Kossuth and Biggs, 1978; Lipton, 1977).

Earlier work indicated that raspberry solar injury could be reduced more by shading with a white polyester row cover than by increasing air movement with fans, even though fans reduced fruit surface temperature as much or more than such shading (Renquist et al., 1987). The present study, therefore, characterized the effects of high temperature and UV radiation on raspberry fruit under laboratory conditions, permitting the two factors to be controlled independently.

Fruit samples were collected from an untrellised planting of 'Heritage' primocane-fruiting raspberry, grown using standard practices. Samples were collected from trusses in full sun. Although samples differed in their angle of exposure to the sun, this proved not to be a critical selection factor in terms of response to treatments in the laboratory. Visual and numerical criteria were established for three categories of fruit maturity: 1) "green"—low surface reflection of light, 16 to 22 drupelets per cm^2; 2) "white"—high surface reflection (glossy), 12 to 16 drupelets per cm^2; and 3) "pink"—some drupelets being light red, eight to 14 drupelets per cm^2. The drupelet count was determined with a template with a circular opening of 0.5 cm^2. Unless otherwise stated, fruit of the white stage of maturity were selected for use in experiments.

Fruit were collected and placed in a closed plastic container without water. If held for more than 1 hr after field collection, they were refrigerated. Experiments were always begun within 4 hr of collection, a holding period that was found to have no impact on treatment response.

The experimental procedure included selecting fruit of uniform maturity within each category and trimming the petioles such that the length of fruit plus petiole was equal to the height of sample cups (2.5 cm). A positioning device was used to keep fruit upright, out of contact with the sides of the cup. The cut petiole, but not the fruit, was in contact with 1.0 ml of distilled water. The cups were translucent size 4 Nalgene hollow stoppers, placed on a wooden tray in a randomized complete block (RCB) design with 10 replications. Each block had up to four cups in a row, perpendicular to the UV bulb, and closely enough spaced to minimize variation in distance between the fruit surface and the bulb. This distance ranged from 5 to 7 cm. None of the blocks were positioned within 7 cm of either end of the bulb, where radiant flux density could have deviated from normal. The controlled temperature chamber was a GE Precision Scientific 805, with air circulation. The inside chamber dimensions were 50 × 60 × 120 cm high.

A single 61-cm-long Westinghouse FS 20 sunlamp was suspended diagonally 50 cm from the bottom of the chamber. Spectra have been published for the sunlamp FS 40 (Sisson and Caldwell, 1975), which differs from the FS 20 in length only. The bulb was used in a fixture without a reflecting surface. Even though a single bulb was used, rather than a bank of FS 40 bulbs as in other studies (Kos-

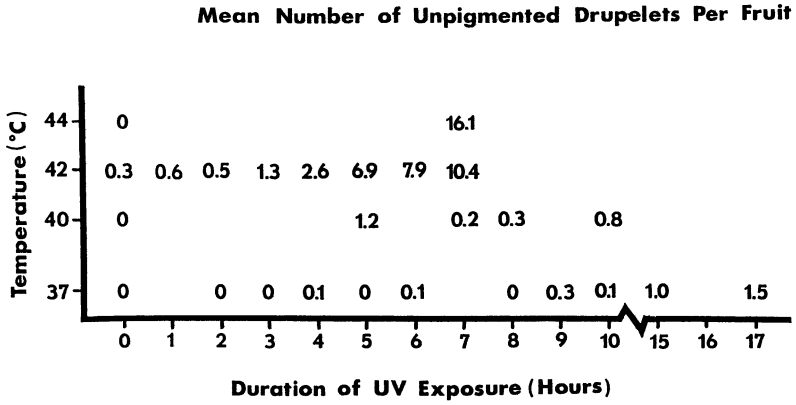

Fig. 1. Extent of raspberry fruit injury [unpigmented (i.e., white) drupelets per fruit] in response to increasing temperature and exposure to ultraviolet radiation. Values are the average of one to four means at each temperature–UV combination. The duration of temperature exposure was 7 hr for all UV treatments of ≤7 hr, and equal to UV exposure for durations >7 hr.

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Table 1. Effect of stage of maturity or UV filters on incidence of white drupelets (solar injury) on red raspberry fruit exposed at 42C to UV radiation.

Variable	No. white drupelets per fruit
Maturity stage[z, y]	
Green	0.2 a
White	8.6 b
Pink	25.8 c
Filter[x, w]	
None	12.6 c
Cellulose acetate	4.2 bc
Mylar	0.8 ab
Aluminum foil	0.2 a

[z]Exposed for 7 hr.
[y]Mean separation between each pair of treatments by Friedman test; means differ significantly at $P = 0.01$.
[x]White stage of maturity exposed 6 hr.
[w]Mean separation by Wilcoxin signed rank test, $P = 0.05$.

suth and Biggs, 1978), the several-fold shorter distance from bulb to plant sample created the likelihood that UV fluence was at least equal to that previously reported. The bulb was unfiltered in most experiments, which increases the short wave UV-B radiation plus allows the highly actinic UV-C (absent in solar radiation at the earth's surface) to be present at relatively low fluence levels down to 270 nm (Teramura, 1983). When a weighting function is included to correct for biological activity, unfiltered sunlamps are estimated to create a several-fold enhancement of UV over that in the field (Teramura, 1983). No photosynthetic radiation was provided during tests, since the occurrence of photorepair of UV-induced injury would, like filters, probably ameliorate injury response. The objective of this study was to simulate the visual field injury to fruit (but not the field environment) using a simple and convenient system to provide the UV radiation factor.

Fruit surface temperature was usually <0.5C warmer than chamber air temperature since the radiant energy of the UV bulb was fairly low. Temperature was measured with 24-gauge thermocouples and recorded using an Omnidata Polycorder datalogger.

Treatments compared in Expt. 1 were the three fruit maturity categories. All were exposed to UV for 7 hr at 42C. In all experiments, the chamber was preheated and the fruit were left in the cups and given a standard posttreatment incubation to allow complete color development. This condition consisted of a minimum of 48 hr at 20C and very high relative humidity in a polyethylene film-covered tray 40 cm from two 40-W fluorescent bulbs (>50 $\mu mol \cdot s^{-1} \cdot m^{-2}$). Light characteristics did not prove to be critical for color development. The response variable in all tests was the number of drupelets per fruit that failed to turn red and were opaque white, similar to those in the field. Colorless translucent drupelets or dull gray drupelets were occasionally noted. Such drupelets were not counted since they were unlike the solar injury observed in the field. Mean separation among the three fruit maturity treatments of Expt. 1 was by Friedman test (Conover, 1971).

Experiment 2 included a series of tests to characterize response to UV duration at three temperatures. Since distance from bulb to fruit was never altered, a given duration of UV exposure also represented a certain cumulative UV fluence (radiant flux incident on a given area). Each test included five treatments, four placed under the UV bulb as in Expt. 1, and one that had no UV exposure (cups placed in an aluminum foil-shaded tray beneath the chamber shelf used for the UV treatments). At prescribed lapse times between 1 and 18 hr, the 10 replicates of a given treatment were moved to the shaded tray. All treatments within each test received the same duration of high temperature exposure, but different durations of UV.

Experiment 3, at 42C, compared raspberry response in open cups to that in individually foil-shaded cups or with attenuating filters over individual cups. The filters were Mylar, which blocks most UV radiation, and cellulose acetate, which transmits much UV-B but blocks UV-C (Teramura, 1983). Duration of UV exposure was 6 hr with a randomized complete block design and 10 replications. Mean separation was by the Wilcoxin signed rank test (Conover, 1971).

Field research into the raspberry "white drupelet" disorder suggested that the period of susceptibility was during the final few days of ripening. Shading fruit for just a few days before harvest reduced injury as effectively as shading for longer periods and removal of shade covers resulted in a high rate of damaged fruit (45%) only 3 days later (Renquist et al., 1987). Such observations were supported by Expt. 1; the green stage proved resistant to injury (Table 1). Damage in the pink stage appeared to arrest further color development in affected drupelets rather than bleach existing red pigment. The white stage was less susceptible than the pink stage, but was selected as the stage to use in Expts. 2 and 3, since damage during that stage results in fruit with the white drupelet condition, as occurs in the field during the final 2 or 3 days before harvest.

Experiment 2 characterized the effects of high temperature and UV radiation, alone and in combination, in disrupting red pigment development (Fig. 1). Note that high temperature without UV, within the range of fruit surface temperatures observed in the field (≤43C), had no effect. Likewise, UV radiation for <9 hr had no effect and only minimal effect up to 17 hr at 37C. Notable injury, approximating that observed in the field (Renquist et al., 1987), only occurred with a combination of 42C or higher and 4 to 7 hr of UV exposure.

While enough data were collected at 42C to well-define an equation by regression analysis (Fig. 1), such quantification was deemed unwarranted since the laboratory UV radiation environment was not equivalent to solar radiation due to the presence of UV-C. Such a regression would have to be weighted, due to higher variance with greater UV duration, and the R^2 value for weighted regression analyses is not meaningful.

The contribution of UV radiation to the injury at 42C or greater may have been due in part to UV-C radiation in the 270- to 280-nm band, emitted by the sunlamp but absent in the field (Sisson and Caldwell, 1975). However, it can be safely concluded that at 40C or below, neither the 270 to 280 UV-C nor the more field-relevant UV-B radiation was injurious with exposures that likely exceeded those experienced by field grown Colorado raspberries.

Experiment 3 reinforced the conclusion that both high temperature and UV radiation are required to cause injury that visually reproduced the injury observed in raspberry fields (Table 1). The Mylar filter, which absorbs nearly all UV radiation (Beckwar et al., 1982), was as effective as an aluminum foil cover at preventing injury. The cellulose acetate (CA) filter resulted in a mean injury level less than for exposed fruit, but the difference was not significant and was probably due in part to reduced UV-B fluence along with the removal of UV-C radiation. Note that, in Expt. 2, injury was proportional to UV exposure at 42C (Fig. 1). It can be inferred that at least part of the injury in this study was due to UV-B radiation, which is the documented cause of several forms of solar injury induced in the field (Kossuth and Biggs, 1978; Lipton, 1977).

The relevance of these findings to the protection of raspberries from solar injury is that high temperature alone did not cause injury (Fig. 1). Measures that adequately attenuate UV radiation should prevent the problem. While shade covers were reasonably effective (Renquist et al., 1987), the mechanics and economics are questionable. A more promising approach is the use of UV-absorbing compounds (Levitt, 1980; Lipton, 1977). If successful, it would overcome the major production problem during the first half of the harvest season for primocane-fruiting raspberries in warm arid regions.

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Guttation as a Technique to Evaluate the Water Status of Strawberry

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Abstract. **The water status of strawberry (*Fragaria* ×*ananassa* Duchesne) was indicated by the occurrence of guttation. Guttation was present when pre-dawn leaf water potential (PLWP) was greater than -0.07 MPa and absent when PLWP was below −0.11 MPa. Plants exhibiting guttation had greater stomatal conductivity and lower leaf − air temperature at midday, indicating a greater transpiration rate. Hydathodes on older leaves did not consistently express guttation; thus, the occurrence of guttation must be evaluated on young leaves.**

Proper cultivar selection, appropriate soil management practices, fertilization, pest control, and irrigation must be used to maximize strawberry production. To date, there is no concensus on the best method for scheduling irrigation for strawberry production. McNiesh et al. (1985) concluded that crop evapotranspiration was not limited by soil water availability as long as the soil water potential was above −0.03 MPa at 15 cm and −0.02 MPa at 30 cm. However, deviations to −0.055 MPa at 15 cm occurred in this study with no reduction in yield. Durner and Poling (1986) and Kaps and Odneal (1986) similarly scheduled irrigation in their studies using tensiometers set to irrigate at −0.03 MPa. Irrigation scheduling criteria have also been based on replacement of pan evaporation amounts (Crandall and Middleton, 1975), predetermined weekly amounts (Hancock and Roueche, 1983) and subjective assessment of crop need (Leblanc et al., 1987; Luby et al., 1987). Dwyer et al. (1987), in a comparison of three scheduling criteria, found that less water was used when irrigation occurred at pre-dawn leaf water potentials below −0.25 MPa compared to low volume frequent irrigation or irrigating when soil available water content was <50%. Yield or fruit size were not reduced by any of these scheduling criteria. They concluded, as others have done (Cannell et al., 1961), that strawberry production is unaffected by scheduling criteria that allow a moderate stress to develop before irrigating. Therefore, a rapid, simple indicator of plant water status should be sufficient to maintain adequate moisture and identify drought areas before water stress limits production. Our objective in this study was to determine how the occurrence of guttation is related to plant water status in the field.

The study was conducted during the 1986 and 1987 growing seasons at the Appalachian Fruit Research Station, Kearneysville, W.Va. The north–south-oriented rows of 'Allstar' were planted in 1986 on a well-drained Hagerstown silt loam (fine, mixed, Mesic, Typic Hapludalf) on a 1% slope. In both years, rows with and without drip irrigation were sampled 3 to 10 days following a major rainfall. Unless otherwise specified, 24 and 20 rows were sampled in 1986 and 1987, respectively. Using this sampling strategy, we were able to measure plant water status of the nonirrigated plants as they were passing through a transition of always guttating to a consistent absence of guttation.

Data were collected on two dates in 1986 and six dates in 1987. Pre-dawn leaf water potential (PLWP) was measured using a Scholander pressure chamber (Scholander et al., 1965) on one to three fully expanded leaves per row. The presence or absence (+ or −) of guttation was noted for each leaf, for the whole plant, and for the row. Canopy − air temperature (Δ_T) measurements were made from north and south directions on each row shortly after solar noon using an infrared thermometer (Everest Scientific, Tustin, Calif.). Stomatal conductance of four mature leaves per row was measured in 14 rows on 29 Aug. 1986, shortly after solar noon, using a LI-COR 1600 steady-state porometer and additional Δ_T measurements were made. Guttation was recorded and the PLWP measured on 29 Sept. 1987 on immature, 28- and 46-day-old leaves. The leaves were then placed in air-tight containers and frozen for solute potential (ψ_s) determination. Solute potential was measured on thawed samples using a Wescor osmometer (Wescor, Logan, Utah).

Data for both years were pooled. Guttation data on a per-plant basis were analyzed using an interaction χ^2 test (Steel and Torrie, 1960) to determine the range of PLWP at which guttation ceased. Regression analysis related stomatal conductance to Δ_T and a paired *t* test determined guttation effect (+ or −) on Δ_T and stomatal conductance levels on 29 Aug. 1986. A paired *t* test was used to determine differences in Δ_T between adjacent irrigated and nonirrigated rows when guttation was present in the irrigated treatment and absent in

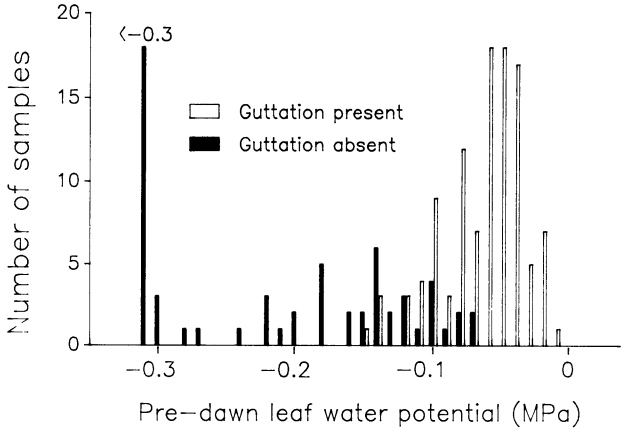

Fig. 1. Frequency distribution of guttation over the range of predawn leaf water potentials in strawberry.

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