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Environmental Factors Inducing High Transpiration at Harvest Increase Peach Bronzing

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Abstract

Peaches with bronzing skin disorder (bronzing) are unmarketable to consumers as they possess blotches of variable shapes and sizes that range from a single patch to covering most of the skin. Little is known about the cause, but in years of high occurrence, the disorder has commonly been associated with rainfall and high temperatures before harvest. In this study, we assessed the influence of environmental parameters on bronzing incidence and severity in orchards with different irrigation regimes. Results showed that environmental factors leading to increased transpiration at harvest were linked to higher bronzing incidence and severity.

Peach bronzing is a discoloration of the peach exocarp in the form of irregular-shaped blotches of bronze color. Symptoms are exacerbated after a few days of cold storage but have been observed on fruit before harvest (Schnabel et al. 2021). In years of high precipitation, peach producers in the U.S. have reported increased losses compared to years with low rainfall (Schnabel et al. 2021). Similarly, unusual rainfall events during summer months have caused extensive skin bronzing damages in Greece (Pantelidis et al. 2021). The combination of excessive irrigation and overfertilization with potassium (K), has also been reported to increase the severity and incidence of the disorder in the southeastern U.S. (Lawton 2021).

Changes in environmental variables such as temperature, relative humidity, and rainfall contribute to micro and macrocracking that could affect the integrity of fruit exocarp (Joshi et al. 2021; La Spada et al. 2024). The high transpiration rate that characterizes peach fruit during the cell expansion stage (Lescourret et al. 2001) determines the imports of water and nutrients through the xylem, and influences phloem unloading and dry matter accumulation in the fruit (Morandi et al. 2010). Thus, seasonal and/or daily changes in fruit transpiration could also lead to nutrient imbalances, which have been linked to higher incidences of pre- and post-harvest physiological disorders in other fruits (Montanaro et al. 2012). Nevertheless, understanding the specific mechanism is not possible if we do not clearly understand the influence of environmental conditions on the incidence and severity of bronzing. Thus, the objective of this study was to evaluate the role of irrigation and environmental parameters such as temperature, rainfall, dew point, and difference between air and wet bulb

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temperature, in the incidence and severity of bronzing. We hypothesized that high soil moisture (due to irrigation) and high relative humidity (due to rainfall) increase bronzing incidence and severity in peaches.

Materials and Methods

Experiment setup and growing conditions. The experiment was carried out at the Clemson University Musser Fruit Research Center (Seneca, SC, USA; 34.61°N, 82.87°W). The orchard comprised two rows of 17 mature 'PF23' peach trees (5 years old at the beginning of the experiment) at a spacing of 6.7 m x 7.3 m. Trees were grafted onto Guardian® rootstock and pruned in an open vase shape. All trees used for this experiment were overfertilized with K (0.68 kg of sulfate of potash, 0-0-50, per tree three times a year, in March, May, and July), as field observations had previously suggested the practice of K overfertilization predisposes trees to develop bronzing. They were also fertilized with 16.81 kg N·ha^{-1} and 44.83 kg K·ha-1 (15-0-40) in March, annually. Half of the orchard was irrigated every day for the last three weeks before harvest at an average rate of 224,500 L·ha^{-1}. The other half of the orchard was not irrigated and relied solely on rainfall. Average daily temperature, rainfall, dew point, and wet bulb temperatures were collected using a weather station (Vantage Pro, Davis Instruments, Hayward, CA; Weather Underground station KSCSENEC14). Fruit thinning was conducted manually at the beginning of April (same crew every year). Other orchard management practices such as insect and disease management were carried out following standard commercial practices (Blaauw 2024).

Sampling and sample preparation. Trees were harvested three times each year: July 9, 12, 16 in 2021, and July 7, 12, 18 in 2022. At each harvest event, 25 commercially ripe fruit per tree were randomly selected and placed in 28-pocket plastic trays and put in the cooler at 4°C and 90% relative humidity for three days. After three days, the peaches were removed from cold storage, kept at room temperature for three days, and evaluated for incidence and severity. Incidence was evaluated on a scale of zero to one (Lawton, 2021): 0: peach with no bronzing; 1: peach with bronzing. Severity was evaluated on a scale of zero to four (Lawton, 2021): 0: no bronzing; 1: less than 5% of the fruit was covered by bronzing; 2: 6-25% bronzing coverage; 3: 26-50% bronzing coverage; and 4: more than 50% bronzing coverage. The study did not include fruit affected by diseases or disorders other than skin bronzing.

Statistical Analysis. A randomized complete block design was used, and each treatment had ten replications, with each replication being a single open-vase tree. The effects of irrigation on bronzing incidence and severity were analyzed with the non-parametric Welch's test due to unequal variance between the main effects of irrigation on bronzing incidence and severity in 2021 and 2022 (JMP Pro 16, SAS, Cary, NC, USA).

Results

Bronzing incidence and severity were higher in 2021 than in 2022, with the highest average severity rating being around 1.7 (out of 4) in 2021 (Table 1) and 1.2 in 2022 (Table 2). During the third pick in 2021, irrigation did not affect bronzing incidence but did reduce bronzing severity ($F = 5.8$; $P \leq 0.05$). However, irrigation increased bronzing incidence ($F = 10.5$; $P \leq 0.01$) and severity ($F = 6.0$; $P \leq 0.05$) in the third pick in 2022. Overall, bronzing incidence and severity were highest at pick 3 in 2021 and lowest at pick 2 in 2022.

Temperatures the days before or the day of harvest were between 20-32°C in 2021 and 20-35°C in 2022, with the lowest maximum (27.2°C) right before the second pick in 2022 (Fig. 1). There were rainfall events before each

Table 1. Incidence and severity of bronzing in 'PF-23' peach fruit harvested over three picks from non-irrigated and irrigated trees in 2021.

Treatment	Incidence[i]			Severity[ii]		
	Pick 1	Pick 2	Pick 3	Pick 1	Pick 2	Pick 3
Non-irrigated	0.83	0.78	0.93	1.20	1.02	**1.70 a**
Irrigated	0.81	0.70	0.88	1.05	0.92	**1.44 b**

[i]Incidence rating was between 0 and 1. [ii]Severity rating was between 0 and 4. Statistical analysis is performed for each pick. Different letters indicate significant differences at $P \leq 0.05$.

Table 2. Incidence and severity of bronzing in 'PF-23' peach fruit harvested over three picks from non-irrigated and irrigated trees in 2022.

Treatment	Incidence[i]			Severity[ii]		
	Pick 1	Pick 2	Pick 3	Pick 1	Pick 2	Pick 3
Non-irrigated	0.75	0.37	**0.68 b**	1.03	0.41	**0.79 b**
Irrigated	0.75	0.66	**0.85 a**	1.00	0.76	**1.15 a**

[i]Incidence rating was between 0 and 1. [ii]Severity rating was between 0 and 4. Different letters within columns indicate significant differences at $P \leq 0.05$.

pick in 2021; however, 2022 was drier than 2021, and there was only some light rain (2 mm) two days before pick 1, and 32 mm of rain four to six days before pick 2.

Temperatures the days before or the day of harvest were between 20-32°C in 2021 and 20-35°C in 2022, with the lowest maximum (27.2°C) right before the second pick in 2022 (Fig. 1). There were rainfall events before each pick in 2021; however, 2022 was drier than 2021, and there was only some light rain (2 mm) two days before pick 1, and 32 mm of rain four to six days before pick 2.

There were no clear patterns observed for the average dew point, other than drops of 2-3 °C between one and three days before picks 2 and 3 in 2022. The average difference of air and wet-bulb temperatures between 9:00 and 21:00, which is a parameter linked to transpiration (Swedan 2021), was highest a few days before pick 1 in 2021, and pick 3 in 2022, and lowest during the days before pick 2 in 2022.

Discussion

According to observations from growers, bronzing incidence and severity increases after significant rainfall events before harvest. Lawton (2021) reported 30.5 mm over the last three weeks before harvest in 2019 and 71.1 mm over the same period in 2020. In our experiment, rainfall over the same period of three weeks before harvest in 2021 was higher (118 mm) than in both years of Lawton (2021), whereas rainfall (72.6 mm) in 2022 was similar to that of 2020. While bronzing incidence and severity were lower the driest of these four years (2021), both studies showed comparable bronzing incidence and severity values, ranging from 0.7-0.9 (incidence) and 0.4-1.2 (severity) for the other three years.

Thus, bronzing seemed to be primarily affected by factors beyond the grower's control, i.e., weather variables. One of the most drastic changes in bronzing incidence and severity was observed between the second and third picks in 2022. However, this time, rainfall did not seem to be a critical factor. There were rainfall events 4 to 6 days before pick 2, although fruit had the lowest bronzing recorded in these two years; in contrast, there were no rainfall events before pick 3, which is when some of the highest bronzing incidence and severity were observed in 2022. Similarly,

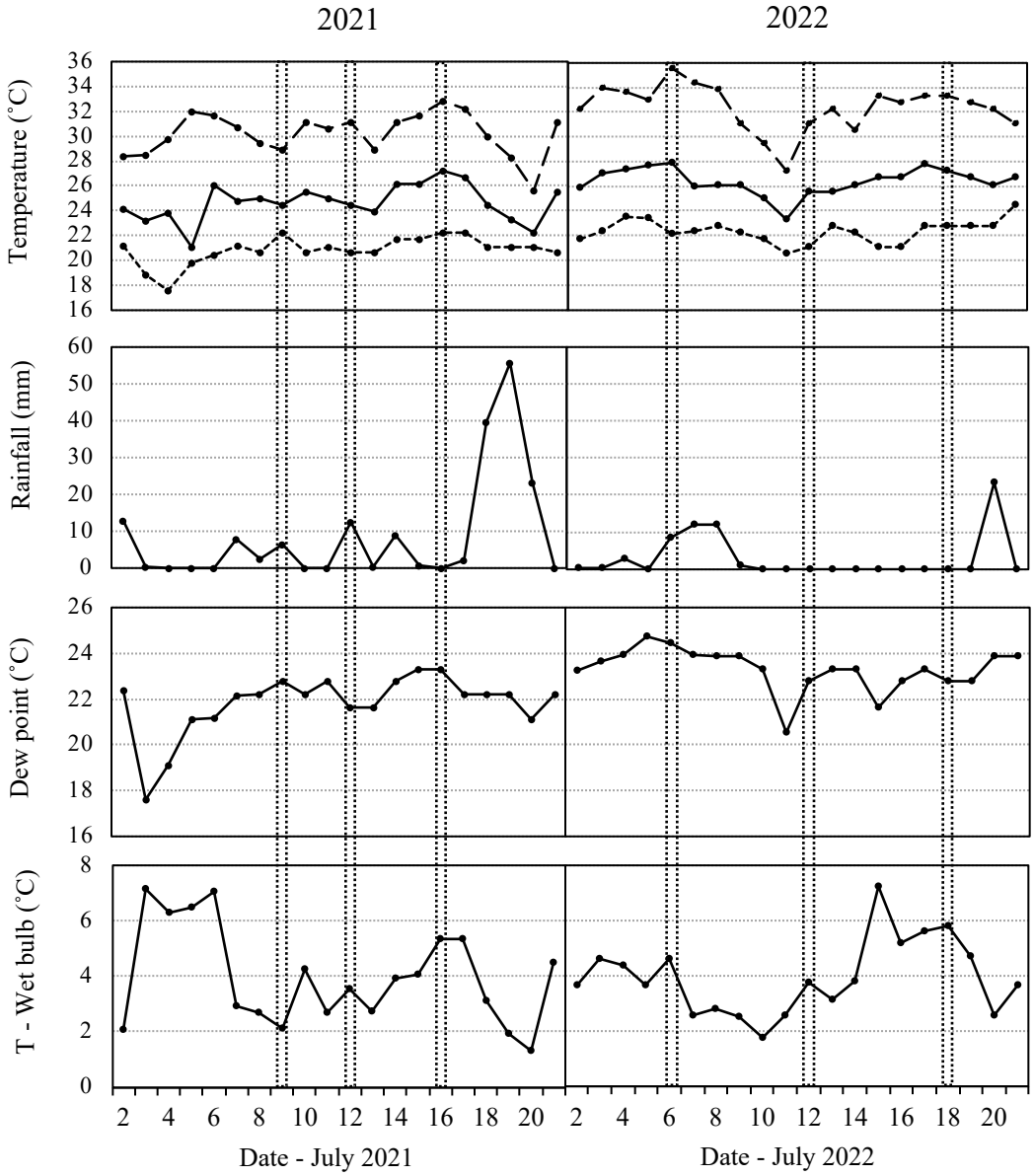

Figure 1. Daily temperature (°C; average, continuous line; maximum, long-dashed line; minimum, short-dashed line), rainfall (mm), average dew point (°C), and average difference between air temperature and wet bulb temperature taken between 9:00 and 21:00, in July 2021 and 2022. In 2021, peach harvest was conducted on July 9, 12, and 16, and in 2022 was on July 7, 12, 18 (dotted columns).

rainfall events were distributed throughout the harvest period in 2021, even though a slight decrease was observed in pick 2. Thus, while previous observations pointed out that rain seemed to be the main factor influencing bronzing (Pantelidis et al. 2021), our data indicates rainfall might, in some cases, be an exacerbator but not a causal factor. On the other hand, the influence of environmental factors such as dew point, wet-bulb temperature, and the difference between air and wet-bulb temperatures on bronzing have not been studied. Specifically, we observed that the latter had lower values during the days

before the picks with lower bronzing incidence and severity, and higher values during the days when we observed the highest incidence and severity values. On a typical day as the sun rises, the air temperature, relative humidity, and the difference between air and wet-bulb temperatures also increase, leading to increased transpiration (Swedan 2021), including fruit transpiration. In 2021 and 2022, the days with the lowest difference between air and wet-bulb temperatures were those before pick 2, coinciding with less bronzing incidence and severity values. Thus, while we did not measure fruit transpiration, we could assume that reduced fruit transpiration during days with a smaller air to wet-bulb temperature difference may be linked to lower bronzing incidence and severity observed shortly after. These observations align with previous reports linking bronzing with conditions conducive to high transpiration (Lawton 2021; Schnabel et al. 2021). Furthermore, fruit transpiration is cultivar dependent (Li et al. 2002), and previous studies have shown that different peach cultivars present different susceptibility to skin bronzing (Schnabel et al. 2021; Pantelidis et al. 2021). However, transpiration rates of cultivars with different susceptibility to bronzing have not been reported in the literature.

Conclusions

In summary, we did not observe a consistent effect of irrigation on the incidence and severity of bronzing. Contrary to previous observations, the assessment of environmental parameters over two years showed that rainfall before harvest was not directly linked to increased bronzing; however, factors inducing high transpiration such as a large difference between air and wet-bulb temperatures right before harvest could be related to and be better predictors of bronzing than rainfall events. Future studies should examine fruit transpiration rates of cultivars with different susceptibility to bronzing during various weather conditions prior to harvest to better understand the interaction between fruit physiology and the bronzing disorder.

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