Project title: Sunburn in apple

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Objectives:
1. Determine the physiological, biochemical and environmental causes of sunburn browning in apples.
2. Refine and improve the computer model we have developed as a predictive model for sunburn of apples.
3. Investigate factors that condition (acclimate) fruit to protect from sunburn (e.g., heat shock proteins).

Significant findings:
1. We have distinguished two types of sunburn in apple: sunburn necrosis and sunburn browning.
2. Sunburn necrosis is induced on the sun-exposed side when the fruit surface temperature reaches 126 ± 2°F for as little as 10 minutes. Thermal death of cells occurs and cell contents leak through cell membranes. A necrotic spot appears later.
3. Fruit that has not been acclimated through exposure to substantial sunlight will develop necrosis at fruit surface temperatures that are 2-7°F lower than those cited in #2 above. When thinning, growers should not remove the uppermost apple from a cluster, as necrosis is likely to develop in sun-exposed fruit that had been shaded by the uppermost fruit before its removal.
4. Sunburn browning occurs at lower fruit skin temperatures and is a non-lethal event. Sunburn browning is induced when the sun-exposed side of an apple reaches a “threshold temperature.” This “threshold temperature” is time dependent. That is, the “threshold temperature” for 1 hour of heating is lower than that required for sunburn browning after a shorter period of heating. This threshold temperature also varies with cultivar.
5. When we induced sunburn by heating fruit under controlled conditions (“experimental induction”) the threshold temperatures ranged from 114-119°F. Of those cultivars studied, ‘Pink Lady’ and ‘Braeburn’ had the highest threshold temperatures and ‘Cameo’ had the lowest. ‘Gala,’ ‘Fuji,’ ‘Granny Smith,’ ‘Delicious,’ ‘Golden Delicious,’ and ‘Jonagold’ were intermediate.
6. When we observed the natural incidence of sunburn (“natural sunburn”), the threshold temperatures were higher (ranged from 117-124°F). ‘Delicious’ had the highest threshold
temperature and ‘Jonagold’ had the lowest. ‘Gala,’ ‘Fuji,’ ‘Braeburn,’ and ‘Golden Delicious’ were intermediate.

7. Sunburn browning occurred only in sunlight (i.e., apples heated in the dark to the same “threshold temperature” did not sunburn) so solar radiation plays a role other than just providing the heat energy to warm the fruit.

8. Apples coated with RAYNOX, which blocks UV-B, or with another UV-B blocker (PABA) prior to heating the apples to the same temperature were usually protected from sunburn browning. This suggests that UV-B radiation is required for sunburn browning in apples.

9. Based on findings #7 and #8, we conclude that solar radiation and skin temperature that has reached a certain “threshold temperature” are both important factors inducing sunburn browning.

10. Fruit skin temperature is highest between 3:00 PM and 4:30 PM most days, and sunburn usually occurs during that period. Fruit surface temperature always reaches a maximum before 5:00 PM. Thus, evaporative cooling is not required after 5:00 PM.

11. Maximum fruit surface temperature on a given afternoon is most highly correlated with maximum air temperature \((r = 0.90^{**})\), average air temperature \((r = 0.88^{**})\) between 11:00 AM and 5:00 PM, and with average solar radiation \((r = 0.65^{**})\) between 11:00 AM and 5:00 PM. Relative humidity and windspeed are negatively correlated with fruit temperature.

12. Fruit sunburn on fully exposed fruit is almost certain when air temperature exceeds 95°F and is unlikely to occur when air temperature is below 86°F. When air temperature is between 86-95°F, other meteorological factors (e.g., incoming solar radiation, relative humidity and wind speed) become important. It is in this temperature range (86-95°F) that our computer models become most useful for prediction of sunburn.

13. In 2000 at our experimental site in Wenatchee, apple skin temperatures exceeded 113°F (range from 113-120°F) on 22 days. On those 22 days, the maximum air temperature between 3:00 PM and 4:30 PM ranged from 90-97°F, and maximum fruit temperature exceeded air temperature by 22-29°F. During 2000, fruit surface temperature never exceeded 120°F.

14. In 2001, apple skin temperatures exceeded 113°F (range from 113-127°F) on 23 days, and maximum air temperature between 3:00 PM and 4:30 PM ranged from 89-100°F. Maximum fruit temperature exceeded air temperature by 22-34°F. Maximum fruit temperature exceeded air temperature by 22-34°F. In 2001, fruit surface temperature exceeded 122°F on seven days during the second week of August.

15. Two computer models have been developed to predict the incidence of sunburn. One is useful to predict, several days in advance, whether sunburn will occur under the weather conditions that are forecast for a locale. The second model is designed to predict, on the basis of actual meteorological data between 10:00 AM and 2:00 PM, whether sunburn will occur after 2:00 PM that day. These predictive models incorporate solar radiation, air temperature, relative humidity and wind velocity as well as tree vigor, time and duration of precipitation, and cultivar differences in vulnerability to sunburn. The second model could be used to initiate evaporative cooling at times when environmental conditions are likely to induce sunburn.

16. Sunburn browning is NOT reversible. In some sunburned apples, pigments change as fruit matures and masks the sunburned spot. If sunburned fruit is bagged, the browning stays.
17. Chlorophyll in a peel with sunburn browning declines rapidly, whereas flavonoids and carotenoids increase. Anthocyanin (red pigments) synthesis is often inhibited in the sunburned area, although in some cultivars red pigments do develop later in the season in the sunburned area and mask some or all of the sunburn damage.

18. Other biochemical changes observed during sunburn include an increase in peroxidase activity, a decrease in superoxide dismutase activity, and an increase in phenylalanine ammonia lyase activity.

19. Apples exposed to sunlight “acclimate” or become conditioned to high light and high temperature stress and develop tolerance to sunburn damage. Heat shock proteins (HSPs) accumulate in apple skin temperatures of 100-110°F. In sunburned tissues, a sharp increase in several HSPs has been observed. The HSPs in the cytosol, chloroplasts and the mitochondria all increase sharply in the sunburned tissue. A large number of samples collected during the 2001 growing season are currently being analyzed.

20. Sunburn damage can be reduced (about 50% on average) by applying RAYNOX, a formulation we invented at WSU.

Results and discussion:

I. Induction of sunburn:
Threshold temperatures for induction of sunburn in different cultivars were studied two ways. The first was to induce sunburn by heating each of nine exposed apples to a different temperature for 1 hour. The second was to observe “natural induction” and record the temperature at which sunburn occurred.

A. Experimental induction: We constructed some special heating devices for induction of sunburn browning in the field. Skin temperature was maintained at the desired temperature for 1 hour with a temperature controller on each device. Nine different fruit temperatures could be imposed simultaneously. After heating, fruits were observed daily to determine whether sunburn occurred, and digital images were taken. Of those cultivars studied, ‘Pink Lady’ and ‘Braeburn’ had the highest threshold temperatures (required a skin temperature of 119°F for 1 hour), and ‘Cameo’ had the lowest (114°F skin temperature for 1 hour). ‘Gala,’ ‘Fuji,’ ‘Granny Smith,’ ‘Delicious,’ ‘Golden Delicious,’ and ‘Jonagold’ were intermediate. A problem with this method is that fruit that had been heated on a given day sometimes experienced a higher fruit surface temperature, due to natural weather changes, on a subsequent day. This higher fruit temperature therefore may have induced sunburn in fruit that would not have sunburned because of the experimental induction.

B. Natural induction: Thermocouples were attached to several well-exposed fruit to monitor their surface temperature throughout the season. Each fruit was examined daily to determine whether sunburn had occurred. If so, the date of the event was recorded, and fruit surface temperatures for several days preceding incidence of sunburn were reviewed to determine the highest temperature that had occurred prior to the sunburn event. This was recorded as the threshold temperature for natural sunburn of that cultivar. The threshold temperatures ranged from 117-124°F. “Delicious” had the highest threshold temperature and ‘Jonagold’ had the lowest. ‘Gala,’ ‘Fuji,’ ‘Braeburn,’ and ‘Golden Delicious’ were intermediate. The disadvantage of this method is that sudden weather changes can cause fruit surface temperature to increase markedly above what it had been previously. Sunburn occurs, but may cause us to overestimate the threshold temperature for sunburn. This explains why the threshold temperatures with this method are higher than for the experimental induction method. In summary, both methods have a shortcoming, and we need to repeat again next season to establish more confidence in these threshold temperatures.
II. Role of light in causing sunburn browning:
Exposure of the fruit to full sunlight was required to induce sunburn browning at the threshold temperatures. That is, exposure to the same temperature in the dark did not result in sunburn browning. Therefore, sunlight plays a role other than just providing the heat energy to warm the fruit surface temperature to the threshold temperature required for sunburn of apple.

III. Role of UV-B radiation in sunburn browning:
During 2000, we applied “UV-B blockers” to attached ‘Fuji’ apples and observed a 60% (P <0.01) reduction in sunburn browning. In the 2001 induction experiments described above, application of RAYNOX or the UV-B blocker, PABA, to the fruit prior to heating also protected most fruit from browning under conditions that caused sunburn browning without a protectant. We also covered the heating device with a special plexiglass that excluded UV-B during the experimental induction. These fruits seldom sunburned. These findings suggest that UV-B radiation is required for sunburn browning, but may not be the only type of solar radiation required for sunburn.

IV. Sunburn browning is not reversible:
In 1999, we used a digital camera to record sunburn and any color changes at weekly intervals for a large number of exposed fruit. Analysis of the digital images indicated that sunburn browning disappeared in several apples and led us to conclude that apples can recover from sunburn browning. During 2000, this conclusion was found to be erroneous, as we found that several pigments can appear as fruit matures, resulting in apparent recovery by masking the sunburned spot on the apple. The most conclusive evidence came from an experiment in which fruits were bagged soon after sunburn occurred. The bags were removed briefly every 10 days to permit us to capture a digital image of that fruit. We found that bagging eliminated many pigments (e.g., chlorophyll, anthocyanins etc.), but the sunburn browning did not disappear in fruit of any cultivars studied. We now conclude that sunburn browning is not reversible.

V. Modeling environmental factors that cause sunburn browning:
Based on extensive data from 2000 and 2001, we have developed two computer models for prediction of sunburn. Both models predict the fruit surface temperature under various meteorological conditions. The major meteorological factors that influence fruit surface temperature are air temperature, solar radiation, relative humidity and wind velocity. These four factors interact with each other. In addition, tree vigor, precipitation and cultivar influence sunburn.

The first model for prediction of sunburn in apples allows the user to use weather forecasts to enter data used by the model to predict sunburn for up to seven days in advance. The second model uses “real time” meteorological data from 10:00 AM to 2:00 PM to predict whether sunburn will occur later that same afternoon. We suggest that this model could serve to control evaporative cooling systems used for sunburn protection.

Publications resulting from this research:

Budget: Summary for three-year period of funding

Sunburn in apple

Larry Schrader

Project duration: 1999-2001
Current year: 2001 (FINAL YEAR)
Original budget request: $69,800

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Current year breakdown

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Project funding 1999-2001: $227,200