EFFECT OF HIGH TEMPERATURES DURING THE BLOOM-SET PERIOD ON FRUIT-SET, OVULE FERTILITY, AND BERRY GROWTH OF SEVERAL GRAPE CULTIVARS

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ABSTRACT

To test the effects of high daytime temperatures (35 or 40°C from 11 AM to 7 PM) from two to eight days before bloom until 12 to 18 days after bloom (bloom-set period) on fruit-set, ovule fertility, and berry growth of several *Vitis vinifera* L. cultivars, three and four years old potted vines were grown in phytotron rooms. Control vines were maintained at day/night temperatures of 25/20°C during the bloom-set period. After bloom-set, vines in all treatments were held at 25/20°C during the remaining period of berry development and ripening.

The percentage of berries set was significantly greater ($P<0.05$) at 25° than at 35 or 40°C for both Pinot noir and Carignane. Ovule fertility and berry weight were also significantly greater at 25 than at 35 or 40°C in Carignane vines. With Pinot noir, however, only vines held at 40°C during bloom-set had significantly fewer ovules fertilized per cluster than occurred at 25°C. During bloom-set, shoot growth was fastest at 25°C (Carignane) or 35°C (Pinot noir), but no significant correlation existed between rate of shoot growth and fruit-set or ovule fertility.

Temperatures of 32.5 to 40°C from 7 AM to 7 PM during bloom-set gave a significantly ($P<0.05$) lower weight and size of Cabernet Sauvignon and Tokay berries during most stages of berry development and ripening than did 25°C. Cabernet Sauvignon berries grown at 32.5 and 35°C during bloom-set had a significantly greater ($P<0.05$) berry weight and size during ripening and at fruit maturity than when grown at 37.5 or 40°C. Tokay berries at 32.5 to 40°C, however, did not differ significantly in weight and size. Anatomical data indicated that the Tokay berries were larger at 25°C than at 40°C due to greater numbers of cells in the pericarp tissue rather than to larger cell size.

In years with excessively high or low temperatures during the period from bloom to fruit-set (berry shatter) of grape vines, or soon thereafter, some vineyards in California have poor fruit-set, accompanied by the formation of many seedless berries (shot berries) and often a generally smaller than normal berry size at harvest. There have been relatively few replicated controlled-temperature experiments dealing with the effects of high temperatures on fruit-set and subsequent berry growth during bloom through berry shatter.

Alexander (1) found that poor fruit-set in Sultana vines was due more to water stress during bloom or within four weeks after, than to high temperatures *per se*. Using temperature-controlled growth cabinets, Kobayashi et al. (14) investigated the influence of night temperature on fruit-set and berry growth of small potted Delaware vines. They reported that fruit-set ranged between 32 and 59% at night temperatures from 15 to 27°C. At 35°C night temperature, however, no berry set occurred. Daytime temperatures were not held constant, but averaged between 18 and 24°C during the bloom-set period. In an unreplicated trial in growth chambers

enclosing Concord vines growing in the field, Tukey (20) found that the size and weight of berries and number of seeds per berry were considerably less from vines maintained at a daily average of 32°C than at a daily average of 26 or 21°C. Haeseler and Fleming (6), using a technique similar to that of Tukey (20), found that fruit-set on Concord vines was usually significantly less on vines held at 17 or 33 ± 2°C daytime (night 12 ± 2°C) than on vines maintained at 25 ± 2°C or on vines grown under natural field conditions (average about 20°C in daytime and 15°C at night). Buttrose and Hale (3) reported that small Cabernet Sauvignon vines started from rooted cuttings and held in growth cabinets at day/night temperatures of 14/9°C and 38/33°C during the period from about budbreak to two weeks after anthesis failed to set a single berry, whereas set was good at 20/15°C and 26/21°C. Hale and Buttrose (7) more recently showed that the size of Cabernet Sauvignon berries was irreversibly reduced by high day/night temperatures (35/30°C) during stage I of berry growth, but not during stage III (second period of rapid berry growth).

The level of ovule fertility in most of the controlled environmental studies with grapevines cited above was not determined. The number of ovules fertilized per berry greatly affects final berry size (4), since the seeds themselves are the primary source of hormones that stimulate cell division and cell elongation. Therefore, estimation of ovule fertility is of paramount importance in evaluating the effects of temperature and other environmental factors on berry growth.

Recent reports (5,19) from our laboratory have dealt with effects of low light intensities and temperatures, in combination with low and adequate levels of nitrogen, on fruit-set and ovule fertility of several wine grape cultivars. Ovule fertility and number of seeds per berry were more than double in vines maintained at day/night temperatures of 25/10°C or 25/20°C during the period from one week before bloom until véraison, than in vines held at 15/10°C. Under high light (2680 ft-c), fruit-set ranged from 13% in White Riesling to 31% in Pinot noir; and the percentage of ovules fertilized per cluster ranged from 0 to 5.1%. They also showed that light intensities of 750 ft-c or less at 15/10°C greatly reduced set and ovule fertility below that at higher light intensities. Use of growth regulators under these conditions did not improve set.

The present study determined the influence of high temperatures immediately preceding and during bloom-set, on ovule fertility, fruit-set and berry growth. A primary objective was to determine the critical daytime temperatures between 32 and 40°C at which ovule fertility, fruit-set, and berry growth of several grape cultivars were reduced from those of control vines held at 25°C daytime temperature. Also presented are some anatomical data on the influence of high daytime temperature (40°C) on number and size of cells in berry pericarp tissue.

MATERIALS AND METHODS

The containers, growth media, experimental design, and methods of growing, handling, and maintaining the vines have been described (11,12). All vines were pruned to two or three shoots, with each trained vertically on separate 2-m stakes. Shoots were thinned to one cluster each shortly after budbreak. The experimental vines were selected for uniformity of shoot length, leaf area, and cluster size just before the temperature treatments were begun. In both experiments 1 and 2, the rotating phytotron (17,22) was used for the temperature treatments (Tables 1 and 2) carried out during the bloom-set period. After fruit-set, the vines were transferred to the stationary phytotron (22) for the remaining period of berry development and ripening. The stationary phytotron room was maintained at day/night temperatures of 25/20°C. In both experiments, the 25°C treatment was considered the control since previous studies (7,15,16) had indicated that to be the usual optimum for photosynthesis and berry and vine growth. So that vines would be available about three weeks apart with clusters at the same stage of development, three-fourth to four-fifths of the dormant vines of each cultivar were held in a cold room at 4°C, and the remaining vines were placed in a heated greenhouse. At 3-to-4-week intervals, beginning about four weeks after budbreak of the vines in the greenhouse, another set of vines was transferred from the cold room to the greenhouse. In this way, four or five different temperature treatments were possible in the same season with only two controlled-temperature rooms.

Experiment 1: This experiment was done in 1973, with the main objective to determine the effect of high temperatures during bloom-set on berry growth and development. Three- or 4-year-old own-rooted *Vitis vinifera* L. cultivars, Cabernet Sauvignon and Tokay, were used. The daytime (7 AM to 7 PM)

Table 1. Effect of high day temperatures[x] during period of bloom and fruit-set on number of Cabernet Sauvignon and Tokay berries per cluster.

Day temperature during bloom-fruit-set period[y] C°	Number of berries per cluster*	
	Cabernet Sauvignon	Tokay
25.0	40.3 a	75.4 a
32.5	30.5 ab	69.5 a
35.0	27.5 b	72.8 a
37.5	25.4 b	—
40.0	10.8 c	54.0 b

* Within a column, means followed by the same letter are not significantly different at the 5% level using Duncan's multiple-range test.

[x] Day temperature was from 7 AM to 7 PM. Night temperature (7 PM to 7 AM) was 20°C for all treatments.

[y] The temperature treatment period extended from two to seven days before initial bloom to 12 to 18 days after initial bloom.

Table 2. Influence of temperature during bloom-set on fruit-set, ovule fertility, berry weight, fruit maturity, and rate of shoot growth of two grape cultivars.

Cultivar	Temperature treatment[a] (°C)	Total no. clusters per treatment	Fruit maturity (°Brix)	Wt./berry (g)	Total no. of flowers per cluster	Fruit-set (%)	Ovule fertility (%)	Amt. of seeded berries (% of berries set)	Rate of shoot growth during bloom-set period (cm/day)
Pinot noir	25	16	19.7	1.10	238	50.8	14.4	82.9	2.39
	35	16	17.6	1.03	238	39.1	11.4	84.5	3.15
	40	15	17.8	0.99	270	30.0	3.8	54.1	1.00
LSD @ 5%	—	—	1.2	NS	—	9.6	5.6	11.1	1.03
Carignane	25	13	20.5	1.45	556	42.2	9.2	82.6	3.15
	35	16	18.2	1.06	563	34.2	6.2	72.0	1.99
	40	14	17.3	0.99	420	29.7	4.8	63.9	1.72
LSD @ 5%	—	—	2.4	0.20	—	6.1	2.9	12.1	0.26

[a] See curves in Fig. 1 for the exact description of the temperature treatments. The temperature treatment period extended from two to eight days before initial bloom to 9 to 14 days after initial bloom.

temperature treatments were 25, 32.5, 35, 37.5, and 40°C, except there was no 37.5°C treatment for Tokay. Night temperature (7 PM to 7AM) was 20°C in all treatments. The temperature treatment period extended from two to seven days before initial bloom to 12 to 18 days after initial bloom. The dates on which initial bloom and 50% of the flowers on a cluster had undergone anthesis, were recorded. Natural sunlight was the source of radiation, and light intensity between 7 AM and 7 PM averaged 4750 ft-c during the experiment. The first temperature treatment (25°C) began April 23, and the last treatment (40°C) began June 25. About 96% of the days during the experimental period were sufficiently cloud-free that average solar radiation in the phytotron room was above the light-saturation point for grapevines (3000 ft-c) (16). Relative humidity in the rotating phytotron ranged between 40 and 80%. Vines were watered twice daily during the treatment period, and once a day thereafter. Care was taken to avoid moisture stress of vines. There were six vines per treatment for Cabernet Sauvignon and five for Tokay, with each plant serving as a replicate.

Five berries per cluster (two from top, two from middle, and one from bottom) were harvested at intervals (Figs. 2-4) and the fruits from each vine were analyzed separately. The berries were counted and weighed, and their volume was measured by displacement. Half of the fruits from each sample were dried to constant weight in a forced-draught oven at 70°C. The remaining berries from each sample were crushed with a mortar and pestle. Total soluble solids in the berry juice was determined with a refractometer.

Pericarp thickness, number of cells across the pericarp, and diameter of pericarp cells were determined for Tokay berries from vines grown at 25 and 40°C. Fruits for anatomical study were obtained by ranking all berries from each sample according to size, and then selecting one medium-sized berry from each of the five replicates. These berries were used for wax embedding, and were fixed in FAA [formalin, acetic acid, 50% ethanol (1:1:18)].

Intercellular air pockets were removed by placing the berries in a desiccator attached to a vacuum line for 12 hr. Large mature berries were cut into four quarters, and the seeds were removed before fixation. This was necessary to prevent the large pericarp cells from becoming distorted, and the pericarp layer from collapsing. Berries were dehydrated with progressively increasing concentrations of ethanol and tertiary butyl alcohol by the procedure of Brooks et al. (2) and were then embedded in paraplast wax (MP 56°C). Transverse sections, usually 10 μm thick, were made with a rotary microtone. Sections were stained with safranin and fast green (2) and then mounted on glass slides with Haupt's adhesive and 4% formalin solution.

A Zeiss photomicroscope with an eye-piece micrometer was used to measure pericarp thickness of the mounted berry sections. The number of pericarp cells between the locule and vascular bundles of transverse slide sections was counted, and the average diameter per pericarp cell was calculated by dividing the total pericarp thickness by the number of cells for each slide section. Two replicates for both the 25 and 40°C temperature treatments were examined. Data from each replicate were obtained from 20 transverse sections taken from the middle of a single berry.

Experiment 2: This experiment was conducted in 1976, with the main objective being to determine the effects of high temperatures during the bloom-set period on fruit-set and ovule fertility. The vines were 4-year-old own-rooted Pinot noir and Carignane. The temperature regimes (Fig. 1) are designated hereinafter as 25, 35 and 40°C. Temperatures were maintained at these levels from 11 AM until 7 PM. The rates of temperature decrease between 7 PM and 7 AM for the 25, 35 and 40°C treatments were respectively 0.42, 1.25, and 1.67°C/hr. The corresponding rates of temperature increase

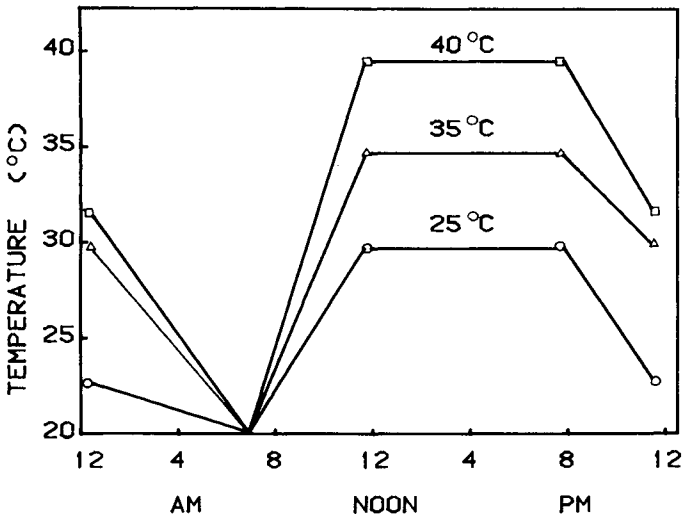

Fig. 1. Daily diurnal temperature cycles for 25, 35, and 40°C treatments in Experiment 2, using the rotating phytotron room.

were 1.25, 3.75, and 5.0°C/hr. These temperature regimes more nearly approximate field conditions, eliminating the "square-day" temperature regimes used in 1973 and by most other investigators (3,7,11,12,14,15). The temperature-treatment period extended from two to eight days before the first visible sign of bloom to 9 to 14 days after initial bloom. At each temperature regime there were eight Pinot noir and eight Carignane vines, with one to two clusters per vine. Each cluster was treated as a replicate, with the total number of clusters per treatment indicated in Table 2.

Percent fruit-set and ovule fertility were determined as described previously (19). At the time the temperature treatments were initiated, each cluster on a vine was enclosed in a fine-mesh white nylon bag that admitted light and allowed free circulation of air but prevented loss of abscised ovaries. The abscised flowers, ovaries, and berries within the bags were collected and counted at fruit maturity. At harvest, the seedless and seeded berries were counted and weighed, and the total number of seeds per cluster was determined after the fruits were gently macerated with a mortar and pestle and squeezed through a layer of cheesecloth. Percent cluster fertility was calculated by dividing the total number of seeds per cluster by the total number of ovules per cluster, assuming four ovules in each ovary. Total soluble solids in the berry juice was measured with a refractometer at harvest.

To determine whether the rate of shoot growth at various temperatures was related to fruit-set or ovule fertility, the length of each shoot was measured at the beginning and end of the 16-day temperature-treament period, and the average shoot growth per day was estimated.

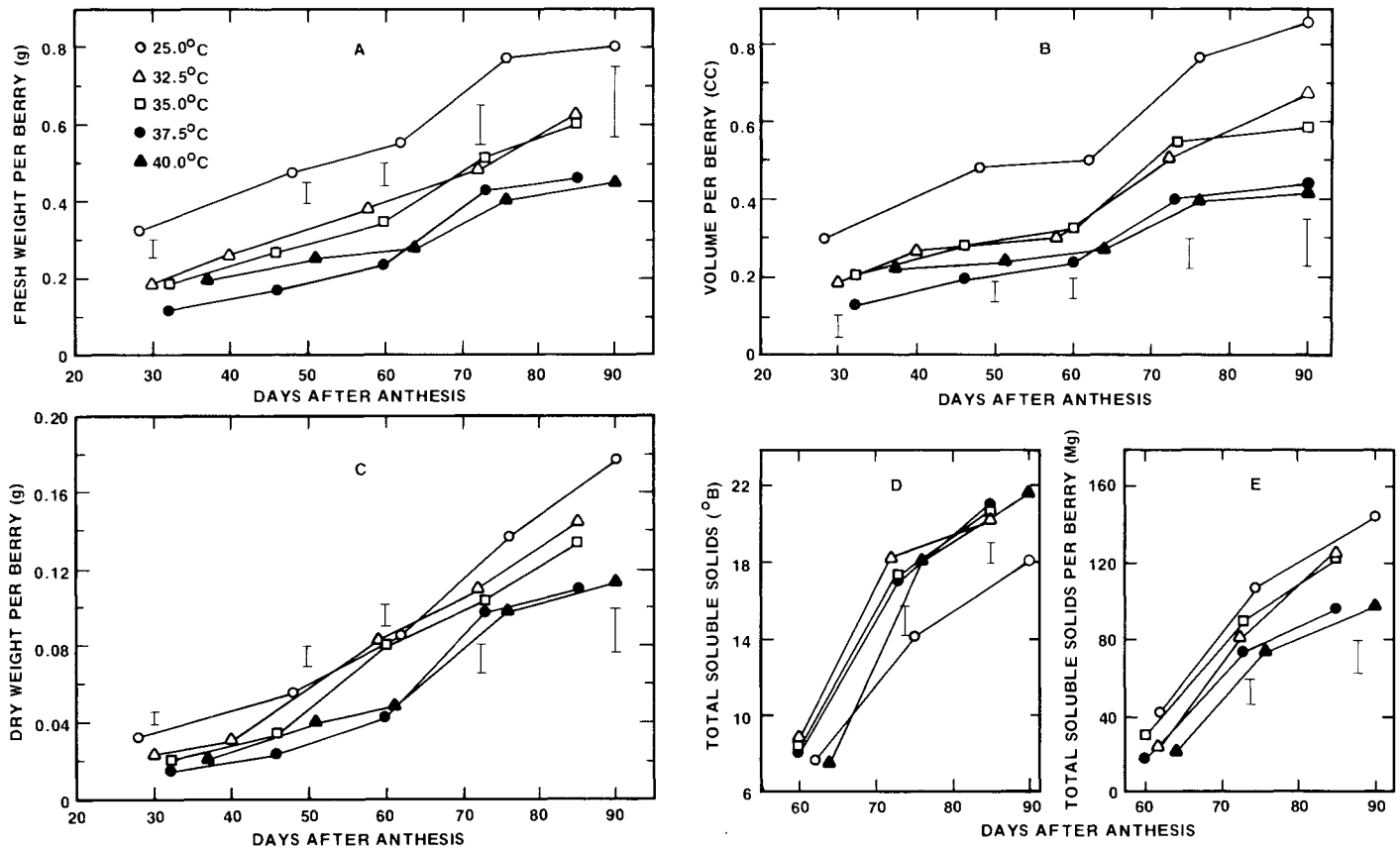

Fig. 2. Influence of high temperatures during bloom and fruit-set on fresh and dry weights per berry, berry volume, level of soluble solids, and total amount of soluble solids per berry during fruit development and ripening in Cabernet Sauvignon vines.

To avoid unduly long phrases in specifying the variables involved in this study, certain simplifications are used herein. For example, the phrase "percentage fruit-set of 40°C fruits" refers to the percent of the total number of flowers per cluster which set berries (seeded and seedless) on vines grown in the phytotron at a daytime (11 AM to 7 PM) temperature of 40°C during the period from two to eight days before bloom to 9 to 14 days after bloom, with the remaining period of berry development and ripening at a daytime temperature of 25°C. Also, the term "significantly different" denotes that the difference between treatment means was significantly different at the 5% level unless otherwise stated.

RESULTS

Experiment 1: Thirty days after bloom, and for the remaining period of fruit development and ripening, size and fresh weight of Cabernet Sauvignon berries held at 25°C daytime temperatures during the bloom-fruit-set period were significantly greater ($P<0.05$) than that of fruits maintained at 32.5°C or higher (Fig. 2). The fresh weight and size of Tokay berries from vines kept at 25°C were also significantly greater than those of fruits held at 32.5°C or higher, between 30 and 65 days after anthesis. However, at the last two sampling dates (Fig. 3), only the 40°C berries weighed less and were appreciably smaller than the 25°C. Fresh weight and size of Cabernet Sauvignon berries held at 32.5 and 35°C during bloom-set did not differ significantly (Fig. 2), nor did weight and size of fruits maintained at 37.5 and 40°C. However, berries held at these latter two temperatures were usually smaller and weighed less than the 32.5 and 35°C fruits. Weight and size of Tokay berries held at 32.5, 35, and 40°C during bloom-set did not differ significantly at any stage of berry development and ripening, although at most sampling dates, the 40°C berries were the smallest and lightest (Fig. 3).

Dry weight per berry is mainly a function of both berry size and level of accumulated sugars. The concentration of soluble solids was usually lowest in the 25°C berries; however, their larger size resulted

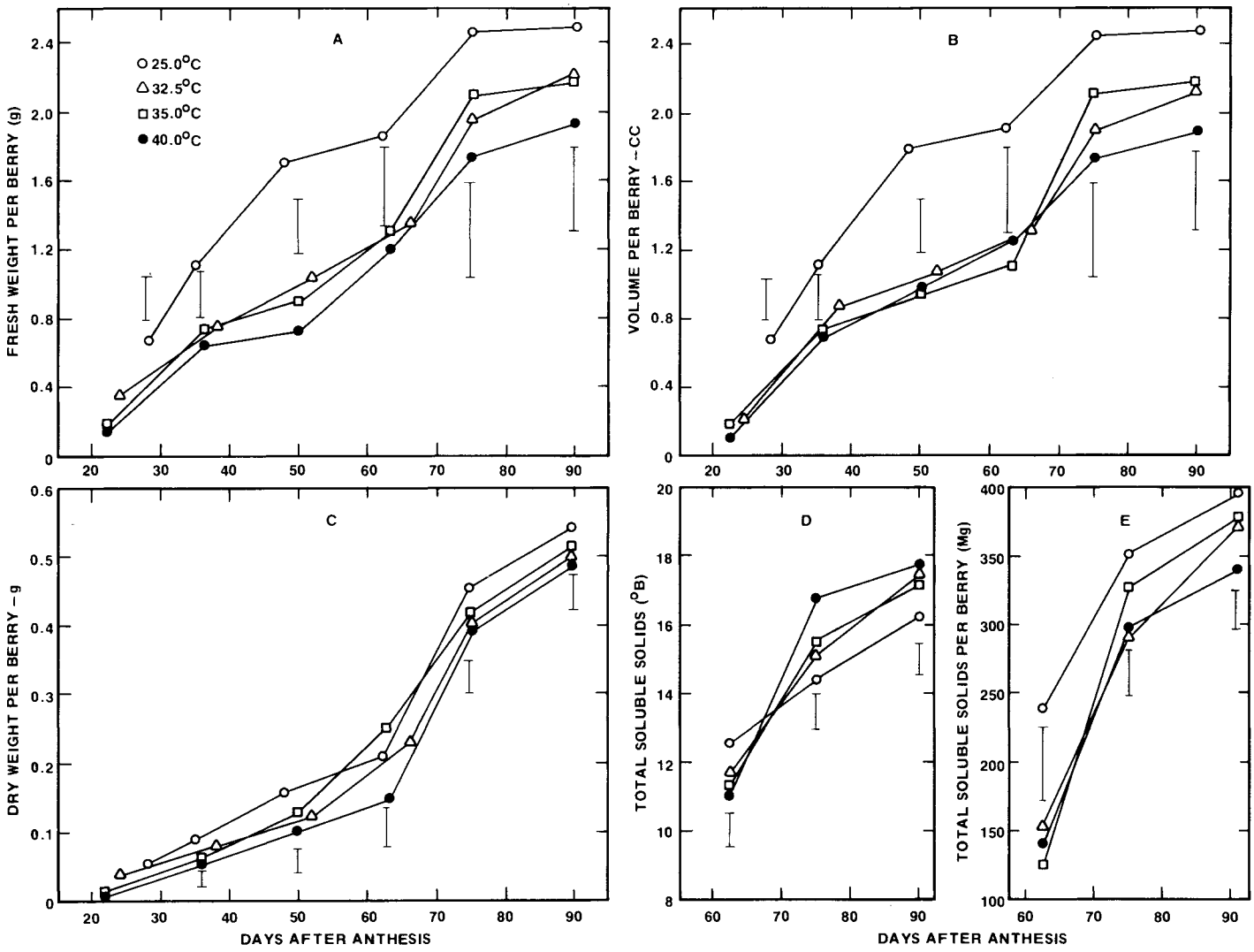

Fig. 3. Influence of high temperatures during bloom and fruit-set on fresh and dry weights per berry, berry volume, level of soluble solids and total amount of soluble solids per berry during fruit development and ripening in Tokay vines.

in their having the highest dry weight and total accumulated soluble solids (Figs. 2,3). At the last sampling date, dry weight and total accumulated soluble solids were signifiantly greater for the 25, 32.5, and 35°C Cabernet Sauvignon berries than for the 37.5 and 40°C berries (Fig. 2). In Tokay, however, only the 25°C berries were higher in soluble solids than were the 40°C fruit (Fig. 3).

Fig. 4 indicates that the larger size of the 25°C Tokay berries than of the 40°C berries was due to a greater number of cells in the pericarp tissue rather than to larger cells. From the fourth through the seventh weeks after anthesis (about the lag period of berry development), the average diameter of pericarp cells was larger for 25°C berries than for 40°C berries. During the second period of rapid berry growth (berry-ripening period), however, there was little difference in size of pericarp cells between 25 and 40°C berries (Fig. 4).

The number of Cabernet Sauvignon berries set per cluster was significantly greater at 25°C than at 35, 37.5, and 40°C (Table 1). At 40°C, the number of berries was about one-fourth that at 25°C, and less than half that at 37.5 and 35°C. The number of berries per cluster did not differ significantly at 32.5, 35, and 37.5°C. Tokay vines held at 40°C during bloom-set had significantly fewer berries per cluster than did vines held at 35, 32.5, or 25°C (which did not differ significantly from each other) (Table 1).

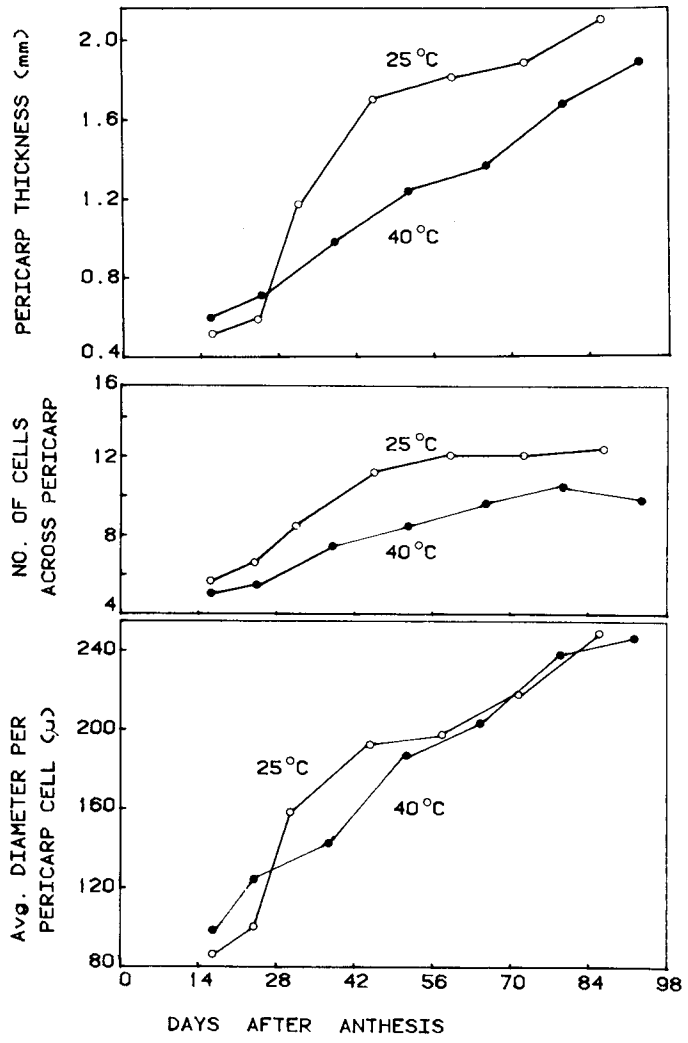

Fig. 4. Changes in pericarp thickness, number of cells across pericarp, and average diameter of pericarp cells in Tokay berries during fruit development and ripening from vines held at 25 or 40°C during bloom and fruit-set.

Experiment 2: The results are presented in Table 2. For both Pinot noir and Carignane, percent fruit-set, percentage of ovules fertilized, and percent of total berries set with one or more seeds per cluster were significantly greater in vines held at 25°C during bloom-set than in vines maintained at 40°C. Fruit-set was also significantly greater at 25°C than at 35°C for both cultivars, although percentage fruit-set at 35°C did not differ significantly from that at 40°C in Pinot noir or Carignane. Percent ovule fertility was also significantly greater at 25°C than at 35°C in Carignane clusters, but not in Pinot noir. In Pinot noir clusters, however, percent ovule fertility and berries with seeds were significantly greater at 35°C than at 40°C (Table 2).

Fresh weight per berry in Carignane vines maintained at 25°C during bloom-set were respectively 37 and 46% heavier at harvest than berries from vines held at 35 and 40°C (Table 2). Berry weight of Pinot noir fruits did not differ significantly among temperature treatments, although the trend was for average berry weight to decrease with increasing temperature (Table 2). The level of soluble solids in berry juice measured about 85 days after anthesis was significantly less in the 40°C fruits than in 25°C fruits of both cultivars. Juice from the 35°C Pinot noir berries also had a lower level of soluble solids than did 25°C fruits, whereas 35 and 40°C fruits did not differ significantly in °Brix.

The rate of shoot growth during bloom-set was considerably greater at 25°C than at 40°C in Carignane, and at both 25 and 35°C in Pinot noir. Regression analysis between rate of shoot growth and percent fruit-set or ovule fertility, over all three temperature treatments, revealed no significant correlation for either cultivar. This indicated that factors other than rate of shoot growth accounted for the reduced fruit-set and ovule fertility at 35 and 40°C.

DISCUSSION

Several workers (6,14,15,20) have reported that temperatures of 32°C or greater during bloom or early stages of berry growth permanently reduce future berry growth and development. In most of those investigations, however, it was not possible to judge from the data whether the differences were statistically significant. In the present investigation, temperature regimes of 32.5, 35, 37.5, and 40°C for 12 hr day (7 AM to 7 PM) for 20 days, beginning shortly before bloom and continuing through berry

shatter, significantly reduced the size of Cabernet Sauvignon berries during the entire period from 4 to 13 weeks after anthesis (Fig. 2). At final harvest, the respective sizes of the 32.5, 35, 37.5, and 40°C Cabernet Sauvignon berries were 22, 36, 49, and 52% less than those of berries held at 25°C daytime temperature. Fresh berry weights were similarly reduced by these high temperatures (Fig. 2). Temperatures of 32.5 to 40°C during bloom-set also markedly reduced the size and weight of Tokay berries. However, reduction in berry growth was most striking during the first 65 days after anthesis; and, at final harvest, only berries held at 40°C were significantly smaller and lighter than control fruits (25°C berries) (Fig. 3). The lack of significant differences between the 25 and 32.5 or 35°C Tokay berries at the last two sampling dates was probably due mainly to the relatively large variability in berry size within clusters, which became greater as the season progressed because there were fewer berries from which to select. The size and weight of Tokay berries grown at 32.5, 35, and 40°C differed relatively little during berry development and ripening. However, Cabernet Sauvignon berries held at 37.5 and 40°C were usually significantly smaller and lighter than fruits grown at 32.5 and 35°C.

Fig. 4 indicates that the fewer cells in the pericarp, not cell size, was mainly responsible for the lower berry volume and weight of Tokay berries grown at 40°C than at 25°C. Harris et al. (8) also reported that the number of cells per berry mainly determined the smaller size of Sultana berries grown in a warm greenhouse than of berries on field vines grown under cooler conditions. Other workers (6,7,8,14,15,18,20) have reported that high temperatures during the early period of fruit development reduced final fruit size. Hale and Buttrose (7) investigated the effect of temperature at different stages of berry development, beginning three weeks after anthesis, on the growth of Cabernet Sauvignon berries. They found that high day/night temperatures presented during the first stage of rapid berry growth, and to a lesser extent during the lag phase (Stage II), irreversibly reduced final berry size. However, high temperatures during the second rapid growth phase (Stage III) had no effect on final berry size. The reduction in berry size caused by high temperature during Stage I could not be reversed by lowering the temperature during Stages II and III. They concluded that, since cell division in grape berries is generally completed within three weeks of anthesis (8,14), the smaller berry size was probably due to effects of temperature on cell enlargement. Kobayashi et al. (14) also reported that the small size of mature Delaware grapes held at a night temperature of 35°C during the early stages of berry enlargement was due mainly to reduced cell size rather than to fewer cells per berry. However, daytime temperatures were not controlled in their experiment.

In seeded grape cultivars, the set of berries is usually dependent on ovule fertilization and seed formation, although some berries may set parthenocarpically (21). As indicated in Table 2, temperatures of 35 and 40°C considerably reduced fruit-set; and, of those berries that did set, the percentage with no seeds was greater than the percentage on vines grown at 25°C (Table 2). Some pollination did occur at 25, 35, and 40°C, but it is not known what percentage of the pollen grains on the stigmas germinated, or whether pollen tube growth was inhibited at the higher temperatures. Kobayashi et al. (15) reported that pollen germination and pollen tube growth on agar media in a humid environment was nearly as good at 35 as at 22 to 25°C in Muscat of Alexandria. In Delaware grapevines, however, pollen germination at 30°C was only about one-third that at 24°C (14). The influence of temperatures higher than 35°C on pollen germination and pollen tube growth has not been investigated, as far as the author is aware. At 35 or 40°C, the supply of organic nutrients available to the ovaries may not be as great as at 25°C, and that may also have contributed to the lower ovule fertility at the higher temperatures. The optimum temperature for photosynthesis in grapevines is within the range of 25 to 30°C (16), the range at which the greatest supply of organic nutrients for pollination and ovule fertilization would also presumably be available. Coombes (4) provided evidence that under "normal" climatic conditions, both ovule fertilization and fruit-set in grapevines are influenced primarily by the supply of organic nutrients to the inflorescence during and after anthesis. It is also possible, however, that at high temperatures of 35 or 40°C during bloom-set, the hormone levels within the flowers or other parts of the vine may be altered and thus contribute to poor set and poor ovule fertility. Iwahori (10) found that exposure of tomato plants to 40°C for 4 hr during 0 to 3 days after anthesis considerably reduced the level of auxin in the fruits. Other hormones greatly affected by thermal stress in plants are abscisic acid and cytokinins (9), and these also may play a role in regulating set and berry growth under high temperature conditions.

Alexander (1) reported that subjecting Thompson Seedless vines to a 3-day period of water stress during the interval from bloom through four weeks resulted in poor fruit-set, whereas water stress imposed six weeks after flowering did not reduce set. In both instances, however, the vines were subjected to a severe water stress, causing several apical leaves to wilt. In a second experiment, Alexander (1) reported that potted vines subjected to a high temperature regime (47 to 64 centigrade-degree-hours above 40°C) during a 3-day period at bloom or one week later did not reduce fruit-set when water was ample. Table 2 reveals that fruit-set was significantly less at 35 or 40°C than at 25°C for both cultivars, in disagreement with findings of Alexander (1). The vines grown at 35 or 40°C were watered twice daily and care was taken to provide sufficient water for

vine growth. Nevertheless, transpiration rates at those temperatures would be very high, and it is possible that the roots were not able to absorb sufficient moisture to offset the loss of water through transpiration during certain times of the day. All the same, no wilting of leaves was visible at any of the three temperature regimes.

Figs. 2 and 3 and Table 2 offer a possible explanation of why years in which excessively high temperature occur during bloom-set are often characterized by poor fruit-set and/or small berry size. Such a "hot spell" occurred in parts of California in the latter half of June, 1976, and several of the late-blooming varieties in the coastal climatic regions had very poor fruit-set and small berries at harvest. Lack of rainfall in 1976 was another important factor affecting vine yields, especially in unirrigated vineyards. Kliewer and Schultz (13) found that sprinkler cooling of grapevines when air temperatures exceeded 30°C between bloom and véraison significantly increased fresh and dry weights of Cardinal, Carignane, and White Riesling berries compared with berries from vines not sprinkler-cooled. Sprinkled berries were generally 5 to 10°C cooler than unsprinkled fruits. In addition to high temperatures and water stress, factors such as overcropping, disease, and mineral deficiency or toxicity can also, of course, greatly affect fruit-set and berry growth.

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