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The Effect of Climatic Conditions on Dormancy Development of Peach Buds. I. Temperature¹

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Abstract. With controlled temperatures low temperature efficiency in releasing peach buds from dormancy follows an optimum curve in which 6°C is the optimum for average lateral leaf buds and 10°C is about half as efficient. "Weighted chilling hours" instead of "chilling hours" was proposed as a chilling measurement criterion. A high temp of 21°C, when alternated daily with low temp, nullified the low temp effect; a high of 18°C had no effect. Interrupting the chilling by 2 separate periods of 11 and 12 days at 20°C did not show any nullifying effect, but greatly enhanced lateral leaf bud break.

Dormancy of buds of woody plants is dependent on winter chilling (3, 4). The effect is cumulative, increasing with the chilling period up to a certain limit, which is genetically controlled in every species or cultivar (12). This is interpreted (3, 22) as the "chilling requirement" of the cultivar. In spite of the awareness of the problem with its commercial applications, no accurate evaluation was performed which could clearly define the efficiency of low temperatures in breaking rest, in deciduous fruit trees. On the other hand, the use of accumulated hr below 45°F was proposed by Weinberger after Hutchins as an index of chilling weather (18, 21).

This index has been used for two purposes: evaluation of the chilling requirement of the cultivar, mainly of stonefruit (18) and evaluation of climates (20). For the first purpose, relative answers are meaningful and are therefore used with old and new cultivars. This is not the case in evaluating the efficiency of a winter climate in breaking the rest of dormant buds. The very good correlation obtained between the number of hr below 45°F and rest breaking of peach buds in Southeastern U.S.A. (20) could not be shown under a different climate in the San Joaquin Valley in California (21) or in Israel (unpublished data). In California mean maxima gave better correlations with length of rest than did low temp with rate of bud opening (21), thus stressing the antagonistic effect of high temp on dormancy development, as shown in pears by Bennett (1) and in peaches by Weinberger (19) and by Overcash and Campbell (8). Naturally, unterminated dormancy creates a commercial problem in countries where high winter temp are frequent.

Another effective climatic factor is light. Early investigators have already mentioned the negative effect of direct sun radiation during the winter and emphasized the beneficial effect of winter shade (1, 22), though the proposed explanation for this shade effect was the reduction in direct sun radiation resulting in lowered bud temp. That light is involved directly in dormancy has been shown by Wareing for various woody forest plants (16, 17) and by Erez et al. (5, 6) for deciduous fruit trees. The special effect of light reduction during winter might introduce the factor of clouds as a third component in the complex of environmental effect on bud dormancy. We report herein laboratory experiments aimed at elucidating the effect of low and high temp on breaking dormancy of peach buds.

Materials and Methods

Excised shoots: Mature shoots 40-50 cm long, of the last season, were collected in the orchard. The terminal 5-10 cm section was cut and the wound was rinsed for one hr in tap water. The shoots were then packed in damp vermiculite in cardboard containers and chilled in an upright position. After termination of the chilling period, the basal cuts of the shoots were renewed and they were put, 12 to a group, into 400-ml beakers with their bases submerged in distilled water, and transferred to forcing conditions.

Whole plants: One-year-old well-developed peach plants were taken from the nursery in early autumn, planted in 4-gal tin containers and kept outdoors in Bet Dagan, Israel (32° N latitude) until the start of the experiment. The temp during this period did not drop below 10°C. Six plants each bearing about 130 lateral buds and about 16 terminal buds were used per treatment.

Controlled environment conditions: All the experiments were carried out in temperature-controlled rooms (accuracy $\pm 1^\circ\text{C}$). Chilling was always applied in the dark. When a fluctuating temp regime was followed, an automatic arrangement operating on 2 timers was used to cut off the chilling unit and start the heating system. Heating was supplied by a 2-kilowatt "Zephyr" heating fan which was controlled thermostatically (accuracy $\pm 1^\circ\text{C}$). The temp-changing pattern in a daily cycle is shown in Fig. 1.

Opening of leaf buds was examined after a period at 23°C or

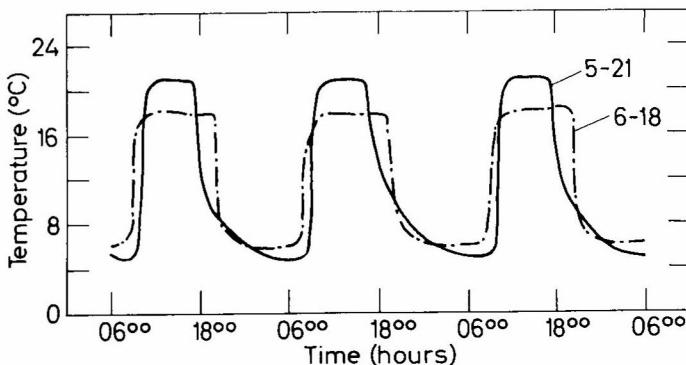


Fig. 1. The diurnal change in temp in the 2 daily cyclic treatments.

25°C in a 16- or 24-hr photoperiod. Cool white fluorescent tubes were the light source, with an intensity of about 10,000 lux at mean plant height. The water table was checked throughout the experimental period. Results are given as mean bud opening in percent (\pm standard error).

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Results

Preliminary experiments on chilling requirements were performed on last-season's mature shoots which were chilled in the dark for varying periods of time and forced at 25°C in light. Typical results for leaf bud opening of 'Elberta' peach shoots after different chilling periods are shown in Fig. 2. Bud

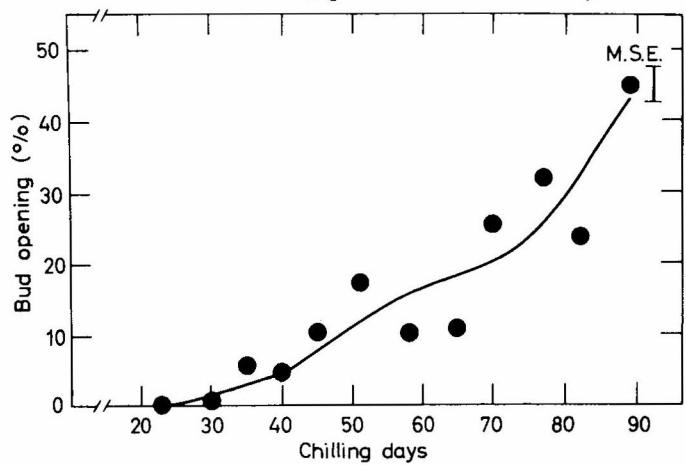


Fig. 2. Leaf bud opening on 'Elberta' shoots after 21 forcing days at 25°C as affected by increasing periods of chilling at 6°C. (M.S.E. = Mean Standard Error).

opening increased steeply only after about 67 chilling days during which more than 1600 chilling hr had accumulated. The chilling requirement of 'Elberta' leaf buds, as measured in the orchard (sum of hr below 7.2°C), reached 950 chilling hr (18) compared with the 1600 hr in the cold room.

The considerable difference between controlled and orchard conditions may be due to one or several causes: (a) Temperatures higher than 7.2°C may also be effective; (b) constant temperatures under controlled conditions may have an effect different from that of natural cyclic temperatures in the open; (c) excised shoots may not behave in the same way as whole plants; and (d) in the open, other environmental factors may modify the effect of low temp. We have tested the first 2 possibilities, as reported below. To avoid the third possibility, whole intact plants were used in all following experiments and our results involved leaf buds only.

In order to examine the rest-breaking effect of different temperatures, one-year-old potted 'Early-Red-Fre' peaches were placed in groups of 6 into dark chambers with different constant temperatures for 30 days. Then the plants were transferred to 23°C under 16 hr daily light. While temperatures below 6°C in most cases showed an effect similar to that of 6°C, chilling efficiency gradually fell to about one half with a rise in temp from 6° to 10°C (Fig. 3). Bud opening, as affected by chilling temperature, followed an optimum pattern, rather than the break of a threshold function. Maximum rest-breaking efficiency was found at 8°C for terminal buds and at 6°C for lateral buds. Lateral buds on lateral shoots exhibited an increased effect of an even lower temp (3°C), especially after a longer forcing period (Fig. 3, B, C). Unfortunately, no results are available for temperatures below 3°C which would enable us to determine the nature of this curve. The efficiency of different chilling temperatures, relative to the optimum at 6°C, is shown in Table 1, based on the avg results obtained for the 2 types of lateral buds after 4 weeks of forcing. In subsequent experiments, the amount of chilling applied was calculated by adding to the number of hr at 6°C those below 6°C and those between 6° and 10°C, as adjusted for their rest-breaking efficiency by means of these coefficients (weighted chilling hr).

The effect of constant and alternating chilling was examined on one-year-old intact 'Redhaven' plants. Opening of lateral leaf

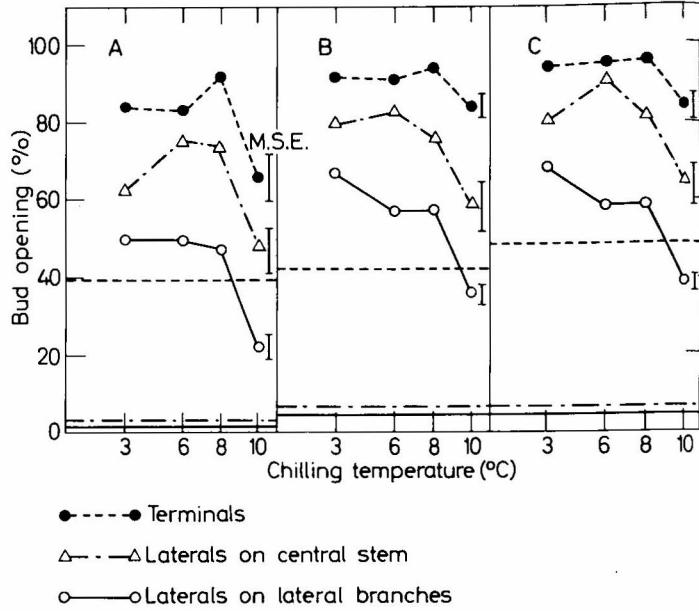


Fig. 3. Bud opening after 28(A), 38(B), and 49(C) forcing days at 23°C of 'Early Red Fre' peach buds from 1-year-old potted plants chilled in the dark for 36 days. The level of bud opening on control plants kept at 22°C is indicated by the horizontal lines.

Table 1. The efficiency of different low temp in breaking the rest of the 'Early-Red-Fre' peach. (Avg lateral bud opening after 28 forcing days.)

Temp (°C)	%	Bud opening relative to 6°C
3	55	0.9
6	62	1.0
8	55	0.9
10	30	0.5

buds after 21 days in the light was plotted against chilling hr (Fig. 4). The advantage due to alternating chilling on the threshold basis (A) disappears when the amount of chilling is

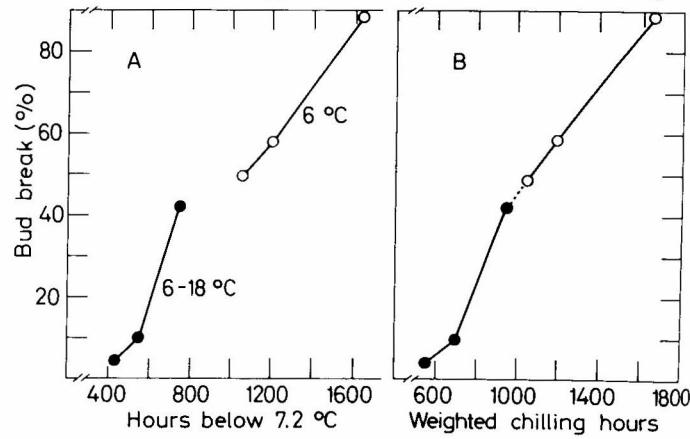


Fig. 4. The effect of different amounts of continuous and intermittent chilling on leaf bud break of the 'Redhaven' peach. One-year-old plants kept in the dark during chilling at continuous 6°C or in a daily cycle of 6° - 18°C, and for 23 days of forcing conditions continuously at 23°C under a 16-hr photoperiod. Chilling hr were calculated A - below the threshold value of 7.2°C and B - as weighted chilling hr.

calculated according to total number of weighted chilling hr (B). A nearly linear increase in bud opening, according to chilling hr, was observed no matter which chilling system was used. It might thus be concluded that chilling expresses a similar effect

whether applied continuously or alternately. No negative effect of temperatures as high as 18°C could be distinguished.

The similar efficiencies of continuous and intermittent chilling systems in 'Redhaven' are contradictory to results reported in the literature. It therefore seemed desirable to examine this point further. An experiment was set up with one-year-old 'Redhaven' plants in containers. Three groups of plants (6 plants each) were exposed to one of the following treatments: (a) Continuous chilling at 6°C; (b) chilling at 6°C interrupted by high temp of 20°C for 2 periods of 11-12 days each (for details, see Table 2); and (c) intermittent chilling with a regular daily temp cycle. Darkness was maintained throughout

Table 2. Effect of constant and interrupted chilling on leaf bud opening of the 'Redhaven' peach. (Bud opening after 29 forcing days in the light; chilling given in the dark.)

Chilling treatment	Temp regime	Weighted chilling hr	Bud opening (% \pm S.E.)
	Days °C		laterals terminals
Continuous	26 } 12-18	1200	
	50 } 6	1200	57.5 \pm 5.3 99.0 \pm 1.0
Intermittent (long period)	38 } 20		
	12 } 6	1200	81.1 \pm 3.6 97.2 \pm 1.8
	7 } 20		
	11 } 6	1200	
Intermittent (Daily cycle)	75 5-21	1000	6.3 \pm 0.8 76.3 \pm 5.7
	66* 6-18	740	42.0 \pm 6.5 61.8 \pm 2.6

*Results from Fig. 4.

the chilling period in all the treatments. The experiment was so designed that all treatments ended on the same day. The plants were then transferred to forcing conditions at 23°C with a 16-hr photoperiod.

The intermittent daily cycle affected lateral leaf bud opening in opposite ways according to the degree of the high temp given. (Table 2). When the high temp did not exceed 18°C a good rate of leaf bud opening was observed which was in linear proportion to the number of weighted chilling hr given (Fig. 4B) without interference of the high temp in the daily cycle. However, when the high temp reached 21°C there was an almost complete disappearance of the chilling effect in spite of the total higher number of chilling hr (1000 vs. 740). Thus, it seems that the negative activity of high temperatures increases steeply between 18 and 21°C.

When the chilling was interrupted by long periods of high temperatures, lateral bud opening was enhanced in comparison with the continuous chilling treatment with the same number of chilling hr.

The extreme high temp in the 5-21°C daily cycle chilling system was only 1 degree higher than in the alternating long period chilling system. Nevertheless, it seems that the cycle in itself is the major cause of the inverted response, i.e., high temp of 20-21°C, when alternated in a 24-hr cycle with chilling, acts antagonistically to chilling, but not when applied during continuous long periods. Terminal leaf buds did not show any difference between continuous and 'long-period-intermittent' chilling. The considerably lower rate of bud opening found in the daily cycle intermittent chilling systems might result from the lower total number of weighted chilling hr given.

Discussion

Our results show that temperatures above 45°F (7.2°C) have restbreaking ability. This makes the use of 45°F as a limit below which hr of chilling are accumulated (18, 20) questionable. Lateral leaf bud burst of peach after forcing increased with descending chilling temperatures from about 11° (extrapolation of the curve in Fig. 3) to 6°C, at which point a maximum response was obtained. With lower temperatures a slow decrease

in efficiency seems to take place with certain bud types. Such a decrease in efficiency in temperatures approaching freezing was reported by Sudakevitch with various stone-fruit trees (13), and by Lamb with raspberries (7), and was also mentioned in Chandler's book (2). Thus, for cumulative chilling exposure, corrected weighted values must be used for the less than max effective temp, whose participation in the cumulative chilling hr is indispensable. As temp between 10° and 6°C are very common in countries with mild winters, we propose the use of "weighted chilling hr" instead of the generally employed term "chilling hr."

A daily cycle of low and high temperatures (up to 18°C) with an intact plant, when calculated on a weighted chilling hr basis, had an effect similar to that of continuous chilling on leaf bud opening. This finding does not agree with ideas reviewed by Vegis (14) that "even a moderate rise in temperature at an early stage of post dormancy can induce secondary dormancy." However, such a situation was found when the high temp in the daily cycle reached 21°C. To our knowledge, no careful systematic work has been done on the results of exposure to various high temperatures. However, high temperatures (15 to 23°C) during winter were shown to antagonize the dormancy-release effect of low temperatures (1, 8, 14, 19). Bennett (1) reduced the rate of bud opening of pears by exposing plants to high temperatures in a daily cycle. When the temp reached 22.7°C only 29% bud burst was observed, as compared with 50% when the warm period had an avg high temp of 17.7°C, and with 72% in uninterrupted chilling. The relatively strong inhibition found with a 17.7°C avg high temp might result from temperatures higher than the avg. Weinberger (19) showed a reduction of 33% in the leaf bud opening of peaches when the avg temp was raised for 15 days from 10-12°C to 18°C. However, when the avg temp was raised for the same period to 22.2°C, bud opening was reduced by 83%.

The relatively small difference in the high temp between the non-active 18°C and the very active 21°C is similar to the sharp change in efficiency of low temperatures in the range between 11° and 6°C. High temperatures over 21°C occur in Israel during winter and early spring mainly on bright sunny days, especially in the southern drier regions, where cloudy and rainy days are few. Bark and bud temperatures of sun-irradiated trees were found to rise frequently above 21°C at mid-day even in January.

When chilling was interrupted by periods of 11 to 12 days of high (20°C) temperatures, no antagonistic effect between the two could be observed. On the contrary, an enhancing effect over the uninterrupted chilling treatment was evident. The explanation for this phenomenon seems to be connected with the cycle length. The chilling effect is susceptible to an antagonistic high temp effect only for a limited period after cooling is applied. This period seems to be of a few days' duration, after which a fixation process prevents reversal. Such an explanation fits the findings of Pollock (9), who showed that the inhibiting effect of high temperatures on the growth of unchilled peach embryos lasted for only 8 or 9 days, and the work of Purvis and Gregory on vernalization of Petkus rye (11), which suggested a temperature-dependent fixation process of chilling.

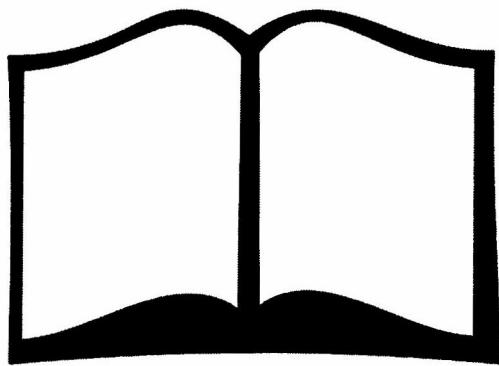
Thus, every formula which tries to establish the effect of winter temp on expected bud opening of deciduous trees must take into consideration low and high temperatures. Mean avg temp for the cold months, as suggested for example by de Villiers (15), seems to be unsatisfactory, as the change in the effect of temp in the low and high ranges is steep and the extremes, not the avg temperatures, are the decisive factors. Before an absolute criterion for the effect of temp on the dormant bud can be suggested, it is essential to carry out a careful study of the negative quantitative effect of high temperatures in a daily cycle on the chilling influence.

We emphasize the striking similarity between the effect of temp on bud dormancy and on vernalization. In both cases chilling effect follows an optimum type of curve with its peak above zero. Slightly higher temperatures are neutral in effect but still higher ones — around 20°C or more — negate the chilling effect and induce devernalization or secondary dormancy. Both phenomena are readily reversible by low temperatures (10).

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