A STUDY OF THE CORRELATION BETWEEN ARTIFICIAL FREEZING TESTS AND OBSERVED VARIETAL DIFFERENCES IN TOLERANCE TO FREEZING AT BLOSSOM TIME OF PEACH AND NECTARINE FLOWER BUDS

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Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in candidacy for the degree of

MASTER OF SCIENCE

in

Horticulture

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May, 1957

Blacksburg, Virginia

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INTRODUCTION

The southern limit of peach culture is determined by the amount of sufficiently cold weather which occurs during the winter. The peach needs a certain amount of cold, called the chilling requirement, in order to break its dormancy. Although an average temperature of 48^{o} F. will break the dormancy, lower temperatures speed the process. The varieties generally in use in the United States are ones which have medium or high chilling requirements. Those with the lowest requirements need about 750 hours of temperatures below 45^{o} to break their dormancy. (43, 44) For this reason it is not possible to grow peaches in climates where they will not be subjected to below-freezing temperatures.

In many areas where the peach is grown, particularly in the south, the periods of cold alternate with periods of mild weather during the winter and spring. Although temperatures seldom get low enough to kill the hardened tissues, a frequent cause of crop failure in these areas and more northern ones is late spring frosts that come at or near the time of blooming. It is at this stage of development that the buds are most sensitive to freezing temperatures. They have lost most of their hardiness due to periods of mild temperatures and have begun active growth. Few peaches are grown around the Blacksburg area due to the frequency of damaging late spring frosts, a frequent phenomenon in mountainous areas.

Observations in variety test orchards at Blacksburg and elsewhere have shown that there are varietal differences in tolerance to freezing at blossom time. In some years the frosts are of such an intensity and occur at such a time that unmistakable varietal differences in tolerance are apparent. These are called test years. However, some years no frost occurs during the blossoming season and other years the frost may be so severe that all varieties are completely killed, as occurred at Blacksburg in 1949. To breed for the desirable high degree of frost tolerance in peaches and nectarines, it would facilitate the program if it were possible to discard the less tolerant progeny without waiting for a test year to occur. If seedlings could be tested by freezing artificially and selected on this basis, the breeding program could be speeded considerably.

The purpose of this study is to determine if the performance of samples in an artificial freezing test shows the same varietal relationship as has been observed after natural spring frosts in the field, and to postulate whether this would be a valid basis for selection of progeny tolerant to spring frosts without waiting for a test year to occur naturally.

II

REVIEW OF LITERATURE

The hardiness of plants is a subject on which many workers have spent considerable time. Of particular interest have been the perennial fruits. The peach has ranked high in interest because it is subjected to occasional cold injury of some type or degree in almost all areas where it is grown. Whether or not freezing temperatures cause injury is determined by several factors.

Excellent reviews may be found in Chandler (12, 13) and Levitt (28, 29). An extensive bibliography of work done before 1935 may be found in Harvey (22).

Different parts of plants have been found to vary in their resistance to cold. Carrier (9) found that, in the Frau Karl Druschki rose, the area of the current season's growth between the terminal and basal six inches of the stem was the hardiest. The bud union was the least hardy. Potter (36) and Howard (24) found that the scion roots of apple were hardier than stock roots. The roots were more tender than the tops. Potter (37) also found that the tender tissues were the base of the trunk, the crotches, the spiral elements of the xylem, the sapwood, and the flower buds. More hardy tissues were the cambium and leaf buds.

Drying of the tissues is another factor that affects hardiness. Chandler (12) found that peach branches cut off and left hanging in the tree showed only 38.5 per cent killing of the buds as compared to

73.7 per cent for buds remaining on the tree. Potter (36) found that a five per cent loss of moisture in apple roots was followed by nearly fifty per cent reduction in the amount of injury from freezing.

The amount of fertilizer applied affects the injury through its effects on the relative vigor and maturity of the trees. Weak trees are less hardy and their hardiness can be increased by fertilizer applications as reported by Cullinan (16). Already vigorous trees lose hardiness after increased nitrogen applications as reported by Burrell and Boynton (7), Carrier (9), Crane (15), and Way (42). They found that, generally, the buds on nitrogen-fertilized trees matured later in the fall and developed more rapidly during the winter. Shear (40) found that deficiencies of zinc, copper, magnesium, and potassium increased cold injury to tung trees. An excess of zinc decreased injury.

The rate of temperature fall has also been found to affect the degree of injury. Potter (37), Hildreth (23), Meader et al. (31), and Scott and Cullinan (39) all found that a rapid fall produced more injury. Brierly (5) uncovered some branches of Haralson apple trees from the snow so that their temperature fell from 25^{o} to 0^{o} in two or three hours. These showed injury while branches which were exposed and had been subjected to 0^{o} slowly in the open showed none. Scott and Cullinan (39) found that, in artificial freezing tests with Elberta, Belle, and Greensboro peaches, a rate of 8^{o} Fahrenheit per hour gave about twice as much killing of the buds as 5.4^{o} per hour.

The duration at the minimum temperature also affects the injury. Scott and Cullinan (39) found that a large percentage of buds was killed the first few hours at the minimum temperature with more being killed as the duration increases. Elberta, after artificial freezing to -7° F. on January 20, showed 38.5 per cent bud survival when removed immediately from the freezing chamber, and only one per cent survival when removed after thirteen hours at this temperature.

Chandler (12) stated that the greatest factor in determining cold resistance was the maturity of the tissues. This accompanies development of a rest period and dormancy in late summer and autumn. Growth stops and activity is reduced. The development of the rest period is associated with the accumulation of carbohydrates. A reduction in carbohydrates reduces the hardiness of the tissues. A heavy crop, or one which is allowed to hang on the tree very late, will reduce hardiness, as reported by Chandler (11), Edgerton and Hoffman (20), and Way (42). A reduction of foliage due to summer pruning as reported by Crane (15) or by disease as reported by Kennard (26) will have the same effect. Reduction of carbohydrates is also the reason why the bottoms of horizontal branches and the insides of upright crotches are more tender (23). There is less carbohydrate accumulation on the sides of branches connected to shaded and less photosynthetically active leaves.

The factor of maturity fluctuates during the year. The buds progress from a very tender state just after they are formed in July to a high degree of hardiness in mid winter (12). They then lose their hardiness until at blossom time they withstand very little freezing. At any time during the frost season, the hardiness is greatly affected by the temperatures just preceding as has been shown by Angelo (2), Brierly et al. (6), Chaplin (14), Cullinan and Weinberger (17), Edgerton (19), Meader and Blake (30), Meader et al. (31), and Scott and Cullinan (39). A few days of high temperatures produce a reduction of hardiness which may be regained after a few days of lower temperatures. Thus the loss of hardiness in the spring is due to a warming trend with a resultant increase in activity of the tissues. The most tender time in the development is at the shuck-split stage when 26° Fahrenheit is about the lowest the young fruit can stand (21). Chaplin (14) recorded 50 per cent kill of Elberta blossoms with a temperature of 25° in an artificial test at the time of full bloom. He reported that differences in the degree of hardiness among varieties are not as great at this period of development, although the varieties remain in the same relative positions.

The earliest artificial freezing tests were conducted with ice and salt mixtures as used by Allen (1), Carrick (8), Chandler (12), Howard (24), and Mix (32). This method is not automatic and must be carefully watched to maintain the desired rates of fall and minimum temperatures. Potter (35, 36) used a salt and ice mixture with the rate of fall controlled automatically. He used a clock mechanism which had one arm of a lever follow a preset lead bar, and the other attached to the contact point of a mercury thermostat, which controlled an electric heater in the freezing chamber.

Hildreth (23) designed a freezing chamber cooled by an ammonia compressor. He achieved temperatures to -40° Centrigrade with a fluctuation of plus or minus 1° C. The rate of fall was about 5° C. per hour. This is faster than might be desired for a test simulating natural conditions.

Cullinan and Weinberger (17) used a refrigerator for their freezing tests. They experienced difficulty in controlling the rate of temperature fall, and, therefore, placed the buds in the freezer and allowed the temperature to fall to the minimum for which it was set.

Smith and Potter (41) described a system to control the temperature change. A beam of light connected to the thermostat shone on a photoelectric cell which controlled the freezer. By moving the photoelectric cell with an electric motor, the rate of fall or rise could be kept constant.

Meader et al. (31) described an apparatus for controlling the rate of temperature fall. They placed the twigs in glass tubes weighted with lead shot and floated them in a solution of fifty per cent alcohol. With the same size sample, the rate of fall could be closely duplicated if the specific gravity and volume of the antifreeze solution, the starting temperature, and the thermostat setting were kept the same.

Scott and Cullinan (39) used a cartridge heater inside the freezing cabinet to control the rate of fall. They also used an alcohol bath. They obtained a rate of fall of 5.5^{o} F. per hour with the heater as compared to 10^{o} per hour without it on different days. With the bath, in the same test, they obtained a rate of 5.5^{o} per hour in it as compared to 8^{o} per hour outside it. Chaplin (14) used a home freezer unit with a thermostat sensitive to a 3^{o} change. He reported that it had to be watched closely to see that the temperature dropped at a uniform rate. Edgerton (19) used a bath to lower the temperature 2^{o} per hour.

III

EXPERIMENTAL PROCEDURE

An International Harvester standard food freezer, as shown in Figure 1, was used in the tests. The thermostat, normally set for 0° Fahrenheit, was set for -20° in order to obtain temperatures thought necessary to produce killing of the buds in the middle of winter. The rate of temperature fall was controlled by a Time-O-Matic time clock, shown at the left of Figure 1, which could be set for various 'on' and 'off' periods. The time clock could also be adjusted for the length of the cycle. It was found necessary to use several settings of the time clock in order to maintain a continuous rate of fall below about 15°. If left at one setting, the temperature either fell too fast at the beginning of the test or too slowly or not at all at the lower ranges. For this reason, it was difficult to maintain a constant rate of fall to the minimum desired. It was found that the time clock did not always switch off when set to do so because the switch arm did not move far enough, but some cellophane tape wrapped around the arm caused it to move farther and switch off at the proper time. The air in the freezer was prevented from stratifying by a six-volt auto fan, which was directed down and toward the side of the cabinet in order not to blow directly on the twigs. The temperature in the freezer was recorded constantly by a Moeller recording thermometer and checked by a minimum thermometer in the freezer next to the bulb of the recording thermometer, both of which are visible on the rack to the left of Figure 1. All temperature readings are given in degrees Fahrenheit.

The samples were set on the racks as shown in Figure 1. Twigs that were small enough were placed in the baskets.

Figure 1. Apparatus used for freezing peach and nectarine buds.

Four varieties of peaches and two varieties of nectarines were used in the trials. They were selected as representative of hardy and tender varieties. The tender varieties of peach were Elberta and Sunhigh. The hardy varieties were Veteran and Redhaven. Garden State was selected as the tender nectarine variety and Cavalier as the hardy one. The tenderness of Elberta as compared with other varieties has been often noted. (4, 12, 14, 25, 31, 33, 34, 38, 39) Scott and Cullinan (38) found that Elberta had a light crop after 24° at blossom time, while Veteran bore a heavy crop after 23° in another part of the orchard. Scott and Cullinan (39) also found Veteran to be appreciably hardier than Elberta and Garden State nectarine after artificial freezing tests in January. Blake, the originator of the variety, and Edgerton (3) reported that the dormant fruit buds of Garden State were even more tender than those of Elberta. Joley and Bradford (25) reported Redhaven showed less killing than Elberta after -17° in the field in December 1942. Oberle and Moore (34) reported the effects of a series of frosts occurring during and after blooming time at Blacksburg, Virginia in 1950. Full bloom was about April 3 - 4. Temperatures below freezing were 24° on April 7, 31° on April 8, 28° on April 13, 24° on April 14, 18° on April 15, 28° on April 16, 23° on April 17 and 26° on April 22. They reported that Elberta and Sunhigh bore no crop at all, while Redhaven required thinning and Veteran heavy thinning. Oberle (33) reported the effects of some other late spring frosts at Blacksburg in 1953. Temperatures of 27° and 28° occurred on April 20 and 22 after shuck-split had occurred on April 19.

Sunhigh, after a medium bloom, required no thinning, and produced a light crop. Garden State had a light crop after a very heavy bloom and no thinning. Elberta produced a medium crop after a very heavy bloom and no thinning. Redhaven, Veteran, and Cavalier all produced heavy crops, with Redhaven and Veteran requiring heavy thinning. All had had heavy bloom production except Cavalier, which had had a medium bloom.

For use in this test the most vigorous tree of each variety was selected from those available in the peach variety test orchard at the experiment station farm about six miles south of Blacksburg. As far as possible, the twigs selected for the samples were vigorous ones from the outside and top of the tree. Due to the difference in the habit of growth, the twigs selected from the Redhaven tree were not as long and did not have as long internodes as those from the other varieties. As the season advanced, some of the trees became depleted of the most desirable twigs and the samples had to be composed of the best twigs available. One-year-old twigs of medium length and diameter and with few or no branches were used in each instance. In the early tests enough twigs were used to give a sample of 150 to 200 buds for each variety, the number found by Scott and Cullinan (39) to give satisfactory results. When the weather became too unpleasant to estimate the number of buds on the twigs in the field, it was decided to use a sample of ten twigs of each variety. In nearly every case, this provided at least 150 buds for each test, although the number varied greatly due to differences in bud set and killing due to the freeze on March 4.

The samples were gathered in the morning in nearly every case and placed immediately in the freezer, which had been precooled and then allowed to warm to about 40°. Tests which did not conform to these and the following specifications will be noted later. When the temperature had reached the minimum thought to be necessary to give a satisfactory differential percentage of bud kill, the freezer and fan were turned off and the freezer allowed to warm up with the cover closed. The fan was turned off because the heat it produced caused the temperature to rise very rapidly. This warming occurred at a rate of about ten to fifteen degrees per hour. The twigs were removed from the freezer when they had reached 45° to 50° and the cut ends placed in a beaker of water. In order for the dead tissues to turn brown, an interval of about thirty-six hours was allowed between their removal from the freezer and the determination of injury, although the interval was shortened as the buds advanced. It was found that, as blossom time approached, the buds developed faster and the dead ones became soft and difficult to cut, with some beginning to abscise, if allowed to remain too long in water before being sectioned. The method used to determine whether a bud was dead or alive was to slice it longitudinally through the pistil with a razor blade. The buds with brown pistils were considered to be dead, while those with green pistils were considered to be alive. This method was used by Chaplin

(14), Cullinan and Weinberger (17), Edgerton (19), and Meader and Blake (30). It was chosen by Scott and Cullinan (39) as preferable to exosmosis of salts as determined by electrical conductance because of the lack of agreement in the latter method with visually determined differences in bud kill, the large variation in conductance readings between samplings, and the fact that the method took more time than anticipated. In the last test, on April 10, the calyx, petals, and stamens were removed, as in emasculation, in order to expose the pistil.

Fourteen trials in all were run, from the time of leaf fall until the trees were in blossom. Trials were run on November 16, December 5, December 19, January 4, January 17, February 7, February 9, February 12, February 21, February 28, March 7, March 15, March 29, and April 10. The minimum temperature used in each test was determined by estimating what the buds might stand after taking into account the performance on the last test and the field temperatures between the two tests. The field temperatures were recorded at a station about 150 to 200 yards from the sites of the trees.

The results were tested for significance by the New Multiple Range Test as given by Duncan (18) and extended by Kramer (27). This test divides the varieties into groups which are significantly different from one another after an analysis of variance has established that there is significance present in the test.

IV

PRESENTATION OF RESULTS

The first test was run on November 16. At this time leaf fall had nearly been completed, with only a very few leaves left on the tips of the twigs. The previous ten days had had a mean temperature of 47.2° with a minimum of 27° on November 13. The last two days of this period had turned warm again with readings of 72° and 72.5° on November 14 and 15. The previously determined time clock settings did not function as anticipated and the rate of fall was irregular. The samples were put in the freezer at 50°, but did not fall to 32° until six hours later. The rate was fairly regular for the next fourteen hours when the temperature had reached 17°. The setting was then changed and the temperature fell to 3° in four hours. A new setting was made and the temperature rose to 27° in four hours. The next setting caused the temperature to fall to 0° in seven hours, when the setting was again changed. After fourteen hours the temperature had levelled off at -11°. The time clock was then removed and the temperature fell to -20° in five hours. The maximum rate of cooling was 12° in one hour from 27° to 15°. The average rate was 1.4° per hour. When the temperature had reached -20°, the freezer was turned off and allowed to warm to 50°, which it did in four hours with the fan on. When the buds were sectioned, it was found that none were alive.

The second test was run on December 5. The mean temperature for the previous seven days was 41.4°. The minimum temperature since the last test was 6° on November 25, which subsequently turned out to be the low temperature of the winter. The minimum temperature within the last seven days was 23.5° on December 2 and the maxima were 62° and 68° on December 3 and 4. The samples were placed in the freezer at 39° and allowed to cool at a rate such that, after twenty-three hours, they had reached -15°. The maximum rate of cooling was 17° in one hour from 39° to 22°. The average rate for the test was 2.3° per hour. The samples were then allowed to warm to 50° over a period of five hours. When these buds were sectioned, no lives ones were found.

The third test was run on December 19. The mean temperature for the previous seven days was 48.1°, with a minimum of 21° on the morning the buds were collected being the only temperature below freezing during this period. The high was 65° on December 16. The buds were collected at 2 P.M. and placed in the freezer at 45°. The time clock was not working properly and the temperature fell to 7° in two hours after which it leveled off at 12°. The clock was then reset and the subsequent settings gave the desired gradual lowering from 12° to -10° in twelve hours. After the clock was reset, the average rate of fall was 1.9° per hour. The twigs were removed when they had warmed to 60° after five hours. This was the first test in which any live buds were found after the test. Redhaven showed 4.6 per cent alive, which were eight out of the thirteen buds on one twig. All other buds were dead. It was decided to use the -10° F. range for future tests until the buds began to show a loss of hardiness on the assumption that the buds would gain some additional hardiness with continuing cold weather.

The fourth test was on January 4. The previous week had been cold with a mean of 32.6°, a minimum of 7.5° on January 3, and a maximum of 55° on December 31. The samples were placed in the freezer at 38° and reached -9° after a period of fourteen hours. This gave an average rate of fall of 3.3° per hour with a maximum rate of 8° per hour after each new clock setting. They remained at approximately this temperature for nine hours, reaching -11° in this period. They were then allowed to warm to 40° over a five hour period and removed. The results of this test are shown in Table 1. As tested by the New Multiple Range Test, Veteran and Redhaven were significantly hardier than all other varieties at the one per cent level. Cavalier and Elberta were significantly hardier than Garden State. At the five per cent level, Cavalier was also significantly hardier than Sunhigh. Had these degrees of killing occurred in the field, Veteran and Redhaven would probably have had a full crop; Cavalier, Elberta, and Sunhigh a partial crop; and Garden State nearly no crop.

The test of January 17 followed a period of even colder weather, with a mean temperature of 30.4° for the previous seven days. The minimum was 6.5° the morning the buds were collected, and 13.5° on January 15. The maximum was 62° on January 10. The two days before the test were particularly cold, with high temperatures of 25.5° and 29° and lows of 13.5° and 15.5°. The samples were placed in the

Table 1. Injury to peach and nectarine blossom buds resulting from test of January 4. Buds frozen to -11° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Veteran	174	85	89	48.9
2. Redhaven	145	55	90	37.9
3. Cavalier	291	43	248	14.8
4. Elberta	184	20	164	10.9
5. Sunhigh	159	10	149	6.3
6. Garden State	169	3	166	1.8

Table 2. Injury to peach and nectarine blossom buds resulting from test of January 17. Buds frozen to -14° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Veteran	149	38	111	25.5
2. Redhaven	84	9	75	10.7
3. Cavalier	211	19	192	9.0
4. Sunhigh	148	0	148	0.0
5. Elberta	171	0	171	0.0
6. Garden State	162	0	162	0.0

Table 3. Injury to peach and nectarine blossom buds resulting from test of February 7. Buds frozen to -8° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Elberta	75	2	73	2.7
2. Cavalier	119	2	117	1.7
3. Veteran	146	2	144	1.4
4. Redhaven	76	1	75	1.3
5. Sunhigh	91	0	91	0.0
6. Garden State	45	0	45	0.0

freezer at 38° and cooled slowly over a period of fifteen hours to -14°. The maximum rate of fall was 10° per hour from 38° to 28°. The average rate was 3.5° per hour. They remained at -14° plus or minus one degree for eight hours, when they were allowed to warm for five hours and removed at 37°. The results of this test are shown in Table 2. The New Multiple Range Test showed that Veteran was significantly hardier than the other varieties at the one per cent level. Cavalier and Redhaven were significantly hardier than Sunhigh, Elberta, and Garden State, also. At the five per cent level, Cavalier was also significantly hardier than Redhaven. Had these amounts of killing occurred in the field, there would have been no crop on Garden State, Elberta, and Sunhigh, probably a partial crop on Redhaven and Cavalier, and a full crop on Veteran.

The test of February 7 followed a period of milder weather with a mean of 45.4° for the previous seven days, minima of 33° on February 2 and 6, and a maximum of 61° on February 4. Some development of the buds was noticeable, many showing yellow anthers when sectioned. Accordingly, the minimum temperature for the test was raised to -8°, which was reached sixteen hours after the buds had been placed in the freezer at 44°. The maximum rate of fall was 17° per hour from 44° to 27° and the average rate was 3.25° per hour. They were allowed to begin warming immediately, and were removed and placed in water after five hours, when they had reached 42°. The results of this test are shown in Table 3. Even with the higher minimum, nearly all the buds were killed. The results were not tested for signicance due to the very small number of buds remaining alive.

Another test was run of February 9 as soon as it was seen that nearly all the buds were dead in the previous test. The two intervening days had moderate temperatures, with maxima of 49° and 49°, and minima of 42° and 36°. It was cloudy and raining. There was probably little change in the hardiness of the buds. The samples were placed in the freezer at 47°. The time clock did not work properly. In slightly more than an hour, the temperature had fallen to 18°. It then fell slowly during the next ten hours, until it had reached 2°, for an average rate of 1.6° per hour during this period. The freezer was allowed to begin warming immediately for three and one-half hours. When it had reached 40°, the buds were removed. The results of this test are shown in Table 4. As tested by the New Multiple Range Test, at both the one and five per cent levels, Sunhigh was significantly hardier than the other varieties. There were no significant differences among the other varieties. As Sunhigh is known for its tenderness, the results of this test were viewed with some skepticism at first, but the author is convinced that, in this test, Sunhigh did have a much larger percentage of buds remaining alive than the other varieties.

The next test was run on February 12. The weather had remained mild since the last test, with maxima of 64°, 63°, and 49°; and minima of 43.5°, 35°, and, turning cold on the night before the buds were collected, 22°. The pistils in some buds had elongated so that

Table 4. Injury to peach and nectarine blossom buds resulting from test of February 9. Buds frozen to 2^{o} F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Sunhigh	193	83	110	43.0
2. Veteran	275	60	215	21.8
3. Cavalier	299	49	250	16.4
4. Redhaven	193	30	163	15.5
5. Elberta	239	27	212	11.3
6. Garden State	242	19	223	7.9

Table 5. Injury to peach and nectarine blossom buds resulting from test of February 12. Buds frozen to 2.5^{o} F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Redhaven	218	215	3	98.6
2. Veteran	228	218	10	95.6
3. Cavalier	324	305	19	94.1
4. Sunhigh	191	164	27	85.9
5. Garden State	270	225	45	83.3
6. Elberta	252	204	48	81.0

the stigma was at the top of the bud. The samples were placed in the freezer at 36° and allowed to cool slowly at a fairly constant rate for eight hours, when they had reached 2.5°. The maximum rate of fall was 13° per hour from 36° to 23° and the average rate was 4.2° per hour. They were then allowed to warm to 40° over a period of about four and one-half hours. The results of this test are shown in Table 5. The New Multiple Range Test showed that Redhaven and Veteran were significantly hardier than Sunhigh, Garden State, and Elberta at the one per cent level. Cavalier was significantly hardier than Garden State and Elberta at the one per cent level, also. At the five per cent level, Cavalier was also significantly hardier than Sunhigh. Rather than showing more killing following continued mild temperatures, there was less at approximately the same minimum, with a very high percentage of surviving buds in all varieties. This difference with the last test may have been due to the more gradual decrease in temperature when compared to the rapid drop (47° to 18° in a little over one hour) that occurred on February 9. The amount of killing as recorded in this test would have made little or no difference in the crop potential of any of the varieties.

The next test was run on February 21. The weather had turned colder again with a mean of 35.3° for the previous seven days. Maxima were 59° and 50° on February 18 and 19. Minima were 19° on February 15, 18° on February 20, and 16.5° the morning the buds were collected. On the basis of a few buds sectioned before the test was run, as

Table 6. Injury in field to peach and nectarine blossom buds on the basis of buds sectioned before test of February 21.

Variety	Total number of buds sectioned	Number of live buds	Number of dead buds
1. Redhaven	16	14	2
2. Veteran	24	23	1
3. Cavalier	23	20	3
4. Sunhigh	13	11	2
5. Garden State	25	18	7
6. Elberta	16	12	4

Table 7. Injury to peach and nectarine blossom buds resulting from test of February 21. Buds frozen to -5° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Redhaven	185	143	42	77.3
2. Veteran	224	171	53	76.3
3. Cavalier	336	183	153	54.5
4. Sunhigh	169	58	111	34.3
5. Garden State	207	47	160	22.7
6. Elberta	220	37	183	16.8

shown in Table 6, there had been some recent killing in the field, especially on Garden State. The buds were placed in the freezer at 41° and cooled slowly at a fairly constant rate until they reached -5° twelve hours later. The maximum rate of fall was 14° per hour from 41° to 27° and the average rate was 3.8° per hour. After warming for three hours, they had reached 49° and were removed. The fan was left on in order to warm the freezer more rapidly because the freezer was turned off at 9:30 P.M. and it was not desired to leave the buds in the warm freezer until the next morning. The results of this test are shown in Table 7. The New Multiple Range Test showed that, at the one per cent level, Redhaven and Veteran were significantly hardier than all the other varieties; Cavalier was significantly hardier than Sunhigh, Garden State, and Elberta; and Sunhigh was significantly hardier than Elberta. At the five per cent level, Sunhigh was also significantly hardier than Garden State. The results of this test show that the buds had gained considerable hardiness during the preceding period of generally moderately low temperatures, although a few buds had been killed in the field. Only Garden State and Elberta would probably have shown any effect on the crop after such a percentage survival.

The next test was run on February 28. This followed a period of quite mild weather, with a mean temperature of 50.3° for the previous seven days. The maximum was 65° on February 26 and four of the seven days had maxima over 60°. The minimum was 22° on February 22,

Table 8. Injury to peach and nectarine blossom buds resulting from test of February 28. Buds frozen to 11° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Veteran	226	88	138	38.9
2. Redhaven	177	58	119	32.8
3. Cavalier	251	51	200	20.3
4. Elberta	204	11	193	5.4
5. Garden State	187	6	181	3.2
6. Sunhigh	203	5	198	2.5

Table 9. Injury in the field to peach and nectarine blossom buds on the basis of buds sectioned before test of March 7.

Variety	Total number of buds sectioned	Number of live buds	Number of dead buds
1. Sunhigh	20	5	15
2. Elberta	7	2	5
3. Garden State	19	13	6
4. Veteran	15	11	4
5. Cavalier	19	17	2
6. Redhaven	16	16	0

which was the last temperature below freezing. Many buds were noticeably swollen and showing white tips. The samples were placed in the freezer at 40° and cooled slowly and steadily to 11° over a period of nine hours. The maximum rate of fall was 13° per hour from 40° to 27°, and the average rate was 3.2° per hour. After five hours, they had reached 50° and were removed. The results of this test are shown in Figure 8. The New Multiple Range Test showed that, at the one per cent level, Veteran was significantly hardier than Cavalier, Elberta, Garden State, and Sunhigh. Redhaven and Cavalier were also significantly hardier than Elberta, Garden State, and Sunhigh. At the five per cent level, Redhaven was also significantly hardier than Cavalier. The results of this test show the possible effects of a moderate freeze after a period of mild temperatures. The three tender varieties would have had nearly no crop with survival as shown here, while Veteran and Redhaven would have had a full crop, and Cavalier nearly a full crop. A curious correlation was noted in this test. Some buds had developed more than others and were round and plump, while others were still pointed and less swollen. In nearly every case, the round buds survived, while the pointed ones were killed.

Following this test the weather turned colder again. Minima of 24° and 22° were recorded on March 3 and 4. Samples taken on March 7 showed that these temperatures had done considerable damage in the field. Table 9 shows the results of a few buds sectioned before the twigs were put in the freezer. Although the samples are too small to be of any significance, it can be seen that there were many dead buds, especially on Sunhigh and Elberta. When the next samples were taken on March 15, most of the buds that had been killed were not swelling and were dropping off. However, the samples collected on March 29 still had many buds that were swelling normally although the pistils had been killed, and thus were incapable of setting fruit. (See Table 11) A cursory inspection of other varieties in the orchard showed that both abscised buds and developing buds with dead pistils were not uncommon on the more tender varieties. This damage must have been the result of the 22° F. temperature on March 4 because the lowest temperature recorded after that was 27°, which should not be low enough to cause much damage at any stage.

The test of March 7 followed a period of fairly cool weather with a mean of 39.5° for the previous seven days. The minimum was the above-mentioned 22° on March 4 and the maximum 52° on March 3. The samples were placed in the freezer at 40° and had cooled to 25° in one-half hour. They then cooled more slowly, reaching 11° six and one-half hours later at a constant rate of about 2.1° per hour during this period. When, after five hours, they had reached 50°, they were removed. None of the varieties, including the tender ones, showed any killing as a result of this test. When the buds were cut, some pink petal color was noticed in the buds of Elberta.

The next test was run on March 15. The previous seven days had been fairly mild, with a mean of 45.4°. The minimum was 27° on

March 11, and the maximum 71° on the same date. Elberta and Garden State buds were showing some pink on this date. The samples were placed in the freezer at 41° and cooled to 14° in five hours. The maximum rate of fall was 13° per hour from 41° to 28° and the average rate was 5.4° per hour. They were held at 14° for one hour. After five hours they had warmed to 50° and were removed. The results of this test are shown in Table 10. The New Multiple Range Test showed that, at both the one and five per cent levels, Cavalier, Veteran, Redhaven, and Elberta were significantly hardier than Garden State and Sunhigh. Except for Sunhigh, which has a rather low bud set anyway, the amount of bud killing as shown in this test would probably have affected the crop very little.

The next test was run on March 29. This followed a period of slightly colder weather than the last test, with the mean for the previous seven days 42.4°. The minima recorded for the period were 27° the morning the buds were collected and 30° the morning before. The maxima were 65° on March 24 and 54.5° the following day. The varietal difference in development of the buds was quite striking at this time, as is shown in Figure 2, which was taken on March 27. Veteran and Redhaven buds were still quite tight with only a little pink showing, while Sunhigh, Elberta, Garden State, and Cavalier had some flowers that were nearly open. Figure 2 also shows the difference in buds remaining on each of the varieties. It should be remembered that the visible buds include those buds which are still developing

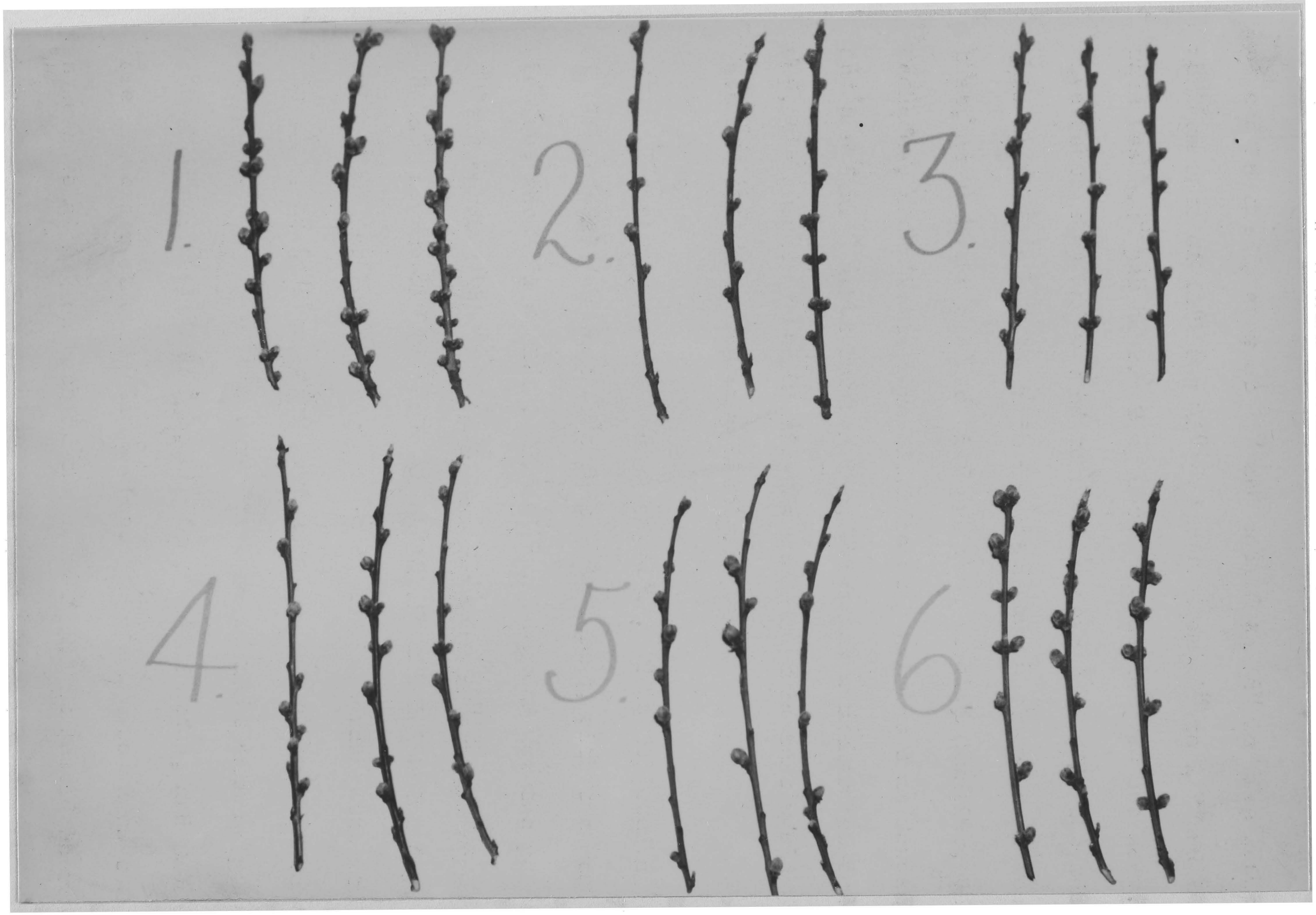

Figure 2. Peach and nectarine twigs showing relative development of blossom buds on March 27. 1. Cavalier nectarine 2. Redhaven 3. Veteran 4. Garden State nectarine 5. Sunhigh 6. Elberta.

although the pistils are dead. From Table 11 it can be seen that these comprise about one-fourth of the buds on Sunhigh and Garden State, about one-half of those on Elberta, and nearly none of those on Cavalier, Veteran, and Redhaven. The buds were placed in the freezer at 40° and eight hours later had cooled to 19°. The maximum rate of fall was 9° per hour from 40° to 31°, and the average rate was 2.6° per hour. After four hours they had warmed to 45° and were removed. When counting was begun about twelve hours later, it was seen that no buds had been killed by the artificial freezing. Therefore, since it has been demonstrated that keeping the buds at warm temperatures for such a short period does not significantly affect their hardiness (19), they were again placed in the freezer, this time at 70°. After three hours the temperature had fallen to 32°, and then, in six more hours, it dropped to 17°, for a nearly constant rate of fall of 2.5° per hour during this period. After four hours they had warmed to 45°, were removed, and again placed in water. The results of this second freezing are shown in Table 11. The New Multiple Range Test showed that, at the one per cent level, Elberta was significantly more tender than all the other varieties, and Sunhigh was significantly more tender than Veteran. At the five per cent level, Sunhigh was also significantly more tender than Cavalier and Garden State. Even the 35 per cent bud survival shown by Elberta would probably produce a satisfactory crop. However, Elberta had already lost about one-third of its buds in the freeze of March 4; so

Table 10. Injury to peach and nectarine blossom buds resulting from test of March 15. Buds frozen to 14° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Cavalier	324	184	140	56.8
2. Veteran	220	121	99	55.0
3. Redhaven	175	93	82	53.2
4. Elberta	207	109	98	52.7
5. Garden State	186	60	126	32.3
6. Sunhigh	193	43	150	22.3

Table 11. Injury to peach and nectarine blossom buds resulting from test of March 29 and 30. Buds frozen to 19° F., then to 17° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds	Number of buds dead before test	Number of buds with pistil lacking
1. Veteran	234	206	28	88.1	3	0
2. Garden State	125	102	23	81.6	20	16
3. Cavalier	291	235	56	80.8	4	2
4. Redhaven	156	119	37	76.3	0	1
5. Sunhigh	101	60	41	59.4	32	0
6. Elberta	108	38	70	35.1	52	0

actually only about 25 per cent rather than 35 per cent are still alive, not counting those which have abscised. Thus there would probably have been a reduction of the crop at these percentages. Noteworthy here is the hardiness shown by Garden State, in previous tests often the least hardy.

The last test was run on April 10. The mean temperature for the previous seven days was 48.1°, with a minimum of 31° on April 9 and a maximum of 72° on April 7. Three other days also had maxima above 60°. The condition of the buds is shown in Figure 3. Elberta was in full bloom and Sunhigh and Cavalier were nearly in full bloom. Garden State had a few blossoms open and some buds on Veteran were just starting to open. Redhaven buds were still quite tight. The twigs were placed in the freezer at 46° and the temperature fell slowly to 23° over a period of eleven hours. They remained at this temperature for about one hour, and then warmed to 40° in about two and one-half hours, when they were removed. The maximum rate of fall was 8° per hour from 46° to 38° and the average rate was 2.1° per hour. Below 32° the rate was 1° per hour. The results of this freezing are shown in Table 12. As tested by the New Multiple Range Test, at the one per cent level, Redhaven was significantly hardier than Sunhigh and Elberta, and Veteran was significantly hardier than Elberta. At the five per cent level Redhaven was also significantly hardier than Garden State and Cavalier, Veteran was significantly hardier than Sunhigh, and Garden State and Cavalier were significantly

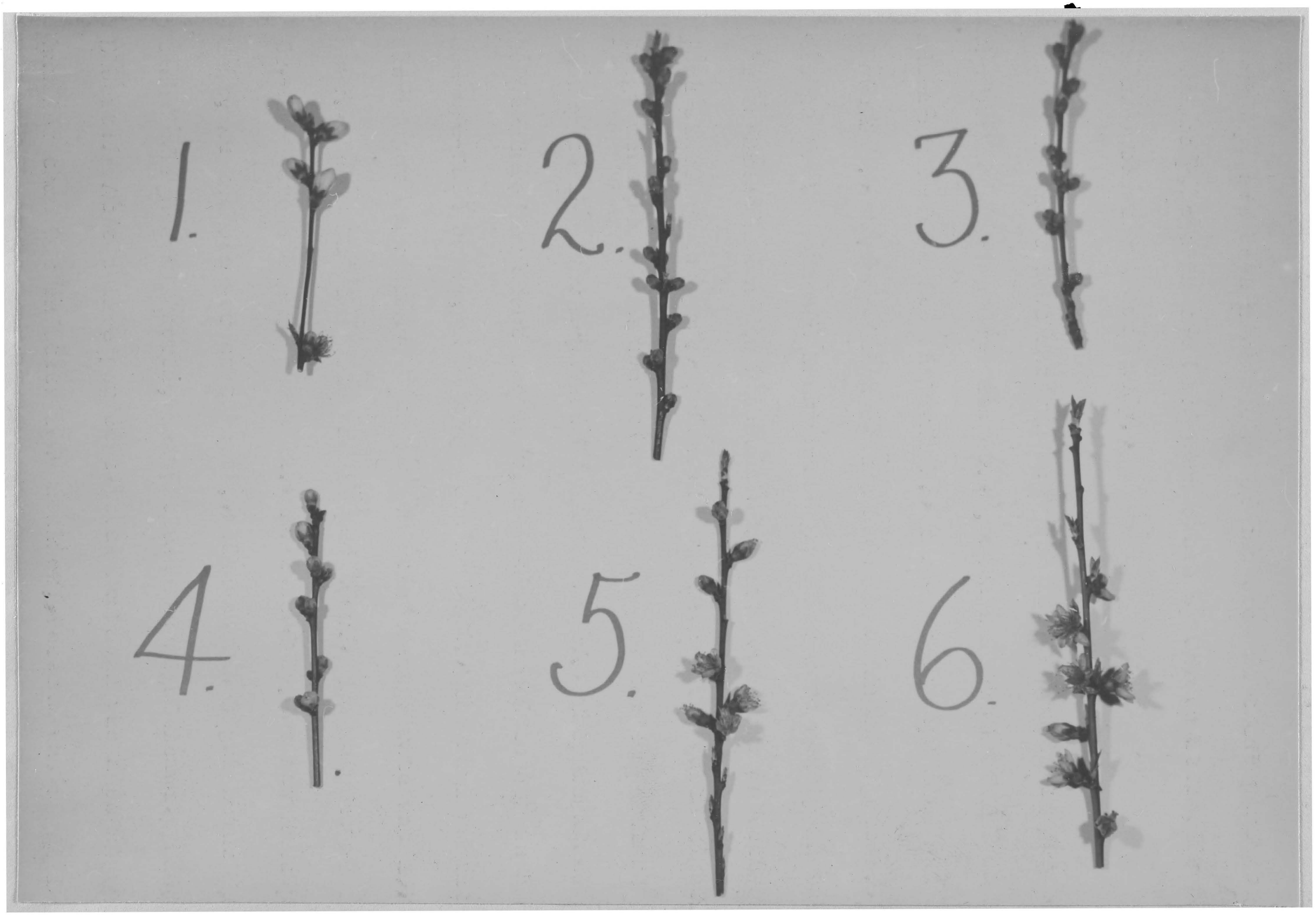

Figure 3. **Peach and nectarine twigs showing relative development of blossoms on April 10. 1. Cavalier nectarine 2. Redhaven 3. Veteran 4. Garden State nectarine 5. Sunhigh 6. Elberta.**

Table 12. Injury to peach and nectarine blossom buds resulting from test of April 10. Buds frozen to 23° F.

Variety	Total number of buds tested	Number of live buds	Number of dead buds	Per cent of live buds
1. Redhaven	170	157	13	92.4
2. Veteran	212	174	38	82.1
3. Garden State	143	98	45	68.5
4. Cavalier	290	179	111	61.7
5. Sunhigh	106	58	48	54.7
6. Elberta	111	30	81	27.0

hardier than Elberta. In this test, as in the test of March 29, Garden State showed considerable hardiness. In this test, the hardier varieties were those which had the least flowers open, although there were cases where open flowers survived the freezing while unopened buds on the same twig did not.

The effect of killing in the field during the winter can be seen in Table 13. Veteran, Redhaven, and Cavalier showed little change in the number of buds per twig from February 9 through April 10. Garden State showed some decrease in the number of buds, and Sunhigh and Elberta showed about a one-half decrease. It should be remembered that all the varieties used except Redhaven have a vigorous habit of growth with long terminal shoots. Redhaven is less vigorous and produces few long shoots. Another factor to be taken into consideration is that, especially on Sunhigh, in the later tests those shoots which had too few buds remaining were avoided; so the decrease in buds per shoot would probably have been greater on Sunhigh and Elberta had a truly representative sample been taken.

On the morning of April 15 the low temperature recorded at the field station in the orchard was 25°. This temperature caused considerable damage to the peaches, nearly all of which were in full bloom or only a very few days from it. On April 16 large branches were selected on the trees which had been used in this study and all the buds and open flowers on them were inspected for killing. The

Table 13. Number of blossom buds per twig of peach and nectarine varieties collected in tests from February 9 to April 10.

Date collected	Variety					
	Veteran	Redhaven	Cavalier	Garden State	Sunhigh	Elberta
February 9	27.5	19.3	29.9	24.2	19.3	23.9
February 12	22.8	21.8	32.4	27.0	19.1	25.2
February 21	22.4	18.5	33.6	20.7	16.9	22.0
February 28	22.6	17.7	25.1	18.7	20.3	22.7
March 15	22.0	17.5	32.4	18.6	19.3	20.7
March 29	23.4	15.6	29.1	12.5	10.1	10.8
April 10	21.2	17.0	29.0	14.3	10.6	11.1
Average	23.1	18.2	30.2	19.4	16.5	19.5

Table 14. Damage to blossoms and buds of peach and nectarine varieties in the orchard by minimum temperature of 25° F. on April 15.

Variety	Total number of buds studied	Number of live buds	Number of dead buds	Per cent of live buds
1. Veteran	533	254	279	47.7
2. Garden State	331	144	187	43.5
3. Cavalier	354	132	222	37.3
4. Redhaven	394	83	311	21.1
5. Sunhigh	430	15	415	3.5
6. Elberta	350	10	340	2.9

results of this inspection are shown in Table 14. It can be seen that Elberta and Sunhigh were almost completely wiped out. There will be very few fruits on these two varieties this year. These two varieties had almost no buds that had not yet opened. On the other varieties which did not show such a complete degree of killing, there were a considerable number of buds which had not yet opened. Almost without exception, this freeze killed every open flower in the orchard. Although there was some killing of unopened buds also, the per cent of buds killed is a fairly reliable indication of the degree of full bloom in each variety. Notable here is the repeated hardiness of Garden State, as was suggested in the tests of March 29 and April 10, but contrary to the observations of Oberle (33) in 1953.

V

DISCUSSION OF RESULTS

The method used to lower the temperature at a slow rate should be improved. The time clock mechanism did not always function properly, causing either too slow or too fast a rate of fall. Even when the clock was set properly and apparently working correctly there were instances when the temperature fell slower or faster than it had in previous runs. It was not possible to use one setting to give a fairly constant rate of fall. The temperature fell rapidly at first after each new setting, then fell slower and slower until it remained constant. In tests in which the minimum temperature desired was not below about 15° it was possible to use one setting to get a fairly constant rate of fall to the minimum. However, any setting which would take the temperature below 15° caused too rapid a fall in the beginning of the test. It would be desirable to use a method which could be preset once to give a constant rate of fall and would not have to be checked or changed during the course of the test, such as those described by Potter (35, 36) and Smith and Potter (41).

Of the nine tests in which there was a significant differential in the amount of bud survival after the freezing test, there were only four in which the three hardy varieties, Veteran, Redhaven, and Cavalier, were significantly hardier than the three tender varieties, Sunhigh, Elberta, and Garden State, at the five per cent level as tested by the New Multiple Range Test. These were the tests of January 17, February 12, February 21, and February 28. In two tests, those of January 4 and March 15, Elberta was not significantly more tender than all of the hardy varieties. On January 4 Elberta did not differ from Cavalier, although it was significantly more tender than Veteran and Redhaven. On March 15 the three hardy varieties plus Elberta were all significantly hardier than Garden State and Sunhigh with no differences among themselves. In two tests, those of March 29 and April 10, Garden State was found to have considerable hardiness. On March 29 Garden State was significantly hardier than Sunhigh and Elberta, but did not show any significant difference from the three hardy varieties. Only Veteran showed less killing in this test. On April 10 Garden State did not show any significant difference from Veteran, Cavalier, and Sunhigh. In this test the per cent of buds killed was correlated with the amount of full bloom. In one test, that of February 9, Sunhigh was significantly hardier than all the other varieties, and there was no difference among any of the other varieties. There does not seem to be any explanation for the results of this test.

During the winter, a representative sample was thought to have been selected. In the tests from February 9 through April 10, ten twigs were selected, of which seven were cut from the outside of the tree at equal distances around the tree as much as possible, and three were cut from the top of the tree. However, considerable variation in the per cent of buds alive after the test was found between twigs. This variability increased in the later tests. The range for each variety for the test of April 10 is given in Table 15. From these figures can be seen the need for a large sample in order to obtain one which is truly representative of the tree. It would probably also be necessary to obtain the twigs from all parts of the tree since some of these differences may be due to the position on the tree. Some of the differences probably were due also to differences in the size of the twigs collected. As far as possible the twigs collected were vigorous terminal growth, but some vigorous lateral growth and less vigorous terminal growth was also included due to the limited number of twigs available from each tree.

The results of this study seem to indicate that, during the winter, Veteran and Redhaven show considerable hardiness when compared to the other varieties. Cavalier does not have quite as much hardiness, but it is still more hardy than Sunhigh, Elberta, and Garden State. As blossom time approaches, the hardiness of all the varieties decreases, but that of Garden State does not seem to decrease as fast as that of the others. Just before and at blossom time Garden State ranked with the hardy varieties. These results generally agree with the observations of Oberle (33) and Oberle and Moore (34). In 1950 after a series of frosts during and after blossom time, Veteran and Redhaven bore full crops while Sunhigh and Elberta bore none, showing a difference in tolerance which is apparent in this study. In 1953,

Table 15. Ranges in per cent of live buds on individual twigs of peach and nectarine varieties for test of April 10.

Variety	Range in per cent of live buds on individual twigs	Per cent live buds of total sample
Redhaven	76.2 - 100	92.4
Veteran	18.8 - 100	82.1
Garden State	0 - 100	68.5
Cavalier	19.2 - 93.8	61.7
Sunhigh	0 - 94.7	54.7
Elberta	0 - 81.8	27.0

it was reported that Redhaven and Veteran showed no effects of the frost which occurred just after shuck-split, while Cavalier showed a slight effect, but all produced a full crop and required some thinning. Sunhigh and Elberta produced medium crops, and Garden State a light crop. None of these required any thinning. Since Garden State had had a very heavy bloom, the lack of crop must have been due to the affects of the frost at shuck-split. This indicates that Garden State is as tender as Sunhigh and Elberta at shuck-split as well as during the winter as shown in this study. A possible solution to these conflicting observations is that, although Garden State does not have the genes for hardiness as do Veteran, Redhaven, and Cavalier, it responds slower to warm temperatures in the spring and thus keeps what hardiness it has for a longer period. It blooms with the hardy varieties rather than with Sunhigh and Elberta and is hardy at this time. Later, at shuck-split, when nearly all hardiness has been lost by all the varieties, it is again relatively tender. This would account for its relative hardiness in the tests of March 29 and April 10 and in the field on April 15.

VI

SUMMARY AND CONCLUSIONS

Four varieties of peaches and two varieties of nectarines were used to determine if artificial freezing tests could be used to predict the tolerance of seedling progeny to frosts at blossom time. The varieties selected on the basis of their reported high tolerance were Veteran, Redhaven, and Cavalier nectarine. Those selected because of their reported lack of tolerance were Elberta, Sunhigh, and Garden State nectarine.

For a test such as this it would be desirable to use an apparatus that could be set to lower the temperature automatically at a constant rate. The time clock mechanism used in this study would not satisfy this condition on two accounts. It does not lower the temperature at a constant rate and it needs to have the setting changed at various intervals to keep the temperature from remaining at one level.

It would be desirable to be able to predict with accuracy the temperature which will give a differential amount of killing of the buds. Several tests were useless because all the buds were killed, or none were killed. One method of avoiding this would be to use large samples and remove parts of them at different temperatures over the range which is thought to be necessary to produce the desired killing. This would not be possible if it was desired to run several tests with a limited amount of material.

Due to the wide variability of bud survival between different twigs from the same tree, it would be desirable to use as many twigs as possible. Since there is such a large variability, it is necessary to use a sample that is as representative of the whole tree as possible.

Numerous tests are necessary to give a true picture of the rrelative hardiness of a particular variety or seedling. Only four out of nine tests showed all the hardy varieties to be significantly hardier than all the less hardy ones. If only one test is run, very erroneous results may be obtained. In the case of Garden State, it would be necessary to run the test at or near blossom time, since it proved hardy then and not during the winter.

It should be possible to predict the relative degree of tolerance to the effects of spring frosts by means of artificial freezing tests. If the seedlings to be tested are frozen along with some varieties of various known tolerances, it should be possible to compare the performances with confidence if a sufficiently large representative sample is used and numerous tests are run at various dates during the winter and spring.

The one exception to the general correlation between the artificial tests during the winter and previously observed effects of natural freezes in the field is Garden State nectarine. It has proven tender in the field and in artificial tests during the winter, but seemed to be relatively hardier as bloom approached, although it was found to be tender also at shuck-split. More study is necessary on this variety to determine its resistance to the effects of freezing temperatures at blossom time and the changes in its hardiness from fall until late spring.

VII

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VIII

ACKNOWLEDGEMENTS

The author of this study wishes to acknowledge the assistance given by Dr. G. D. Oberle, who suggested the study and arranged for the apparatus used. Acknowledgement is also due the assistance and suggestions rendered by Mr. J. B. Hardigree.

Acknowledgement is due Mr. R. E. Moser, who took the photographs used in the study.

Acknowledgement is also due Mr. T. H. Starks, who instructed and assisted in the statistical analysis of the data.

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