

## ON THE COMPARATIVE RESISTANCE OF THE AVOCADO AND CERTAIN OTHER TENDER SUBTROPICALS AND TROPICALS TO LOW WINTER TEMPERATURES

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### INTRODUCTION

The winters of 1947-48 and 1948-49 respectively witnessed the lowest temperatures recorded to date on the Los Angeles campus of the University of California and caused injury to the Subtropical Horticulture fruit plant collections which, both in extent and degree, greatly exceeded that of the general freeze of January, 1937. Exceptional opportunities were provided, therefore, to observe the comparative resistance or sensitivity to frost of many subtropical and hardy tropical fruit plants.

The plant materials available for observation consisted of a series of collections of subtropical and hardy tropical fruits which, in number of species and varieties represented, is comparatively extensive. They are located on and occupy the greater part of a 14-acre block, roughly rectangular in form (approximately 700 feet wide and 1,600 feet long), the principal slope of which is small but uniformly to the south. There is also a very slight slope to the west. With the exception of the east side, the area was surrounded by windbreaks. Moreover, a double windbreak crosses the area about midway between the upper and lower ends, dividing it into two parts of approximately equal size.

The official temperature-recording station is located slightly to the north of the center of the lower part of the area and consists of a standard Weather Bureau type shelter in which a Friez hydrothermograph has been in continuous operation for some eighteen years. At periodic intervals it is adjusted to a standardized thermometer. During the winter months several self-registering minimum thermometers are operated in modified shelters, one of which is located nearby, for comparison of the minimum temperatures.

The observations upon which this report is based were made independently by the authors. They were started almost immediately following the frosts or freezes of greatest severity and were repeated several times during the succeeding growing season.

### WEATHER CONDITIONS PRECEDING THE FROSTS OR FREEZES AND THE METEOROLOGICAL CONDITIONS WHICH ACCOMPANIED THEM

The winter of 1947-48 was characterized by pronounced deficiency in rainfall, prevalence of unusually low atmospheric humidity, and exceptionally wide range of diurnal temperature fluctuation. There was also considerable prevalence of hot, dry

desert winds.

Rainfall deficiency was most marked and acute during the first half of the season and extended well beyond the period of the frost reported on herein. The unusually low atmospheric humidity of the season is evidenced by remarkably low dewpoint temperatures in general, on several occasions dropping below 0°F. The wide diurnal fluctuation in temperature is reflected in the fact that whereas there were numerous bright and warm days, including several unusually hot ones, nevertheless the winter of 1947-48 registered the largest number of frosty and near-frosty nights on record in many districts.

The frosts which caused injury on the campus that winter occurred during the nights of December 30-31, when a minimum of 28°F. occurred, and January 27-28, during which a minimum of 24.5°F. was reached. Injury from the first frost was negligible but that resulting from the second frost was the most extensive and serious experienced to date. Not only was the minimum temperature a full degree lower than that recorded during the freeze of January, 1937, when comparatively little injury occurred, but the duration of injuriously low temperatures was considerable. In the thermometer shelter the minimum temperature registered below 28 °F. for 5 hours, below 27 °F. for 3 hours, below 26° for 1½ hours, and below 25° for 30 minutes. At lower levels and in other locations slightly lower temperatures and longer durations may have occurred, though observational evidence and past experience suggest that the thermometer location, in question is probably representative for the area.

With respect to the accompanying meteorological conditions, the facts of greatest significance appear to be the complete calm which existed and the pronounced temperature inversion which developed. In the absence of wind, the only air movement which seems to have occurred was a slow drift of cold air down the main slope. There is evidence of backing up of cold air on the upper side of the cross-slope windbreak.

Striking evidence of temperature inversion was observed in the injury which occurred to trees and larger shrubs of tender fruits, such as the West Indian avocado, common or tropical guava and rose-apple. These plants were severely injured up to levels which ranged from 9 to 12 feet, above which virtually no injury occurred, even to succulent foliage and tender terminal shoots and buds.

In view of these conditions it seems virtually certain that minimum temperatures at near-ground levels were appreciably lower than those recorded. This likelihood is reflected in the virtual destruction of an avocado nursery and the severe injury noted for young citrus and avocado trees and low-growing shrubs of species ordinarily considered to be moderately cold-resistant.

The winter of 1948-49 was similar to that of the previous year with respect to deficiency in rainfall, prevalence of unusually low atmospheric humidity, and wide range of diurnal temperature fluctuation. In many districts it established new records for number of frosty and near-frosty nights. The frosts which caused injury on the campus that winter occurred during the nights of January 3-4, 4-5, and 9-10 respectively, when temperatures of 28°F. or lower were registered. During the first night, when most of the injury occurred, the temperature was 28°F. or lower for 8½ hours, 27° or lower for 7½ hours, 26° or lower for 6½ hours, 25° or lower for 3½ hours, and at approximately 24°

for 1 hour. During the other two nights it dropped to 28° or slightly lower for 1 hour and 30 minutes respectively. While the coldest nights registered low atmospheric humidity, there were several nights when ice was formed on the foliage and fruit, notably following a light snow which occurred during the early part of the night of January 11-12.

The meteorological conditions which accompanied the freeze of 1949 were quite different from those of the previous year and closely approximated those of the great freezes of 1913, 1922 and 1937, during which temperature inversion was wholly lacking at the outset and developed to a limited degree only after the freeze was nearly over. Thus the larger shrubs and trees of tender evergreen subtropicals or hardy tropicals, which in 1948 escaped injury above certain levels, in 1949 were severely injured throughout. Moreover, the orchard heating operations of 1949, although considerably more extensive, were much less effective.

#### **OBSERVATIONS ON COMPARATIVE DEGREE OF FROST INJURY**

It should be emphasized that the comparisons here reported are valid only for the range of minimum temperature extending down to approximately 23°F. and for relatively short durations of injurious temperatures. At lower minima and for longer durations they would doubtless change in important respects. Moreover, for the most part they relate to injury to the foliage and growth rather than to the fruit.

#### **TENDER EVEREN SUBTROPICALS**

The following fruit plants exhibited injury ranging from very slight to rather severe: the citrus fruits (*Citrus spp.*), avocado (*Persea americana* and *var. drymifolia*), cherimoya (*Annona cherimola*), white sapotes (*Casimiroa edulis* and *tetrarneria*), Cattley guavas (*Psidium cattleianum* and *var. lucidum*), macadamia nut (*Macadamia ternifolia* and *var. integrifolia*), African carissa or Natal plum (*Carrissa grandiflora*), purple-fruited granadilla (*Passiflora edulis*), kei-apple (*Dovyalis caffra*), mountain papaya (*Carica candamarcensis*), coffee (*Coffea robusta*), sapodilla (*Achras zapota*), and para guava (*Britoa acida*).

#### **AVOCADOS**

*Mexican horticultural race.*—Under the temperature conditions in question, mature trees of a dozen or more varieties and numerous seedlings of this race exhibited very little injury, hardly exceeding that of mandarins, oranges and grapefruit. The injury which occurred was confined to flower clusters and a few exposed leaves, mainly on the south side of the trees. Young bearing trees were not appreciably worse injured than mature trees.

*Fuerte horticultural race (Aguacates de China).*—Varieties and seedlings belonging to this group were definitely worse affected than those of the Mexican group, though some trees exhibited comparatively little injury. The difference was much more marked in 1949 than in 1948. The injury was confined largely to exposed foliage and tender shoots, mainly at low levels, and to early flower clusters, though considerable fruit-stem

freezing took place in 1949. Under comparable conditions foliage injury was obviously considerably worse than on nearby Eureka lemon trees. Very young trees had virtually all the leaves killed and some of the tender tips, but were very much less injured than those of the Guatemalan race.

*Guatemalan horticultural race.*—Following the 1948 frost, observations on mature trees in a collection of 30 or more varieties indicated that in general foliage injury was worse than in the Mexican and Fuerte groups, though many trees were not noticeably more affected than the latter. In the case of young trees, however, the differences were more pronounced—without exception varieties of the Guatemalan race were much worse injured than those of the Fuerte group—and there was slight evidence of varietal variation in resistance. As noted above, however, the differences were much more pronounced in 1949. Moreover, varietal differences were greatly accentuated, some being much worse injured than others.

Among the worst injured were Anaheim, Carlsbad, Dickinson, Hellen, Nabal and Prince. Those least injured included Edranol, Itzamna, Mayapan and Panchoy.

*Presumed Guatemalan-Mexican hybrids.* — In general these varieties exhibited cold resistance equaling or exceeding that of Fuerte and several were not noticeably more affected than Mexican race varieties. Among the latter were Coit, Lodge, Monica, and Nowels.

*Lula variety.*—This Florida variety exhibited much worse foliage injury than any other variety or form in the collections with the exception of a young bearing seedling of the West Indian horticultural race, which was badly injured (see later section). Moreover, in 1949 there was considerable killing back.

## **CHERIMOYA**

In an unprotected area, where the 1937 freeze reduced a young cherimoya collection to a pair of trees each of the Deliciosa and Booth varieties, the one remaining Booth tree was killed back to branches up to 2 inches in diameter.

In a younger collection of a dozen or more varieties, planted in 1940 in another location where orchard heaters were operated, in 1948 there was little evidence of injury beyond slight defoliation on some of the trees. Loma and Ryerson exhibited the most leaf injury and slight tip-killing in the upper parts of the trees. Younger top-worked trees in the same location were worse affected, with some evidence of varietal differences.

Two lots of nursery seedlings in the same general location were affected differently. One lot, in the northwest corner, showed very little injury; another, to the east of the heater protected area, was badly injured, many being killed to the ground. In the latter area a young plant of *Rollinia emarginata*, a distant relative, escaped injury altogether.

An extensive collection of 7-year-old bearing seedlings in the southwest quadrant, although partially protected by orchard heaters, suffered severe injury. All were badly defoliated and killed back more or less severely, some to the ground. Under the variable temperature conditions which existed in this collection it was impossible to detect variation in frost resistance.

The 1949 freeze was very much more injurious than that of the previous year and emphasized the varietal differences previously noted and brought out still others in the variety collection, which again was inadequately protected by orchard heaters. Varieties which exhibited the least injury included Bays, Booth, Carter, Deliciosa, and White. Among those most injured were Ryerson, Macpherson, Mira Vista and Sallmon. Several trees were so badly injured they subsequently died.

The collection of 8-year-old seedlings in the southwest quadrant had been reduced to the 26 considered to be the most promising and this area was unheated in 1949. Twenty of these were very severely injured, being completely defoliated and killed back to the crotch or lower. The remaining 6 were less injured and one retained considerable foliage to a height of eight feet.

## **WHITE SAPOTES**

In a collection of mature trees of a dozen or more varieties in the northwest quadrant there was little evidence of injury beyond the killing of a few leaves and an occasional tender tip, approximately the situation with the sweet orange and grapefruit. Evidence of varietal differences was observed, however, in that Anderson and Coleman were definitely most affected.

A collection of 7-year-old bearing seedlings in a colder location in the southwest quadrant exhibited a wider range of injury, from none to considerable, but was very much less injured than an adjoining cherimoya seedling collection of the same age.

In contrast, the matasano or woolly-leafed white sapote (*C. tetrameria*) — a very near relative of the white sapote—proved to be much more sensitive. Mature bearing trees exhibited worse foliage injury than any of the Guatemalan avocados and 7-year-old seedlings were badly defoliated and killed back, in some cases up to half-inch parts, in contrast with adjacent white sapote seedlings. The differences between the two were most pronounced in 1949 when the foliage of all matasano trees was completely destroyed and considerable killing back occurred.

## **CATTLEY GUAVAS**

Mature bearing plants of the Cattley or Strawberry guavas were strikingly cold resistant alongside plants of the same age of the common or tropical guava (see later section). In 1948 the only observable injury consisted of slight defoliation and the killing back of a few small terminals. Younger bearing plants were somewhat worse affected. Comparable plants of the Yellow Cattley appeared to be slightly less injured than those of the Red Cattley. Both of these guavas were nearly as cold resistant as nearby Eureka lemon trees.

In 1949 the Cattley guavas were very much worse injured than in 1948, and than nearby Eureka lemon trees, and the differences between the Red Cattley and the Yellow Cattley were much more pronounced. The former lost all the leaves and considerable killing back occurred, whereas the latter retained a moderate amount of foliage and suffered appreciably less killing back.

## **MACADAMIA NUTS**

In 1948 good sized bearing trees carrying bloom, and younger trees in two widely separated locations, were apparently little worse affected than orange and grapefruit trees. The injury consisted of the killing of a few young tips and exposed leaves and of part of the flower clusters at lower levels. Above the 7 to 8 foot level no injury was observed. No differences were noted between the two botanical forms. In 1949 injury was appreciably greater, notably on the younger trees, and a much wider range of injury was observed— from slight to moderate—which was not localized at the lower levels. Moreover, it appeared that in general trees of the *integrifolia* form were less injured than those of *ternifolia*. Some of the latter were definitely worse injured than nearby orange and grapefruit trees. Evidence of injury was notably slower in development than in other materials.

## **AFRICAN CARISSA OR NATAL PLUM**

Injury to old vigorous and healthy hedge seedlings was comparatively slight but highly variable in 1948, ranging from virtually none to moderate defoliation and some killing back of exposed terminals at near ground levels. Plants in poor condition, however, were noticeably much worse injured.

Younger bearing, and more exposed, orchard plants were considerably worse affected, with fairly clearcut evidence of varietal differences. Frank, MacPherson, and Chesley (Alles) were less injured than Serena, and Torrey Pines more. Young non-bearing plants of named varieties were the worst injured of all; most of the leaves were killed and some shoots up to ¼ inch in diameter.

In 1949 the injury was considerably worse, some of the smaller and more exposed orchard plants having been killed virtually to the ground; a few subsequently died. The range of variability in injury to young bearing hedge plants was notable and the effects of wind and radiation protection remarkable.

## **PURPLE-FRUITED GRANADILLA OR PASSIONFRUIT**

In a bearing planting of local origin the injury noted was comparatively slight, ranging from none to the killing of some of the young shoots and leaves and a few of the older leaves. Injury was likewise slight in a planting of young non-bearing vines.

By contrast, however, in a nearby planting, the seed for which was sent in from Brazil, injury was markedly worse, consisting of rather general defoliation and killing back.

No passionfruit vines were available for observation in 1949, all having been removed in 1948 for reasons unrelated to frost injury.

## **KEI-APPLE**

In 1948 mature pistillate and staminate plants were partially defoliated and some exposed peripheral growth killed with no observable differences between the two forms.

In 1949 defoliation was complete and the killing back more general and severe.

### **MOUNTAIN PAPAYA**

In 1948 exposed young bearing and staminate plants and large old semi-protected plants both suffered the loss of all of the leaves but were otherwise uninjured, in comparison with the common papaya (see later section). In 1949, however, all were killed to the ground though most subsequently resprouted.

### **COFFEE**

Partially protected young bearing coffee plants exhibited no detectable injury in 1948; comparable plants were not available for observation in 1949, all having been transplanted in 1948 with the result that they were killed outright.

### **SAPODILLA**

A young non-bearing partially protected sapodilla tree exhibited only the killing of a few leaves in 1948. Another young tree in a 5-gallon can nearby was similarly affected but in addition suffered the killing of one small branch. Both were moved in 1948 with the result that they failed to survive.

### **PARA GUAVA**

In a small planting of young non-bearing plants, in 1948 injury was confined to slight defoliation and killing back of some of the young tips. In 1949, however, these plants were completely defoliated and severely killed back.

### **EVERGREEN TROPICALS**

The following fruit plants or species exhibited injury ranging from severe to very severe: Papaya (*Carica papaya*), guava (*Psidium guajava*), banana (*Musa paradisiaca* var. *sapientum* and *cavendishi*), rose-apple (*Syzygium (Eugenia) jambos*), West Indian avocado (*Persea americana*) and its relative, *P. schiedeana*, sugar apple (*Annona squamosa*), atemoya (*A. squamosa* x *A. cherimola*) and the related species, *Annona senegalensis*, and water lemon (*Passiflora ligularis*).

### **PAPAYA**

Young exposed non-bearing plants were killed outright and older partially protected bearing plants were killed to the ground or virtually so. None remained in 1949.

## **COMMON OR TROPICAL GUAVA**

In 1948 mature bearing seedling trees, 12 to 15 feet in height, exhibited complete defoliation and killing back of branches up to 24 inch or larger in diameter below a height of about 10 feet. Above that level there was little if any twig injury and some of the fruits escaped damage. There was little evidence of clonal differences. Younger bearing and non-bearing plants were severely killed back, several nearly to the ground.

In 1949 the tops which had escaped injury the previous winter, and all new growth from the lower parts of the trees, were killed outright. Several trees subsequently died but most resprouted, either from below ground or just above. In a few cases resprouting occurred at levels up to 3 or 4 feet, suggesting differences in varietal resistance.

## **BANANA**

In 1948 partially protected bearing plants of the Lady Finger and Cavendish varieties exhibited severe leaf injury but were not killed to the ground. Cavendish was noticeably less injured than Lady Finger and a nearby plant of the ornamental Abyssinian banana (*Musaensete*) was considerably less affected. In 1949, the only remaining plant, the Abyssinian banana, had most of the leaves killed but the growing point escaped injury.

## **ROSE-APPLE**

In 1948 a mature, full bearing tree was very badly injured up to a height of about 10 feet, above which no detectable injury occurred. Some large limbs, up to 2 to 3 inches in diameter, were killed. The injury was seemingly even worse than that suffered by the tropical guava trees nearby. In 1949 all growth in the top of the tree was killed and it appeared that the tree had been killed back to the largest limbs or the trunk. A few months later, however, it was evident that the injury, while severe for the outer parts, was decidedly less than had appeared to be the case. Several inside upright scaffold limbs were resprouting almost to the top of the tree.

## **WEST INDIAN AVOCADO**

In 1948 a young bearing seedling tree, 12 to 15 feet in height, was likewise completely defoliated up to the 10-foot level, above which no injury seemed to occur. Below that height killing-back of limbs up to an inch or larger in diameter was noted. In 1949 this tree was protected by an orchard heater located close by on the northeast side, in spite of which the top and south and west sides lost all the foliage and parts were killed back up to 2 inches in diameter.

A small, non-bearing tree of *Persea schiedeana* was killed to the ground in 1948; in 1949 a 15-inch rootsprout was likewise killed.

## **ANONA SPECIES AND HYBRIDS**

Experience with previous and lighter frosts had demonstrated that the sugar apple is very sensitive to cold. That this is likewise true of atemoyas in general was confirmed in



the frost of 1948. A collection of 7-year-old seedlings adjoining a similar but larger collection of cherimoya seedlings exhibited much worse injury, many being killed virtually to the ground and all showing rather severe injury. Only one atemoya seedling was found to be significantly less injured than the rest and it was worse injured than most, if not all, of the adjoining cherimoya seedlings. This seedling was killed to the ground in 1949.

Young bearing trees of *Annona senegalensis* grafted on the cherimoya were killed back to the graft-unions or lower in 1948.

## **WATER LEMON**

Partially protected plants in 5-gallon cans were completely defoliated and killed back badly, in some cases to the ground.

## **FACTORS RELATED TO OR AFFECTING FROST INJURY**

Although the minimum temperature reached in the frost of 1948 was scarcely more than a degree lower than that registered in the freeze of January 1937, as previously noted the injury which resulted was very much greater in both degree and extent. In our opinion the principal contributing factor was the less than usual degree of hardening of the plant materials in question, caused by the wide diurnal fluctuation and resulting high mean temperature which characterized the fall and winter of 1947-48.

Although the minimum temperature reached during the winter of 1948-49 was certainly not more than a degree and a half lower than that of the previous winter, as previously noted the injury which occurred was considerably more pronounced and extensive. The principal reason for the greater injury appears to be materially longer duration of injuriously low temperatures, particularly those below 26°. Another factor, possibly of considerable importance, is the fact that the injurious freeze of 1949 occurred more than three weeks earlier than that of the previous winter. Other possible factors include the formation of ice on the foliage and fruit following the principal freeze and carryover effects from the injury of the previous winter. The latter are considered to have been operative only for the very tender subtropicals and hardy tropicals which were badly injured by the frost of 1947-48.

During the course of the observations summarized herein the effects of certain modifying factors or conditions were noted, which were associated with and presumably responsible for marked departures from the normal situation with respect to degree of frost injury. Among these were protection against air drift and radiation to the sky, effect of amount of crop, degree of pruning the previous season, and condition of health and vigor of plant.

*Effect of protection against radiation heat losses:*—In both winters the effect of partial protection from overhanging trees was striking on carissa hedge plants. Because of rather extensive hedges of this plant running both north-south and east-west, it was possible to make numerous comparisons of exposed and partially protected plants. Virtually without exception, exposed plants were worse injured than protected plants;

many of the latter exhibited little if any injury. Similar effects were noted for overhanging eaves, nearby solid walls or lath fences, and for close-planted materials in comparison to more widely spaced plants.

Where injury was confined to near-ground levels, on comparable materials it was invariably worse on the side or sides of widest spacing and least elsewhere; in many cases it was confined to the exposed side or sides, being notably worse at the ends of the rows where they abutted on the orchard roadways.

*Effect of amount of crop.*—A number of cases were noted where injury appeared to have been associated with the effect of an excessively heavy crop, either recently harvested or currently on the tree. Thus a Satsuma mandarin tree on trifoliolate orange rootstock (a hardy combination) from which an excessively heavy crop had recently been harvested exhibited significantly worse foliage injury than any other healthy Satsuma mandarin, irrespective of root-stock. The same relation was noted for one tree each of the Hass and Nabal avocado varieties, the only difference being that the crops were still on the trees; in each case the crop was excessive.

*Degree of pruning the previous season.*—The effect of degree of pruning the previous season was most marked in the Mexican avocado and cherimoya. With both fruits excellent comparisons existed during the 1949 freeze. Of a large number of comparable bearing Mexican avocado seedlings half or more were pruned more or less severely in late summer incident to partial top-grafting. None of the unpruned trees exhibited injury; almost without exception the pruned trees were injured. The cherimoyas consisted of an extensive variety collection, each variety represented by a pair of trees. In the spring of 1948 these were pruned, one member of each pair lightly and the other rather severely. In nearly all cases the more severely pruned trees were worse injured.

*Effect of tree health and vigor.*—The relation between tree health and vigor and degree of frost injury was striking. Virtually without exception, where comparable materials existed, weak and unhealthy plants were notably worse injured than those in good health and vigor.

Rootstock-scion incompatibility was almost certainly one of the causes for the lack of health and vigor which resulted in injury. This was noted for the Juan, Lyon and Murrieta Green avocado varieties on Mexican race rootstocks.

Another cause of lack of vigor, associated with greater frost injury, was competition with adjacent and more vigorous trees. This was notably evident in portions of the Carissa hedge subject to competition from nearby avocado or carob trees. Invariably the plants most affected by this competition were the worse injured.

In some cases, however, the cause for the lack of vigor was not evident; nevertheless the plants exhibiting this condition at the time of the frost or freeze were invariably worse affected than more healthy and vigorous plants nearby.

## DISCUSSION

A somewhat limited search of the literature reveals the fact that, for the most part, the observations here reported are in agreement with those of other workers (1 to 7),

insofar as temperature conditions permit of comparison. A few exceptions may be noted, however, among which the most important appear to be the following:

1. The Lula avocado is reported to be more cold resistant than Guatemalan race varieties (2 and pp. 31-32 of 4). This is certainly at variance without observations.

The greater susceptibility of this variety in comparison with others of Guatemalan race or Fuerte race parentage casts doubt on the assumption that it is Guatemalan-Mexican race hybrid and suggests Guatemalan-West Indian race parentage (see p. 30 of 4).

2. The only classification of subtropical and tropical fruits based on cold resistance which has come to our attention is that employed by Mowry, Toy, and Wolfe (3). In the light of our observations it does not reflect the marked differences which exist between the cherimoya and atemoya, the white sapote and woolly-leaved white sapote, and the Cattley and common or tropical guavas, or the differences we have noted between the Red and Yellow Cattley guavas.

In our opinion, perhaps the most significant and important contribution of this study is the extension of knowledge it has provided concerning the range of cold resistance which exists in certain of the minor subtropical fruits, some of which appear to have commercial possibilities. Among those in which a significant wide range of variation was noted are the cherimoya, white sapote, purple-fruited granadilla or passionfruit, and the African carissa. Through the utilization of this variation, by means of selection and breeding, it should be possible to develop superior varieties of maximum cold resistance.

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