Pistachio Production Problems

JULIAN C. CRANE[1]

The production, processing, and marketing of pistachio nuts is one of California's newest and most rapidly growing agricultural industries. From less than 300 acres in 1968, rapid expansion occurred during the 1970s to over 43,000 acres (28,000 bearing; 15,000 nonbearing) in 1982. Of the deciduous tree fruit and nut acreage in the state, the pistachio is exceeded only by almond, walnut, prune, and peach. The first commercial crop of significance—4½ million pounds—was harvested in 1977, while in 1982 over 43 million pounds were produced having a value of 61 million dollars. Production is expected to reach 80 million pounds in 1990. The average annual consumption of pistachios in the United States during the past decade has been 22 million pounds, most of which came from Iran and Turkey. Thus, the projected growth of the industry dictated the need for a program of effective domestic and foreign market development and expansion. It also had become apparent that research related to production and postharvest handling was needed. A referendum of the producers in 1981 established the California Pistachio Commission to raise funds for the support of research and marketing activities, as well as to direct other industry functions.

The pistachio tree, *Pistacia vera* L., is thought to have originated in Central Asia under extreme climatic conditions of high temperatures and no rainfall during the summer with relatively low temperatures during winter. Climatic conditions in the southern San Joaquin Valley of California, where 85% of the acreage is located, seem ideal for growth and production of the pistachio. In addition to long, hot and dry summers, this area provides adequate chilling (700-1000 hours of 45°F or below) during winter to break the rest period of the buds. The area is also free of frosts the last of March and early April when blossoming occurs and new vegetative growth is succulent. Trees in areas with high summer humidity and rainfall may suffer from foliage and other diseases not found in a dry climate.

BOTANY

Pistacia is a genus of the Anacardiaceae which comprises such widely known trees and shrubs as cashew, mango, poison ivy, poison oak, and sumac. Eleven species were recognized in the latest monographic study of the genus (25), some of which are used as rootstocks for pistachio. The latter may reach 20-25 ft in height and 25-30 ft in width.

The pistachio is deciduous and is characterized by imparipinnate leaves, most often 2-paired. Shoot extension begins the last of March and terminates the last of April to the middle of May. A leaf at each node subtends a single axillary bud (Fig. 1). Most of these differentiate into inflorescence buds during April and grow to their ultimate size for the season by late June (21). Generally, 1 or 2 axillary buds located distally on the new growth are vegetative. They are considerably smaller than inflorescence buds, and may give rise to lateral branches the following year or they may remain dormant. Inflorescence buds begin expansion the last of the following March and anthesis occurs generally in early April. Thus pista-

[1]Department of Pomology, University of California, Davis, California 95616.

Fig. 1. The nut-bearing branch (right) abscised its inflorescence buds in the leaf axils on new growth, whereas the nonbearing branch (left) retained its inflorescence buds to produce fruits the following year.

chio bears its fruits laterally on wood produced the previous season (Fig. 2).

Pistachio is dioecious and both staminate and pistillate inflorescences are panicles that may consist of 100 to several hundred individual flowers (Fig. 3). Both types of flowers are apetalous and wind is the pollinating agent. Time of bloom among staminate and pistillate cultivars may differ as much as 2 to 3 weeks. Staminate and pistillate cultivars having similar bloom periods must be provided to ensure adequate pollination of the latter. The fruit produced is a semi-dry drupe. Certain tissues or organs develop in time and space like those of other drupes in general, while others develop differently (6, 12). Growth in diameter of the pericarp of fleshy drupaceous fruits such as apricot (16) occurs in 3 distinct periods—2 cycles of rapid growth separated by one of slow growth (Fig. 4). Growth of the almond (2), a dry drupe, occurs in 2 periods only, i.e., a rapid growth phase followed by one of practically no growth (Fig. 4). Thus, almond has the equivalent of Periods I and II of fleshy drupes, but lacks a final phase of rapid growth (Period III). The semi-dry pistachio drupe exhibits growth similar to that of almond, but has a second cycle of relatively accelerated growth (Period III) which adds little to the final fruit diameter (Fig. 4).

Period I in fleshy drupaceous fruits, as well as in almond, encompasses complete and simultaneous growth of the endocarp and the nucellus and integuments of the seed. While ultimate size of the pistachio endocarp (shell) also is attained by the end of Period I, the nucellous and integuments do not undergo extensive growth until more than a month of Period II has elapsed. Development of the embryo in fleshy drupes and in almond is delayed, and is not macroscopically evident until the end of Period I. Embryonic development in pistachio is delayed even longer, not being macroscopically visible until Period II has been underway for about 6 weeks. Once the embryo becomes evident, it grows simultaneously with the integuments to ultimate size during a 6-week period about midway in Period II of pericarp growth. Lignification of the endocarp begins at the initiation of growth Period II and continues for 4 to 6 weeks. Endocarp dehiscence is first noted along the ventral suture the last week in July, about the time ultimate kernal size is attained, and progresses along both sutures until physiological maturity, about the middle of September (Fig. 5). Physiological maturity is signaled by easy separation of the epicarp and mesocarp (hull) from the shell (5), the equivalent of flesh separation from the pit in a free-stone peach.

CULTIVARS

The California pistachio industry is based on the nut-producing Kerman and the pollen-producing Peters cultivars. Kerman originated as an open-pollinated seedling from seeds introduced by the USDA from Rafsanjan, Iran. It is a late blooming, vigorous, upright growing tree that produces large, high quality nuts. Peters was discovered in the early 1900s by A. B. Peters, Fresno, CA. Its parentage is unknown. The tree produces pollen in great abundance at a time that coincides with blossoming of Kerman, as well as some of the earlier blooming female cultivars.

Joley was named and released in 1979 by the University of California. It originated from an open-pollinated seedling introduced as seed (P.I. 143-707) by the USDA from Damghan, Iran. It blooms 3 to 5 days before Kerman and matures its nuts a week or more ahead of Kerman. Joley pistachios are slightly smaller than Kerman but shell splitting is superior and blank production is less. The incidence of "epicarp" lesion is also less.

Cultivars such as Bronte, Red Aleppo, Sfax, and Trabonella were introduced into California by the USDA in the early 1900s. Size of nuts and yields of these cultivars, however, precluded their commercial production. Sfax, which originated in Tunisia, produces nuts somewhat smaller than Kerman, but the percent of split shells is high and nut quality is good. It is worthy of trial in locations where winter chilling is insufficient for Kerman.

Kerman alone is the current choice for commercial pistachio production, but it has several faults, any one of which is serious enough to make development of better cultviars highly desirable. For example, only 64% of the total nuts have split shells (Table 1). Another serious fault is that 21% of the nuts produced are blanks (empty). Probably the most serious fault of Kerman is its strong tendency for biennial bearing. While most pistachio cultivars are prone to bear biennially, Kerman would appear to be notorious in that respect. The need for better cultivars is obvious.

Fig. 2. The pistachio produces its fruits in clusters that are borne laterally on 1-year-old wood.

Table 1. Annual variation in Kerman pistachio nut characters.*

Year	Type of Nut: Blank (%)	Unsplit (%)	Split (%)
1973	25	7	68
1974	27	5	68
1975	38	3	59
1976	20	9	71
1977	14	17	69
1978	25	20	55
1979	17	15	68
1980	19	29	52
1981	16	23	61
1982	12	22	66
Avg.	21	15	64

*Data are averages based on at least 2 100-nut samples from each of 22 trees.

CURRENT RESEARCH AREAS

Pruning

The pistachio characteristically produces 1 bud in the axil of each leaf on current growth. All axillary (lateral) buds on young trees are vegetative the first 4 or 5 years. During that period, the response to pruning for establishing properly spaced scaffold branches is like other deciduous fruit and nut trees, as removal of terminal portions of branches (pruning by heading back) stimulates lateral buds to grow. The tree begins forming flower instead of vegetative buds in the leaf axils the 5th or 6th year and, each year thereafter for several years, more and more flower buds and less and less vegetative buds are produced. Eventually, all lateral buds on some shoots are flower buds, while on others all are flower buds except for 1 or 2 near the tips of the shoots. Many of the latter subsequently fail to grow because of strong apical dominance exerted by the terminal vegetative bud. Thus, it is not uncommon for a branch to continue growth in length for 8 to 10 years with no lateral branching. Nut production subsequently occurs progressively further and further from the center of the tree. Eventually, the branches are bent out of position from the weight of foliage and nuts and are then subject to sunburn. They also crowd and bring about shading of branches below them.

Conventional pruning procedures to prevent the situation described above, as well as to keep the tree in bounds and to promote formation of renewal fruiting wood on scaffold branches, have failed to bring about the desired response. Two factors are responsible. Unlike other deciduous fruit and nut trees that generally produce at least 1 vegetative bud per node, a bearing pistachio tree characteristically produces relatively few lateral vegetative buds, practically all are flower buds, as pointed out above. Consequently, when a branch is indiscriminately headed-back in pruning to force lateral branching, in many instances there are no lateral vegetative buds present and the portion remaining dies back to the first lateral branch or to a lateral vegetative bud that is stimulated to

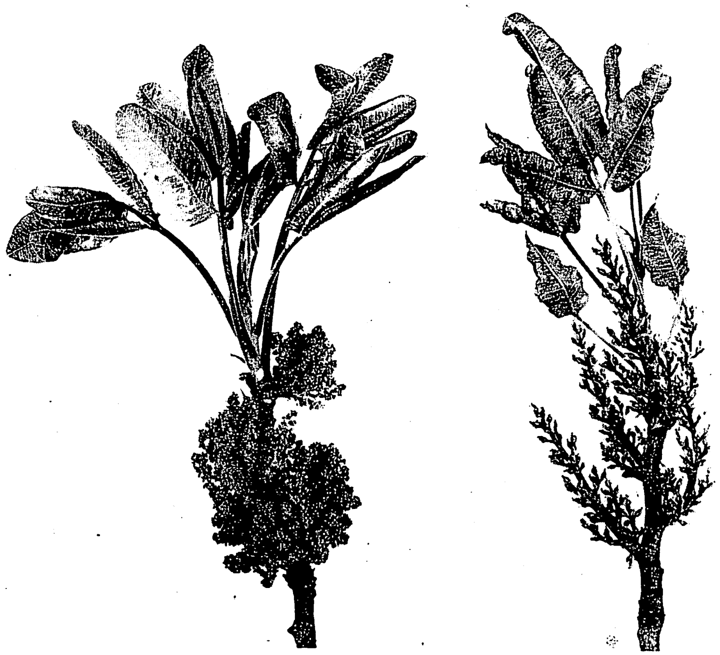

Fig. 3. Male (left) and female (right) pistachio inflorescences photographed on April 15 a few days past full bloom and before shoot growth and leaf expansion were complete.

grow. The other factor responsible for unconventional behavior of pistachio is apical dominance. Apical dominance in pistachio is so strong that reducing the number of growing points (branches) 50% by the thinning-out type of pruning resulted in practically no new shoots arising laterally from the remaining branches. Removal of all terminal buds by the heading-back type of cut and the consequent elimination of apical dominance stimulated new shoot growth throughout the tree, even on scaffold branches that were 3 - 6 inches in diameter. While this method of pruning stimulates the growth of new fruiting wood throughout the tree, it also eliminates one year's crop of nuts. It should be done, therefore, in the winter prior to the "off" year of production in the biennial bearing cycle to minimize loss of yield.

Work is in progress to determine growth and fruiting responses to different degrees of heading back. Terminal bud removal can be done by making small cuts near the buds or by making fewer, but larger, cuts in 3- to 5-year-old wood. To reduce labor costs and as a substitute for the former, chemicals to kill the growing points might be applied. Topping and hedging machines may be used if larger cuts prove better. The extent to which heading-back is done is also dependent upon the tree size reduction desired. Information is needed regarding tree response to pruning in the "on" versus the "off" year and the frequency at which this type of renewal pruning must be done.

Biennial Bearing

The specific cause of biennial bearing in such crops as apple, mango, orange, pear, pecan, and prune has not been elucidated, but the presence of a heavy crop of fruits limits the formation of flower buds for the year following. It is not known if this limitation is the result of a critical depletion of assimilates by the developing fruit or the action of an inhibior originating in the fruit. The pistachio, a biennial bearing species, produces abundant inflorescence buds every year, but they abscise in such numbers during the summer of a heavy crop that few remain to produce a light crop the next year. Thus, biennial bearing in pistachio is the result of abscission of premature inflorescence buds during a heavy crop year rather than lack of flower bud formation (9). The period of maximum bud abscission coincides with that of rapid seed growth and development during July and August. This, as well as adjustments in crop load and/or in leaf area, indicates that assimilate depletion is responsible for bud abscission (10, 11). Carbohydrate and nitrogen levels in bark and wood of nut-bearing branches, however, were found to be similar to those in identical tissues of nonbearing branches during the period of bud abscission (7, 13, 19).

Since the data indicated that bud abscission might not be the result of carbohydrate depletion, it was speculated that the phenomenon might be hormonally controlled (11, 13). An abscission-inhibiting hormone produced in the leaves may be directed away from the inflorescence buds to developing nuts with large demand for carbohydrates. Nut removal would change the source-sink translocation relationship and make the proposed inhibitor immediately available to the buds. An abscission-promoting compound originating in the developing nuts also might be a control mechanism of bud abscission. Determinations of levels of abscissic acid (20) and gibberellin-like substances (17) in developing seeds and inflorescence buds, however, indicated that these potential abscission-promoting compounds are not involved.

In spite of similarity in carbohydrate levels in bearing and nonbearing branches during the main period of inflorescence bud drop, the presence of a nut crop depresses inflorescence bud growth on current wood during the summer (21), starch storage in branches during fall and winter (7), and vegetative growth in length the following spring (10). Thus, production of a crop of nuts brings about direct and long lasting effects in the pistachio tree. A study of the effect of developing nuts on translocation and distribution of photosynthates from leaves revealed that most of the ^{14}C-photosynthate transported from leaves accumulated in developing nuts. Inflorescence buds competed poorly against the developing nuts for photosynthate as those on bearing branches had about half as much as those on nonbearing branches (22). Thus, carbohydrate deficiency in the buds themselves may be responsible for the bud drop phenomenon and subsequent biennial bearing.

Vegetative Propagation

Because of greater resistance to root-knot nematodes and verticillium wilt, as well as to subsequent growth and production, the pistachio is grown on

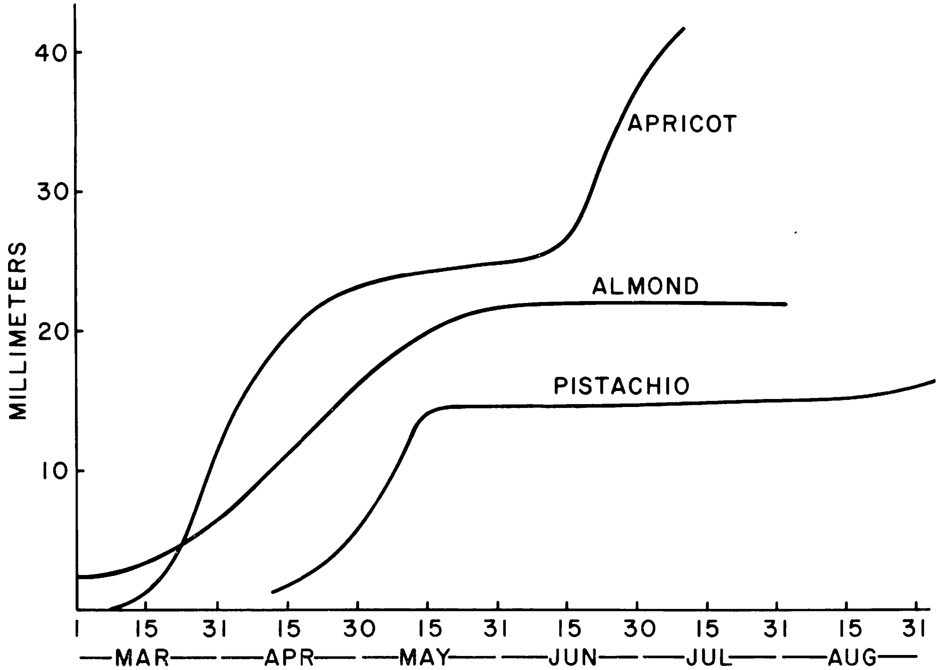

Fig. 4. Curves of growth in diameter of fruits in almond, apricot, and pistachio.

P. atlantica, P. integerrima, and *P. terebinthus* rootstocks. These rootstocks are propagated by seeds, since no satisfactory method for rooting cuttings has been developed. Blank nut production, shell splitting, and resistance to verticillium wilt all reflect, in part, the natural variation in rootstock performance that is expected as a result of gene segregation. Tissue culture techniques are being used to develop a method for vegetative propagation of *Pistacia* to generate sufficient quantities of superior rootstocks with uniform characteristics.

Blank Production

Blank (no kernal) production in *P. vera* is a problem wherever pistachios are grown. The extent to which it occurs is dependent upon cultivar (3), year to year (Table 1), and from rootstock to rootstock (4). Kerman produces excessive amounts of blanks, averaging 21% of the total number of nuts produced.

Blank production is the result primarily of embryo abortion (1, 4), but also from vegetative parthenocarpy (3). Aberrations in seed also occur at various stages and result in subnormal size at maturity. Apparently, because of the parthenocarpic tendency, fruits with aborted seeds do not abscise but grow to practically normal size (12). Growth of blank fruits is identical to that of seeded fruits during Periods I and II, but there is no Period III.

Embryo abortion and consequent blank production is apparently governed somewhat by the seedling rootstock, for some trees consistently produce high percentages of blanks and other trees consistently produce low percentages. Whether the effect of rootstock is mediated through a nutritional or a hormonal mechanism remains an unanswered question. Studies are being made to determine the distribution of blanks in relation to position in the cluster, on individual branches, and in the tree as a whole. The data may provide insight as to whether apical dominance and/or nutrition are involved.

Shell Dehiscence

The shell of the pistachio nut, unlike that of other *Pistacia* species, partially dehisces beginning at the apical end and progressing along the ventral and dorsal sutures to varying degree. Shell dehiscence begins the last of July, at least a month before maturity of the fruit, and continues until harvest during the first half of September. The bulk of the pistachio crop is marketed in-shell, and dehiscence is a desirable trait as it facilitates shell removal by the consumer. Nuts with undehisced shells must be separated and their shells either cracked or removed by machines before processing and marketing.

The extent to which endocarp dehiscence occurs varies from one cultivar to another (15, 18), among individual nuts from a single tree, among those from different trees of the same cultivar, and from year to year (8). The data in Table 1 show that the percentage of total nuts having split shells may vary from a low of 52%, as in 1980, to a high of 71%, as in 1976. This variation results from differences in both percentage of blank nuts (in which shell splitting never occurs) produced from year to year and percentage of nuts with kernals in which shell splitting does not take place (Table 1). Evidence indicates that shell dehiscence is a manifestation of abscission that is triggered by a substance(s) emanating from the seed (8). Ethylene apparently is not involved in the process as the application of (2-chloroethyl)phosphonic acid (ethephon) failed to enhance dehiscence (14). Additional materials are being tested for that purpose.

Epicarp Lesion

"Epicarp" lesion is a misnomer because lesion development generally involves the mesocarp (inner layer of hull) and the endcarp (shell), not just the epicarp (skin). Symptoms associated with the problem are variable. Brown to almost black spots, which may be the diameter of a pea or which may eventually cover half to all of the fruit's exterior surface, appear any time from several days after bloom to as late as a month before maturity. Darkening of the hull sometimes occurs, but it generally invades the shell also. In some cases, the exterior of the nut appears normal but darkening of the shell to varying extent occurs. Fruits affected early in the season shrivel and drop from the trees. Those affected later in the season may remain on the tree, but kernel development is poor and the shells are incompletely developed and discolored. The severity of the problem varies from tree to tree, from one location to another, and from year to year. It is more severe generally in Kerman than

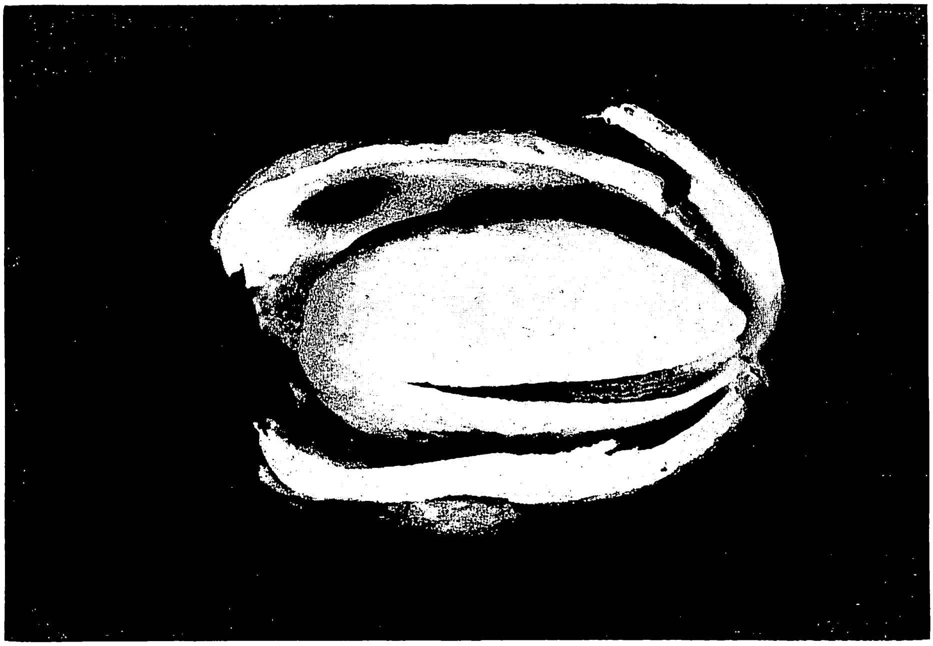

Fig. 5. At fruit maturity, the hull separates easily from the dehisced shell which partially exposes the kernel.

in other cultivars. Crop losses due to epicarp lesion have been estimated to be as high as 30% in some years.

Since no disease organism has been shown to be associated with affected fruits, the problem has been thought of as a physiological disorder. Evidence obtained by University of California personnel in the summer of 1983, however, indicates that the leaf-footed plant bug (*Leptoglossus clypealis* Heidemann), a sucking insect, is associated, at least in part, with epicarp lesion. This insect, observed feeding in pistachio orchards throughout the state, may secrete an enzyme that causes deterioration of the fruit tissues. All aspects of this serious and unusual problem are being investigated.

Nutrition

Although the pistachio has been grown commercially in several Middle Eastern countries for many years, there is nothing in the literature concerning nutritional requirements other than the fact that it responds ". . . to applicaions of nitrogen the same as most other trees" (24).

Concentrations of several mineral elements in normal appearing pistachio leaves have been determined (23) as a basis for comparing data from analysis of leaves suspected as being deficient in a particular element(s).

Both boron and zinc deficiency have been identified and confirmed. Extensive nitrogen fertilizer plots have been established in several commercial orchards.

CONCLUSIONS

The above discussion points out only a few of the horticultural problems with pistachio production that have received some attention during the past decade. There are other diverse problem areas that have received little or no attention. For example, no breeding work has ever been conducted and apparently all culitvars, both male and female, originated as chance seedlings. The potential for alleviating such problems as blank production, shell dehiscence, and biennial bearing through new cultivars remains untested. Critical comparison of the various rootstock species, as well as their hybrids, has not been made with regard to relative compatibility with *P. vera*, disease resistance, blank production, shell dehiscence, biennial bearing, etc. The pistachio, because of climatic conditions where it originated, is thought to be drought tolerant. Its water use requirements, however, and physiological response to water stress have not been determined.

Pollination is another area that urgently needs research. Conditions under which pollen should be stored to maintain viability must be determined before supplemental or complete artificial pollination may be accomplished effectively. Pollen carriers or dilutants, as well as methods of application, must be tested. The most effective ratio of staminate to pistillate trees and their relative placement to one another have never been determined experimentally.

In addition to problems of horticultural nature, insects and diseases are appearing as potential problem areas that will require research. Everyone associated with the industry agrees that it has a great future, but there is much to be learned.

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The California Almond Industry

DALE E. KESTER AND WARREN C. MICKE[1]

Almonds have been grown in California for over 100 years. The climatic requirements of the almond are such that production in the U.S. is restricted almost entirely to California (99%) where the Sacramento and San Joaquin Valleys are almost ideally suited to production.

Characteristics that allow almonds to be successfully grown in these California valleys include:

a. Sufficient winter chilling (300 to 500 hours below 45°F) to allow bloom of major cultivars to occur from mid-February to early March with normally enough sunny, warm days free of rain and wind during bloom to allow for cross pollination by bees.

b. Relative freedom from spring frosts in most years and districts. Almonds are vulnerable to frost in most parts of U.S. and world due to their early bloom. In areas of frequent spring frosts in California, protection has been provided in recent years by application of irrigation water, often by under tree sprinklers.

c. Usually a long, rainless spring, summer and fall. These conditions avoid diseases accentuated by spring and summer rains as well as harvest interference and disease from late summer and fall rains. The most significant crop limiting diseases which attack the almond at bloom are fungi, brown rot *(Monilinia)*, shot-hole fungus *(Stigmina)*, and bacterial blast *(Pseudomonas)*. The first two are controlled by fungicides, but timing is critical.

[1]Professor of Pomology and Extension Pomologist, University of California, respectively, University of California, Davis, CA 95616.