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THE CYCLAMEN MITE, TARSONEMUS PALLIDUS, AND ITS CONTROL ON FIELD STRAWBERRIES[1]

LESLIE M. SMITH[2] AND EARL V. GOLDSMITH[3]

INTRODUCTION

DURING THE PAST SEVERAL YEARS, strawberry fields in California have shown an increasing decadence, until, at the present time, a commercial planting may be expected to produce a crop of fruit for two years, or in some cases only one year, and then become commercially unproductive. This is strikingly in contrast with the conditions which existed 15 or 20 years ago, when, according to reports, strawberry plantings produced crops for 4 to 6 years. This decadence may be caused by one or more relatively obscure factors, of which the most important is, no doubt, in certain varieties at least, the virus disease known as yellows or xanthosis. In addition, strawberries suffer from accumulation of salts in the surface soil, and from root diseases of obscure etiology. Recently Thomas (1932) has discovered that the causal agent of a hitherto puzzling wilt disease is a fungus belonging to the genus *Verticillium*. Among the animal parasites of strawberries are the cyclamen mite, red spider, the strawberry root-worm, white grubs (larvae of various scarabaeid beetles), the stem nematode, the root-knot nematode, and aphids. The most important economically of these parasites of strawberries at the present time is the cyclamen mite, *Tarsonemus pallidus* Banks.

IDENTITY OF THE SPECIES

The species which has been injuring strawberry plantings on the Pacific Coast and known to the growers as the strawberry mite has been identified for the authors by Dr. E. H. Ewing as the cyclamen mite *Tarsonemus*

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pallidus Banks. This species was named by Banks (1898), whose specimens were collected in a greenhouse in New York on leaves of chrysanthemums. About seven years later, Zimmerman (1905) described the strawberry mite, *T. fragariae* from specimens taken from strawberry plants growing out of doors in Austria. Since that time workers in Europe have known the species under the name *fragariae,* while in America the species has generally been called *pallidus.*

In the past, *Tarsonemus pallidus* and *T. fragariae* were believed to be distinct for several reasons, chief among which were the facts that cyclamen plants are not attacked in certain parts of the range of the strawberry mite and that until recently the strawberry was not attacked in the range of the cyclamen mite. Thus, in England, although the strawberry mite has been present for several years, no tarsonemids have been found attacking cyclamens, begonias, or other hosts of the cyclamen mite.[4] On the other hand, although the cyclamen mite has been in the United States since 1883 (Munger, 1933), no tarsonemid pest was discovered on strawberries until 1928 (Darrow, 1928).

Early attempts by the present authors to transfer mites from the strawberry to the cyclamen, and vice versa, were without success. Massee (1933) also described trials of this nature which were unsuccessful. Recently Ewing and Smith (1934), however, have successfully transferred mites from the strawberry to the cyclamen, and the present authors also have been able to complete the transfer to 92 per cent of the plants in one test, as described later.

This species is not readily transferred from one host to another. Floyd Smith[5] states: "I have frequently failed in getting *pallidus* established on strawberry and cyclamen, even when transferred from the same hosts. Although both these plants are favored hosts of *pallidus* in the East and are severely injured, they are not accepted under certain conditions." Massee (1933) states: "Experiments have been carried out at East Malling to see whether the (strawberry) mites could be induced to live upon such plants as the Cyclamen, Begonia. . . . The investigations were extended over three seasons, from 1930–1933, but negative results were obtained every time." In 1930 the present authors transferred mites from the cyclamen to small cages fixed to strawberry leaves, and similarly from strawberry to cyclamen, but the mites died in every case. Again in the summer of 1934, 25 cyclamen plants were each infested with about 100 mites from strawberry, but in no case did they survive on the cyclamen. However, in the fall of 1934, another set of 25 cyclamen plants were each infested with about 50 mites from strawberry, and sub-

[4] Personal correspondence with A. M. Massee, September, 1934.

[5] Personal communication.

sequent examination showed strong colonies established on 92 per cent of the plants. Twenty-five check plants remained free from mites.

Ewing and Smith (1934) recently have made morphologic and biologic comparisons and conclude that no differences exist between *Tarsonemus pallidus* and the similar form on European strawberries. They list *T. fragariae* Zimm. as a synonym of *T. pallidus* Banks.

HISTORY OF THE OCCURRENCE OF TARSONEMUS PALLIDUS ON STRAWBERRIES

The cyclamen mite has been observed on garden strawberries in Finland since 1892, by Reuter (Morstatt, 1908). Zimmerman (1905) first observed the mite in 1900 in Maerisch-Eisgrub, Austria, on garden strawberries, and it was subsequently recorded in Europe injuring field strawberries as follows: in 1906, Germany (Morstatt, 1908); 1906, Finland (Reuter, cited by Massee, 1930*a*); 1912, Norway (Schoyen, 1914); 1915, Sweden (Tullgren, cited by Massee, 1930*a*); 1916, Denmark (Ferdinandsen, 1919); 1924, England (Massee, 1930*a*); 1928, Russia (Savzdarg, 1928); 1928, Switzerland (Osterwalder, 1928); 1930, Holland (Sprenger, 1930).

In the United States the first observation of this species attacking field strawberries was that of Darrow (1928). A simultaneous discovery was made by M. B. Davis in Ontario, Canada (Darrow, 1928). In 1928, Darrow discovered the mite in strawberry fields in Maryland, New York, and Massachusetts. In response to a questionnaire the present authors were informed that this species also had been found injuring strawberries in Wisconsin, Washington, and Oregon. From data furnished by J. A. Hyslop, of the United States Department of Agriculture Insect Pest Survey, supplemented by replies to the questionnaire, the cyclamen mite is now known to occur (on various hosts both out of doors and in greenhouses) in the following states: Washington, Oregon, California, Montana, Colorado, Nebraska, Kansas, Texas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Mississippi, Kentucky, Michigan, Ohio, Alabama, Virginia, Pennsylvania, Maryland, New Jersey, New York, Massachusetts, Connecticut, Delaware, and New Hampshire.

In California the cyclamen mite occurs in most of the major berry-producing areas, where varieties acceptable to mites are grown. The greatest economic injury occurs in the coastal belt in the vicinity of Salinas, Watsonville, and Santa Cruz, and in the Santa Clara Valley. Some injury is also produced in the areas around Los Angeles and San Diego. Although susceptible varieties are grown inland in the southern part of the state, near Riverside and in the Imperial Valley, no mites could be found in these sections; and it seems likely that the high temperatures or low humidities of summer annually exterminate the mites which may be brought into these areas.

LIFE HISTORY

In their development to mature males and females, the mites pass through the egg, larval, and "pupal" stages. The eggs (fig. 1, *B*) are white, opaque, smooth, ovoidal, and unusually large when compared with the size of the adult mites. They are approximately 125 microns in length and 75 microns in diameter. The egg stage was found to last three or four days at about 20° C. Savzdarg (1928) states that the egg stage requires 9 to 13 days at a temperature of 15°–18° C. The shell is very thin and the embryo is clearly visible in the egg for some time before hatching.

The eggs hatch into six-legged larvae, with the first two pairs of legs situated close to the head and the third pair on the posterior half of the body. The larvae are opaque white, and have at the posterior end of the body a peculiar triangular enlargement. Larvae average approximately 200 microns in length and 80 microns in width. At room temperatures the larval period was completed in from 1 to 4 days, with an average duration of 2.8 days.

When the larvae are fully grown the larval integument becomes loosened from the body, but still covers it to form a "pupal" case. The legs are withdrawn from their integuments and lie in the loose skin of the larval body. The two anterior pairs of legs are directed anteriorly and closely appressed to the head while the third pair of legs is directed to the rear. A fourth pair of legs appears in this stage, posterior to the third pair of the larva. This form, or "pupa," is without means of locomotion. "Pupae" are approximately 225 microns long and 95 microns wide. The "pupal" stage lasts for 2 to 7 days, with an average duration of 3.8 days.

At the completion of the "pupal" stage, the larval skin splits and the adult mite emerges. The adults are of two distinct structural types: the female and the male. The body of the adult female (fig. 1, *A* and *C*) is regularly oval, with a relatively large, distinct, nearly heart-shaped capitulum projecting anteriorly. There are four pairs of legs. The first and second pairs are situated close to the head while the third and fourth pairs are on the posterior half of the body. The fourth pair of legs of the female are reduced to thin, rod-like structures which project to the rear and are not used for walking. At the apex, the fourth leg carries one long and one short bristle. Each of the other legs terminates in a retractile bladder-like structure which is expanded when the leg is in contact with the substratum, and is retracted while the leg is carried forward. The two sides of the bladder are heavily chitinized to form a sheath over the retracted structure. When the bladder is expanded these chitinizations resemble claws. Each leg of the anterior pair possesses, in

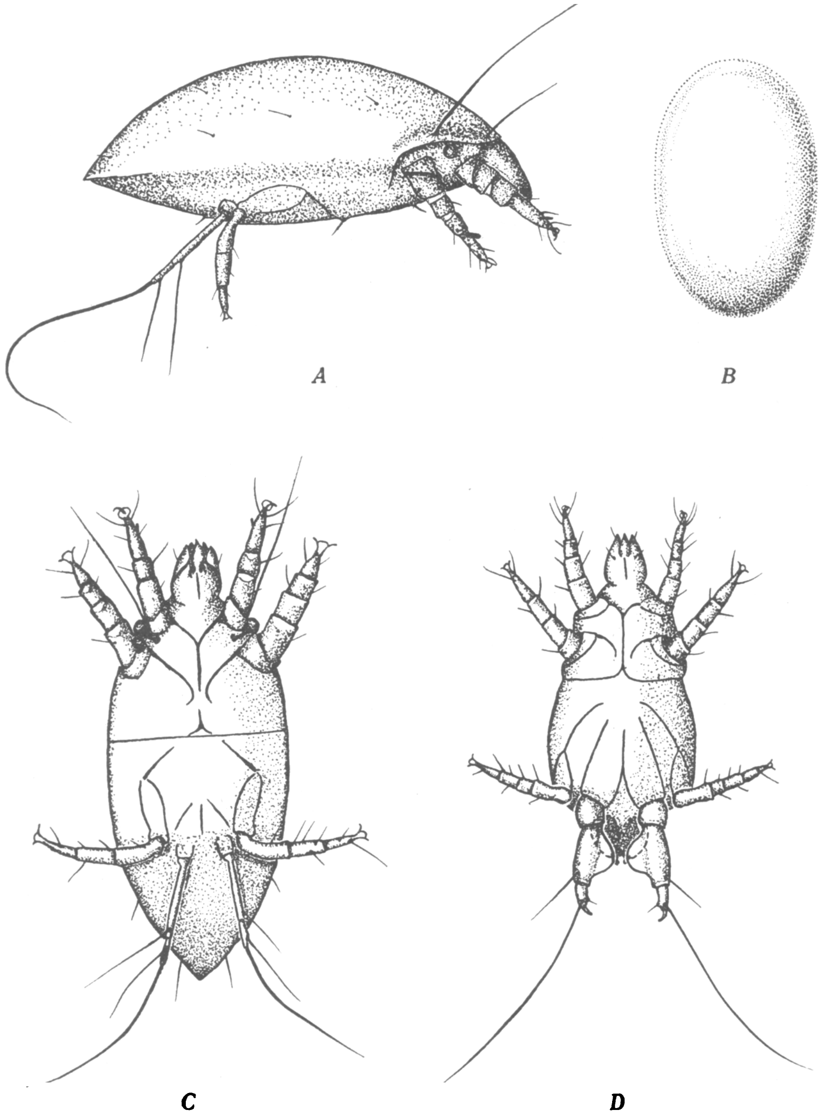

Fig. 1.—*Tarsonemus pallidus* Banks: *A*, adult female, lateral view; *B*, egg; *C*, adult female, ventral view; *D*, adult male, ventral view. All at same magnification.

addition, a median, single claw. On either side of the body between the first and second pairs of legs occurs (in the adult female only) the so-called clavate organ. This is apparently a solid sphere which is supported by a stalk attached to the body in a cup-like formation of the integument. When cross sections of the mites were examined it was found that the whole clavate organ is situated in a deep pocket between the dorsal shield and the bases of the first and second legs, so that the apex of the sphere is scarcely visible beyond the edge of the dorsum. Adults which have newly emerged from "pupae" are pale-amber-colored but as they become older they darken. Old adults are sometimes brown. The integument glistens as though covered with oil. While the legs are provided with numerous bristles and a few clavate hairs, the body is nearly devoid

TABLE 1

LENGTH OF STADIA OF THE CYCLAMEN MITE ON VARIOUS HOSTS, IN DAYS

Stadium	Geranium 20°–25° C*	Cyclamen 18°–21° C†	Strawberry 16°–21° C	Average
Egg	5.0	11.0	3.5	6.5
Larva	2.3	7.0	2.8	4.0
"Pupa"	2.0	3.5	3.8	3.1

* Data averaged from Garman (1917).
† Data from Moznette (1917).

of vestiture. Females average about 230 microns in length and 120 microns in width. The thickness of a few specimens which could be measured averaged about 80 microns.

The adult male (fig. 1, *D*) resembles the female in color and vestiture, but is smaller. In the male, the legs of the posterior pair are considerably enlarged, and are not used in locomotion. The penultimate segment bears a membranous dilation which projects mesad. Males average 170 microns in length and 95 microns in width.

The technique used for rearing was that described by Garman (1917), with pieces of strawberry leaves substituted for geranium. Garman reared the mites on geranium at a temperature of 20°–25° C; Moznette (1917) reared them on cyclamen at a temperature possibly ranging from 18° C to 21° C; and the present authors reared them on strawberry at a temperature ranging from 16° to 21° C. The results of these three rearings are summarized in table 1.

HABITS AND ENVIRONMENTAL REQUIREMENTS

The cyclamen mites avoid light. They are rarely found on exposed surfaces of the plant. The majority of mites always occur in the unopened leaflets in the center of the crown. Here they are usually found between the two closely appressed halves of the dorsal surface of the folded leaflet. In this situation the colony of mites is usually located at the base of the midrib near its junction with the petiole of the leaf (fig. 2). Mites are also found on the outer surfaces of the folded leaflets when these leaflets are closely appressed. This is especially the case in varieties which have dense pubescence on the ventral leaf surface, as in *Fragaria chiloensis*. Mites, in all stages of development, are also commonly found in strawberry flowers. Here they generally occur at the bases of the

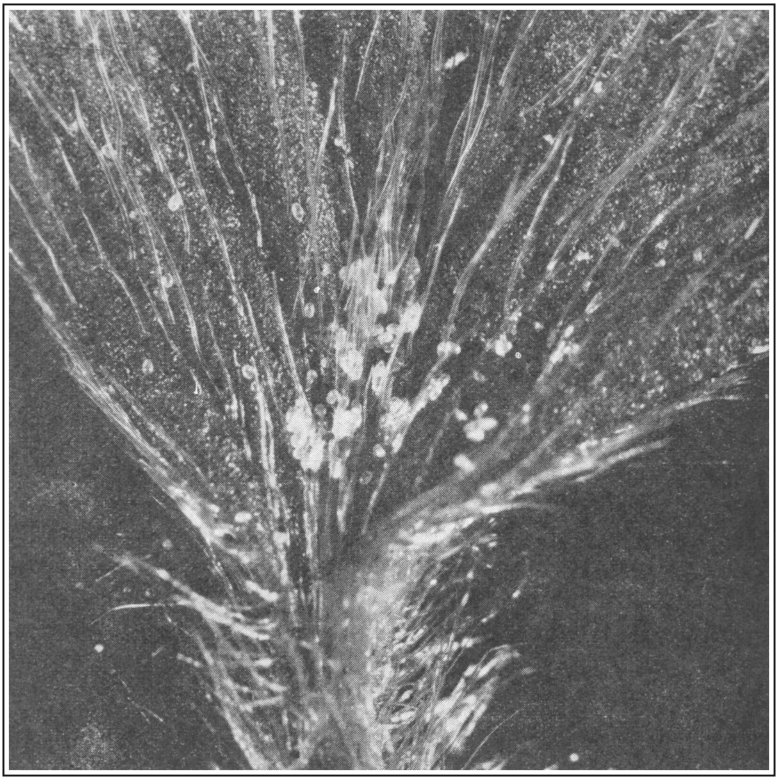

Fig. 2.—Upper surface of a young leaflet of Nich Ohmer strawberry which has been opened to show mites and eggs at the base of the leaflet.

petals and on the inner bases of the sepals. In cases of heavy infestation, all stages of mites can be found distributed over the green seeds of the immature berry, but protected by the dense formation of the styles. After the styles dry, mites can no longer be found on the fruit.

The cyclamen mite requires a high humidity. In rearing the mites in micro-cages in the laboratory it was found that the mites died when the humidity in the cage was allowed to decrease; and that the mites survived and developed better when the humidity was near saturation. Garman (1917) states that *Tarsonemus pallidus* "prefers a high relative humidity (80%–90%) and a temperature ranging from 60°–80° F." Plants wet with rain and dew have been examined and mites have been found alive in droplets of water, indicating that they may survive submergence, for hours. In control experiments (discussed later) wherein mites were immersed in hot water, a check was generally conducted by submerging mites in cold water for two hours. This submergence was without injurious effect on the mites.

The cyclamen mite can exist through a wide range of temperature. Adult females and larvae lived for 3 days on strawberry leaves which were allowed to freeze in a beaker of water. At San Jose the authors have frequently seen the mites endure subfreezing temperatures during the winter. On a few occasions the temperature dropped to 17° F without killing the mites. On the other hand (as indicated later in control tests), prolonged exposure to a temperature of 100° F proves lethal to the mites. Furthermore, the authors were unable to find the mite in strawberry plantings in the inland section of southern California where summer temperatures frequently exceed 100° F; but whether these high temperatures prove lethal, or whether the coincident low humidity is the lethal factor could not be determined.

Adult females overwinter in a true condition of hibernation in the crowns, at the bases of the petioles of the leaves. In the strawberry plant the petiole of the leaf becomes flattened, crescentic in cross section in the basal half inch of its length, and is applied closely against the stem of the plant and bases of other petioles. On either side of the flattened portion is borne a large foliaceous stipule which often attains a length of 1¼ inch. The stipules soon die and become brown and paper-like. They likewise ensheathe the crown. The inner base of the petiole is glabrous; the outer portion and the stipules are pubescent. Adult females are found during the winter between the glabrous inner surface of one petiole and the pubescent outer surface of the one above it. This situation is usually above the level of the soil, but is occasionally covered. On heavily infested plants 10 to 15 hibernating females may be found on one petiole. A limited amount of brown scarring indicates that normally little feeding is done during hibernation.

Females emerge from hibernation in the spring. The time of emergence apparently varies considerably with the mildness or severity of the weather. Observations during the past five years indicate that females usually leave their hibernating quarters about the latter part of February. They migrate to the center of the crown and commence oviposition at this time. Only adult females can ordinarily be found during the winter; but during the winter of 1933–34, a phenomenally mild winter, oviposition was carried on through the late fall and winter until the middle of January, at Watsonville. There occurred a short period in the latter part of January and early February when eggs could not be found, although "pupae" and males each constituted about 5 per cent of the total population during this period. Hence, it seems likely that during exceptionally warm winters the mites may breed throughout the year in central California.

The rate of oviposition is unusually rapid when the relation of the size of the egg to the size of the female is considered. Isolated females in cages, fed on small pieces of strawberry leaves, deposited 3 eggs a day for 4 consecutive days. Although the average rate of egg deposition falls below 3 a day in cage tests, it seems likely that this rate may be maintained when mites are in their normal environment. Parthenogenesis of these eggs was proved by Garman (1917). He reared several generations without the appearance of males. In the field, males do not normally overwinter. They appear in very limited numbers in May and increase slowly until the advent of cold weather in the fall. At this time, in colonies containing many "pupae," they may number 30 per cent of the total population. On the average, males probably constitute about 5 per cent of the total population.

The modified fourth pair of legs of the male is used as a pair of claspers with which to pick up "pupae"; males are frequently seen carrying them about, with the anterior end of the "pupa" to the rear. Males are occasionally seen holding mature females in the same manner. They can be distinguished from females with a 14-power hand lens, chiefly because of their greater activity and faster rate of walking. The smaller size and enlarged fourth pair of legs also aid in recognition of the male.

HOST PLANTS

The cyclamen mite attacks many species of plants, other than strawberries (*Fragaria*). Floyd Smith (1933) lists the following plants attacked, for the most part, in greenhouses: *Amaranthus retroflexus,* pigweed; *Antirrhinum majus,* snapdragon; *Begonia semperflorens,* wax begonia; *Capsicum annuum,* common red pepper; *Chrysanthemum frutescens,* marguerite; *Chrysanthemum hortorum,* common chrysanthemum; *Crassula rubicunda; Cyclamen indicum,* cyclamen; *Dahlia rosea,* old garden dahlia; *Delphinium ajacis,* rocket larkspur; *Delphinium* sp., a hybrid of belladona larkspur; *Fragaria* sp., strawberry; *Fuchsia speciosa,* common fuchsia; *Galinsoga parviflora; Gerbera jamesonii,* flame-ray gerbera; *Impatiens sultani,* sultan snapweed; *Lantana camara,* common lantana; *Oxalis* sp., wood sorrel; *Parthenocissus tricuspidata,* Boston ivy; *Pelargonium peltatum,* ivyleaf geranium; *Pelargonium hortorum,* fish geranium var.; *Petunia hybrida,* common petunia; *Rubus* sp., blackberry; *Verbena* spp., common verbenas; *Veronica peregrina,* purslane speedwell.

In addition to some of the plants mentioned above, Munger (1933) lists as hosts: forget-me-not, African violet, sweet pea, larkspur, cybodium, moccasin flower, rhododendron, orchid, heliotrope, stevia, daisy, and gloxinia.

It should be borne in mind that the cyclamen mite is primarily a greenhouse pest and that practically all of the above-mentioned hosts

TABLE 2

PLANTS TESTED AS HOSTS OF TARSONEMUS PALLIDUS

Species	Number of plants used	Number of plants infested 72 days later	Species	Number of plants used	Number of plants infested 72 days later
Fragaria cuneifolia (Mariposa, Calif.)	17	7	*Fragaria californica* (Mariposa, Calif.)	16	9
Fragaria chiloensis (Pigeon Point, Calif.)	8	2	*Rubus parviflorus*	5	0
			Rubus vitifolius	8	0
Fragaria chiloensis (Chile)	3	2	*Potentilla lindleyi*	2	0
Fragaria sp. (China)	2	2	*Potentilla glandulosa*	10	7
Fragaria californica (Alma, Calif.)	3	1	*Geum*, sp.	4	3
			Acaena microphylla	7	0

have been infested under greenhouse conditions. In response to a questionnaire addressed to entomologists in each of the several states, only two records of the occurrence of the cyclamen mite out of doors were obtained (exclusive of the occurrence of this species on strawberry). Both of these records pertained to occurrence on *Delphinium.*

The authors attempted to determine whether or not under out-door, California conditions, other plants than strawberries were hosts of the mite. Two types of plants were tested: wild species of *Fragaria,* and rosaceous plants closely related to the genus *Fragaria,* which may occur at times near berry-producing areas. The plants were grown in pots in an open lath house at San Jose. Each plant was infested in May by placing small leaflets from infested strawberry plants deep into the crowns of the test plants, until approximately 75 to 100 mites had been colonized on each plant. Seventy-five days later the plants were examined and the data, given in table 2, recorded. The majority of the infested native *Fragaria, Potentilla,* and *Geum* plants were severely injured and some were completely killed by the mites. No mites survived the winter on any of these potted plants, and have not been observed on any of these species growing under natural conditions.

All commercial varieties of strawberries are hosts of the cyclamen mite. However, in some sections certain varieties are much more susceptible to mite attack than certain other varieties which escape commercial injury. Various authors have indicated differences in susceptibility as shown in table 3.

In variety trial plots at San Jose, observations in the fall of 1930 and of 1931 indicated that the varieties grown in the open were infested as shown below:

	Severely Attacked	
Aberdeen	Ford	Mascot
Big Joe	Fruitland	Mastodon
Big Late	Giant 999	Missionary
Blakemore	Haverland	Nich Ohmer
Boquet	Kellogg's Premier	Paul Jones
Buback	King Wealthy	Prince
Champion K	Klondike	Red Gold
Chesapeake	Lord Salisbury	Sample
Eaton	Lucky Strike	World Wonder
	Slightly Attacked	
Beacon	Gandy	Stevens Late Champion
Bliss	Kalicene	St. Louis
Clarke Seedling	Marvel	Superb
Cooper	Progressive	Washington
	Not Attacked	
Aroma	Burgess	Senator Dunlap
Banner	Early Bird	Wild (*Fragaria californica*)
Booster	Marshall	Wild (*Fragaria chiloensis*)
Brandywine	New Oregon	

In considering the varieties which were found to be free of mites as given in the above list, it should be pointed out that both *Fragaria californica* and *F. chiloensis* were found to be acceptable to mites when infested by hand (table 2). Furthermore, commercial plantings of Brandywine and Aroma plants were found to be infested at Watsonville. The varieties Early Bird, Burgess, Booster, and Senator Dunlap are not grown commercially in California and hence have not been definitely proved to be resistant. The varieties Marshall, New Oregon, Oregon Plum, and Banner are either identical or very similar. Henceforth in this paper, all will be indicated by the name Marshall. This variety is resistant in central California.

The chief commercial varieties grown in California are the Marshall and Nich Ohmer in the northern and central part, and the Klondike in the southern part of the state. In addition, the varieties Mastodon, Capitola, Magoon, Blakemore, and Brandywine have been grown to a limited extent in the north, while a few Missionary, Blakemore, Nich Ohmer, and Champion K have been grown in the south. All of these varieties have been found to be injured by the cyclamen mite, in commercial fields. The major loss however, occurs with the variety Nich Ohmer in the coastal portion of central California, particularly in the vicinity of Watsonville, Salinas, and San Jose. During the past five years no serious injury has been done to Marshalls by the cyclamen mite, in this section (with one exception), although Marshalls adjacent to heavily infested Nich Ohmer patches are generally found to support a few mites.

TABLE 3

VARIETIES OF STRAWBERRIES REPORTED AS SUSCEPTIBLE TO ATTACK BY TARSONEMUS PALLIDUS

Varieties heavily attacked	Varieties slightly attacked	Location and authority
Deutsch Evern	Roskilde	Denmark (Ferdinandsen, Lind, and Rostrup, 1919)
Sejrherren	Victoria	
Dybdahl	Rubezahl	
Laxton's Noble	Ohne Bedenken	
Konigin	Purpurkugel	
Louise	....	
Abundance	....	
Bedford Champion	....	
American Everbearing	Sieger	Germany (Naumann, 1924)
Dresden	....	
Royal Sovereign	....	England (Massee, 1930*b*)
Mastodon	Dr. Burril	Canada (Ross and Caesar, 1929)
Vanguard	Premier	
Parsons	....	
Mastodon	Marshall	Washington State (Arthur Hansen, personal communication)
Clark	....	
Improved Clark	....	

In the southern part of the state the variety Klondike is grown almost exclusively. The usual practice in this area consists of harvesting a large crop in the first crop year and a second smaller crop in the second crop year, after which, because of decrease in size of fruit, the field is disked out. This type of culture, and the low humidity which prevails during the summer in most of the berry-producing sections of the south apparently combine to reduce the injury of the cyclamen mite to a point where it is of slight economic importance on Klondike.

INJURY AND SYMPTOMS ON THE STRAWBERRY PLANT

The symptoms produced on the strawberry plant are so pronounced that it is difficult to believe that the few mites usually present could have produced them. In order to definitely determine the effect of the mites, 24 Nich Ohmer plants were infested with either 5 or 20 females each, in the middle of February. Twenty-four noninfested plants from the same source were held as a check. Six Marshall plants were likewise infested and 6 held as checks. The check plants remained free from mites

TABLE 4

COURSE OF MITE INFESTATIONS AND INJURY ON STRAWBERRY PLANTS, 1931

Plant No.	Mites used for infestation February 18	Observations, May 23*				Observations, June 30	
		Eggs	Larvae and "pupae"	Adults	Degree of infestation	Degree of infestation	Injury
Nich Ohmer							
1	5	+	+	+	Light	Very heavy	Medium
2	5	+	+	+	Medium	Heavy	Medium
3	5	+	+	+	Medium	Light	Heavy
4	5	+	+	+	Heavy	Light	None
5	5	+	+	+	Heavy	Light	Heavy
6	5	+	+	+	Heavy	Heavy	Medium
7	5	–	–	–	None	Medium	None
8	5	+	+	–	Very light	Very heavy	Light
9	5	–	–	–	None	Medium	None
10	5	+	+	+	Heavy	Heavy	Heavy
11	5	+	+	+	Medium	Medium	Medium
12	5	+	+	+	Medium	Heavy	Medium
13	5	+	–	–	Very light	Heavy	Light
14	5	+	+	+	Light	Very light	None
15	5	+	+	+	Medium	Very heavy	Heavy
16	5	+	+	+	Heavy	Light	Medium
17	5	+	+	+	Heavy	Very heavy	Heavy
18	5	+	–	+	Light	Light	None
19	5	+	+	+	Heavy	Very heavy	Heavy
20	5	–	–	–	None	Medium	Light
21	20	+	+	+	Heavy	Light	Heavy
22	20	+	+	+	Very heavy	Medium	Heavy
23	20	+	+	+	Heavy	Heavy	Light
24	20	+	+	+	Heavy	Very light	Light
Marshall							
25	20	+	+	+	Light	None	None
26	5	+	+	+	Medium	Heavy	Medium
27	5	+	+	+	Light	Medium	Medium
28	5	+	+	+	Light	Medium	None
29	5	+	+	+	Medium	None	None
30	5	+	+	+	Medium	Medium	Light

* Plus sign, stages present; minus sign, stages absent.

throughout the year and indicate that all plants were clean at the beginning of the test. The observations on the infested plants are recorded in table 4. From this table it is evident that 5 females are capable of establishing large colonies in a period of three months, since plants which were classified as heavily infested on May 23, supported from 200 to 500 mites in all stages. Three plants appeared to be free of mites

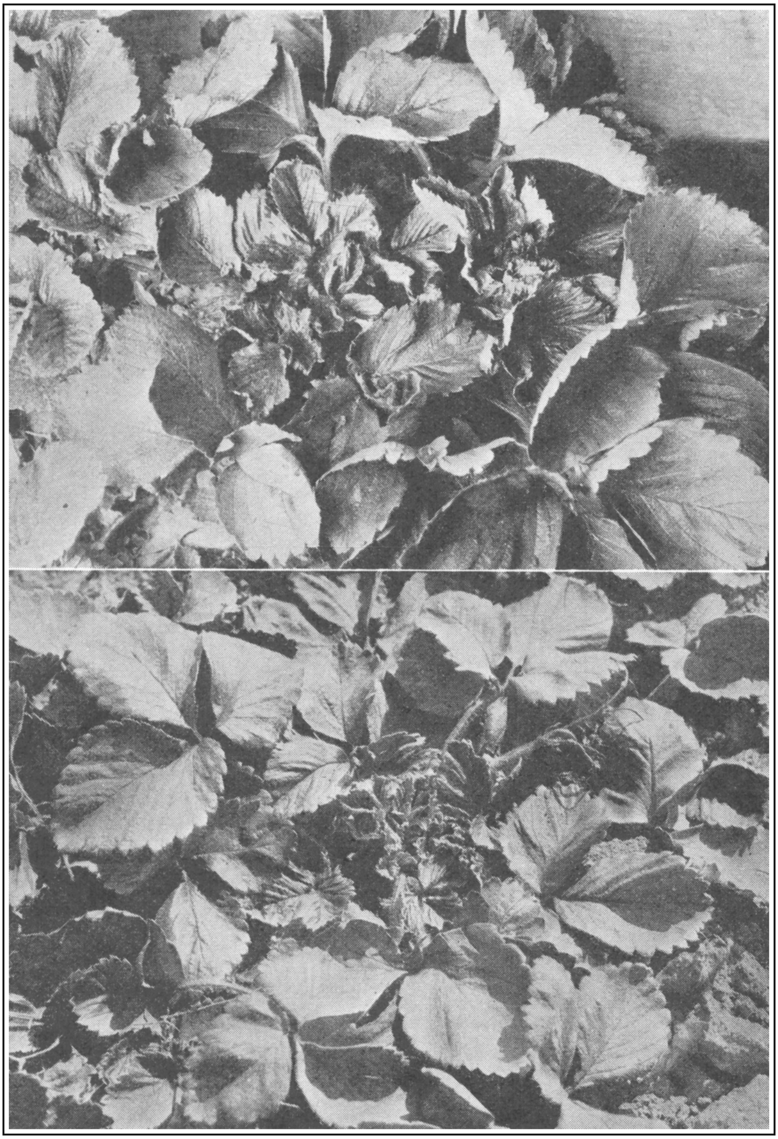

Fig. 3.—Strawberry plants showing advanced symptoms of injury. Upper, variety Nich Ohmer; lower, Boquet. (Photograph by Harold Thomas.)

on May 23 which indicates that a high percentage of mortality occurred among the 5 original mites placed on each plant. The differences in general infestation on May 23 are probably the result of the death of some of the original females.

Symptoms of injury were apparent on 22 of the 30 plants, four months after infesting. "Heavy" injury consisted of severe dwarfing and stunting; "medium" injury consisted of wrinkled leaves and may be considered as of economic importance. These tests indicate that a

Fig. 4.—Upper: Nich Ohmer plants dwarfed by mites. Lower: plants of the same variety not infested. Both photographs taken in commercial fields, at the same time, in the fall of the first crop year.

very few females, possibly 1 or 2 per plant, are capable of giving rise to progeny sufficient to severely injure the plants in a single growing season.

Deviations from the normal course of infestation, as indicated by plants 4, 5, 16, and 29 are discussed under "Natural Control."

Symptoms of mild injury on the Nich Ohmer are indicated by a roughened, wrinkled appearance of the upper surfaces of the leaves, together with an irregular folding and fluting of the leaf margin. Upon closer inspection, the areas on the upper surface of the leaf between some of the larger veins are seen to be bulged upward and when these bulges are examined with a hand lens they somewhat resemble blisters. In cases of mild injury the plant assumes a dense appearance, as a result of the failure of the petioles to elongate properly. In such cases the wrinkled leaf blades remain nearly vertical in the crown, and crowded together, rather than assuming the normal horizontal position.

Symptoms of severe injury (figs. 3 and 4) consist of a pronounced dwarfing of the center of the crown. Small leaflets do not unfold completely and attain less than one-tenth of their normal size. Petioles are much reduced. Small, severely injured leaflets become pale, yellowish green in color, and of a hard, brittle texture. Finally, many small leaflets are killed in the crown before they unfold. These turn brown and appear somewhat silvered by the dense pubescence on the exposed underside leaf surfaces. Infested flowers and young fruits are brown near the inner bases of the sepals, and in severe cases entire flowers and young berries turn black and dry up.

Symptoms on other varieties are similar, with the exception that in some, particularly Klondike, the bases of the midribs turn reddish brown.

All of these symptoms are believed to be the result of feeding punctures made by the mites, which puncture the tender growing tissues with their styliform mouthparts and extract the plant protoplasm. This results in minute dead areas which fail to grow with the other expanding portions of the leaf, so that bending and twisting of the leaf occur.

Several investigators (Harmsen, 1934) have conducted similar trials to determine the extent of damage caused by the mite, and at times, it seems that the injury is greater than the number of mites present could produce. Thus Massee (1930*b* and 1933) hand-infested 12 Royal Sovereign plants and, after symptoms had developed, eradicated the mites; five of the plants died. He suggested that a virus may be associated with mite attack. The present authors believe, however, that in those cases wherein severe symptoms occur and mites are scarce on the plant, some factor such as predators or climate has intervened to control the mites (see discussion under "Natural Control").

In commercial strawberry plantings the mite usually becomes of economic importance in the fall of the first crop year (that is, when the planting is nearly two years old), and by the fall of the second crop year all of the plants are dwarfed and the field is entirely unproductive. When, however, planting stock is obtained from a heavily infested field, the injury may be severe by fall of the first growing year, and the field may have to be abandoned by the middle of the first crop year.

INTRODUCTION AND DISTRIBUTION OF MITES IN THE STRAWBERRY FIELDS

The primary method of introduction of the mites into new strawberry plantings consists of planting infested nursery stock. Mites have not been found on shipments of planting stock, but because of their minute size and the limited time spent in such inspection, failure to find them is not surprising. On the other hand, clear-cut cases of mite introduction on planting stock have been seen in the commercial berry fields.

Before cases resulting from infested planting stock can be recognized, it is necessary to determine the extent of infestation which will result from natural spread from old infested fields, into adjacent, clean plantings. In the fall of 1933 several ranches were studied to determine the rate of natural spread. In the optimum case examined new Nich Ohmer plants had been set on about five acres, separated by only a narrow road from an old, heavily infested four-acre field of Nich Ohmers. The prevailing wind blew from the old field into the new. The latter field was mapped in the fall of the first year, by examining two rows, then skipping five and again examining two rows and skipping five, etc. Every mother or daughter plant which showed symptoms of mite injury was recorded. When the area was divided into four equal strips parallel to the old field it was found that in the strip adjacent to the old there were 35 mother plants and 7 daughter plants which showed symptoms of mite attack. In the next quarter there were 7 mother plants; in the third quarter 7; and in the fourth, and most remote quarter, there were 4. Assuming that 8,000 mother plants were planted to the acre, the total of 53 mother plants amounts to 0.13 per cent of mother plants infested by fall of the first growing season. The distribution of infested plants in the new field and the presence of infested daughter plants attached to noninfested mother plants, indicate clearly that the planting stock used in this field was free from mites when planted.

A number of berry fields were examined which showed unmistakably that mites had been brought in on the planting stock. One of the clearest cases consisted of about three acres planted to Nich Ohmers. Half of the field was planted with plants from one source while the other half was planted with plants from a different source. Mother plants in one-half of the field averaged 0.4 per cent infested, while in the other half they averaged about 30 per cent infested. All other factors such as situation, time of planting, etc., were uniform for the two lots. There is no doubt that the first lot of plants was free from mites when purchased, whereas the second lot was infested.

After the mites are once established they spread rapidly from plant to plant. This distribution is accomplished by (1) spread along runners, (2) transported on the bodies of insects, (3) blown by wind, and (4) carried by pickers, baskets, irrigation water, etc.

Mites reach daughter plants from an infested mother plant either by living in the terminal bud of the elongating runner, or, probably more frequently, by walking along the runners to the daughter plant, after the formation of the latter. Munger (1933) found that the mites could crawl about half an inch a minute. At this rate a mite could crawl from the mother plant to a daughter plant, via a runner, in about half an hour. In strawberry fields where but a limited number of mother plants were originally infested, it is generally found that all of the daughter plants attached to an infested mother plant are infested while most of the adjacent plants are free from mites.

Mites are doubtless spread from flower to flower by bees and other insects which visit the strawberry flowers. In heavy infestations a single flower may contain several hundred mites in all stages of development. There is every reason to believe that bees may successfully transfer any stage of mites, including eggs, from infested to noninfested flowers.

Mites have been shown to be wind-borne, by Dustan and Matthewman (1932) who succeeded in catching them on tanglefoot screens in infested areas. Finally, mites are probably distributed in the field by the various human agencies, such as on the hands and clothing of pickers, on baskets and crates, on hoes, and probably to a minor extent by irrigation water.

By these various means a very rapid distribution occurs, once the mites are established. Cases have been noted wherein the infested plants in the fall of the first year approximated 0.5 per cent of all the plants. A year later, in the fall of the second year, these fields generally show 100 per cent of the plants infested and giving evidence of injury.

NATURAL CONTROL

A large amber-colored predatory mite, identified by H. E. Ewing as *Seiulus* sp., feeds on the cyclamen mite on strawberries in all parts of California. This species is often responsible for considerable destruction of the cyclamen mite, and in rare instances, coupled with unfavorable breeding conditions for the mite, this predator has reduced its numbers nearly to extinction. In such a field *Seiulus* reach their maximum numbers. They are often twice as numerous as the cyclamen mites. Because of their smaller size the cyclamen mites enter small interstices in the folded leaflets which the predators cannot enter. Conditions which favor an increase of predators at the expense of cyclamen mites are those which retard the production of new leaflets in the center of the crown, while the leaflets already formed open out to expose the contained cyclamen mites. The resistance of certain varieties, such as the Marshall, to mite attack may be due to the fact that their leaflets open more rapidly and thus facilitate biological control.

In Nich Ohmer fields of normal vigor the predators and cyclamen mites reach an oscillating balance, in which the cyclamen mites increase for a time, then decrease under the attack of the predators; this change in population trend may occur two or three times during a single season.

In spite of these periodic reductions in their numbers, however, the cyclamen mites are able to render the planting unprofitable in one or two years.

The effect of predators can be seen on the experimentally infested plants, reported in table 4. Plant number 4, for instance, showed a heavy infestation in May but a light infestation in June. The same is true of plants 5, 14, 16, and 21. Predators were found on some of these plants and probably occurred on all. It appears that among the Marshalls, predators became established on plants 25 and 29.

ARTIFICIAL CONTROL

Attempts to Control Mites on Established Plants.—The mites penetrate deeply into the crowns of the plants and are there protected from insecticides. Several attempts to control the mites on the established plants in the field were unsuccessful. In this connection calcium cyanide dust, nicotine dust, Selocide[6] spray, and nicotine spray were used. Naphthalene and carbon disulfide were tested, as fumigants, on plants under bell jars, but proved highly injurious to the plants. None of these materials proved to be of value.

Spraying established plants with lime-sulfur, and dusting with sulfur, were tested by Massee (1933) without appreciable success. An extended series of field tests were performed by Savzdarg (1928) who tested 22 different sprays including soap, oil, nicotine, quassia, sodium arsenite, iron sulfate, and sulfuric acid. None of these materials gave satisfactory results. He further performed 55 tests with dusts and fumigants including calcium cyanide, sulfur, naphthalene, paradichlorobenzene, and tobacco dust. These materials either failed to kill the mites, or else killed the plants. All of these tests indicate that field control on established plants is exceedingly difficult.

Attempts to Control Mites on Planting Stock.—Since the control of this pest on established plants seems impracticable, in the light of present knowledge, the remaining alternative consists in establishing fields free from mites. This can be done by planting clean plants in clean soil, sufficiently far away from other patches to prevent reinfestation.

The present conditions of strawberry culture in California lend themselves readily to this procedure. Planting stock is produced in the northern part of the state and in Oregon and Washington. (Klondike plants for southern California are grown in the East.) Hence, large shipments of packaged plants are concentrated in the hands of nurserymen and may be easily treated by a short stop-over en route or at final destination. New plants are always planted in soil which has not been cropped to

[6] Potassium ammonium seleno-sulfide.

strawberries for many years. At the present time, in central California a planting generally bears fruit for two years, and is then abandoned. Hence, under this system new plants are shipped in, planted in new, clean ground, and the whole acreage is replaced every three years. The major problem, therefore, lies in securing mite-free planting stock.

This might be accomplished by producing plants on mite-free soil, from mite-free mother plants. This method, however, has not been tested, and it is open to criticism, since a light reinfestation, difficult to detect, might occur at any time. However, under certain conditions, it may be possible to establish and maintain mite-free plantings in isolated areas. In the commercial production of plants, newly developed daughter plants are planted in the spring. These become the mother plants of the new field. They produce many stolons and daughter plants during the first growing season. These plants are dug in the following spring, the mother plants are discarded, and the rest are marketed. Some of the most vigorous daughter plants are kept and planted to produce another crop of plants. Thus while the mother plants reach an age of two years, the remainder of the plants are removed when one year old. Because of this rapid turnover of plants, the mites do not have an opportunity to increase in numbers, as is the case in fields devoted to fruit production, where the plants are generally four years old when discarded. Although mites have been found in plant-producing fields it is generally difficult to discover them. Hence, inspection of a plant-producing field in order to certify the plants as free from mites is impossible.

The most feasible procedure, therefore, apparently lies in the disinfection of planting stock. The first attempts to disinfect planting stock were conducted with fumigants in a tight chamber. A series of tests using cyanide, carbon disulfide, nicotine, and paradichlorobenzene were performed at atmospheric pressure and outdoor temperature. Results showed that these materials produced serious plant injury at dosages necessary to produce a complete kill of mites.

Early Tests of Hot-Water Immersion of Planting Stock.—During the winters of 1930–31 and 1931–32 a series of tests was conducted in which plants were immersed in hot water, in an attempt to determine a temperature and length of time of immersion which would prove lethal to the mites and yet noninjurious to the plants. In this work it was found necessary to use old, heavily infested plants for mite-control tests, since mites do not occur in sufficient numbers on young planting stock. On the other hand, it was necessary to use young planting stock for the plant-injury tests since old mother plants, especially when heavily infested with mites, are not properly indicative of the heat injury that would be suffered by young plants.

The plants were treated in a small vat made of two-inch redwood, containing 45 gallons of water. The water was heated by a 5,000-watt electric heater. When the atmospheric temperature was 61° F the heater raised the temperature of the water at the rate of 75° per hour. A verti-

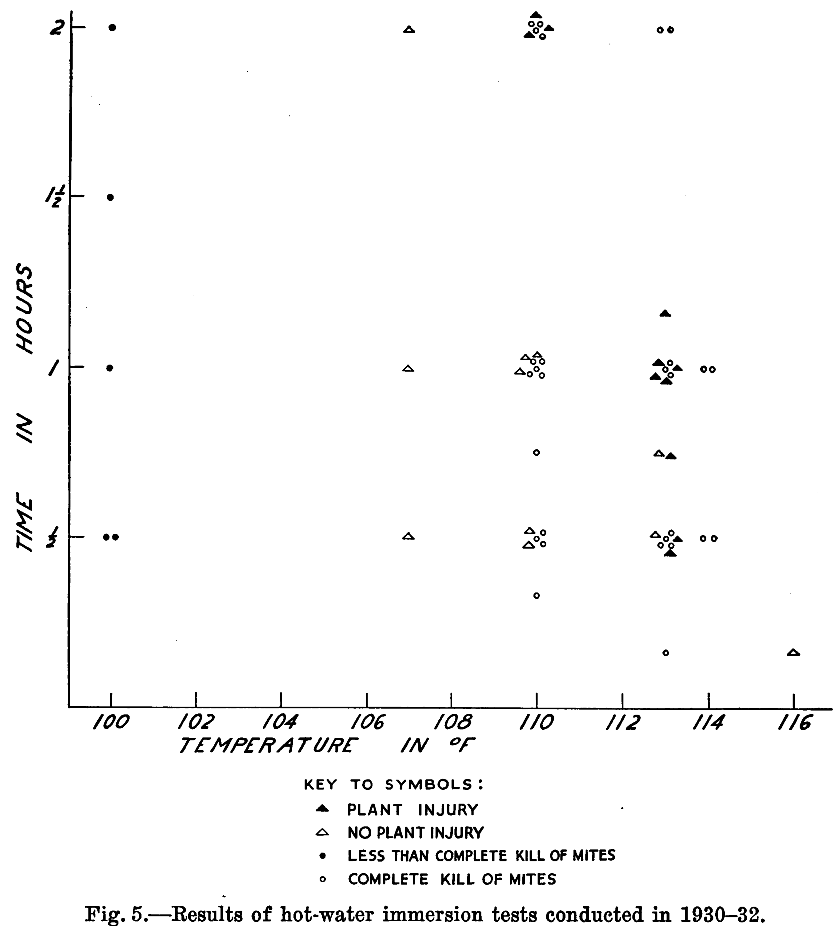

Fig. 5.—Results of hot-water immersion tests conducted in 1930–32.

cal agitator shaft provided with four propeller blades, each 3 by 4 inches was turned at the rate of 145 revolutions per minute in a direction to force the water up along the shaft. The plants were suspended in the tank in a basket of quarter-inch hardware cloth. When the temperature of the water had reached the desired point, two-thirds of the heating unit was disconnected. The rate of heating was then about the same as the rate of cooling. The temperature was thermostatically controlled, and checked with a three-inch immersion thermometer calibrated in

0.1° C. In the earlier work, the temperature of the water varied ± 1.0° F but in later work the range was ± 0.4° F.

The results of tests conducted during the winters of 1930–31 and 1931–32 are presented in figure 5. In this chart each mark indicates an independent treatment. The results show that a complete kill may be obtained by as short a period as 20 minutes at a temperature of 110° F and that no apparent plant injury was detected when the plants were immersed for as long as one hour at 110°.[7] As a consequence, subsequent work was centered around a temperature of 110° F for periods varying from 20 minutes to 2 hours.

Hot-Water Immersion Tests Conducted in 1932–33.—In the winter of 1932–33 two series of hot-water treatments were carried out in which lots of 15 plants each were immersed at temperatures of 109°, 110°, and 111° F for periods of ½, 1, 1½, and 2 hours. The tests were duplicated with young infested planting stock, and heavily infested two-year-old plants. After treatment, the plants were held indoors, in moss in pots. Approximately one month after treatment each plant was carefully dissected under a binocular microscope. A few plants in the half-hour and one-hour treatments were found to support a single mite each, while a very few plants supported several mites each. The absence of eggs and larvae indicated that no breeding had occurred although the plants had been in a warm room for about a month. It was discovered later that the survivors of the heat treatment were specimens of another species of *Tarsonemus*[8] which was found in great numbers on raspberries. The strawberry plants used in these tests were obtained from a commercial field contiguous to a large planting of raspberries. Raspberry canes, bearing specimens of the new species of *Tarsonemus* were subjected to hot-water immersion. The results of this test, shown in table 5, indicate that this species is much more resistant to heat treatment than *T. pallidus* and that an appreciable percentage may survive an hour at 110° F.

The presence of this new species on strawberry plants is probably accidental. No cases of injury produced by this mite have been discovered. Floyd Smith[9] states "The species apparently does not cause primary injury as does *pallidus* and until this status changes we may ignore its presence from an economic standpoint."

In addition to the above-mentioned tests on mite control a series of treatments was conducted during the winter of 1932–33 to yield further information on the question of plant injury. The factors which varied

[7] Later work indicated that under certain conditions injury may be produced by this treatment; see discussion of 1934 results.

[8] Identified by Floyd Smith and E. H. Ewing of the United States Department of Agriculture Bureau of Entomology, as an undescribed species.

[9] Personal communication.

in these tests were (1) temperature of the water, (2) length of time of immersion, (3) time of year of treatment, and (4) variety of strawberry. The temperatures used were 109°, 110°, and 111° F. The periods of immersion were ½, 1, 1½, and 2 hours. The treatments were conducted on January 1 and February 5. The varieties were Nich Ohmer, Blakemore, and Z-54 (a hybrid between Fendalcino and Marshall; Fendalcino is derived in part from wild *chiloensis* parentage). Ten, or in some cases 5, young runner plants were used in each lot and every possible combination of the above factors was tested, except that Z-54

TABLE 5

RESULTS OF HOT-WATER IMMERSION OF RASPBERRY CANES AT 110° F TO KILL AN UNIDENTIFIED SPECIES OF TARSONEMUS*

Immersion, minutes	Number alive	Number dead	Per cent killed
20	54	1	1.9
30	16	12	42.8
40	64	11	14.7
50	15	12	44.4
60	7	31	81.6

* Identified by Floyd Smith and E. H. Ewing of the United States Department of Agriculture Bureau of Entomology, as an undescribed species.

was not treated on January 1, and two time intervals were omitted. Checks of 10 untreated plants of each variety were planted on the same dates as the treated plants. In all, plants of 52 different treatments were planted.

Observations on March 10 on the February treatment indicated no differences in growth resulting from the variation in temperature. Nich Ohmer appeared the most tolerant to heat treatment and Z-54 was the most susceptible to injury. In the case of Nich Ohmer, plants of the half-hour and one-hour treatments grew more vigorously than the check. Definite injury appeared only in the two-hour treatments. In the case of Blakemore, injury appeared in the 1½ hour treatments and in Z-54, injury appeared in the one-hour treatments.

All of the plants were dug during the last few days of March. The number of flowers and young fruits were recorded as well as the weights of the plants.

Observations on the growing plants and counts at the time of digging indicate that the flower buds were much more susceptible to hot-water injury than other parts of the plant. In the commercial strawberry fields, flowers are removed by hand from the plants during the first year, so that strong vegetative growth may occur. Hence, hot-water injury to flower buds is not detrimental from the economic standpoint.

When all the treatments (except Z-54) at various periods, for various lengths of time, were summarized on temperatures, the average number of flowers and fruits per ten plants was 79 for the 109° F treatments, 78 for 110° F, and 31 for 111° F treatments; while untreated plants produced 125 flowers and fruits. This relation to temperature was not

TABLE 6

PERCENTAGE REDUCTION OBTAINED BY IMMERSION AT 110° F FOR FOUR TIME INTERVALS, DATA ARRANGED TO CONTRAST DATES OF TREATMENT

Variety	Weight of plants		Number of fruits	
	Jan. 1	Feb. 5	Jan. 1	Feb. 5
Nich Ohmer	2.2	−1.9	78	68
Blakemore	0.2	−0.3	67	86
Average	*1.2*	*−1.1*	*73*	*77*

TABLE 7

INFLUENCE OF LENGTH OF TIME OF IMMERSION AT 110° F, AVERAGE PER TEN PLANTS

Period of immersion, hours	Weight of plants, grams	Number of fruits
½	153	125
1	125	60
1½	114	16
2	118	14
Control	119	137

indicated by the weights of the plants. The average weight per 10 plants was 119 grams for the 109° F treatment, 123 for the 110° treatment and 128 for the 111° F treatment. The check plants weighed 119 grams. In table 6 and 7, values obtained for each temperature were averaged and assigned to the mean temperature of 110° F. For a comparison of the two dates of treatment, the data have been computed in terms of percentage reduction from the check values, and grouped on time of treatment in table 6. For a comparison of the length of time of treatment, the data have been regrouped and presented in table 7.

Effect of Heat Treatment on Mite Eggs, 1933–34.—During the winter of 1933–34, which, as stated above, was an unusually warm winter, the mites continued to deposit eggs. This raised a question as to the efficacy of hot-water immersion for killing the eggs of the mite. A series of treatments with 10 plants per lot was conducted on February 19, at 110° F for periods of 20, 40, 60, and 80 minutes. After treatment, the plants were potted in moss, and kept indoors. On March 12 and 29 the plants were dissected under a binocular microscope. The plants of all treatments were found to be free from mites. Since these plants carried many eggs at the time of treatment it appears that a treatment as short as 20 minutes at 110° F will give complete control of all stages.

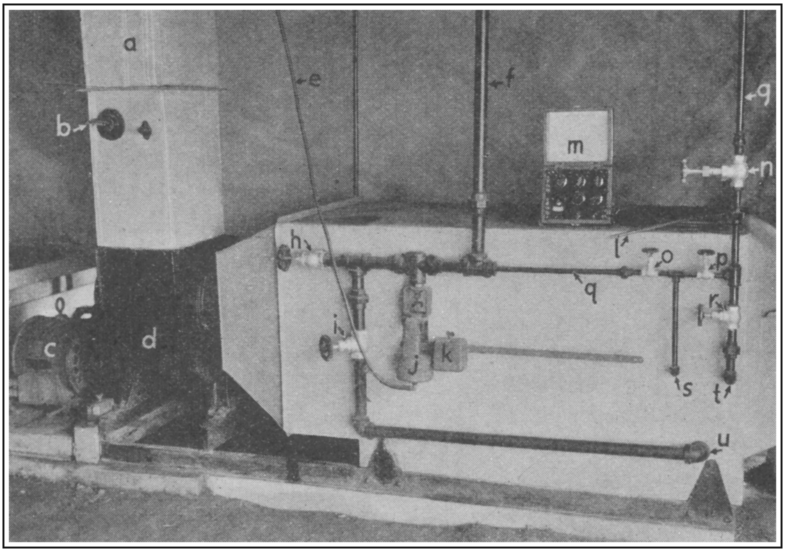

Fig. 6.—Air conditioning unit of the vapor apparatus: *a,* air duct from blower to vapor room; *b,* wet and dry-bulb thermometers for determination of relative humidity; *c,* motor for driving the blower; *d,* blower; *e,* armored cable lead from sensitive-bulb unit located in air duct *a,* which acts thermostatically on automatic steam valve *j; f,* main steam line from boiler to air conditioner; *g,* main cold-water line to air conditioner; *h,* steam valve to radiator unit, the opening of which gives a dry heat, which reduces the relative humidity as the air blast passes through and around the radiator; *i,* manually controlled steam valve which is auxiliary to automatic steam valve *j; j,* thermostatically controlled steam valve; *k,* sliding weight, the action of which works directly on automatic valve *j,* and thus provides for entrance of more or less live steam as desired; *l,* sensitive-bulb unit (several of which are buried in the strawberry plants at various locations in the vapor room), in which the resistance, recorded at the galvanometer *m,* varies directly with the heat in the room and, by converting ohms resistance to degrees Fahrenheit, makes it possible to obtain the temperature of any location in the vapor room at any time; *m,* galvanometer unit; *n,* main cold-water valve; *o,* auxiliary steam valve for combination steam and water jet, the entrance to the conditioner of which is *s; p,* auxiliary cold-water valve for combination steam and water jet, entering at *s; q,* auxiliary steam line for entrance of combination jet at *s; r,* cold-water valve for entrance to main water jet at *t; s,* entrance to auxiliary combination steam and cold-water jet; *t,* entrance to main cold-water jet; *u,* entrance to main live steam jet. (Photograph by California State Department of Agriculture.)

Infested planting stock was treated on February 2, 1934, at a temperature of 110° F for periods of 20, 30, 50, and 80 minutes. One hundred plants were used in each lot. After treatment, the plants were potted in soil and kept outdoors. On May 4, symptoms of mite injury appeared on

70.3 per cent of the check plants and no symptoms appeared on any of the treated lots.

Hot-Vapor Treatments.—A series of tests was conducted in an attempt to control the mites by heat applied to the plants by hot air and water

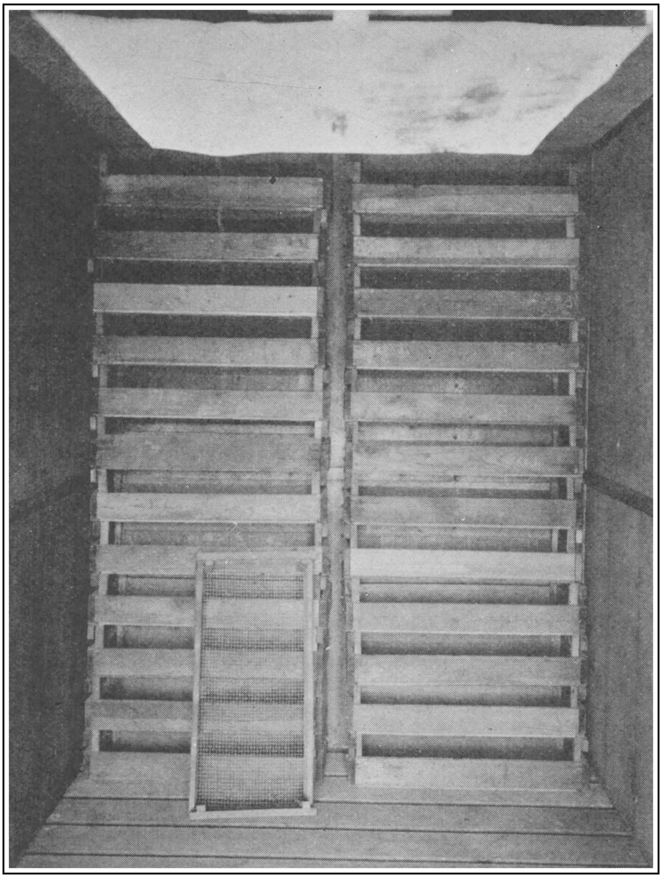

Fig. 7.—Treating room of the vapor apparatus, showing type of trays used and their arrangement in the room.

vapor. An apparatus (figs. 6 and 7) described by Mackie (1931) was used. Either 10 or 20 old, heavily infested plants were used in each lot. The relative humidity was 99 per cent. Plants were subjected to a temperature of 114° F for 25 minutes, 45 minutes, 1¼ hours, 2 hours, and 3 hours; and at a temperature of 110° F for 45 minutes, 1¼ hours, 2 hours, and 3 hours. These treatments were conducted on March 5, 1934. After treatment the plants were held in boxes in moss, outdoors. The plants were dissected under a microscope on March 14 to 28. Of the ten plants treated for 25 minutes at 114° F, 8 were free from living mites, although several hundred dead adults and eggs were found on each. One plant carried one living adult female, and one had several living females and eggs. None of the plants in any of the other treatments contained living mites.

Varietal Tolerance to Heat Treatment.—During the winter of 1933–34, ten varieties and selections, listed in table 8, were treated by immersion in water at 110° F for one hour. Time and temperature were constant throughout, while each of the ten varieties was treated on February 4 and 20, and on March 3 and 18. Ten or 15 plants were used in each lot. The inclusion of the varietal factor in this experiment had its origin in a treatment in 1932. The limitations of hot-water immersion for strawberry plants were not well known at this time; but since it was desirable to replant certain varieties and selections held for observation and breeding work, without transferring mites, about 20 different lots were immersed in hot water. It is believed that certain controllable factors may have contributed to the rather severe root injury that resulted generally; but regardless of these factors, it was observed that certain varieties such as Heflin and Warfield showed but little injury. On the other hand, three pure *chiloensis* strains were nearly or entirely killed.

The choice of a group for this experiment covering different varietal reactions was to some extent influenced by the availability of plant material. It was thought that possibly varietal tolerance might be to some extent related to the following characters: early as compared to late-fruiting varieties, fleshy versus fibrous-root types, and selections carrying recently introduced *Fragaria chiloensis* strain. Three out of the ten lots used are commercial varieties; the remaining ones are from seven clones selected from crosses made in connection with the strawberry-breeding work of the Division of Plant Pathology of the University of California. The identification numbers and letters of the selections mentioned herein are those used by the Division and as such are a part of the permanent record for this project. Four of these selections contain some *F. chiloensis,* namely: J-31 (Marshall × Ettersburg 614[10]), 36.4 (Kalicene × Howard 17, synonym Premier), 37.2 (Kalicene × Missionary), and 99.2, a selection from a cross between descendants of Marshall × Ettersburg varieties. Selections 7.18 and 7.26 were derived from a cross between Nich Ohmer and Blakemore, while 103.3 is from Nich Ohmer by AO-8, the latter a seedling of U.S.D.A. 253.[11]

[10] The varieties, Ettersburg 614 and Kalicene were originated by Mr. A. F. Etter of Ettersburg, California, who has been crossing named varieties with various strains of *F. chiloensis* for a number of years.

[11] Field record number of the United States Department of Agriculture strawberry-breeding project.

TABLE 8

Varietal Tolerance to Treatment; Plants Treated on February 4 and 20 and on March 3 and 18

Variety	Percentage reduction in weight			
	Flowers and fruit, March 29	Flowers and fruit, June 2	Plants	Average
Klondike	13.3	−3.1	4.4	4.9
J-31	29.4	58.1	−37.6	16.6
Nich Ohmer	41.1	26.2	5.6	24.3
103.3	28.9	33.9	18.9	27.2
7.18	55.6	29.5	4.6	29.9
Dorsett	65.9	60.4	7.1	44.4
7.26	64.7	57.8	10.9	44.5
99.2	55.1	63.1	20.7	46.3
37.2	70.0	72.2	18.4	53.5
36.4	85.4	62.8	21.4	56.5

TABLE 9

Influence of Time of Treatment Upon Plant Growth

Treated	Percentage reduction in weight			
	Flowers and fruit, March 29	Flowers and fruit, June 2	Plants	Average
February 4	42.8	50.0	9.9	34.2
February 20	76.2	68.2	15.1	53.2
March 3	34.0	21.5	15.4	23.6
March 18	....	24.0	4.6	14.3

TABLE 10

Results in Plant Growth from Immersion of Nich Ohmer Planting Stock at 110° F; Treated February 2

Immersion in minutes	Weight of flowers and fruit, grams			Weight of runners, grams
	March 30	May 4	Total	
None (check)	127.0	307.8	434.8	5.7
20	220.0	342.8	562.8	14.7
30	222.0	327.5	549.5	18.0
50	212.2	320.8	533.0	21.4
80	187.3	343.9	531.2	29.4

After treatment, all lots were planted outdoors in a mixture of sand, peat, and manure. A lot of untreated plants of each variety, equal in number to the treated lot, was planted on each of the four dates of treatment. Each individual lot of treated plants was planted in a row beside the row of check plants. The number of check plants was therefore equal to the number of treated plants. On March 29 all flowers and fruits together with fruiting stalks were picked and weighed. On June 2, all plants were dug, the weights of the new crop of reproductive structures were taken, as well as the total weight of the plants, after the reproductive structures were removed.

When the weight of the treated plants was subtracted from the weight of the untreated plants, the difference was believed to be the result of treatment. This difference has been computed into per cent of the weight of the untreated plants as presented in table 8. A minus quantity indicates a gain.

When the data on these ten varieties and selections are averaged to show the influence of time of treatment the results presented in table 9 are obtained.

On February 2, 1934, locally grown Nich Ohmer planting stock was immersed in water at 110° F for periods of 20, 30, 50, and 80 minutes. One hundred plants were used in each lot. After treatment plants were potted in soil, outdoors, and moved into a greenhouse on March 10. On March 30, all flowers and fruit were removed and weighed; on May 4 a second crop of reproductive structures was removed and weighed, as well as all runners. The data so obtained are given in table 10. In this test, it was found that the weight of reproductive structures decreased slowly with an increase in length of immersion, but the plants of all treatments surpassed the untreated. Runner production increased with an increase in length of immersion.

Comparison of Water-Immersion with Water-Vapor Treatments.—A test to compare immersion with water-vapor treatments at 110° F for plant injury was conducted on March 1, 1934. In this test, northern-grown Nich Ohmer planting stock was used, approximately 20 plants in a lot. Vapor treatments were conducted at a humidity of 95 per cent and at 99 per cent each for periods of ¾, 1¼, 2, and 3 hours. Hot-water immersion tests were performed simultaneously at the same temperature (110° F) for periods of ¾ and 1¼ hours. All plants, together with an untreated check, were planted in a commercial field immediately after treatment.

On June 2 the mortality of the plants and the number of runners produced were recorded as given in table 11. This table indicates that by June 2 only minor differences in growth were noted. However, the fact that runner production was greater in every treated lot than in the check is of considerable importance from the commercial viewpoint.

A test of varietal tolerance to vapor treatment and to hot-water immersion was conducted on March 2. In this test five varieties were treated at 110° F for 1¼ hours each in vapor and water immersion. Ten plants were used in each lot. After treatment, all plants, together with untreated checks, were set outdoors in a mixture of sand, peat, and manure.

TABLE 11

Comparison of Immersion and Vapor Treatments at 110° F, on Nich Ohmer Plants

Treatment	Time treated	Plants alive	Plants dead	Number of runners per 20 plants
Immersion	45 minutes	20	0	51.0
	75 minutes	18	2	49.0
Vapor, humidity 99 per cent	45 minutes	19	0	54.8
	75 minutes	18	1	76.6
	2 hours	16	0	66.2
	3 hours	17	3	62.6
Vapor, humidity 95 per cent	45 minutes	18	1	52.2
	75 minutes	18	0	62.2
	2 hours	19	0	64.2
	3 hours	37	1	63.8
Untreated	....	25	0	49.6

On April 16 all flowers, fruits and fruiting stalks were picked and weighed. On June 1 the plants were dug and the weights of reproductive structures and of the plants, recorded. The weights of reproductive structures obtained on April 16 and June 1 were combined. The difference between the treated and untreated plants was computed as per cent reduction from the untreated condition. These data are presented in table 12. A negative reduction represents a gain in weight.

Influence of Storage of Plants in Relation to Treatment.—Several tests were conducted to determine the influence of storage on plants, before and after treatment. These tests were duplicated with the varieties Blakemore and U.S. 542. All treatments were hot-water immersion for one hour at 110° F. Twenty plants were used in each lot. The temperatures of storage were constant at about 34° F in some cases, and storage outdoors in normal February weather in other cases. Plants were stored before and after treatment for three weeks at 34° F. Checks consisted of plants treated without storage, and stored without treatment. Plants were held at outdoor temperatures for three weeks, then treated and planted. Plants treated in the above-stated manner were nearly uniform in growth on June 2. The plants which had been held in storage at 34° F for two weeks following treatment were slightly more vigorous than those of the other treatments and checks.

TABLE 12

COMPARISON OF WATER-IMMERSION AND VAPOR TREATMENTS OF STRAWBERRY PLANTS AT 110° F FOR 1¼ HOURS COMPUTED AS PERCENTAGE REDUCTION FROM WEIGHTS OF CHECK PLANTS

Variety	Treatment	Flowers and fruit	Runners	Plants	Total
Nich Ohmer	Immersion	6.8	......	−23.0	−16.2
	Vapor	−160.7	......	−43.9	−204.6
Dorsett	Immersion	94.6	−89.2	−21.5	− 16.1
	Vapor	71.4	−91.4	−20.9	− 40.9
58.5	Immersion	36.8	30.0	21.1	87.9
	Vapor	−160.2	62.4	−15.6	−113.4
66.6	Immersion	90.8	......	−53.2	37.6
	Vapor	− 10.2	......	−61.2	− 71.4
103.2	Immersion	62.8	......	24.6	87.4
	Vapor	52.7	......	23.3	76.0
Average all varieties	Immersion	58.3	−11.8	−10.4	36.1
	Vapor	− 41.4	− 5.8	−23.7	− 70.9

TABLE 13

INFLUENCE OF HOT-WATER IMMERSION ON WEIGHTS OF REPRODUCTIVE STRUCTURES OF NICH OHMER PLANTS

Length of time immersed	Temperature, degrees Fahr.	Time (hours) × temperature (degrees Fahr.)	Weight of flowers fruit, grams	Length of time immersed	Temperature, degrees Fahr.	Time (hours) × temperature (degrees Fahr.)	Weight of flowers fruit, grams
2 hours	109	218	3.6	45 minutes	110	83	41.9
1½ hours	110	165	5.7	30 minutes	111	56	47.8
1½ hours	109	164	22.6	30 minutes	110	55	75.0
1 hour	111	111	24.2	30 minutes	109	54	65.0
1 hour	110	110	15.7	20 minutes	111	37	104.3
1 hour	109	109	54.2	20 minutes	110	36	78.8

Further Tests of Immersion Conducted in 1934–35.—During the winter of 1934–35, mite-control tests conducted earlier were repeated. Two-year-old Nich Ohmer plants were obtained which (by microscopic examination after treatment) were found to contain from 300 to 500 adult females each. Fifteen plants were used in each lot. Treatments for 20, 30, and 45 minutes were given by hot-water immersion at 110° F. After treatment the plants were carefully dissected under a microscope and no living mites were found.

An attempt was made to secure data on mite control and plant injury by treating Nich Ohmer planting stock which had been infested by hand transfers of mites in August, 1934. The plants were dug and treated in lots of 40 plants each at temperatures of 109°, 110°, and 111° F for

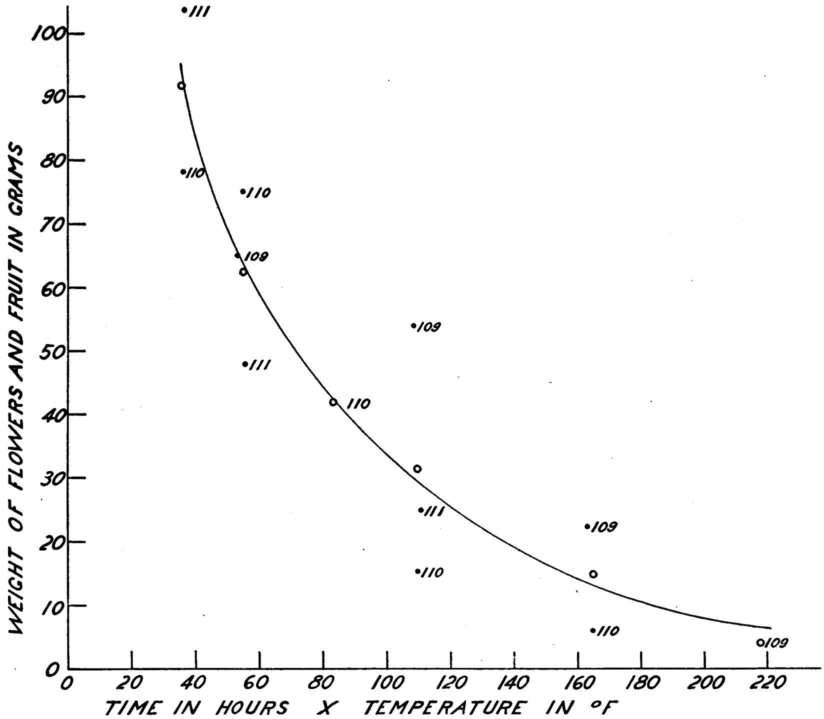

Fig. 8.—Relation of weight of reproductive structures produced, to time and temperature of immersion.

periods of 20, 30, 45, 60, 90, and 120 minutes. One hundred untreated plants constituted a check. After treatment all lots were planted in soil boxes in a heated greenhouse. The check plants were all found to be infested with mites and no mites appeared on any of the treated plants. At the time the first fruits were coloring, all fruits, flowers, and fruiting stalks were picked and weighed (table 13). Signs of hot-water injury appeared on the leaves of the plants treated at 109° F for 1 hour, as well as on those of the higher temperatures and longer treatments, but were absent on those subjected to the lower temperatures. When the weights of fruit obtained at the different temperatures were averaged on each time interval, and plotted against time in hours multiplied by temperature in degrees Fahrenheit, the curve plotted in figure 8 was obtained.

DISCUSSION AND CONCLUSIONS

The success of the control measures herein recommended depends upon the thoroughness with which mites are killed on the planting stock, and the thoroughness of the precautions taken to prevent reinfestation of the plants in the field. In view of the large number of plants listed as hosts of the mite, it might seem impossible to establish and maintain a field sufficiently remote from all of these plants to prevent contamination. However, most of the plants listed are attacked only in greenhouses, and of the remainder, which are attacked out of doors, only a very few, if any, are capable of carrying the mites through the winter. Under out-door California conditions, the authors to date have not found *Tarsonemus pallidus* occurring naturally on any plant other than strawberry.

Varieties of strawberries exhibit varying degrees of susceptibility to mite injury. However, the Marshall (Banner) variety is the only commercial variety grown in central California which generally escapes injury of economic proportions. The variety Klondike, while severely injured in the central coastal section is seldom severely injured in southern California. Hence, Marshall and Klondike will not, under ordinary conditions, require treatment. All other varieties, and particularly Nich Ohmer, should be treated.

After the plants have been disinfested by heat treatment, *utmost precautions must be exercised to prevent reinfestation.* Boxes of treated plants must not be stacked near untreated plants; treated plants must not be repacked in unsterilized boxes, and in unsterilized moss, etc. The most important measure to prevent reinfestation consists in locating new plantings sufficiently distant from old heavily infested plantings. The rapidity with which mites are spread from old infested fields to new uninfested fields is indicated above. Wherever possible new disinfested plantings should be at least 500 yards from all old infested areas.

Under the present practice, workmen who plant, weed, cultivate, and irrigate a new planting, alternate such labor with a few days of berry picking in old established fields. *Such movements of laborers from old to new patches is a dangerous potential source of reinfestation,* and should be accompanied by all possible precautions, such as washing the hands, changing clothing, or not entering the new patch on the same day as the old.

The only satisfactory method found for killing all mites on planting stock consists in heating the plants. Two methods of accomplishing this result have been studied namely hot-water immersion and hot-vapor treatment. In the immersion method, 20 minutes at 110° F kills all mites; but in order to insure a complete kill under all conditions the treatment should be continued for half an hour. In the hot-vapor method a complete kill is obtained in 45 minutes at 110° F, but, as an additional precaution, this treatment should be continued for one hour.

The findings presented in this paper are supported by the results of other workers, since heat treatments of strawberry runners for the control of *Tarsonemus pallidus* have been studied in other parts of the world. The first recommendation of a hot water dip was that of H. Garman in 1884 (Munger, 1933), who stated that infested verbenas were freed from mites by dipping in water at 120° F for half a minute. Hodson (1933) in England, was apparently the first to apply heat treatment to strawberry runners. After four years of investigation he concluded that immersion for 20 or 30 minutes at a temperature of 110° F was the most desirable treatment. Hot-water immersion of strawberry plants was studied in Canada by Dustan and Matthewman (1932) who obtained favorable results. This method was further tested in England by Massee (1934) who concluded that 20 minutes immersion at 110° F was preferable. Doucette and Baker (1932) treated plants in a vapor apparatus at 110° F for periods of 1½ and 3 hours and considered that the method could be perfected to be of economic value. Floyd Smith (1933) tested vapor treatments on greenhouse plants and concluded that 30 minutes exposure to vapor at 110° F was as effective as 15 minutes immersion in water at the same temperature.

While either vapor treatments or hot-water immersion may be used satisfactorily, the authors prefer the vapor treatment, because the plants are more easily handled and respond better in growth. Plants removed from a vapor room are nearly dry, and as they cool rapidly (in 45 to 60 minutes) they can soon be repacked for shipping. In contrast, plants removed from a dipping vat are saturated with water, and must be dried before they can be repacked. This requires considerable space under roof, as they must be protected from direct sunlight and excessive air movement. When large numbers of plants are treated by this method, it is necessary to turn them, to facilitate even drying. All of this is laborious, expensive, and requires unusual facilities. Inherent in such a situation will be a tendency to hasten some phase of the process, resulting in either allowing the surface plants to become too dry or packing the plants too wet. This latter may involve serious losses because of the activity of saprophytic organisms, particularly if it is not possible to plant immediately.

In addition to the advantages existing in the mechanics of plant management for the vapor method, the plants themselves show less injury, and grow better, as is indicated in table 12. This comparative response is corroborated by field experience. In the spring of 1934 a strawberry grower treated about 200,000 Nich Ohmer plants in hot water, and another lot of 200,000 plants in a vapor apparatus. These plants were set out in alternating small patches in the same field. During the first month the vapor-treated plants excelled the water-immersion plants, but by September no differences could be seen.

Plants destined to be treated by either method should be given every possible protection from drying. Observations indicate that any appreciable drying of the plants renders them more susceptible to heat injury; also the added exposure to the air, incident to treatment, may cause some dehydration of the roots, which is injurious in itself. If, in the use of the vapor method particularly, plants must be held in the trays two or three hours prior to treating, they should be covered with a canvas. If the roots are very dry or the weather is unfavorable, some method of lightly sprinkling them probably should be devised. After they have cooled following treatment the same protection should be given. The practice of some plant growers of sprinkling their fields before digging, if soil moisture or temperature are unfavorable, is a further protection, in addition to the suggestions given above. One other safeguard needs mentioning here. If, at planting time, the soil is dry or the weather very warm, irrigation should be given immediately.

As mentioned in the reference to commercial use of heat treatments for mite control, heat-injured or retarded plants have pronounced recuperative powers. In general, the data herein presented were taken while the effects were still measurable, but not as visibly distinct as earlier. Thus, notes taken February 28, 23 days after treatment, indicate definite retardation and twisting of the leaves in some varieties listed in table 8; but by June 2, when the final readings were taken, these symptoms had disappeared. On this date some varieties in this group still showed a 20 per cent reduction in weight. This loss would in all probability have been overcome by the end of the growing season.

For the purpose of discussion, plant injury is divided roughly into four distinct categories. Probably the most common one is temporary inhibition of the growth processes. This is not necessarily a concomitant of the control measure, for the authors have records of definite stimulation. Results to date do not indicate that this form of injury is of any practical consequence. Next in the order of discussion is what has been termed "crown injury." It is characterized by retardation and production of small, twisted leaves. It usually disappears in a few weeks. It is not expected that this form of injury will be encountered in the present commercial varieties used in the central district and treated at the time-temperature interval that is herein recommended. The third type of damage is the killing of the foliage, indicated by a brown or blackened appearance of the leaves the day after treatment. It occurs only when plants which have become rather active in the spring, are treated, and then mostly in the longer time intervals used in the experiments. In spite of their poor appearance such plants usually grow, but the presence of this injury in commercial practice should mark the seasonal limits for any particular year. The last category to be considered is that of root injury. It can easily be recognized by the dark, water-soaked appearance of the cortex and may affect only a few or, in some cases, all the roots. Usually the degree of injury is progressively less from the root tips toward the crown, often ending before reaching that point. Generally the stele in the basal part of the root will not be damaged and will initiate new growth. The strawberry-breeding project with which the junior author is associated has afforded an excellent opporunity for observation of this phenomenon. In one case 900 different selections were treated for mite control. Unexpectedly, severe root injury ensued, entailing, it was thought, serious losses. As a matter of fact, only 10 or 12 plants out of approximately 1,800 died, and the entire planting made very good growth. Subsequently, many of these same selections have been given much more severe treatment, without any appreciable amount of this type of reaction. The factors conditioning this form of injury are not well understood. Degree of dormancy, low temperature, and heavy frosts when plants are dug and treated are suggested as possibly having some relation to injury. In some cases it is apparently definitely related to varietal tolerance, of which more will be said later. Any cortical lesions or discoloration of the stele existing in the roots prior to treatment may result in killing of the roots, with symptoms somewhat similar to those mentioned above; but such killing should not be attributed primarily to the treatment. Some surface discoloration of the roots often occurs, particularly in immersion-treated plants. It is caused chiefly by prolonged exposure to the air and is in no wise injurious.

The studies in plant tolerance, relative to certain of its conditioning factors herein reported are in their implications no wise final; it is believed, however, that some generalizations and practical applications can be derived from their consideration.

Experience showed that the reproductive structures were much more sensitive to heat than the vegetative structures. As an example of this, in table 12, the variety Dorsett shows a difference of 23.2 per cent in favor of vapor treatment, in the reproductive structures, in contrast to only 0.6 per cent in favor of vapor in the vegetative structures. Because of this sensitivity the weight of the reproductive structures served as a useful index to the various factors studied.

In general this index, supplemented by weight of plants, has been found of value, particularly with reference to time and temperature, methods of heat application, and varietal tolerance. No satisfactory data have been obtained for the best season to apply treatment. It is difficult to arrange any set of experiments designed to study this factor that are directly comparable.

In general, and contrary to expectation, the supposedly fully dormant plant seems to be the more susceptible to heat injury. In one experiment it was evident that plants treated on February 5 made far better growth than those treated on January 1. It was obvious that this advantage was not wholly a function of the treatment, because the untreated plants for the respective dates reflected the same relative values. Apparently much of this retardation was the result of moving and resetting plants during the dormant or rest period. This and other observations seem to imply an optimum season for the digging and treating of plants, with reference to favorable plant response. From the information now available, and because no identical calendar dates will be comparable for any consecutive period of years, no fixed dates can be given for this optimum season. For the region in which these investigations were conducted, the latter part of February and most of March is suggested.

Time of treatment is undoubtedly of some importance, but regardless of the time of year which seems most desirable, it will be necessary to treat when weather conditions permit the digging of planting stock, and the setting of plants in the field. Further, it must be adapted to the practices proven best by experience for any specific region. Thus in the district to which these studies are pertinent, plants are usually set in March and April, after winter rains have ceased. Because of the recuperative powers of the strawberry, it is recognized that from the practical viewpoint the end result, in terms of mite control, final costs, vigor, and stand of the planting at the close of the growing season, is the only adequate measure of this or any other phase of the treatment for mite control.

Earlier in the discussion the relation of variety to heat injury was mentioned. The wide range of response of several varieties to both methods of treatment are given in tables 8 and 12. The relative resistance of these varieties as indicated in table 8 cannot be expected to maintain the same sequence under all conditions of treatment. Replication of this test would probably show some shifts in position. Different stages of bud differentiation in the several varieties and selections may account in part for the varying degrees of injury to these parts; but regardless of such considerations the conclusion can be drawn that great differences as to heat tolerance exist in strawberry varieties, and that certain varieties such as Klondike, J-31, and Nich Ohmer are relatively resistant. Further, that some varieties such as Dorsett are relatively susceptible, as has been substantiated by field experience, and that selections 36.4 and 37.2 are very susceptible. The latter selections have for one of their parents Kalicene. This fact serves to introduce the subject of recent incorporation of *Fragaria chiloensis* in strawberry varieties in its relation to heat tolerance. Susceptibility to injury has been frequently observed in such selections, but sufficient exceptions have been noted, such as J-31, to make any generalization relative to them unwarranted. In recent treatments of breeding stock it was noted that some selections from certain crosses showed considerable root injury, whereas all selections from other crosses showed practically none. So far as is known no recent *F. chiloensis* is involved in this case. Summing up, it may be said that to date no type of plant or character of growth could be definitely associated with heat injury in the varieties studied. In the use of any varieties not previously tested, it is suggested that preliminary trials be made to determine their specific reaction.

In the spring of 1934, 6,000 plants were treated for one-half hour at 110° F and distributed to growers in lots of 1,000 plants each. In two cases the plants were held in packing boxes for two or three weeks after treatment and a high mortality of plants occurred. In the tests of storage described above, made before and after treatment, there was no air conditioning in the cold-storage room used, so that the plants tended to be dehydrated. Some plants were held for six weeks and apart from this drying no unfavorable results were observed. The use of a room in which the humidity can be kept relatively high and constant should largely obviate this difficulty. By repacking the contents of one planting box into two or three boxes, alternating a layer of plants with a layer of moist moss, it should be possible to hold plants in storage satisfactorily for a considerable period of time. The best practice, of course, is to treat the plants as soon as possible after digging, and to plant as soon as possible after treatment.

In the experiments reported in this paper, considerable work has been carried on in the longer time intervals. By this means it has been possible to study more satisfactorily certain factors involved in heat injury. Further, outside of a temporary retardation, the time-temperature interval of one hour at 110° F is within the practical limits for Nich Ohmer under most conditions. As shown in the data (table 7), definite injury generally occurs in the hour-and-a-half, and two-hour intervals, and is usually directly observable in the form of "crown injury." Root damage does not necessarily occur with this type of injury, so that under experimental conditions such plants usually grow. Tests show that considerably longer time intervals may be used in the vapor method before comparable injury occurs.

SUMMARY

The cyclamen mite, *Tarsonemus pallidus* Banks, incorrectly known as the strawberry mite, *Tarsonemus fragariae* Zimm., is a widely distributed pest of field and green house strawberries. Since its first appearance on strawberries in 1892 it has been reported in 10 European countries and 27 states in the United States.

The mite causes severe injury to Nich Ohmer strawberries in central California, while the Marshall variety is resistant in this area. The Klondike variety is not seriously affected in southern California.

The majority of adult mites are females, which lay two or three eggs a day. The immature stages are completed in about 13 days, hence a very rapid increase in population is possible.

The mites live in the folded leaves in the center of the crown of the plant. Their feeding punctures cause severe distortion and dwarfing of the leaves.

Only adult females survive the winter. They hibernate in the crowns between the bases of the petioles. They emerge from hibernation about the latter part of February.

No satisfactory method of controlling the mites on established plants has been found. However, they can be eradicated from planting stock and the field subsequently kept free from mites.

A complete kill of mites on planting stock can be obtained by immersing the plants in water at 110° F for 30 minutes, or by treating the plants with saturated air at 110° F for one hour. Of these two methods, the vapor treatment is superior to the immersion method.

For treatment, plants must be removed from shipping boxes, and loosened if tied in bundles. They should be placed loosely in screen or slat trays or boxes and stacked to allow a maximum of penetration of either the hot water or vapor. After treatment the plants should be cooled and dried before repacking. Precautions should be taken to prevent excessive drying. If plants are repacked while wet, saprophytic fungi may kill a large percentage of them.

Varieties show varying sensitivity to heat treatments. Klondike and Nich Ohmer are relatively resistant while Dorsett is more easily injured.

In either method the temperature must be accurately held at 110° F and should not vary more than one degree. The heating medium (water or vapor) must be thoroughly agitated to insure uniform exposure of all plants to the desired temperature.

Planting should follow treating as soon as possible. Plants should be set in clean soil as far from old infested fields as possible, preferably 500 yards or more.

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