THE USE OF GROWTH-REGULATING CHEMICALS TO INDUCE PARTHENOCARPIC FRUIT IN THE CALIMYRNA FIG

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(WITH TWO FIGURES)

Introduction

Certain varieties of many species of plants develop their fruits parthenocarpically or without fertilization. The apple and pear occasionally produce parthenocarpic fruits but generally under special nutritive conditions (10). In some varieties of grapes, figs, bananas, and oranges, parthenocarpy is of great economic importance (4, 14). Because of this naturally occurring phenomenon, attention has been directed toward inducing parthenocarpy in other fruits and vegetables by the application of hormones of various synthetic growth-regulating substances.

Early investigations by GUSTAFSON (9) on chemically-induced parthenocarpy stimulated research in this field and, at the present time, it is possible to produce parthenocarpically several different vegetables, as well as fruits of some ornamental plants. Similar attempts to increase fruit set or to induce seedlessness in some of our more important tree crops, such as the apple, orange, and grapefruit (1, 8, 11, 15) have failed entirely. A review of literature has revealed that all attempts to promote parthenocarpic fruit development in a temperate zone commercial tree fruit, where it did not already occur naturally, have been unsuccessful. This paper presents the results of preliminary experiments that were successful in chemically inducing parthenocarpic development of fruit of the Calimyrna fig.

Of the four most important fig varieties produced in California, the Mission, Adriatic, and Kadota, which are considered to be of the common type, are characterized by being completely parthenocarpic. On the other hand, the Calimyrna, the leading drying variety in the state, is of the Smyrna type, and exhibits the typical characteristics for this group by being almost completely non-parthenocarpic. The syconia of the Smyrna type mature only after the flowers have been pollinated and the ovules fertilized.

Pollination of the Calimyrna variety is accomplished by the fig-wasp, *Blastophaga psenes* L., which carries pollen from the male or caprifig to the stigmas of the Calimyrna, a process termed caprification. Thus in the production of Calimyrna figs the use of caprifigs and fig-wasps is indispensible. However, accompanying commercial caprification are several problems of vital concern to the grower. He must either maintain caprifig

trees in his orchard, which occupy valuable land area, or purchase caprifigs from other growers.   In either case there is the risk that the caprifigs and the Calimyrna figs will not reach the proper stage of development at the same time.   Placing the caprifigs in the orchard is laborious, expensive, and is, of necessity, based largely on experience rather than on a standardized procedure.   Over- or under-caprification must be avoided, an optimum that is very difficult to achieve.   The former favors the incidence of internal rot or endosepsis, a disease spread by the wasps, while the latter reduces the quality and quantity of yield.   For a complete discussion of the process of caprification and its problems the papers of CALDIS (2), CONDIT (5), and SMITH and HANSEN (12, 13) are suggested.

The entire operation of caprification is costly, and to say the least, haphazardous.   It is plainly evident that the fig grower would be interested in new techniques which have as their objective elimination of caprification from the list of cultural operations associated with the production of Calimyrna figs.   With this in mind, investigations were initiated to determine the possibility of promoting parthenocarpic fruit development by the use of certain synthetic growth-regulating chemicals.

Materials and methods

Three synthetic growth-regulating chemicals were used: 2,4-dichlorophenoxyacetic acid (2,4-D), β-naphthoxyacetic acid (NOA), and γ-(indole-3)-n-butyric acid (IBA).   All three were applied as water suspensions or solutions, and, in addition, the latter two were applied in oil emulsified in water.   For the water-based formulations, the 2,4-D and NOA were dissolved in a minimum amount of ethanol, which was then diluted to give clear solutions.   The IBA was prepared according to the method given by WITHROW and HOWLETT (16), using ethanol and gum arabic.   A preparation containing both NOA and IBA was made by combining the stock solutions in the desired proportions.   The oil-based formulations were prepared by dissolving the NOA and IBA in a minimum amount of normal butanol.   This solution was then added to a light emulsive oil, the normal butanol serving as a mutual solvent.   The oil stocks were then vigorously hand shaken with the required amount of water to give emulsions of the desired concentration of active material.   Here also, a preparation containing both NOA and IBA was made by combining the stock solutions in the desired proportions.

Two methods of application were employed.   The first consisted of injecting with hypodermic syringes the preparations (exclusive of the oil emulsions) into the small figs through their ostioles.   The amount used varied with the size of the fig, but in every case the fig cavity was filled.   The second method consisted of spraying the entire branch.   With the water-based materials a nasal atomizer, connected to an air compressor, was used to give complete coverage and minimize spray drift.   A paint gun,

operated at five lbs. pressure, was used in applying the oil emulsions to give a light deposit approximately equivalent to 25 gallons per acre.

The following table summarizes the materials, concentrations, and methods of application that were employed.

Material	Concentration	Water-based		Oil-based
2,4-D	10 and 5 p.p.m.	Injected	Sprayed	....
NOA	100 and 50 p.p.m.	" "	" "	Sprayed
IBA	2670 and 1500 p.p.m.	" "	" "	Sprayed
NOA + IBA	100 + 2670 p.p.m.	" "	" "	....
NOA + IBA	50 + 1500 p.p.m.	" "	" "	....
NOA + IBA	25 + 750 p.p.m.	....	....	Sprayed

The above materials and concentrations were selected after a general survey of the literature was made on chemically induced parthenocarpy. Treatments were made on three different dates, May 24, June 5, and June 12, 1947, using a different set of branches on each date. These dates approximated the beginning, the middle, and the end of the normal caprification period. Paper bags containing caprifigs were placed in the orchard on May 29 and removed on June 20. The branches used were selected for uniformity of size and number of small figs, and all treated branches bore 5–7 figs larger than 0.4 cm. on May 23. Randomization of treatments was not attempted, the branches being used as found. To prevent pollination by the fig-wasp, all selected branches were bagged on May 23 (whether they were treated on that date or later) with white muslin bags commonly used for this purpose, and remained covered until June 24. Three branches were used as replicates for each treatment, except for the oil emulsion sprays, where only two were used.

At the time of the first treatment, and at frequent intervals thereafter, measurements were made of the transverse diameter (in mm.) of each treated fig on each branch, numbering the figs from base to tip of the branch. In addition, observations were made on the color and shape of the treated figs, and on the condition of the foliage. As controls, 10 untreated and unbagged branches, scattered through the various treatments, were measured and observed. In all, about 175 branches were used on 40 trees, and the development of over 1000 figs was followed for a period of 90 days.

Results and discussion

The injection of water solutions or suspensions of growth-regulators into the fig cavities through the ostioles failed, with three exceptions, to induce fruit set, and all such figs shriveled and dropped from the trees at the same time as uncaprified control figs. The exceptions to these results were IBA at both concentrations and NOA + IBA at the lower concentration injected into syconia toward the end of the caprification period (June 12). From this treatment several of the figs at nodes 1 to 3 reached normal size and were mature, but seedless, just 12 days later on June 24. This was a phenomenal response as evidenced by the fact that the caprified con-

trol fruits did not mature until the first week in August. On the other hand, parthenocarpic fruits, induced as a result of spray treatments, were slower to mature than the caprified control fruits, as will be discussed later. The significance of this abnormally rapid fruit development is not understood as yet.

No apparent foliage or twig injury was present on any of the branches bearing syconia that were injected. Spraying the branches, figs, and foliage with the two different concentrations of 2,4-D and NOA likewise caused no foliage or twig injury. However, the use of IBA, either alone or in combination with NOA, caused moderate leaf curl and moderate to severe chlorosis, a condition that persisted throughout the season until leaf drop.

Of the various spray treatments, 2,4-D and NOA in water solutions at both concentrations failed to set fruit. Likewise, NOA alone and in combination with IBA in an oil emulsion failed to stimulate fruit development. In other words, parthenocarpic fruit development resulted only from aqueous spray applications of both concentrations of IBA alone and in combination with NOA and the oil emulsion spray containing IBA at a concentration of 2670 p.p.m.

It should be pointed out that 2,4-D, when injected or sprayed, gave some indication of being able to set figs parthenocarpically. Several days after treatment, syconia treated with this material were definitely further along in development than the controls, as measured by shape and color. Although all of the syconia treated with 2,4-D eventually dropped when about half grown, for a time they exhibited all the appearances of being set in that their color changed from a dark green to a light yellowish green and all ridges had disappeared as a result of swelling. Higher concentrations or repeated applications of the material to the same figs might possibly result in parthenocarpic development.

Treatments that were effective in inducing parthenocarpic fruit development are set forth in table I, together with the average percentage fruit set with each treatment for the different times of application. The average percentage fruit set with the three applications of each chemical was from 15 to 20 per cent. higher than fruit set in the normally caprified controls, with exception of the aqueous IBA (2670 p.p.m.) treatment which was about equal to the controls. These data indicate that no benefit was derived from combining NOA with IBA. The apparent inadequacy of NOA at the concentrations used is further corroborated by the fact that when used alone and applied as an injection or spray it failed to induce fruit set. It is evident, likewise, that 1500 p.p.m. of IBA is just as effective as applications of the same material at a concentration of 2670 p.p.m. Perhaps concentrations considerably lower than 1500 p.p.m. would prove to be highly effective in inducing parthenocarpic fruit set in the fig.

Data in table I suggest that there is a relatively short period of time during which there is a maximum number of syconia on the tree that are

in a receptive condition for pollination or for being set parthenocarpically. Although the time between the first and second and the second and third applications of a particular preparation was only 14 and 8 days, respectively, in general, the treatments applied about the middle of the caprification period resulted in a much higher percentage of fruit set than treat-

TABLE I

RELATION OF TIME OF GROWTH-REGULATOR APPLICATION DURING THE CAPRIFICATION PERIOD
TO THE PERCENTAGE FRUIT SET FOR EACH TREATMENT

TREATMENT AND TIME OF APPLICATION*		FRUIT SET
		%
Indolebutyric acid (2670 p.p.m.) in water	Beginning	41.2
	Middle	60.0
	End	53.8
	Average	51.1
Indolebutyric acid (1500 p.p.m) in water	Beginning	66.7
	Middle	70.6
	End	75.0
	Average	70.6
Naphthoxyacetic acid (100 p.p.m.) and indolebu-tyric acid (2670 p.p.m.) in water	Beginning	66.7
	Middle	82.4
	End	52.9
	Average	67.3
Naphthoxyacetic acid (50 p.p.m.) and indolebu-tyric acid (1500 p.p.m.) in water	Beginning	50.0
	Middle	88.2
	End	60.0
	Average	66.7
Indolebutyric acid (2670 p.p.m.) in oil emulsion	Beginning	72.7
	Middle	90.9
	End	50.0
	Average	71.9
Check (caprified)	Average	51.7

* Time in relation to caprification period: Beginning—5/23/47, Middle—6/5/47, End—6/12/47.

ments applied either before or after. Since the fig bears its fruits laterally in the axils of leaves on current season's wood, each successive fig on the shoot is somewhat later in development to the one it succeeds. The percentage fruit set for figs sprayed with an oil emulsion containing 2670 p.p.m. of IBA indicates that at a particular time as many as 90 per cent. of the figs are in a receptive condition or, at least, in a state whereby they can be set parthenocarpically.

Data in table II, on the relation of the time of application to the percentage fruit set at the various nodal positions, show that, in general, all

treatments applied at the beginning of the caprification period set fruits at nodes one through four. The same treatments applied about the middle of the caprification period showed a tendency to set fruits at all of the nodal positions, while applications near the end of this period set the greatest percentage of fruits toward the end of the new shoots. Appar-

TABLE II

RELATION OF TIME OF GROWTH-REGULATOR APPLICATION DURING THE CAPRIFICATION PERIOD
TO THE PERCENTAGE FRUIT SET AT THE DIFFERENT NODE POSITIONS

TREATMENT AND TIME OF APPLICATION*		NODE POSITION†					
		1	2	3	4	5	6
Indolebutyric acid	Beginning	100	100	33	0	0	0
(2670 p.p.m.) in water	Middle	100	67	67	67	0	....
	End	0	0	100	100	100	....
Indolebutyric acid	Beginning	100	100	100	100	0	0
(1500 p.p.m) in water	Middle	67	33	100	67	67	100
	End	0	67	100	100	100	100
Naphthoxyacetic acid	Beginning	100	100	100	100	0	0
(100 p.p.m.) and indolebu-	Middle	100	100	100	100	67	0
tyric acid (2670 p.p.m.) in water	End	0	0	33	100	100	100
Naphthoxyacetic acid	Beginning	67	100	33	33	33	0
(50 p.p.m.) and indolebu-	Middle	100	100	100	100	67	50
tyric acid (1500 p.p.m.) in water	End	0	33	67	100	100	....
Indolebutyric acid	Beginning	100	100	100	100	0	0
(2670 p.p.m.) in oil	Middle	100	100	100	50	100	50
emulsion	End	0	50	50	50	100	100
Check (caprified)		0	60	50	80	60	50

* Time in relation to caprification period: Beginning—5/23/47, Middle—6/5/47, End—6/12/47.
† Nodes numbered 1 to 6 beginning at base of current season's growth.

ently syconia at nodes five and six had not yet reached a receptive condition when the first treatments were made, whereas the picture was reversed as regards the last treatment when the syconia at nodes one and two had apparently passed this point. It is interesting to note that at the first node position on the control branches not a single fig was set. Evidently figs at this position had passed their receptive state for pollination before the caprifigs were suspended in the trees. Likewise, it is significant to note that in no case was there complete set of fruit at any of the various nodal positions on the check branches. The significant fact of the data in table II is that by the correct timing of the growth-regulator application it appears possible to obtain 100 per cent. set of fruit. Perhaps this might be accomplished by two successive treatments but the data indicate that one application at the critical time might result in a complete set of fruit.

Periodic cross-diameter measurements of caprified control fruits and chemically-induced parthenocarpic fruits are represented in figure 1 by

typical curves of growth for these two types of figs. Attention is called to
the fact that the fig fruit, like stone or drupaceous fruits, goes through
a double cycle of growth which may be represented by a double sigmoid
curve. Development of the peach fruit was segregated by CONNORS (7)
into three definite stages of growth: stage I, rapid rate of growth following
fertilization; stage II, a period of rest during which time the seed devel-
ops; and stage III, accelerated growth rate of the flesh to maturity. In
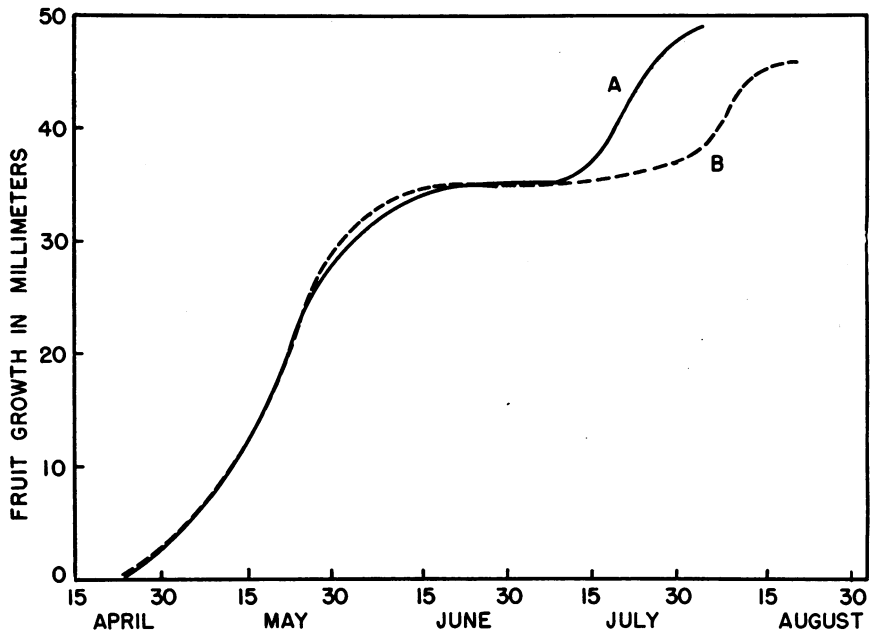
FIG. 1. Typical curves of growth in diameter or caprified (A) and growth-regu-
lator-induced (B) parthenocarpic Calimyrna fig fruits.

figure 1 it is shown that the rates of growth during most of stage I were
identical for those fruits that were destined to develop parthenocarpically
and those that were to produce seeds as a result of caprification. Shortly
after the sprays were applied on May 24, the treated figs grew at a some-
what more rapid rate but later ceased enlargement in stage II at the same
average diameter as figs that were caprified. A difference of about 20 days
in the length of time the two types of fruit remained in the resting stage,
or stage II, was responsible for the fact that parthenocarpic fruits did not
mature until somewhat after maturation of fruits that were caprified.
Similar observations on maturity have been made on the Kadota variety
which is completely parthenocarpic in its development. When a caprifig
tree is in close proximity to a Kadota orchard, wasps drift in on the wind
and caprify occasional syconia that invariably ripen about two weeks in
advance of fruits that develop parthenocarpically.

In the Calimyrna variety, the chemically-induced parthenocarpic fruits

were not markedly different, in external characteristics, from fruits that were caprified. Mature caprified fruits had an average diameter of 46 millimeters as compared with 48, 44, 50, 47, and 44 millimeters for parthenocarpic fruits induced by aqueous applications of IBA at 2670 and 1500 p.p.m., NOA 100 p.p.m. + IBA 2670 p.p.m., NOA 50 p.p.m. + IBA 1500 p.p.m., and by an oil emulsion containing IBA at 2670 p.p.m., respectively. The two types of fruit exhibited about the same degree of color intensity, both being typically golden yellow. As shown in figure 2, the neck of the caprified fig is typically compressed and flattened laterally and joins the body abruptly, while the necks of the parthenocarpic figs taper more gradually from stalk to body.
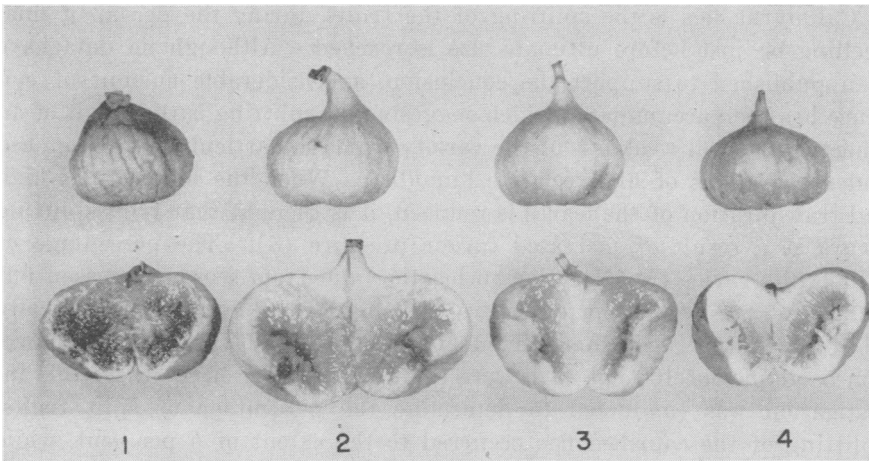

FIG. 2. Typical caprified and growth-regulator-induced parthenocarpic Calimyrna fig fruits. 1, caprified; 2, indolebutyric acid (1500 p.p.m.) in water, applied 5/24/47; 3, naphthoxyacetic acid (50 p.p.m.) and indolebutyric acid (1500 p.p.m.) in water, applied 6/12/47; and 4, indolebutyric acid (2670 p.p.m.) in water, applied 6/5/47. No significance should be attached to the difference in fruit sizes.

The most striking internal difference between caprified and parthenocarpic Calimyrna figs is the complete absence of seeds (achenes) in the latter (fig. 2). Figs, such as the Mission and Brown Turkey, which are completely parthenocarpic, are characterized by having numerous hollow and infertile achenes with the ovary wall fully sclerified. In the chemically-induced parthenocarpic Calimyrna figs, however, there was no sclerification of the ovary wall.

According to CONDIT (6), the pulp of the fig is composed of the inner part of the meat, the perianth and floral peduncles, the parenchymatous outer cell walls of the ovaries, and the seed. The parenchymatous tissue surrounding the floral organs becomes greatly enlarged and serves as storage tissue. As the flowers mature, they may completely fill the cavity and form a solid pulp as is characteristic of caprified Calimyrna figs. In some

instances, floral organs in the induced parthenocarpic figs did not enlarge to the same degree as those in the caprified figs, leaving their cavities incompletely filled. Repeated applications of the growth-regulator to the same fruit might possibly correct this condition.

The pulp of the caprified figs was light strawberry in color while that of the parthenocarpic figs was light amber yellow. The flavor of the two types of figs was the same, so far as could be detected. Apparently the lack of seeds did not detract from the flavor of the parthenocarpic figs. Sugar analyses showed that the dried caprified figs contained 30.0 per cent. sugar and the dried parthenocarpic fruits 27.4 per cent., all the sugar being of the reducing form in both cases.

A problem of rather serious consequence accompanying the production of Calimyrna figs is the splitting of the fruits during the period of final swelling or just before ultimate size is reached. Although no data have been published to support the conclusion, a considerable amount of evidence has been accumulated which suggests that splitting is the result of an inherent physical weakness of the variety which is particularly pronounced under conditions of high relative humidity. When the humidity is high and transpiration of the leaves is reduced, it is thought that fruit splitting occurs as a result of increased turgor pressure (3). The percentage of · split fruits varies from location to location and from season to season but instances have been reported where splitting had occurred in practically all of the mature figs examined in several orchards (12). In this connection 5 samples of 100 figs each were counted in the orchard where this investigation was conducted to determine the percentage of split fruits. Splitting of the caprified figs occurred to the extent of 5 per cent. while no splitting was found to have taken place on any of the parthenocarpic figs. These observations indicate that splitting may be the result of a growth phenomenon associated with seed development which occurs, as pointed out above, under certain environmental conditions.

A method that would eliminate the costly, uncertain, and potentially disease-spreading caprification techniques, and at the same time maintain quality and quantity of yield, would be of great material benefit to the Calimyrna fig grower. The present results indicate that such a method is within the realm of possibility.

Summary

1. This paper presents the preliminary results of investigations on the chemical induction of parthenocarpic development in the Calimyrna fig. This variety, as well as all varieties belonging to the Smyrna group, requires cross-pollination in order for the syconia to set and mature.

2. Aqueous sprays containing indolebutyric acid at concentrations of 1500 and 2670 p.p.m., and an oil emulsion spray containing 2670 p.p.m. of indolebutyric acid resulted in parthenocarpic fruit set that was equal to or better than the caprified (pollinated) controls. Neither naphthoxy-

acetic nor 2,4-dichlorophenoxyacetic acids at the concentrations used were effective in promoting parthenocarpy. No apparent foliage injury resulted from applications of 2,4-dichlorophenoxyacetic or naphthoxyacetic acids but indolebutyric acid caused moderate curling of the foliage accompanied by chlorosis which persisted throughout the season.

3. A higher percentage of figs were set when treatments were made about the middle of the caprification period than when they were made either at the beginning or toward the end of this period. By applying an aqueous spray of indolebutyric acid at the proper time, the data presented indicate that it may be possible to set parthenocarpically nearly all the syconia on the tree.

4. The injection of these growth regulators through the ostioles and into the cavities of figs, produced no consistent parthenocarpic development. However, some figs treated in this manner reached full maturity in 12 days, as compared to approximately 80 days for caprified and 95 days for parthenocarpic figs induced through spraying.

5. Parthenocarpic figs were not markedly different from caprified fruits as regards color, size, shape, flavor, and sugar content, but they were completely seedless with no sclerification of the ovary walls.

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