FURTHER STUDIES ON THE CHEMICAL INDUCTION OF PARTHENOCARPY IN THE CALIMYRNA FIG

RENÉ BLONDEAU AND JULIAN C. CRANE

(WITH FOUR FIGURES)

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Introduction

During the summer of 1947 investigations were initiated to find chemicals which would induce parthenocarpic development of second-crop Calimyrna figs, and thus relieve the grower of the problems of caprification. In that preliminary work three growth-regulating chemicals were employed, namely, 2,4-dichlorophenoxyacetic acid, beta-naphthoxyacetic acid, and gamma-(indole-3)-n-butyric acid. At the concentrations tested only the latter compound was effective. The purposes, problems, and details of this preliminary study have been reported (**3**).

With the experience gained from the 1947 studies the work was expanded in 1948 with considerable success, and the results are presented here.

Materials and methods

The investigation was primarily concerned with the testing of several synthetic growth-regulating compounds to determine their effectiveness in promoting parthenocarpy in second-crop Calimyrna figs. However, other studies incidental to the main program also were made which will be discussed later.

The methods employed were essentially similar to those used in the original work, differing only in minor details. The investigations were conducted in commercial orchards under standard practices of production. Materials under test were applied with a continuous delivery type, hand-operated fly-spray gun, wetting both leaves and syconia with the spray. Individual branches were used and were selected for uniformity of vigor and number of syconia. Five branches were used per treatment, each bearing at least five syconia at the time of treatment. To exclude the pollen-carrying fig wasp (*Blastophaga psenes* L.) these branches were covered with muslin bags during the period of caprification. A total of 50 branches selected at random throughout the orchard served as controls and were caprified by the grower, along with the rest of the orchard, in the accepted commercial fashion. Ten additional branches were bagged to serve as controls with no caprification or chemical treatment.

All test branches were bagged on June 24 and with the exception of a few minutes during treatment remained covered until July 12. Caprification was started in the orchard on June 25 and the last introduction of caprifigs was made on July 5, 1948. All spray applications were made on June 30 and July 1, 1948.

Nine chemicals at a number of concentrations were tested, both alone and in various combinations. In all, 83 treatments were made which represented a total of 475 branches that were observed through the growing season. Table I lists the treatments employed.

Chemicals in the acid form were dissolved in distilled water with the aid of a minimum quantity of ammonium hydroxide, following which the pH of the solution was adjusted by the addition of HCl to between 5.0–5.5.

TABLE I

CHEMICALS AND CONCENTRATIONS TESTED TO DETERMINE THEIR EFFECTIVENESS IN PROMOTING PARTHENOCARPY IN THE CALIMYRNA FIG

CHEMICAL USED	CONCENTRATIONS (P.P.M.)				
Sodium 2,4-dichlorophenoxy acetate (2,4-D)	20	40	60	80	100
Isopropyl ester of 2,4-D in oil emulsion (2,4-DE)	20	40	60	80	100
2,4,5-trichlorophenoxyacetic acid (2,4,5-T)	10	25	50	75	100
Isopropyl ester 2,4,5-T in oil emulsion (2,4,5-TE)	10	25	50	75	100
para-chlorophenoxyacetic acid (PCPA)	10	20	40	60	80
Sure-Set*	22	33	44	67	
alpha-(2-chlorophenoxy) propionic acid (alpha 2)	50	100	150	200	
alpha-naphthaleneacetic acid (NA)	25	50	100	250	
Endrop*	25	50	100	250	
beta-naphthoxyacetic acid (NOA)	100	250	500	750	
Indole-3-acetic acid (IA)	25	50	100	250	
Indole-3-propionic acid (IP)	50	100	250	500	
gamma-(Indole 3)-n-butyric acid (IB)	200	400	600	900	1200 1500
NA 125 p.p.m. plus 2,4-D at =	20	40	60	80	100
NOA 125 p.p.m. plus 2,4-D at =	20	40	60	80	100
NOA 125 p.p.m. plus PCPA at =	10	20	40	60	80
NA 125 p.p.m. plus PCPA at =	10	20	40	60	80

* Sure-Set, supplied by the Dow Chemical Company, contains PCPA in a water-miscible solvent, and Endrop, supplied by Shell Oil Company, Incorporated, contains NA in a light emulsive oil.

The sodium salt of 2,4-D was dissolved directly in water and the pH adjusted as above. The isopropyl esters of 2,4-D and 2,4,5-T were dissolved in a light emulsive oil which was then emulsified by vigorous shaking with the proper amount of water so that the final spray contained 1.0% oil.

Results and discussion

The following compounds were completely ineffective in inducing parthenocarpy at the concentrations employed: 2,4-D, 2,4-DE, NOA plus 2,4-D, alpha-2, NOA, IA, and IP. The negative results obtained with 2,4-D and NOA are in agreement with the previously reported work (**3**). However, it was found that 100 p.p.m. of 2,4-D did not cause injury to the tree and it is possible that higher concentrations may be effective in inducing parthenocarpy.

Those treatments that effectively induced parthenocarpy are set forth in table II, along with the percentage of the treated syconia that matured and the average air-dry weight of the ripe fruit.

The data show that NA, 2,4,5-T, IB and PCPA were effective in inducing parthenocarpy in the Calimyrna fig. The use of an oil emulsion with NA increased the activity of the material, but only at the three lower concentrations. Increasing concentrations of both NA and PCPA caused an increase in per cent. fruit set within the range of concentrations used here.

TABLE II

PER CENT. FRUIT SET AND AVERAGE AIR-DRY WEIGHT OF FRUIT PRODUCED BY VARIOUS TREATMENTS

MATERIAL	CONC. P.P.M.	PER CENT. SET	AVERAGE DRY WEIGHT GRAMS/ FRUIT	MATERIAL	CONC. P.P.M.	PER CENT. SET	AVERAGE DRY WEIGHT GRAMS/ FRUIT
2,4,5-T	10	56	.....	Endrop	25	39	14.1
	25	64			50	72	
	50	69			100	72	
	75	72			250	80	
	100	65					
2,4,5-TE	10	60	.....	IB	200	23	13.4
	25	77			400	56	
	50	83			600	76	
	75	63			900	69	
	100	67			1200	78	
					1500	79	
PCPA	10	4	17.2	NA 125 plus	20	77	15.1
	20	18		2,4-D at:	40	83	
	40	67			60	58	
	60	76			80	70	
	80	62			100	50	
Sure-Set	22	58	14.6	NA 125 plus	10	76	14.4
	33	76		PCPA at:	20	79	
	44	46			40	88	
	67	46			60	78	
					80	54	
NA	25	8	16.4	NOA 125 plus	10	19	12.9
	50	42		PCPA at:	20	36	
	100	63			40	74	
	250	85			60	77	
					80	67	
Caprified Controls	A*	45	16.9	Untreated-uncaprified		0	
	B*	83					

* A—Controls in orchard where sprays were applied. B—Controls in a nearby orchard.

PCPA apparently was most effective at about 60 p.p.m. The acid and ester forms of 2,4,5-T showed somewhat the same trend, although the data are more variable. The combination of two chemicals did not greatly affect the results, the per cent. fruit set being about equal to that obtained with the most active material alone.

Although NA, 2,4,5-T, and IB were effective in promoting parthenocarpy

they were also toxic to the tree in varying degree. NA produced little or no injury at the lowest concentration but severe chlorosis at 250 p.p.m., the concentration at which it was most effective in stimulating parthenocarpy. The same symptoms were apparent when NA was used at 125 p.p.m. in combination with other materials. At concentrations of 75 and 100 p.p.m., 2,4,5-T, under these conditions, caused death of the treated branches in about a month. However, this material produced some unusual effects and will be discussed in detail below. IB, in agreement with the previous work, was moderately toxic at concentrations of 600 p.p.m. or more. Chlorosis was the typical symptom, although some leaf epinasty was evident.

FIG. 1. Fig branches bearing mature fruit. Right, caprified control, left, parthenocarpic fruits induced with 60 p.p.m. para-chlorophenoxyacetic acid.

On the other hand, PCPA was a highly effective compound without any observable symptoms of injury. Figure 1 illustrates branches of caprified and PCPA parthenocarpically induced fruits at maturity.

The significance of the injury produced by these chemicals is somewhat difficult to evaluate because the sprayed branches were enclosed within muslin bags for a period of 19 days, 12 of which were after the sprays were applied. Just what influence the bagging might have on the susceptibility of the branches to chemical injury is not known, but it is possible that such a treatment might accentuate injury through reduced light intensity and also by confining vapor from the applied chemicals. This seems particularly true of 2,4,5-T, since branches adjacent to those treated with the 100 p.p.m. preparation received small quantities of spray as drift and yet showed very little injury, even though many of the fruits responded similarly to those in the experiment.

The percentage of sprayed fruit that reached maturity in the successful treatments was far greater than in the caprified controls in the orchard in which the work was done. However, when compared to the percentage of fruit set in a near-by orchard, the set on the sprayed branches was slightly lower. This difference in control data is due simply to differences in thoroughness of caprification. The same method was followed in each case, but the frequency of placing caprifigs and the number used were different. The percentage fruit set of the controls in both orchards have been included in order that valid comparisons could be made.

All the fruit produced by chemical stimulation was completely devoid of achenes ("seeds"), and there was no sclerification of ovary walls. The

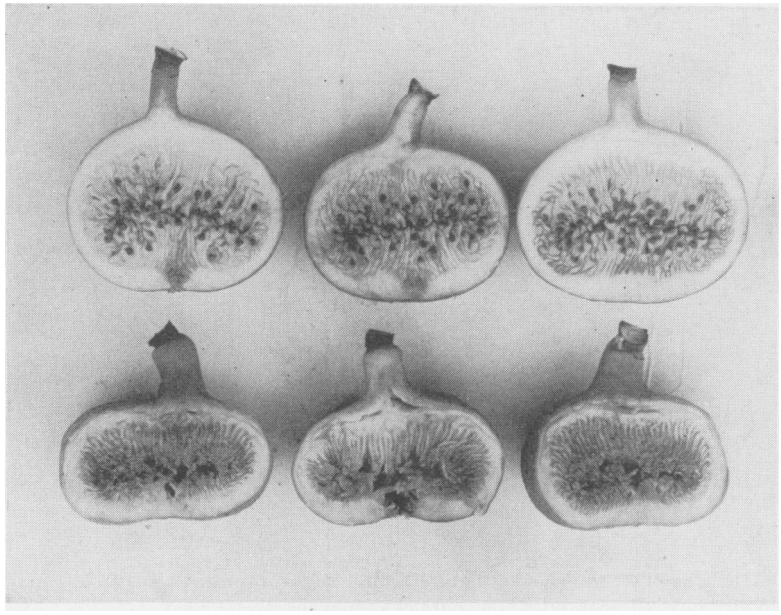

FIG. 2. Sectional views of caprified fruit (upper) and parthenocarpic fruit (lower) induced by 60 p.p.m. para-chlorophenoxyacetic acid.

flavor and color of the fresh fruit was the same as that of the caprified controls. There was a difference in shape between the parthenocarpic and caprified fruit, the former being somewhat flattened from top to bottom. Figure 2 illustrates this difference.

The sugar content of the mature PCPA produced fruit was 51% of the dry weight and that of the mature caprified fruit 46%. Despite the lack of achenes, the average air-dry weight per fig produced by NA and PCPA was essentially equal to that of the controls. IB produced fruit that was about 79% of the weight of those caprified, although equal in diameter.

Diameter measurements of fresh mature fruits were made only in the case of IB, PCPA, and controls. IB at 1200 and 1500 p.p.m. produced fruit of 51 and 52 mm. average diameter, respectively, PCPA at 60 and 80 p.p.m. 55 and 56 mm. respectively, and the controls, orchard A and B, 53 and 51

mm. respectively. All other parthenocarpic fruits, although not measured, were observed to be normal in size.

Periodic diameter measurements were made of developing fruits of the controls and those produced by IB and PCPA. The growth curves were practically alike as to general form, and are typified by those previously published (**3**), except that the PCPA-induced fruits matured at the same time as those caprified.

All parthenocarpic fruits were combined into a common lot and processed and packed in the usual commercial manner. There was insufficient fruit for experimentation on processing methods so all fruit was treated exactly like commercial caprified fruit. The resulting pack was of good appearance and equal in weight to normal fruits. A number of taste tests were made of the processed material, and, although the flavor was considered acceptable in most instances, it was generally agreed that the flavor was milder and somewhat different from the caprified fruit. It is believed that this difference was due in part to the processing method, since the flavor of dried parthenocarpic fruit before processing was comparable to dried caprified fruit, and in part to the lack of the essential oils of the achenes. The "nutty" texture of the normal fruit was of course lacking in the parthenocarpic material.

As a result of this season's work it is believed that a solution is in sight for the Calimyrna fig grower's problems of caprification. Because of its relatively low cost, low required dosage, and lack of injurious effects, parachlorophenoxyacetic acid appears at this time to have much promise as a material to induce parthenocarpic fruit development in the Calimyrna fig. More work must be done on the problem before any general recommendations can be made, but the results to date are very encouraging.

In addition to results obtained on the original practical problem, interesting fundamental aspects have developed. It was mentioned above that 2,4,5-T produced some very unusual results. Syconia that were sprayed with preparations of this material, either in the acid form or as the ester in an oil emulsion, reached maturity, as judged by color, size, texture, and taste about two weeks after treatment. Normally, such syconia when caprified or treated with other effective growth-regulators require about 75 days in which to attain a comparable stage of maturity. (See figure 3, curves A & C). This stimulation of the maturation process was found at concentrations as low as 10 p.p.m. of the acid or ester, but lower concentrations of the acid were not effective. The fruit thus produced was completely devoid of achenes.

The stimulating effects were not confined to those syconia which were receptive to pollination (or to parthenocarpic stimulus by other hormones) but were obtained on all syconia on the branch. Even the very young syconia, which would not have been receptive to pollination for a week or more after the time of spraying increased somewhat in size, became yellow, soft, and sweet.

Following the initial discovery, sprays of 2,4,5-T were applied to caprified fruits on July 29. Here it was found that the lowest effective concentration was 25 p.p.m., as contrasted to 10 p.p.m. for uncaprified syconia. The caprified fruits reached maturity in about two weeks although they normally would not have matured for another 30 days. (See figure 3, curves B & C.)

Further trials were made with the acid at 20 p.p.m. on fruits of the Black Mission variety. Since the spray was applied considerably later in

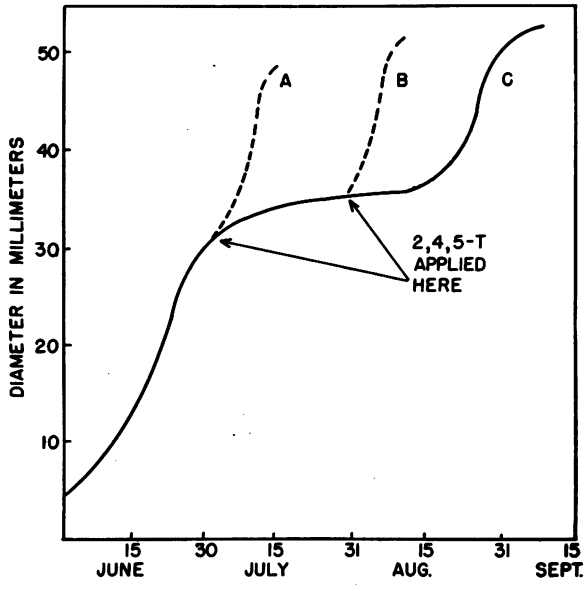

FIG. 3. Curves of growth in diameter of unpollinated (A) and pollinated (B) Calimyrna fig fruits sprayed with 25 p.p.m. 2,4,5-trichlorophenoxyacetic acid as compared to pollinated but unsprayed control fruits (C). Curves represent the average diameters of the four proximal-most figs on current season's growth.

the season, the difference in time of maturity between the sprayed and unsprayed fruit was not as pronounced as with the Calimyrna. The treated Black Mission fruits matured 17 days ahead of the untreated controls (see figure 4).

The rapid acceleration of the fruit maturation processes by the application of a synthetic plant hormone is considered to be of considerable fundamental significance and has been discussed in a previous publication (**2**).

The data obtained in this work emphasize the high degree of specificity of the synthetic growth-regulators in regard to the reactions they induce. Three very closely related compounds—PCPA, 2,4-D, and 2,4,5-T—produced widely different results. PCPA induced parthenocarpic fruit which developed in a manner very comparable to caprified fruit; 2,4-D was completely ineffective in the concentration range used; and 2,4,5-T induced parthenocarpic development at an extremely rapid rate. While it is believed that

these diverse reactions are actually the result of differences in the manner in which the synthetic materials alter the normal chain of events leading to maturation the effect of such factors as rate of penetration into the plant and translocation within the plant cannot be overlooked.

It is of interest to compare the results of these chemicals on the fig with data of ZIMMERMAN and HITCHCOCK (7) on the induction of parthenocarpy in the tomato. Of the six chemicals common to both sets of data, three, IB, PCPA, and 2,4,5-T, are effective on both fruits in about the same concentration ranges, whereas the other three, 2,4-D, NOA, and alpha 2, are ineffective on the fig at concentrations five to 10 times that necessary for the tomato. The reason for these differences in activity is not immediately ap-

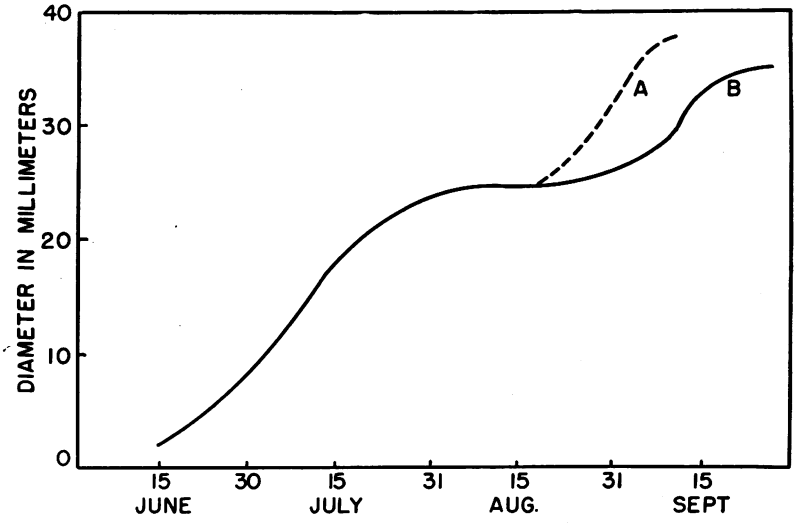

FIG. 4. Curves of growth in diameter of Mission figs sprayed with 20 p.p.m. of 2,4,5-trichlorophenoxyacetic acid on August 17, 1948. Sprayed fruits (A) and unsprayed control fruits (B).

parent but the great difference in fruit type is no doubt largely responsible.

The necessity for translocation of growth-regulators to regions of reactivity was illustrated by means of IB. This material at concentrations of 1200 and 1500 p.p.m., was applied to either syconia or leaves only. When applied to the leaves typical injury occurred, indicating penetration, but parthenocarpy did not result. However, application to syconia alone did induce parthenocarpic fruit growth to maturity without leaf injury. Apparently under the conditions of this experiment, IB was not translocated from the leaves to the syconia in sufficient quantity to induce parthenocarpy. The "transmission of effect" as found by Batjer (1) for NA on apple drop clearly did not occur in the above experiment.

The fig offers considerable promise as a test plant for studies on the hormone relations of fruit development. Complete natural parthenocarpy occurs in several varieties, such as Adriatic, Black Mission, and Kadota,

whereas the Calimyrna is practically completely non-parthenocarpic. In the latter variety a few syconia of the first crop may develop parthenocarpically, while the second crop is completely non-parthenocarpic. In addition, parthenocarpy can be induced in second crop Calimyrna figs with PCPA, resulting in a normal rate of fruit development, or with 2,4,5-T, where an accelerated rate of development occurs. Furthermore, the maturation of caprified Calimyrna or parthenocarpic Black Mission fruits can be greatly accelerated with 2,4,5-T. Thus it seems possible that studies of the hormone relations of fruit development in the fig might yield valuable information on fruit development in general.

It is clear that the source of hormones for fruit development to maturity is not in the developing embryo, since the parthenocarpic fruits of the Black Mission and similar varieties are devoid of embryos, as are the induced parthenocarpic fruits of the Calimyrna. This source is probably the developing ovarian tissue, as pointed out by VAN OVERBEEK (**6**) and shown by MUIR (**5**), or the receptacular tissue.

It also is probable that figs which are normally parthenocarpic have a higher hormone content in the early stages of development than the non-parthenocarpic varieties, as shown by Gustafson for other fruits (**4**). This higher level is sufficient to initiate development, other sources becoming available as growth progresses. In the non-parthenocarpic varieties pollination, or externally added hormone, supply the initiating stimulus, following which an adequate hormone level is maintained as in a normally developing fruit. Apparently 2,4,5-T is so effective, either due to its chemical structure or factors of penetration, etc., that it not only initiates the growth reaction, but greatly accelerates the subsequent processes.

Summary

1. Results obtained during the 1948 season of investigations on the chemical induction of parthenocarpy in the Calimyrna fig are presented. Studies were made of nine chemicals applied as aqueous or oil emulsion sprays. These chemicals consisted of four chlorinated phenoxy acids, naphthalene and naphthoxy-acetic acids, and indole-acetic, propionic, and butyric acids.

2. Of these, indole-butyric, naphthalene-acetic, 2,4,5-trichlorophenoxyacetic, and para-chlorophenoxyacetic acid were effective in inducing parthenocarpic fruit development to maturity.

3. Indole-butyric acid, previously reported as active at 1500 p.p.m. was found to induce parthenocarpy at 200 p.p.m. Leaf chlorosis was evident at 600 p.p.m. or more. Naphthalene-acetic acid was increasingly effective from 25 to 250 p.p.m. It was slightly toxic at 50 p.p.m. and caused severe chlorosis at 250 p.p.m.

4. 2,4,5-trichlorophenoxyacetic acid induced parthenocarpy at a concentration as low as 10 p.p.m., and in addition greatly accelerated fruit maturation. Syconia sprayed with this material were judged mature on the

basis of size, color, texture, and flavor two weeks after treatment, in contrast to caprified fruit which required 75 days to reach a comparable stage of maturity. This compound also accelerated the maturation of caprified fruit and the normally parthenocarpic fruit of the Black Mission variety. It was also toxic, causing chlorosis at low concentrations and death in about a month at 75 and 100 p.p.m.

5. Para-chlorophenoxyacetic acid at 40, 60, and 80 p.p.m. resulted in a set of parthenocarpic fruit which matured normally and was essentially equal to the caprified controls in all respects. No injury was apparent from this material at these concentrations.

6. All parthenocarpic fruit was devoid of achenes and there was no sclerification of ovary walls. The flavor and color of the fresh fruit were equal to the caprified controls. The parthenocarpic fruit was slightly flattened dorsi-ventrally.

7. All parthenocarpic fruit was combined into a common lot, air dried, and processed and packed in the accepted commercial method. The resulting unit package was of good appearance and equal in weight to caprified fruit. A limited number of taste tests of the processed fruit indicated that the flavor was acceptable in most instances, although milder and somewhat different from similar caprified fruit.

8. Because of its relatively low cost, low required dosage, and lack of injurious effects, para-chlorophenoxyacetic acid appears to offer considerable promise as a means of eliminating the problems of caprification in the Calimyrna fig industry.

9. A brief discussion is included of the relationships of hormones to the growth of the fig fruit and to fruit growth in general.

SHELL OIL COMPANY, INCORPORATED
AGRICULTURAL LABORATORY
MODESTO, CALIFORNIA
AND
DIVISION OF POMOLOGY
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA

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