ment of sepals, petals, stamens, and pistil(s) until bloom the following spring (8). By contrast, 7 cultivars of Persian walnut (*Juglans regia* L.) have been shown recently to begin flower bud differentiation (flattening of the shoot apex) from the first of June to the middle of July (5). Sepal initiation occurred in July and August in 2 cultivars, while it did not occur in other cultivars until the following February or March. Pistil initiation and development generally began in March, and pollination and fertilization occurred the first of May. Thus, initiation and development of the components of pistillate flowers of walnut were shown not to be continuous, as there were periods of 7 to 9 months in which little or no growth and development took place. Our study shows that in development of the pistillate flower of pistachio there are inactive periods of 3 to 5 months. Like the walnut, pistachio has apetalous, imperfect flowers. The reason for discontinuous floral development in these species is not known, but it may be associated with the incomplete complement of floral parts.

It may be significant that the period from late June to early September encompasses the time at which 3 important events occur: cessation in floral bud growth and development, rapid seed growth and development, and inflorescence bud abscission. We have found, however, that cessation in floral bud development is apparently unrelated to seed development, since it occurred in buds from both bearing and nonbearing trees. Abscission of inflorescence buds is influenced by seed development and the lack of morphological change within the buds suggests a correlation phenomenon. Seed development and transition of inflorescence buds to a period of inactive growth may lead to a depletion of growth hormones in the buds and shift the hormonal balance in favor of an abscission promoting factor, possibly abscisic acid. Foliar application of auxin (2) and application of benzyladenine (Takeda, unpublished) directly to inflorescence buds on bearing trees in June retarded bud abscission during the July-September period. Neither carbohydrate (2) nor nitrogen (7) depletion appear to be the primary factor involved in floral bud abscission in pistachio. Thus, the evidence accumulated to date continues to support the theory that the phenomenon of abscission of inflorescence buds is controlled by a hormone(s).

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Effect of Photoperiod on Growth Responses of Citrus Rootstocks[1]

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Abstract. **Trifoliate orange [*Poncirus trifoliata* (L.) Raf.] and various other commonly-used rootstocks, submitted to long-day (LD) of 16 hours, (normal day + 4 hr incandescent light break), normal day (ND) of 12 hours ± 1 hr 10 min and short-day (SD) of 8 hour photoperiods fell into 2 groups—those which responded to LD tratment and those which did not. Rootstocks in the first group, Christianson, Beneke, Pomeroy, Rubidoux and Yamaguchi, trifoliate orange cultivars; Carrizo and Savage citranges [*P. trifoliata* × *C. sinensis* (L.) Osbeck.]; Sacaton citrumelo [*P. trifoliata* × *C. paradisi* Macf.]. Hawaiian sweet orange (*C. sinensis*) and Milam lemon (*C. jambhiri* Lush.), responded strongly to LD treatments in shoot growth and stem diameter. Rootstocks less responsive to photoperiod include Cleopatra mandarin (*C. reshi* Hort. ex Tan.), Estes lemon, (*C. jambhiri*), Troyer citrange, Swingle citrumelo, *C. macrophylla* Webster, *C. taiwanica* Tan. and Shin and *C. volkameriana* Pasq. This second group was considered better adapted to tropical conditions because they made better growth under SD conditions.**

Virtually all citrus trees are budded to rootstocks. One group of rootstocks, the trifoliate orange and its hybrids are popular in temperate areas of the world (1) but trees on trifoliate orange often grow poorly under tropical and subtropical conditions. Preliminary research in Hawaii has indicated that the growth response of trifoliate orange may be photoperiod related (7,8).

A series of 4 experiments was conducted to determine the relative growth responses of rootstock seedlings to photoperiod and evaluate performance of several cultivars of trifoliate orange, citrange, citrumelo, rough lemon and Cleopatra mandarin under Hawaii conditions.

Piringer et al. (4) subjected 3 citrus species and trifoliate orange to 8-, 12- and 16-hr photoperiods. The 8-hr treatment produced shortest stems, and 16-hr the longest stems by producing more and longer internodes. Extending photoperiods

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with fluorescent light gave only 8-hr response but accelerated flushing under long-day treatment. Trifoliate orange grew slowly under 8-hr treatment but did not become dormant after 18 months. An incandescent light break in the dark period, however, produced long-day response. Grapefruit and trifoliate orange flushed more frequently under long-day treatment but lemon grew continuously and did not go dormant in 20 weeks. They concluded that the response of citrus to photoperiod was typical of tropical plants in which short days do not generally induce dormancy, and the longer the photoperiod, the more was the total growth produced in a given period.

Air and soil temperatures must be above the minimum for plant growth before photoperiod responses can be expected. Young (9) observed that low day and night temperatures induced bud dormancy in citrus. Cooper et al. (2) reported cold-tolerant trifoliate orange and mandarin types become dormant around 15.6°C while sweet oranges require 12.8° for cessation of growth.

Stathakopoulos and Erickson (5) found soil temperature to be critical for Pomeroy trifoliate orange; rapid shoot extension only occurred above 15.6°C. Short-day photoperiod did not induce dormancy in *P. trifoliata* but low temperature did under SD conditions. They observed that quiescent trifoliate orange readily resumed growth under short days provided temperature was favorable.

In Hawaii, Rubidoux trifoliate orange responded to LD treatments by increasing stem diameter, total linear growth, and number of branches as compared to SD treatments (8). Shoot growth of trifoliate orange, Troyer citrange and Cleopatra mandarin was lowest under 8-hr photoperiod, medium under normal-day (12 ± 1 hr 10 min) treatment and highest under 16-hr photoperiod (normal day + 4 hr incandescent light break) treatments (7).

Materials and Methods

Four experiments were conducted in the present study. The experimental design was a split plot with photoperiod as main plots and rootstocks as subplots. The number of replicates varied with experiment. Rootstocks were replicated within main plots.

Experiments were conducted in the nursery area of the Hawaii Agricultural Experiment Station, Honolulu, 30 m elevation, 3 km from the ocean and 21°N latitude. Expt. 1 conducted under fiberglass which reduced light intensity about 20%. The 3 other experiments were in full sun.

Normal daylengths on June 21 and December 21 are 13 hr 10 min and 10 hr 50 min, respectively, at Honolulu. The 3 photoperiod treatments were SD (8 hr daylength), ND (12 hr ± 1 hr 10 min daylength) and LD (normal-day plus a 4 hr dark period interruption with 100 watt incandescent lamps between 2200 and 0200 hr). Incandescent lamps furnish supplemental light of about 0.002 Langleys at the plant level. Plants in short-day treatments were covered at 1600 each night until 0800. Eight-month-old seedling rootstocks were planted in 4 liter cans in a potting mix of equal parts of peat moss, sponge rock, compost and pasturized soil.

Air temperature in Hawaii is moderated by the surrounding ocean. However, warm and cool seasons are recognized at Honolulu, the warm mostly dry summer from May to October and a cooler somewhat rainy winter from November to April. Mean temperature recorded at the nursery site were a summer mean maximum and minimum of 28.2° and 21.7°C, respectively, and a winter maximum and minimum of 26.0° and 19.6°C, respectively, based on 5-year averages during these experiments. Diurnal temp changes were usually between 7° and 10°C.

Measurements were made of stem diam 3 cm above the pots and also above and below the bud unions. Length and number of branches and frequency of flushes were determined. Treatment replications were 5 for expt. 1, 7 for expt. 2, 5 for expt. 3, and 2 to 8 for expt. 4.

Expt. 1. Seedlings of Rubidoux trifoliate orange, Troyer citrange, Cleopatra mandarin, Hawaiian sweet orange and rough lemon were given SD and LD photoperiods under fiberglass from August 30, 1965 to March 12, 1966 (Table 1).

Expt. 2. Seedlings of 5 trifoliate orange cultivars, Beneke, Christianson, Pomeroy, Rubidoux and Yamaguchi; 3 citranges, Carrizo, Savage and Troyer; Sacaton citrumelo, *Citrus macrophylla, C. Taiwanica* and *C. volkameriana* were treated with SD, ND and LD photoperiods; there were 7 replications. The experiment was conducted from July 20, 1967 to May 28, 1968 under full sun (Table 2).

Expt. 3. Seeds for this experiment were from US Dept. Agr. Horticultural Research Laboratory, Wesleco, Texas. Seedlings of rough lemon, Estes and Milam rough lemons, Rio Cleopatra mandarin, Rubidoux trifoliate orange and Swingle citrumelo were treated when 8 months old with SD and LD photoperiod, under full sun. The experiment continued from May 1969 to April 1970. (Table 3).

Expt. 4. Several citrus cultivars were budded on Rubidoux trifoliate orange, Troyer citrange and Cleopatra mandarin rootstocks. Scions budded on these rootstocks were 'Frost' navel sweet orange, 'Clementine' and 'Dancy' tangerines (*C. reticulata*) 'Minneola' tangelo, (*C. reticulata* x *C. paradisi*) and 'Owari' satsuma (*C. unshiu* Marcov.). The duration of SD vs. LD experiment was April 9, 1966 to December 27, 1966, under full sun. Replications varied from 2 to 8 (Table 4).

Results and Discussion

Stem diameter was increased significantly under LD over SD treatments at the 1% level for Rubidoux trifoliate orange and at the 5% level for Troyer and Hawaiian sweet orange seedlings in expt. 1 (Table 1). In contrast, a significant increase in stem diameter was obtained for Cleopatra mandarin under SD. There were no significant differences in stem diameter of rough lemon as a result of photoperiod.

Table 1. Effect of short-day (SD) and long-day (LD) photoperiods on stem diameter increase, linear growth increase and No. branches of 8-month-old seedlings, August 30, 1965 to March 12, 1966 under fiberglass (expt. 1. 4 replications per treatment).

Seedling and photoperiod	Stem diam increase (mm)	Linear growth increase (cm)	No. branches[z]
Ribidoux trifoliate orange			
SD[y]	6.58	17.3	1.3
LD	12.77**[x]	84.8*	2.9
Troyer citrange			
SD	14.97	57.2	1.5
LD	15.98*	96.5*	2.1
Cleopatra mandarin			
SD	15.70*	47.4	2.0
LD	12.55	116.8**	5.1**
Hawaiian sweet orange			
SD	13.21	64.0	2.9
LD	14.7*	109.2*	5.6**
Routh lemon			
SD	16.40	66.5	3.2
LD	16.16	125.5	8.3*

[z]Mean of 4 replications.
[y]SD = 8 hr day, LD = normal day + 4 hr incandescent light break.
[x]Means separation by Duncan's multiple range test (3), 5% (*) and 1% (**) level.

Table 2. Mean growth responses of 12 citrus rootstocks to 10 months exposure to short-day (SD), normal-day (ND), and long-day (LD) photoperiod (Expt. 2, July 20, 1967 to May 28, 1968, under full sunlight).

Species Cultivar	Mean stem diam (mm)[z] photoperiod SD[y]	ND	LD	Mean linear growth (cm) photoperiod SD	ND	LD	Mean bunches (No.) photoperiod SD	ND	LD
Poncirus trifoliata									
Christianson	10.14 a	13.86 b	13.57 b	83.4 a	163.4 b	192.1 b	11.1 a	20.3 b	24.6 b
Pomeroy	10.29 a	13.86 b	12.57 ab	91.1 a	144.7 b	188.0 c	13.0 a	17.9 ab	22.6 b
Yamaguchi	9.57 a	13.71 b	12.57 b	78.4 a	157.4 b	196.4 b	11.8 a	17.1 a	24.1 b
Beneke	9.57 a	12.86 b	11.71 b	92.3 a	125.4 ab	170.4 b	14.9 a	15.1 a	18.1 a
Rubidoux	10.00 a	13.14 b	12.57 b	78.0 a	155.6 b	157.6 b	11.6 a	17.4 a	16.4 a
Citrange									
Troyer	12.43 a	14.86 b	13.00 ab	145.1 a	148.1 a	137.7 a	10.3 a	14.3 a	11.0 a
Carrizo	12.00 a	13.00 a	13.71 a	109.0 ab	86.4 a	143.9 b	8.4 a	8.4 a	14.9 a
Savage	14.57 a	14.86 a	16.29 b	135.6 ab	107.6 a	167.1 b	13.1 a	13.0 a	14.9 a
Citrumelo									
Sacaton	14.86 a	19.71 b	19.14 b	114.7 a	202.1 b	263.9 c	12.7 a	24.7 b	37.3 c
Citrus									
Taiwanica	15.00 a	16.86 a	16.29 a	193.4 b	157.3 a	173.6 ab	16.0 a	12.1 a	16.6 a
Volkameriana	15.71 a	19.14 b	17.71 ab	218.7 b	139.9 a	194.9 b	26.6 b	19.1 a	22.3 ab
Macrophylla	15.43 a	17.43 a	17.14 a	338.6 b	275.1 a	303.1 ab	39.9 a	39.4 a	33.7 a

[z]Mean separation for each growth parameter within a cultivar by Bayes LDS (6) 5% level, 7 replications.
[y]SD = 8 hr day, ND = Normal day length at Honolulu, 12 hr ± 1 hr 10 min, LD = Normal day + 4 hr incandescent light break.

Shoot growth and number of branches were significantly greater under LD than SD for all rootstocks (Table 1) except for number of branches of Rubidou trifoliate orange and Troyer citrange. Rough lemon, sweet orange and Cleopatra had the most branches.

All 12 citrus rootstocks tested had smaller mean stem diameter under SD than under ND or LD (Table 2). The differences were not significant with 3 of the rootstocks and at least 1 of the comparisons was significant in the remainder. Short days produced significantly less linear growth on all *Poncirus trifoliata* rootstocks and the Sacaton citrumelo rootstock while the citrus rootstocks made greater linear growth under SD than under LD or ND. Short days generally resulted in fewer branches than LD for all rootstocks except those in the citrus group. The only differences that were significant were those of the Christianson, Pomeroy and Yamaguchi trifoliate orange and Sacaton citrumelo rootstocks.

Effects of LD and SD on 3 rough lemon selections as well as 3 other rootstocks were evaluated in expt. 3 (Table 3). Milam rough lemon and Rubidoux trifoliate orange rootstocks had consistently greater growth with LD than SD and these differences were significant. Rough lemon, Estes rough lemon and Swingle citrumelo, on the other hand, generally made greater growth under SD. Cleopatra mandarin was unaffected by day length.

Citrus budded on trifoliate orange generally responded to long-day by producing less scion linear growth than on Troyer citrange (Table 4). The difference was not significant on Cleopatra mandarin except for stem diameter of 'Frost Washington' navel. Results might have been more precise if more replications of some scions had been available. It is evident that trifoliate orange and citrange seedlings can be grown more rapidly in the tropics under long days.

Data reported here indicate that SD limited growth of tri-

Table 3. Photoperiod effects on growth increase of 3 rough lemon selections, Cleopatra mandarin, Rubidoux trifoliate orange and Swingle citrumelo (expt. 3, May 1969 - April, 1970, under full sun).

Rootstock	Photo-period	Stem diam increase (mm)	Rank	Linear growth (cm)	Rank	Branches (no.)	Rank
Rough lemon	SD[z]	10.43 ab[y]	3	203.4 b	2	14.3 a	2
	LD	9.94 b	4	175.5 bc	3	10.0 b	4
Estes rough lemon	SD	11.38 a	1	261.9 a	1	16.9 a	1
	LD	11.05 a	2	166.4 bc	4	10.8 b	3
Milam rough lemon	SD	5.18 g	11	30.8 g	11	1.8 e	12
	LD	9.73 bc	5	157.1 cd	5	5.9 cd	7
Cleopatra mandarin	SD	8.14 de	7	123.3 de	7	5.9 cd	7
	LD	7.16 ef	8	124.4 de	6	6.0 c	5
Rubudoux trifoliate	SD	4.38 g	12	23.3 g	12	1.8 e	12
	LD	6.89 f	9	116.0 e	8	5.6 cd	8
Swingle citrumelo	SD	8.64 cd	6	68.8 f	9	3.3 e	10
	LD	6.55 f	10	56.9 fg	10	3.6 de	9

[z]SD = 8 hr day, LD = normal day + 4 hr incandescent light break.
[y]Means separation by Bayes LSD, 5% level (6).

Table 4. Growth responses of various scions on 3 citrus rootstocks with short-day (SD) and long-day (LD) photoperiod treatments, (expt. 4, April 9, 1966 to Dec. 27, 1966, under full sun, replications 2-8).

			Mean stem diam (mm)				Mean linear increase (cm)		Mean branches (no.)	
			Scion		Stock					
Scion[z]	Rootstock	Replications (no.)	SD[y]	LD	SD	LD	SD	LD	SD	LD
F. Navel	trif.	8	9.0	13.5**[y]	11.6	16.4**	68.6	334.0**	6.0	17.0**
Clementine	trif.	3	10.0	14.0 ns	19.0	14.0 ns	75.0	412.0**	14.0	47.0**
Dancy	trif.	2	10.0	12.0 ns	14.0	18.0 ns	142.0	363.0 ns	8.0	26.0 ns
Minneola	trif.	3	11.3	15.7 ns	14.0	17.2 ns	69.7	287.3*	7.3	12.0 ns
E. Naval	Troyer	6	13.0	16.5**	18.0	20.0*	302.7	509.7+	18.5	24.5 ns
Clementine	Troyer	4	16.8	17.6 ns	22.8	22.3 ns	372.0	505.3 ns	51.2	51.8 ns
Dancy	Troyer	5	15.6	19.0**	20.4	28.4*	350.2	920.0*	27.4	58.0**
Minneola	Troyer	8	12.6	15.3**	16.0	19.0**	141.0	272.4*	12.6	12.5 ns
Owari	Troyer	3	12.6	16.1 ns	16.7	20.3 ns	80.3	370.0+	11.0	24.0 +
F. Navel	Cleo	7	12.1	15.3*	15.0	18.3 ns	170	268 ns	18.6	19.1 ns
Dancy	Cleo	3	14.0	16.3 ns	17.7	19.7 ns	208	248 ns	19.7	35.0 ns
Minneola	Cleo	6	12.8	15.2 ns	15.7	17.0 ns	204	282 ns	8.8	20.0*
Owari	Cleo	3	13.7	15.0 ns	17.0	17.7 ns	157	123 ns	11.3	20.3 ns

[z]See text for names of scions and rootstocks.

[y]SD = 8 hr day, LD = Normal day + 4 hr incandescent light break.

[x]Means for SD and LD for a particular variable in a scion-stock combination are significantly different at the 1% (**), 5% (*) and 10% (+) levels respectively, according to the F-test in an analysis of variance.

foliate orange to a much greater degree than other rootstocks. Ambient temperature during these experiments was much less a limiting factor to vegetative growth than were short photoperiods. Flushes were most frequent under LD and least under SD.

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