Effect of the Early Environment on Flowering in Pepper (*Capsicum annuum* L.)[1]

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Abstract. Air and soil temp have a great influence on the development and flowering of the pepper plant. The time interval between emergence and flowering increases as temp drop. Plants which grew under low temp in any particular growth stage developed an equal or greater number of leaves before the first flower than did plants growing under high temp, regardless of day length.

A soil temp of 10°C retarded plant development, whereas 17°C allowed normal development. The rate of growth increased as soil temp rose. The total plant wt after 100 days of growth under various soil temp increased with rising temp. The top continued to develop with rising temp, but root development was retarded at a soil temp of 30°C or above.

Fundamental research on the morphology and physiology of the pepper plant was undertaken by Cochran (3-5) in the years 1933-1942. Dorland and Went (7) studied the development of the pepper plant under controlled conditions, as did Deli and Tiessen (6). Flowering is affected by environmental factors such as day length and temp. Cochran (5) and Studencova (11) investigated the effect of day length on plant development and concluded that the pepper plant reaches flowering in the shortest time under a 12-hr photoperiod. Artyngina (1) obtained similar results with 8 different varieties of pepper. According to Cochran (5), initiation of the first flower takes place when the fourth leaf unfolds. It took 23 days, with a photoperiod of 12 hr, from seedling emergence to flower initiation; when the day length was only 8 hr, it took 20 days; and with a 24-hr photoperiod, 31 days were needed. Our purpose was to study the effects of soil and air temp, as well as day length in the early stages of growth, on development of the pepper plant.

Materials and Methods

Plants of the pepper cv. California Wonder were grown in pots containing a soil mixture of loam, peat, compost, and vermiculite, 10:4:1.5:3 w/w/w/w, respectively. The plants were watered with a commercial nutrient solution, "Mei-On."

Exp. 1: To determine the effect of night temp on flowering, plants were divided into 4 lots grown for 8 hr (7:30 A.M. to 3:30 P.M.) in a temp-controlled glasshouse at 25°C and then one lot was placed in each of 4 night temp (10, 15, 20, and 25°C) in a plastic-covered greenhouse with natural light. Treatments began when the cotyledons were unfolded, and lasted 45 days. All the plants were then returned to the temp-controlled glasshouse and kept at a constant 25°C.

Observations were made of the no. of leaves prior to first flower, and the no. of days before the appearance of flowers at the 3 lower nodes.

Exp. 2: Plants sown on January 29, 1968 were divided into 4 lots. The first lot was kept at a constant temp of 25°C (control). The second and third lots were transferred for 3 and 6 weeks, respectively, to a cold room at 4°C for 12 hr (in the dark) from the cotyledon unfolding stage. The fourth lot was exposed to the same low temp treatment for three weeks from the stage of two true leaves. For the rest of the time prior to and following the cold treatment period, the plants were grown in a 25°C glasshouse with natural light.

Exp. 3: Plants sown on January 22, 1970 were kept in a plastic-covered greenhouse in which mean day temp ranged from 23°C to 26°C and mean night temp ranged from 19°C to 22°C. The plants were transferred to a similar greenhouse in which mean day temp ranged from 17°C to 25°C and mean night temp ranged from 9° to 11°C at different stages of development, i.e., unfolding cotyledons, 2, 3, and 4 true leaves, for 25 days, and then they were returned to the first greenhouse. Another lot was transferred to the cool house for 50 days from the unfolding cotyledon stage and also returned to the first greenhouse. One lot remained in the higher temp regime and an additional lot was kept continuously in the temp controlled glasshouse at 25°C. Data were collected on no. of leaves prior to first flower, no. of days to flowering, wt of flower, and wt of ovary.

Exp. 4: Plants sown on May 21, 1970 were grown at a constant 25°C temp until they reached the 3-leaf stage. Then they were transferred for 25 days to long- and short-day conditions, with different temp prevailing during the night, as described in Table 4. Photoperiod for all treatments consisted of 7 hr of natural light and temp of 28-30°C. For extending the photoperiod to 17 hr the plants of the appropriate treatments (Table 4, No. 1 and 2) were transferred to a room at 23-25°C temp, lit with a fluorescent and a 200W incandescent lamp, together creating a light intensity of 2700 lux.

Exp. 5: The effect of various soil temp on flowering was tested. After the cotyledons had opened (November 6, 1966), uniform plants were transferred to the non-heated greenhouse (air temp min 5-10°C, max 20-30°C). The pots were held in water troughs (Wisconsin Chambers) at 10, 17, 24, and 30°C. Twenty plants were grown at each soil temp; 6 of them were removed after 50 days to a temp (air and soil) of 25°C, the rest remaining an additional 50 days (total 100 days) at the different soil temp and then transferred to 25°C.

Data were collected on no. of leaves prior to the appearance of the first flower, no. of days to flowering, no. of flowers at first and second flower nodes, and fresh and dry wt of tops and roots.

Table 1. The effect of various night temp on flowering in pepper[z] (Experiment 1).

Night temp[y] (°C)	No. leaves prior to first flower	No. of days from beginning of treatment until: 1st flower bud	anthesis of the 1st flower	anthesis on 2nd node	anthesis on 3rd node
25	8.8a*	34.3a	51.3a	58.0a	64.9a
20	9.4b	45.1b	61.7b	68.2b	73.7b
15	9.9c	47.8c	64.0b	70.3bc	75.5bc
10	10.3c	50.8c	67.2c	72.0c	77.3c

[z]Average of 17-18 plants.

[y]During the 45 days from cotyledon unfolding; thereafter, 25°C in all treatments.

*Values in a column followed by the same letter do not differ significantly at P = 0.05.

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Table 2. The effect of low (4°C) night temp on flowering in pepper[z] (Experiment 2).

Time of treatment at low (4°C) temp	No of leaves prior to 1st flower	No. of days from sowing to 1st flower bud	No. of days from sowing to anthesis of the 1st flower
25° constant	8.8	57.6a*	71.3a
3 weeks following unfolding of cotyledons	8.2	74.1b	88.4b
3 weeks following 2-leaf stage	8.6	74.3b	88.5b
6 weeks following unfolding of cotyledons	8.9 N.S.[y]	79.9c	93.0c

[z]Average of 10 plants.
*Values in a column followed by the same letter do not differ significantly at P = 0.05.
[y]N.S., non-significant.

Results

Effect of night temp and day length. The no. of leaves prior to anthesis was inversely proportional to night temp (Table 1): the lower the temp, the more leaves. In addition, the period from commencement of the temp treatment (or sowing) to anthesis increased with decreasing temp. The greatest effect on flowering was brought about by a night temp of 20°C: a delay of about 10 days in flowering as compared with those at 25°C night temp. As night temp dropped to 15° and 10°C, there was an additional delay of only 2-3 days in flowering; this effect was maintained also at the second and third flowering nodes.

Plants grown at 10°C night temp attained normal flowering, despite the long delay in anthesis, so we examined the effect of still lower temp (including shorter periods of exposure) on delay in flowering.

There was a slight, though not significant, tendency toward reduction in no. of leaves prior to the first flower, when the cold treatment was given for 3 weeks after the cotyledon-unfolding stage (Table 2). The rate of growth was also slowed down as the period of cold treatment was extended.

Low temp caused a delay in anthesis and an increase in the no. of leaves prior to the first flower when the plants were exposed to low temp from the stage of cotyledons to the stage of 3 leaves (Table 3). The flower and ovary were smallest under the influence of constant temp of 25°C and were largest when plants were exposed to low temp for 25 days at the 4-leaf stage.

Plants which grew under short-day conditions developed more leaves prior to the first flower than did those growing under long-day conditions (Table 4). Cold treatment for 7 hr at night, in plants growing under short-day conditions, reduced the no. of leaves to the same level as of plants growing under long-day conditions.

Effect of soil temp. A soil temp of 10°C inhibited plant development, whereas 17°C allowed plant development. The growth rate of plants increased with rising soil temp (Fig. 1). Growing plants at different soil temp for 50 days affected the time of flowering. The number of days prior to the appearance of the first bud decreased from 68 days at 10°C soil temp to 47 days at 30°C. On the other hand, there was no difference in the number of leaves prior to the first flower at temp ranging from 10 to 24°C. At 30°C an average of 10.5 leaves were formed, whereas at the lower temp there were 11 to 11.5 leaves prior to the appearance of the first flower. The difference is not statistically significant. At the second node there were fewer flowers at 10° and 30°C than 17° and 24°C, when plants were held for only 50 days at varying temp.

Maintaining the plants at the soil temp for an additional 50 days had little effect on the pattern described above, at soil temp of 17°C and above, but 10°C retarded flowering at the first node. The no. of leaves prior to flowering in these plants increased. In addition, whereas there was flowering at the first node after 50 days at 10°C, only 4 out of 14 plants flowered after 100 days. Development was apparently arrested to some degree.

A comparison of plant wt after 100 days of growth at different soil temp showed that fresh and dry top wt (Table 5) increased consistently with rising soil temp; however, root wt increased up to 24°C only, and there was no further increase when soil temp rose to 30°C. The retarding effect of high temp on shoot development was most conspicuous when comparing the relative shoot and root wt.

Table 3. The effect of low temp in various development stages on flowering in pepper (Expt. 3).[z]

Treatment	Development stage at beginning of treatment	Duration of treatment	Number of leaves prior to first flower	Number of days from sowing to first flower	Weight (mg) Flower	Weight (mg) Ovary
25° constant	emergence	continuous	10.5a*	71b	111a	42a
High temp[y]	emergence	continuous	10.7ab	68a	169b	82b
Low temp[x]	cotyledons	50 days	12.1d	79d	204c	103c
Low temp	cotyledons	25 days	11.7cd	72b	187bc	91bc
Low temp	2 leaves[w]	25 days	12.0d	77cd	175b	88bc
Low temp	3 leaves[w]	25 days	11.7cd	76c	194bc	103c
Low temp	4 leaves[w]	25 days	11.2bc	78cd	225d	119d

[z]Average of 40 plants.
[y]19-22°C night temp, 23-26° day temp.
[x]9-11°C night temp, 17-25°C day temp.
[w]Last leaf 1 cm long.
*Values in a column followed by the same letter do not differ significantly at P = 0.05.

Table 4. The effect of low temp, at different photoperiods, on the number of leaves on the pepper plant prior to flowering[z] (Experiment 4).

Treatment no.	Light (hr)	Hours of darkness at low temp	Hours of darkness at high temp	No. of leaves prior to first flower
1	17	–	7	8.8a*
2	17	7	–	8.8a
3	7	–	17	9.6b
4	7	7	10	8.8a
5	7	17	–	9.3ab

[z]Average of 18 plants.
*Values in a column followed by the same letter do not differ significantly at P = 0.05.

Discussion

Air and soil temp have a marked effect on the development and flowering of the pepper plant. As temp drops, there is an increase in time required by the plant to reach the different development stages, from emergence to first flower bud, and

Fig. 1. The effect of different soil temperatures (after 100 days) on the growth of the pepper plant (period of treatment – 100 days).

from then to flowering. Our findings are similar to those of other investigators (6); however, the no. of leaves developing in our work from the cotyledon stage until flowering which was affected by temp, differed from that obtained by Deli and Tiessen (6), who claimed that pepper reacts similarly to tomato in this respect. Calvert (2), Hasegawa (8), and Wittwer and Taubner (13) reported that low (12°C) night temp for 25 days before and after flower initiation in the tomato brought about the development of fewer leaves to anthesis than did high (18°C) night temp.

A comparison of the growth pattern of the pepper plant under winter and summer growing conditions in the field shows that the winter plant invariably develops more leaves before the first flower than does the summer plant: 10 to 11 vs. 8 to 9. This phenomenon was reproduced in our experiments under controlled conditions. Plants grown at low temp, at any one of the different growth stages, produced an equal or greater no. of leaves prior to anthesis than plants growing at high temp under a long or short photoperiod. The differences between our findings and those of Deli and Tiessen (6) could be attributed to other differences in growing conditions, such as light intensities, prevailing in the two sets of experiments. Deli and Tiessen did not find any effect of different light intensities, nor did we find any effect of photoperiodicity on anthesis; nevertheless, there is a possibility of a combined effect of the 3 factors in different combinations, which could bring about different results. High soil temp enhance plant growth in pepper, similar to enhancement in tomato (9). On the other hand, a low (10°C) temp retards plant development and flowering, as was demonstrated in our experiments. When plants were irrigated with cold (10-12°C) water, Ugarcinski (12) found that there was flower abortion. The principal difference between the flowering of the pepper and the tomato plant lies in the fact that in the former the flowers appear singly or in pairs, whereas in the latter, flowers appear in clusters. In the tomato plant, low soil temp increase the no. of flowers in the cluster (10), as a result of sub-branching of the inflorescence (2). On the other hand, the no. of flowers (terminal) in pepper plants increase as a result of the branching-off affected by low temp (6).

Table 5. The effect of different soil temp on flowering of pepper (Experiment 5).

Soil temp (°C)	No. of leaves prior to 1st flower	No.of days to: Appearance of first flower bud	No.of days to: anthesis of the 1st flower	No. of flowers on 1st node	No. of flowers on 2nd node
		Period of treatment – 50 days[z]			
10	11.5	68.2d	87.7b	1.3	2.0a
17	11.0	58.7c	71.0a	0.8	3.8b
24	11.3	53.2b	68.5a	1.0	3.8b
30	10.5	46.7a	65.6a	1.2	2.5a
	N.S.			N.S.	
		Period of treatment – 100 days			
10	12.7b	91.5d	125.7d	[y]	
17	10.5a	58.0c	80.1c	1.0	2.8
24	10.7a	54.5b	75.8b	1.2	2.4
30	10.4a	48.2a	71.1a	1.3	2.1
				N.S.	N.S.

[y]Flowers developed on only 4 plants out of the 14 when exposed to 10° C for 100 days.

[z]Values in a column followed by the same letter do not differ significantly at P = 0.05. N.S., non-significant.

Table 6. The effect of different soil temp on wt of roots and tops (per plant)[y] (Experiment 5).

Soil temp (°C)	Fresh wt[z] Top	Fresh wt[z] Roots	Dry wt[z] Top	Dry wt[z] Roots	Top/root ratio
10	2.4a	0.6a	0.4a	0.1a	4.0
17	50.8b	20.6b	8.0b	2.6b	2.4
24	75.2c	31.1c	11.3c	3.9c	2.4
30	99.4d	29.8c	13.9d	3.5c	3.3

[z]Values in a column followed by the same letter do not differ significantly at P = 0.05; N.S. = non-significant.

[y]Period of treatment – 100 days.

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Peach Seed Dormancy in Relation to Endogenous Inhibitors and Applied Growth Substances[1]

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Abstract. An inhibitor was present in both seed coat and embryo of a high and a low chilling cv. of unstratified peach seeds and its concn decreased as stratification proceeded. Embryonic tissue retained more of the inhibitor than the seed coat. As the concn of inhibitor decreased, seed germination increased. The inhibitor was tentatively identified as abscisic acid (ABA) by chromatography. A bound inhibitor was also present in the seed parts of both cvs., and its concn increased in the embryo as stratification proceeded. More ABA and bound inhibitor were present in the high-chilling cv. than in the low-chilling counterpart, indicating that they may be related as factors which cause a cv. to require long periods of chilling. Application of ABA reduced germination percentage on stratified seeds without seed coats. Application of gibberellic acid (GA) and N-benzyladenine (BA) combined had a synergistic effect in promoting germination of dormant seeds.

Eagles and Wareing (5) reported a growth inhibitor in birch leaves and named it "dormin." Later it was found to be the same compound as "abscisin II" (4), extracted from young cotton fruits (1). Recently, the name abscisic acid has been adopted for both dormin and abscisin II (2). A bound inhibitor, (+)-abscysil B-D glucopyranoside, has been described by Koshimizu et al. (8) in *Lupinus lutens* and Milborrow (13). This fact suggests that the glucoside may be the major rapid-storage product of ABA.

Abscisic acid is present in seeds which require chilling to germinate, and its concn, nature, or both are altered during a chilling treatment. Further, these alterations during dormancy have been correlated with the release of seeds from the dormant condition. Lipe and Crane (10) found ABA in peach seed coats, and reported its disappearance by the 6th week of stratification, after which the seed germinated. Martin et al. (11) observed a significant decrease of ABA in walnut kernels after 2 weeks of chilling, and after that, germination occurred. Lin and Boe (9) reported a decrease of ABA in plum seeds during a 90-day chilling period.

Growth inhibitors apparently have a profound effect on seed dormancy, but some research emphasizes a balance between growth-promoting and growth-inhibiting compounds. In *Corylus avellana* seeds, GA concn increased slightly during chilling (6) and Mathur et al. (12) found an increase in GA_3 and GA_7 concn in peach seeds during stratification. Lin and Boe (9) noted an increase in GA-like substances in plum seeds during 90 days of stratification. A role for cytokinins and ethylene in dormancy was indicated by induced germination of certain species as a result of exogenous applications of BA and ethylene. Khan (7) suggested that the action of cytokinin was both antagonistic to the inhibitory effect of ABA and permissive to the action of GA_3.

We studied the changes of an acidic inhibitor and its bound form during stratification of peach seeds, and determined the effect of applied growth substances on germination of peach seeds.

Materials and Methods

We used 'Lovell' peach seeds, which require a long period of stratification, and 'Tetela' seeds, which require a very short period. The seeds, with endocarps removed, were soaked in water 24 hr before being stratified at 3°C in moist vermiculite. 'Lovell' samples were removed from stratification at 2-week intervals over a 3-month period while 'Tetela' seeds were removed at 5-day intervals during a 25-day period. A sample of seeds from each cv. was separated into seed coats and embryos for extraction and purification. Other samples were tested for germination.

Extraction and purification. Growth regulators were extracted with 80% methanol at 0°C for 72 hr, with the methanol being changed every 24 hr. The methanolic extracts

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