Effect of Night Temperature on Shape and Size of Sweet Pepper (*Capsicum annuum* L.)[1]

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Abstract. The correlation of fruit size with seed no. was high (r = 0.96 to 0.99) in fruit growing at high or low night temperatures.

The proportionate wt of fruit per seed decreased with increasing seed no., and was higher in fruit growing under low temp than under high temp. The night temp prevailing before anthesis was not significant for parthenocarpic fruit development, but low temp after anthesis did enable such fruit to develop. High (18-20°C) temp during flower development is a prerequisite for the formation of good-shaped, elongated fruit. The highest length/diam ratio in both fertilized and non-fertilized fruit was obtained with high night temp up to anthesis and low (8-10°C) thereafter.

Temperature determines fruit size in various crops. At night temp of 14°C, Went (14) obtained tomato fruit 3 times the size obtained at 26°C. Temp which affects vegetative growth can also indirectly affect fruit development. Carlsson (1) found a high correlation between leaf and fruit size (wt or volume) in different cultivars of pepper, but only a low correlation (r = 0.20) between the length/width ratio of leaves and the length/diam ratio of fruit, which determines fruit shape. Howlett (6) and Yamaguchi et al. (15) concluded that tomato fruit size might be determined by the no. of seeds present. Clear results and a high correlation between seed no. and fruit size in tomatoes were found by Verkerk (13) and by Dempsey and Boynton (4). Johnson and Hall, however, did not find any correlation between seed no. and fruit size in tomato selections which bear small fruit with a tendency toward parthenocarpic fruit set (7). A correlation between seed no. and fruit size has also been observed in strawberries (9), melons (8) and other fruits. Night temp drops to below 10°C during winter in Israel. Under these climatic conditions, peppers grown under unheated plastic covers produce many small, oblate fruits which are seedless or seed-deficient. Our objective was to obtain information on the effect of night temp on size and shape of the fruit, and especially its effect on seed no. and fruit development.

Materials and Methods

'California Wonder' pepper plants were sown during the first week of November in a plastic-covered nursery. In the 1st experiment, 2-month old plants were planted in plastic-covered greenhouses. In all other experiments, seedlings at the stage of unfolding cotyledons were picked off, singly, into pots 20 cm in diam, which were then placed under the experimental conditions in temp-controlled greenhouses.

Experiment 1. (1966-1968). During 3 growing seasons, 20 to 40 plants were grown in a plastic-covered greenhouse at high 18 to 20°C and low 8 to 10°C min night temp. In the first 2 seasons the fruit was picked green ripe, and in the last season the fruit was picked as it turned from green to red. This added degree of maturity at picking time resulted in more reliable determinations of fruit wt. In order to obtain more information on the relationship between seed no. and fruit size, an additional experiment was set up in an attempt to increase the no. of seed produced at different (high and low) temp. The flowers on half of the plants were given supplementary hand pollination with pollen collected from flowers grown at 18 to 20°C.

The fruits were weighed, and the seeds from each fruit were weighed and counted separately.

Experiment 2. (1968). Thirty plants were grown in a plastic-covered greenhouse with a min temp of 18 to 20°C. When plants began to flower at the 5th and 6th nodes, each flower was marked (at anthesis) and 10 plants were transferred to each of the following min temp: 18 to 20°C (as before), 13 to 15°C, and 8 to 10°C, respectively. Twenty fruits (2 per plant) which developed from the marked flowers were picked from each treatment every 7 days (starting 7 days after anthesis). The fruits were weighed and their length, diam, and pericarp thickness measured; the seeds were also weighed, separately.

Twenty additional plants were grown in greenhouses at each of the different night temp. From these plants fruits were picked green ripe and cut for observation of their different components.

Experiment 3. (1969). Forty pepper plants were grown at 2 different min night temp; 8 to 10°C and 18 to 20°C, until flowering began on the 5th and 6th nodes. The flowers on these nodes were marked and 20 plants from each treatment were transferred to the conditions of the other one; thus, 4 different treatments were obtained, differing from each other in temp before and after anthesis. Every 7 days, starting with the day of anthesis, 1 developing fruit per plant (from the marked flowers) was removed and counted as in the previous experiment. At the 6th sampling, 42 days after anthesis, only 8 to 10 fruits remained per treatment.

Experiment 4 and 5. (1969 and 1970, respectively). Plants were grown under conditions identical to those of Exp. 2. Flowers were emasculated 2 days before anthesis and in each of the 4 treatments half of the emasculated flowers on each plant were left unpollinated while the other half was hand pollinated with pollen collected from flowers grown at min night temp of 18 to 20°C. Fruit set counts were made. Fruits were picked 33 days after anthesis, weighed, and their length, diam and pericarp thickness measured.

Results

Correlation between fruit size and seed number. Fruit wt increased with the increase in the no. of seeds per fruit. The correlation coefficient in fruit size and seed no. was high: r = 0.96 to 0.99 in fruit grown under both high and low temp (Fig. 1 a). The no. of seeds produced at low temp varied from 120 to

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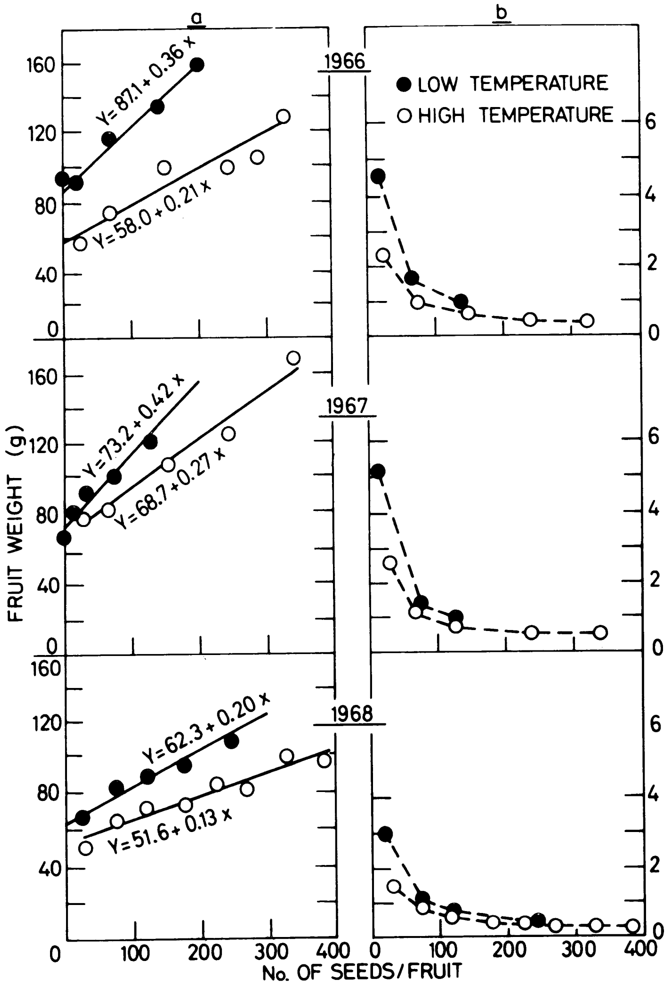

Fig. 1. Correlations between a) seed no. and fruit wt and b) seed no. and relative fruit wt (g/seed) of pepper grown under low (8-10°C) and high (18-20°C) night temp (means of 150-300 fruits per treatment).

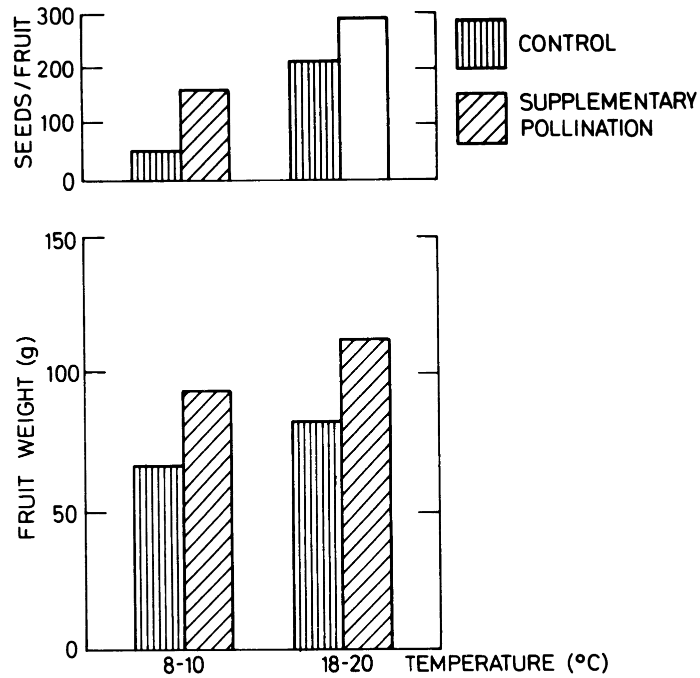

Fig. 2. The effect of supplementary pollination on seed no. and fruit size of pepper grown under low and high night temp (means of 20 fruits per treatment).

250 and never reached 300, being only 50% of the potential no. of seeds as determined by ovule count. The no. of fertilized ovules in fruit grown under high temp reached 450.

The proportionate wt of fruit per seed was high in fruit grown at low temp as compared with those growing at high temp (Fig. 1 b). At both temp the wt of fruit per seed decreased with the increase in seed no.

Additional information on correlation between fruit wt and seed no. was obtained from results of the experiment in which we tried to increase seed no. by supplementary pollination (Fig. 2). The no. of seeds which developed in hand-pollinated fruit exceeded the no. of seeds in fruit pollinated naturally, especially at low temp. Furthermore, the greater no. of seeds significantly increased fruit size.

The effect of night temp on fruit development. High night temp (20°C) after flowering, accelerated fruit development (Tables 1 and 2). This was most pronounced during the initial period following flowering. When the plants grew at high temp prior to flowering (Exp. 2), the highest length/diam ratio was obtained at low min night temp (8 to 10°C) during fruit development. Fruit developing at low temp had a higher length/diam ratio if during pre-anthesis it had been subjected to a high min night temp (18 to 20°C; Exp. 2). At anthesis, ovaries borne on plants grown at low pre-anthesis temp weighed almost twice as much as those grown at high temp. Plants subjected to low temp both before and after anthesis produced fruits with a small length/diam ratio.

The relative wt of various parts of the fruit was not the same when fruit was grown at different night temp although total fruit wt was similar (Fig. 3). As the temp rose, seed, placenta, and stalk wt increased, whereas pericarp wt decreased. The presence or absence of seeds affected the development of different fruit parts (Fig. 4). Fruit containing a normal no. of seeds had a well-developed placenta, whereas seed-deficient or seedless fruits had underdeveloped placentas and consisted mainly of pericarp.

The effect of night temp before and after anthesis, on parthenocarpic fruit set. Temp before anthesis had no

Table 1. Effect of night temp during fruit development, and fruit age (days from anthesis) on pepper fruit and seed wt, fruit shape (length/diameter ratio) and pericarp thickness.

Days from anthesis (B)[z]	Night temp °C (A)											
	20	15	10	20	15	10	20	15	10	20	15	10
	Fruit wt (g)			Seed wt (g/fruit)			Length/diameter			Pericarp thickness (mm)		
7	1.2	0.7	0.4	0.07	0.05	0.02	1.02	0.91	0.89	–	–	–
14	13.7	4.0	2.2	1.40	0.32	0.11	1.28	1.11	1.08	2.3	1.4	1.2
21	27.3	15.3	8.7	1.74	1.26	0.53	1.20	1.37	1.41	2.8	2.3	1.6
28	34.6	25.0	21.7	1.66	1.24	1.39	1.06	1.15	1.39	3.4	2.6	2.5
35	45.0	43.9	35.0	2.04	1.50	1.33	1.00	1.10	1.20	4.2	3.8	3.1
42	–	49.9	49.5	–	1.63	1.23	–	0.98	1.14	–	3.8	4.1

[z]Main effects of both night temp (A) and age (B) were highly significant (1%) in all 4 parameters. The A x B interaction was also highly significant in all parameters except wall thickness, which was not significant.

Table 2. Effect of night temp during flower and fruit development on pepper fruit and seed wt, fruit shape (length/diameter ratio), and pericarp thickness.[z]

Days from anthesis (C)[y]	Night temp (°C) before anthesis (A) → / after anthesis (B) →	Fruit wt (g)				Seed wt (g/fruit)				Length/diameter				Pericarp thickness			
	before anthesis (A)	10		20		10		20		10		20		10		20	
	after anthesis (B)	10	20	10	20	10	20	10	20	10	20	10	20	10	20	10	20
0		0.1	0.1	0.05	0.05	–	–	–	–	0.78	0.78	0.94	0.94	–	–	–	–
7		0.4	1.2	0.5	1.4	0.01	0.05	0.03	0.15	0.68	0.77	0.88	1.05	–	–	–	–
14		3.9	13.8	4.3	14.6	0.11	0.72	0.54	1.52	1.05	1.05	1.19	1.31	1.3	2.1	1.3	2.1
21		20.1	40.8	17.0	37.5	1.20	1.51	1.72	2.09	1.18	1.08	1.43	1.10	2.1	3.4	1.9	3.0
28		37.6	58.9	37.7	63.4	1.20	1.21	2.86	1.80	1.21	0.98	1.41	1.02	2.5	3.8	2.8	4.4
35		55.2	70.8	55.4	69.2	1.38	1.37	3.02	2.92	1.19	1.03	1.32	1.06	3.4	4.8	3.5	4.7
42		64.0	63.2	79.9	77.3	1.54	0.83	3.17	3.08	0.88	0.92	1.41	1.05	4.1	4.6	4.0	4.9

[z]All main effects in all 4 parameters were significant (5% or 1%), except for factor A in wall thickness.
[y]All interactions with age (factor C) were significant at 1%. Length/diameter ratio at the A x B and A x B x C interactions were also significant at 1%.

significant effect on parthenocarpic fruit set, but those prevailing later were crucial. Parthenocarpic fruit-set percentages on plants subjected to low post-anthesis temp were high in all cases, i.e., following either high or low pre-anthesis temp. High temp after anthesis resulted in low fruit set on plants previously grown at low temp and no set at all in those grown at high pre-anthesis temp (Table 3).

The effect of night temp before and after anthesis, on

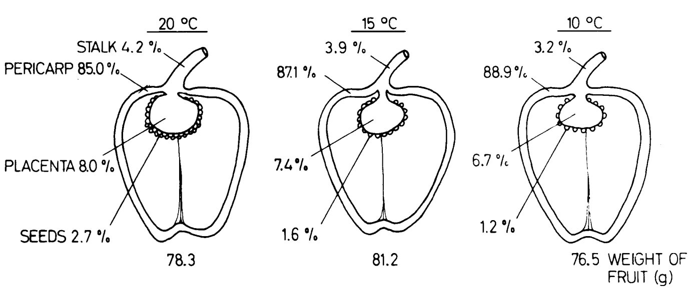

Fig. 3. The effect of night temp on wt of the various pepper fruit parts (as % of fruit wt) grown under different temp conditions.

parthenocarpic and fertilized fruit shape. High temp during flower development resulted in the development of elongated fruit (Table 4). The highest length/diam ratio was obtained in both fertilized and non-fertilized fruit at high pre-anthesis and low post-anthesis temp. Flowers grown at low temp produced small oblate fruits with elongated styles which, at low temp, continued to grow (Fig. 5).

Discussion

The effect of seed no. on fruit size in pepper is similar to that found in tomatoes by Verkerk (13) and by Dempsey and Boynton (4).

"Seed efficiency," i.e., the proportionate wt of fruit per seed, was variable and depended upon temp as well as on the no. of seeds in the fruit. Highest "seed efficiency," 5 g per seed, was found in seed-deficient fruit grown under low night temp. At high night temp and the same no. of seeds per fruit, "seed efficiency" reached only 2.5 g per seed. It was lowest, 0.3 to 0.5 g per seed, in fruits which contained more than 250 seeds, at both low and high night temps.

The final shape and size of pepper fruit is influenced by the temp prevailing at the initial stages of flower development. Flowers developing at low temp have an elongated stigma which

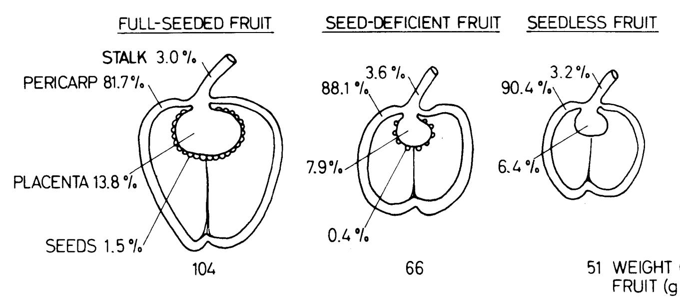

Fig. 4. The effect of seed no. on the relative wt of various fruit parts of peppers grown at low temp.

protrudes above the stamens, thereby making self-pollination, which is the principal though not only means of fruit set, difficult. Low, as well as excessively high, night temp result in the production of non-viable pollen or in non-production of

Table 3. Effect of night temp before and after anthesis on parthenocarpic pepper fruit set.

Night temp (°C) Before anthesis	Night temp (°C) After anthesis	Fruit set (%) 1968	Fruit set (%) 1969
8-10	8-10	96.7	71.9
18-20	8-10	96.7	86.2
8-10	18-20	25.0	8.7
18-20	18-20	0	0

Table 4. Effect of night temp before and after anthesis on shape of pollinated and non-pollinated pepper fruits.

Night temp before anthesis (°C)	18 – 20				8 – 10			
Night temp after anthesis (°C)	8 – 10		18 – 20		8 – 10		18 – 20	
Pollinated (+) Parthenocarpic (–)	+	–	+	–	+	–	+	–
				1968				
No. of seeds/fruit	151	–	154	–	94	–	132	–
Fruit wt (g)	20.7	6.4	39.9	–	34.8	10.4	46.0	25.7
Length/diameter ratio	1.47	1.54	1.22	–	0.89	0.87	0.99	0.93
				1969				
No. of seeds/fruit	251	–	252	–	235	–	204	–
Fruit wt (g)	50.4	16.6	62.9	–	52.9	22.9	70.4	18.6
Length/diameter ratio	1.21	1.23	1.07	–	0.95	0.75	0.91	0.68

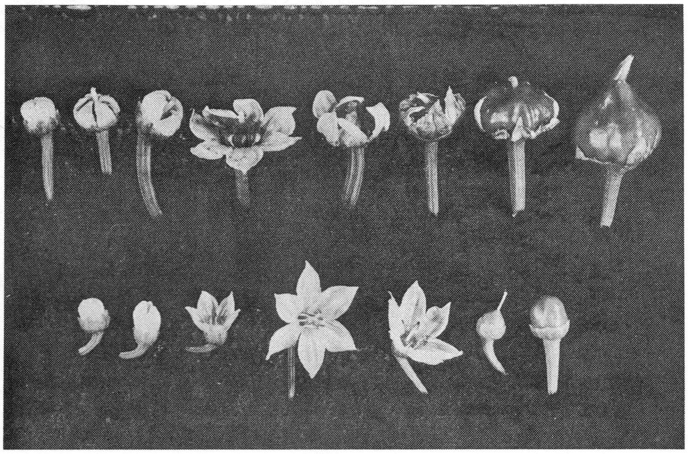

Fig. 5. The development of flower under low (upper row) and high (lower row), night temp.

pollen (3, 5). When conditions are not conducive to fertilization, flowers usually abscise; but, occasionally, when night temp after anthesis is low, these flowers set parthenocarpic fruit. High temp after anthesis causes abortion of non-fertilized flowers.

Parthenocarpic fruit set as a result of low temp is fairly common in pepper, eggplant, tomato, squash, and cucumber in the growing conditions of the Israeli winter. Nitsch et al. (11) reported similar results for cucumbers and eggplants; Osborne and Went (12), for tomatoes; and Cochran (2), for pepper. Parthenocarpic fruit is generally smaller than fertilized fruit. In our experiments, parthenocarpic peppers reached only half the wt of fertilized fruit.

The opinion that a large ovary produces large fruit (10) is not correct under all circumstances. At temp which allow normal flower development, a large ovary with many ovules will produce larger fruit than a small, ovule-deficient ovary. However, under suboptimal conditions during flowering, large ovaries produce smaller fruit than do small ovaries developing at high temp. Fertilization of ovaries developing in suboptimal conditions will increase the size of the resulting fruit, but the length/diam ratio will remain small. Flowers developing under low temp produce small oblate fruit which high temp after anthesis cannot rectify. Low temp retard fruit development at the pre-anthesis stage only, whereas low temp after anthesis actually enhance final fruit wt and length.

Good ventilation in greenhouses can be most important in preventing flower abscission, especially of non-fertilized flowers. The resulting fruits are unattractive in appearance but are saleable locally and are even profitable, making the culture of pepper in unheated plastic-covered tunnels worthwhile during Israeli winters. Good ventilation also enhances the size of fertilized fruit.

Since it has been shown that large, high quality fruit can be obtained only from flowers which develop at relatively high night temp, growing the plants in heated structures until they are in full bloom and subsequently continuing the culture without heating will ensure high yields of large fruits having the shape required by the export market.

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