Plant Size Influences Bell Pepper Seed Quality and Yield

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Abstract. This study investigated the influence of plant size, as determined by plant density, and fruit load variation on the production and quality of bell pepper (*Capsicum annuum* L.) seeds. Six-week-old 'Resistant Giant no. 4' bell pepper seedlings were transplanted 15, 30, 45, and 60 cm apart. Plants spaced 45 cm apart were not thinned or were thinned to one or three fruit per plant. Pepper plants grown at low plant densities produced larger fruit and seeds that germinated faster and at higher percentages than plants grown at higher densities. Assimilate export rate (AER) increased linearly with plant spacing. At harvest, C exchange rate (CER) and AER of plants with nonthinned fruit loads were $\approx 300\%$ and 500% higher, respectively, than those of plants with one or three fruit. Fruit thinning decreased CER and AER; however, seeds produced by plants with one or three fruit had significantly higher germination percentages than plants with full fruit loads. These observations suggest that the high CERS of smaller plants with nonthinned fruit loads may have been insufficient to compensate completely for the higher sink demands. Therefore, crop cultural practices that increase the ratio of pepper plant size to total fruit count may increase the quality of seeds produced by those plants.

There is little information about the effects of plant size, as determined by plant density, on bell pepper seed quality. Fruit thinning and high soil nutrient levels can increase bell pepper seed yield and quality (van Uffelen, 1984, 1986). Fruit from the lower parts of pepper plants produced seeds with higher dry weight and superior germination characteristics compared with fruit set later in development (Osman et al., 1984). Thinning treatments also have reduced net photosynthesis within hours or days in peppers (Kriedemann et al., 1976). When bell pepper plants were subjected to fruit thinning and branch removal, total seed yields were not affected (Nielsen and Veierskov, 1988). Removing the earliest flowers

from pepper plants increased fruit and seed yields (Wang et al., 1982).

Bell peppers can fix C, but provide only $\approx 13\%$ of the total assimilates; the rest is translocated from primary axis leaves (Steer and Pearson, 1976). Cultural practices can affect carbohydrate partitioning in plants. Thinning pepper plants reduced sink load; consequently, stem and leaf dry weights increased when fewer fruit developed (Nielsen and Veierskov, 1988). Removing flowers from bell pepper plants increased the concentrations of stored carbohydrates in stems (Hall, 1977).

The purpose of this study was to investigate the effect of pepper plant size fruit load manipulation on seed quality and on plant C exchange rate (CER) and assimilate export rate (AER).

'Resistant Giant no. 4' bell peppers were seeded in a peat-like medium in Todd planter flats in the greenhouse in Spring 1988 and 1989. After 6 weeks, the seedlings were hardened and transplanted to the field. The soil was an Olivier silt loam (fine-silty, mixed, thermic aquic, Fragiudalf) with 0.60% organic matter and a pH of 6.3.

All plots received a preplant band application of 8N-0. 1P-0.2K at a rate of 636 kg·ha⁻¹, 10 to 12 cm under row center, and 67 kg of ammonium nitrate (NH₄NO₃)/ha as a side-dressing 3 weeks after transplanting and immediately after fruit set started. Seedlings were transplanted in rows 1.2 m apart in a completely randomized design. Plant manipulation was performed by varying plant density and fruit load.

Plant density study. This study began in Spring 1988 and was repeated in Spring 1989. Four in-row plant spacing treatments (15, 30, 45, and 60 cm) with 10 plants per treatment were applied at random within each of eight rows. At ≈ 50 days postanthesis, five plants per treatment were chosen randomly and destructively harvested. Stems, leaves, and fruit of each plant were separated in the laboratory for measurement. Plant leaf area was recorded on an area meter (Delta-T Devices, Cambridge, England). Plant dry weight was measured on leaves and stems after drying at 70C for 48 h. The total number and fresh weight of green and red marketable fruit also were recorded.

Seeds were extracted immediately from marketable red fruit and allowed to surface-dry for 24 h at 25C. Only those seeds that passed through a 4-mm sieve, but were unable to pass through a 3-mm standard testing sieve (American Society for Testing and Materials index), were used to measure dry weight and test germination. Dry weight (based on percentage of fresh weight) was recorded after seeds were dried at 75C for 24 h. Germination tests consisted of eight replications of 50 seeds placed in 90-mm petri dishes on one layer of Whatman no. 2 filter paper moistened with 4 ml of distilled water. All petri dishes were placed in dark incubators at 25C. Germinated seeds were counted daily under light for 15 days. Seeds were considered germinated at the first sign of radicle protrusion. Germination percentage, mean time to germination (MTG) [MTG = day number (T) x number of seed germinated (N) + T₂N₂ + . . . + T_nN_n/(total number of seed germinated)], and the mean number of days for radicle emergence were calculated as described by Edwards and Sundstrom (1987). A tetrazolium assay (Grabe, 1970) for viability was performed on any seeds that had not germinated after 15 days.

Fruit load study. Based on the results of the preliminary 1988 plant density study (Sanchez, 1989), this study was designed to determine if seed quality was influenced by the number of

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fruit per plant. 'Resistant Giant no. 4' seedlings were hardened and transplanted at a 45-cm within-row spacing in a completely randomized design. There were three fruit load treatments: 1) thinning all fruit except one per plant, 2) thinning all fruit except three per plant, and 3) no thinning (control). Treatments were applied randomly at anthesis, and fruit were removed about every 10 days until harvest. At harvest, five plants per treatment were selected at random, destructively harvested, and measured as previously described. Only seeds from red fruit were used for measurements.

CER and AER. In 1989, CER and AER were measured on pepper plants at anthesis in the plant density study and at anthesis and harvest in the fruit load study. In the plant density study, measurements at harvest could not be recorded due to unfavorable field conditions. In the fruit load study, fruit removal began $\approx$ 1 week before CER and AER measurements were able to be taken due to unfavorable field conditions.

CER was measured on fully expanded source leaves that subtended developing fruit. Measurements were made using a portable infrared gas analyzer (model 6200; LI-COR, Lincoln, Neb.) at an ambient CO_2 concentration of $350 \mu\text{l}\cdot\text{liter}^{-1}$. Sample leaves were placed in a 0.25-liter cuvette, and ambient air was passed over the adaxial and abaxial leaf surfaces at a flow rate of $1100 \mu\text{mol}\cdot\text{s}^{-1}$. Differences in CO_2 concentration between air supplied to the leaf and exhausted air were measured in clear sky conditions. All measurements were made near midday. CER was calculated using the method of Hesketh and Moss (1963) and expressed as milligrams of CH_2O per square decimeter per hour.

AER was estimated on the same source leaves as those used to measure CER following the method of Terry and Mortimer (1972). Four leaf disks (each 0.5 cm in diameter) were removed from sample leaves at the beginning and end of the 5-h sampling interval (time₁ = 0900 and time₂ = 1400 HR). Leaf disks were freeze-dried and weighed. AER rates were calculated as estimates based on net CER and dry weight change per unit leaf area during the sampling interval [AER = (CER) - (dry wt_{time2} - dry wt_{time1})].

In both studies, all germination and viability percentage data were arcsin-transformed, and MTG data were log-transformed before analysis using SAS's (1985) general linear model procedure. Only nontransformed data are presented for ease of interpreting the tables. In the plant density study, year significantly interacted with some dependent variables. Trends between 1988 and 1989 data were similar, so only 1989 representative data are presented with the regression analysis. In the fruit load study, means were separated by least significant difference.

Effects of plant density. Plant density significantly affected pepper plant leaf area and fruit yield (Table 1). Plant leaf area, dry weight, and red and total fruit count per plant increased linearly with plant spacing. As found by Palevitch (1969) and Saamin (1978), red fruit

weight was not significantly affected by density. The ratio of leaf area to total fruit count did not vary significantly between plant spacings, a result indicating that larger plants did not have a greater ability to partition photoassimilates to developing seeds than smaller plants.

The total seed count in red fruit produced by each plant was influenced significantly by plant population (Table 2). Larger plants produced more seeds. Plants spaced at 45 cm produced 96% of the viable seeds that germinated faster and at higher percentages than those at other spacings (Table 2). At anthesis, there were no significant differences in CER, but AER increased linearly as plant spacing increased (data not shown). Average AER in 15- and 30-cm spacing treatments was $6.33 \text{ mg CH}_2\text{O}/\text{dm}^2 \text{ per h}$ vs. an average AER in 45- and 60-cm spacing treatments of $7.33 \text{ mg CH}_2\text{O}/\text{dm}^2 \text{ per h}$.

Linear correlation coefficient values indicated that plant spacing correlated significantly ($P \leq 0.01$) with plant leaf area and dry weight ($r = 0.28$ and 0.70 , respectively). Plant dry weight correlated positively ($P \leq 0.01$) with germination percentage ($r = 0.31$) and inversely with MTG [$r = (-0.27)$].

Effects of fruit load. A second study was initiated to investigate 1) whether plants of

comparable size with different fruit loads would produce seeds of comparable quality and 2) the influence of radically altered source-sink relationships on seed quality. Leaf area and plant dry weight increased as total fruit count decreased on the plant (Table 3). Removing fruit at anthesis increased pepper plant dry weight (Table 3), as previously observed by van Uffelen (1984) and Hurd et al. (1979) in tomatoes (*Lycopersicon esculentum* Mill.). The influence of fruit thinning on fruit size, however, was not consistent. At 50 days post-anthesis, thinning had affected photosynthesis and photoassimilate partitioning significantly (Table 4). Smaller, nonthinned plants fixed C at rates $\approx 300\%$ higher than larger, thinned plants. Additionally, AER was $\approx 500\%$ higher in nonthinned plants vs. thinned plants. These observations suggest that pepper plants with high sink demand and low ratios of leaf area to total fruit count respond by increasing source-leaf CER and AER.

Plants that were thinned to three fruit produced significantly more seeds than those of other treatments (Table 5). Contrary to Wang et al. (1982), no statistical differences were found between treatments with regard to the number of seeds per red fruit or seed dry weight. Fruit load did not affect seed viability (Table 5). The germination percentage of seeds

Table 1. Influence of plant spacing on bell pepper plant leaf area and weight, total marketable green and red fruit number, and red fruit weight.^a

Within-row spacing (cm)	Leaf area (1000 cm ²)	Plant dry wt (g)	Total fruit/plant (no.)	Red fruit/plant (no.)	Red fruit wt (g)	Leaf area : total no. fruit ratio
15	3.86	46.5	6.6	1.8	261	671
30	5.34	67.0	8.4	2.0	333	818
45	6.21	103	11.6	2.7	401	566
60	7.05	105	12.4	2.7	376	686
Significance						
Linear	**	**	**	**	NS	NS
Quadratic	NS	*	NS	NS	NS	NS

^aMeans of 1989 data only.

NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01 , respectively.

Table 2. Influence of plant spacing on characteristics of seeds extracted from red bell peppers?

Within-row spacing (cm)	Seed				MTG ^a (days)	Viability ^b (%)
	Per plant (no.)	Per fruit (no.)	Dry wt (mg)	Germination (%)		
15	275	159	7.5	73	6.3	86
30	385	195	7.3	63	7.1	83
45	417	157	7.6	88	5.0	96
60	458	187	7.1	80	5.4	89
Significance						
Linear	*	NS	NS	**	**	*
Quadratic	NS	NS	NS	NS	NS	*

^aMeans of 1989 data only.

^bMTG = mean time to germination.

^cViability by tetrazolium test.

NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01 , respectively.

Table 3. Influence of fruit thinning at anthesis on bell pepper plant size and red fruit weight.

Fruit remaining on plant	Leaf area (1000 cm ²)	Plant dry wt (g)	Red fruit wt (g)	Leaf area : total no. fruit ratio
All ^a	5.34 b ^c	66.0 b	165 ab	485 C
3	7.44 a	114 a	149 b	3335 b
1	8.40 a	136 a	175 a	8397 a

^aMean total number of fruit = 9.

^bMean separation within columns by LSD, $P \leq 0.05$.

Table 4. Influence of fruit thinning on C exchange rate (CER) and assimilate export rate (AER) of bell pepper leaves at anthesis and at 50 days postanthesis harvest.

Fruit remaining on plant	Anthesis		Harvest	
	CER	AER	CER	AER
	(mg CH ₃ O/dm ² per h)			
All ^a	4.41 a ^c	2.73 a	9.47 a ^c	5.39 a
3	3.67 b	2.62 a	3.05 b	1.15 b
1	3.59 b	1.97 b	3.35 b	1.17b

^aMean total number of fruit= 9.

^cMean separation within columns by LSD, $P \leq 0.05$.

Table 5. Influence of fruit thinning at anthesis on characteristics of seeds extracted from red bell peppers.^a

Fruit remaining on plant	Seed					
	Per plant (no.)	Per fruit (no.)	Dry wt (mg)	Germination (%)	MTG ^b (days)	Viability ^c (%)
All	365 b ^c	200 a	7.3 a	63 b	7.1 h	94a
3	483 a	188 a	7.4 a	82a	7.4 b	92 ^a
1	223 b	223 a	7.5 a	79a	8.1 a	92a

^aMean total number of fruit= 9.

^bMTG = mean time to germination.

^cViability by tetrazolium test.

^cMean separation within columns by LSD, $P \leq 0.05$.

produced by nonthinned plants, however, was significantly lower than that of seeds in the other treatments. As in the plant density study, plant dry weight correlated ($P \leq 0.05$) with seed germination percentage ($r = 0.28$).

The influence of plant density on seed development was unclear. Plant density did not affect the ratio of pepper leaf area to total fruit count significantly, yet larger plants (in 45- and 60-cm spacing treatments) produced seeds that germinated faster and at higher percentages. Low plant densities resulted in larger plants that apparently transported photoassimilates from source leaves to sinks at higher rates than smaller plants. The primary influence of fruit thinning was to increase plant size and the ratio of leaf area to total fruit count, which in turn increased seed germination percentage. Smaller plants with high fruit loads responded to high sink demands by maintaining high CERS and AERs, yet these rates were insufficient to produce

seeds of similar quality as plants with lower sink demands. The germination percentage of seeds from smaller plants was significantly less than that of seeds from larger plants. The difference between viability and germination percentages of seeds produced by smaller plants in both studies is unclear, but may be due to increased seed dormancy. Therefore, crop cultural practices that increase pepper plant size may increase the quality of seeds produced by those plants.

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