Yield in Nonpungent Jalapeño Pepper Established at Different In-row Spacings

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Abstract. It is not known how plant spacing affects fresh yield in transplanted nonpungent jalapeño peppers (*Capsicum annuum* L.). Transplants of a nonpungent jalapeño, cv. Pace 105, were established at 8, 16, 24, 32, 40, and 48 cm between plants in mid-April of 2006 and 2007 and in early July in 2007. Fruit were harvested once when 5% of marketable-sized pods in rows were red. Distance to first flower and yield characteristics were determined. Fruit were culled based on pod size and presence of blemishes. Height on the stem to the first flower averaged 15.8 cm over all treatments. Plants in the Spring 2006 season had the highest marketable and cull yields. Numbers of marketable fruit/ha were higher at the 8-cm spacing than at the 40- or 48-cm in-row spacings. There was little difference in marketable yield as a result of in-row spacing. The greatest number of cull fruit per plant was on plants spaced 48 cm apart. Plant spacing had no effect on number of cull fruit or cull yield/ha. Culls accounted for ≈22% of total yield. Individual cull fruit weights were ≈50% less than for marketable fruit. Spacings tested did not appear to greatly affect development or yield of this pepper. This will allow producers to have the option of either using fewer plants on the same amount of land or more plants on less land without much reduction of quantity or quality of yield.

The increased appetite of Americans for various ethnic foods (Andrews, 1995) has contributed to the development of salsa-type products with varying degrees of pungency. The pungency in the product is determined by the pepper (*Capsicum annuum* L.) cultivar; this genus–species contains plants that have pungency values from 0 to 500,000+ Scoville Units. The industry adjusts pungency during processing to provide the desired levels in their products. In some cases, peppers with high pungency are diluted in the postharvest production process to obtain varying degrees of pungency in the final product. Some nonpungent jalapeño pepper cultivars have been developed. These types of peppers are used to provide the jalapeño flavor with a known amount of capsaicin added during processing to regulate pungency.

Most research examining cultural conditions for jalapeño peppers have focused on cultivars with some degree of pungency. For ‘TAM Mild Jalapeño 1’ and ‘Vera Cruz’, plants in stands established from transplants had higher yields than direct-seeded plants (Leskovar and Boales, 1995). In greenhouse studies with ‘Jalapa’ jalapeño, increasing nitrogen and potassium concentrations caused pod formation and Scoville Heat Units to fit a quadratic equation, whereas dry weight increased linearly (Johnson and Decoteau, 1996). Russo (1996a) determined that planting later in the season, combined with higher than the recommended rate of fertilizer, and a single harvest improved yield of the pungent jalapeño pepper ‘Mitla’.

Increasing the number of plants in proximity to each other can cause competition for water, sun, and nutrients and it is expected that plant development would possibly be detrimentally affected. For cayenne, jalapeño, paprika, Pepperoncini, and cv. Mississippi Sport peppers (all *C. annuum* L.), fresh pod yields decreased as in-row spacing increased with some of the highest yields occurring at the closest spacing (Decoteau and Graham, 1994; Kahn et al., 1997; Leskovar and Boales, 1995; Motsenbocker, 1996; Motsenbocker et al., 1993). However, total marketable yields for the pungent jalapeño peppers ‘TAM Jalapeño 1’ and ‘Jalapeño M’ were unaffected by varying in-row plant spacings from 10.2 to 40.6 cm (Motsenbocker et al., 1997). Increasing in-row spacing of bell pepper (*C. annuum* L.) plants did not consistently improve yield (Russo, 1991), and Locascio and Stall (1994) reported that

increasing in-row spacing of bell pepper increased yield. These results indicate that there are differences in how different pepper types respond to varying plant populations.

Machinery exists that can be used if a single-pass strategy is desired to harvest peppers. However, height to the first flower, and consequently the first fruit, can have consequences for mechanical damage to fruit occurring during harvesting operations.

There has been little published concerning the cultural factors affecting yield of nonpungent jalapeños, a relatively new type of pepper. Russo (2003) found that if two seedlings of the nonpungent jalapeño pepper ‘Pace 105’ were established at a planting site, as opposed to a single plant, with 48 cm between planting sites in the row, yields were increased by 25%. The optimum plant population(s) for nonpungent jalapeños needs clarification. This study was undertaken to determine how plant density affected height to the first flower and yield of the nonpungent jalapeño pepper ‘Pace 105’.

Materials and Methods

Transplants were grown in a greenhouse using the methods of Russo (2005). Briefly, Reddi-Earth potting mix (Sun Gro Horticulture, Bellevue, WA) was placed in extruded Styrofoam planting trays (128 cells; 30-cm³ volume per cell; Speedling, American Plant Products, Oklahoma City, OK). Seeds of ‘Pace 105’, a cross between a normal jalapeño and a bell-type pepper, were planted into the mix and thinned to a single plant per cell. Developing plants received irrigation daily and fertilization (1.5 g·L⁻¹; Peters 20–20–20, Scotts-Sierra, Marysville, OH) weekly beginning with expansion of the first true leaves.

The field experiment was conducted on a Bernow fine-loamy, siliceous, thermic Glossic Paleudalf soil at Lane, OK. The soil was disked and formed into rough beds oriented east–west. Fertilizer was applied preplant on 12 Apr. 2006, 16 Apr. 2007, and 12 July 2007 to levels to 70N–112P–300K kg·ha⁻¹ according to recommendations for the area (Motes and Roberts, 1994). Nitrogen was from ammonium nitrate, phosphorus was from triple superphosphate and potassium was from muriate of potash. The herbicide trifluralin was applied and finished beds formed with a tractor-mounted, PTO-driven tillage (Ferguson, Suffolk, VA). Finished beds were formed on 0.9-m centers within 2 d of fertilizer application. If necessary to supplement precipitation, plants received a minimum of 30 mm of water per week in the form of overhead irrigation.

Six-week-old transplants that were ≈10 cm in height with an average 2.6-mm stem diameter were moved to the field on 21 Apr. 2006, 19 Apr. 2007 (spring plantings), and 15 July 2007 (late summer planting). Transplants were set by hand in single rows in the middle of beds in plots at spacings of 8, 16, 24, 32, 40, and 48 cm between plants in a row in 3.1-m long plots. Approximate plant

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populations were 137,000, 68,800, 46,000, 36,000, 29,000, and 21,500 plant/ha, respectively. Fruit were harvested once from all plants when $\approx 5\%$ of the numbers of fruit were red, on 11 July 2006, 10 July 2007, and 12 Oct. 2007, 81, 82, and 90 d after establishment in the field, respectively. Number and yield of marketable and cull fruit were determined. Fruit less than 6.5 cm long or misshapen were culled. Average numbers of fruit per plant and fruit weights were determined. Distance from the soil to the first flower was determined from two plants in each plot after harvest.

The experimental design was a randomized complete block with three replications. The data were subjected to analysis of variance with the general linear models procedures in SAS (Version 7; SAS, Cary, NC). If an interaction was present, it was used to explain results. If an interaction was not present, means were separated with the Ryan-Einot-Gabriel-Welsch multiple F-test. Spacing was continuous and quantitative, and means of responses were tested for conformance to linear distributions.

Results

There were environmental differences in air temperature and precipitation during the growing seasons (Table 1). Average air

temperatures for the same months in the spring growing season were comparable, and the average air temperatures over the late summer growing season was higher than for the spring growing seasons. Precipitation levels for the Spring 2006 and late Summer 2007 growing seasons were similar but well below what occurred during the Spring 2007 growing season. There was little pressure from insects or diseases.

Season affected all variables, and in-row spacing affected all but the distance to the first flower, average marketable fruit weight, and numbers and yield of cull fruit/ha (Table 2). The season $\times$ in-row spacing interaction was not significant. Numbers of marketable fruit per plant and per hectare, numbers of cull fruit per plant, and cull yield were distributed linearly over in-row spacing (Fig. 1A–D).

In response to season, distance to the first flower was shortest for plants established in the spring of 2006, and the greatest numbers of marketable fruit were on these same plants (Table 2). The highest average marketable fruit weight was for plants established in the spring of 2006. The greatest number of marketable fruit/ha was from plants established in the spring of 2006, the least was from Spring 2007, and that for Summer 2007 was similar to the other seasons. The highest marketable yields per hectare were from

plants established in the spring of both years. The highest numbers of cull fruit per plant, average cull fruit weight, number of cull fruit/ha, and cull fruit yield were from plants established in the spring of 2006. Average cull fruit weight was $\approx 50\%$ of marketable fruit weight.

In-row spacing did not affect distance to the first flower, average marketable fruit weight, or numbers of cull fruit, which had values of 15.8 cm, 37.6 g, and 129,100 fruit/ha, respectively. In-row spacing affected marketable yield and average cull fruit weight (Table 3). Marketable yield from plants spaced 32 cm apart was greater than for those from plants spaced at 40 and 48 cm. Marketable yields from plants spaced from 8 to 24 cm apart were similar to those from plants at all other spacings. Average cull fruit weight from plants spaced 32 cm apart was greater than for cull fruit on plants at all other spacings, except for those from plants spaced at 40 cm, for which it was similar.

Number of marketable fruit per plant increased (Fig. 1A), but marketable yield/ha decreased (Fig. 1B) as in-row spacing increased. Numbers of cull fruit per plant increased as in-row spacing increased (Fig. 1C). Cull fruit yield/ha decreased as in-row spacing increased (Fig. 1D). Cull yield was $\approx 26\%$ of the marketable yield.

Some development and yield variables were correlated (Table 4). Marketable yield/ha was positively correlated with numbers of marketable fruit/ha produced, average marketable fruit weight, cull yield/ha, and average cull fruit/ha. Average marketable fruit weight was positively correlated with cull yield/ha and average cull fruit weight. Numbers of cull fruit was positively correlated with cull yield/ha, and cull yield/ha was positively correlated with average cull fruit weight. Height to the first flower was negatively correlated with marketable yield/ha, numbers of cull fruit, cull yield/ha, and average cull fruit weight.

Discussion

Rainfall amount did not appear to be the reason that season affected yields. Plants in the spring plantings were exposed to variations of 325% in precipitation amounts, but yields were similar. The fall planting yield

Table 1. Temperature and precipitation over growing seasons.

Planting season	Month	Avg. temp ($^{\circ}\text{C}$)		Precipitation (cm)
		High	Low	
Spring 2006	April ^a	25	13	8.64
	May	28	16	13.74
	June	33	18	3.10
	July	34	16	0.08
Average/total		30	16	25.56
Spring 2007	April	24	13	1.63
	May	27	17	31.62
	June	30	21	31.75
	July	33	22	18.11
Average/total		29	18	83.11
Late Summer 2007	July	34	22	11.89
	Aug.	33	22	4.49
	Sept.	30	18	6.83
	Oct.	29	24	4.75
Average/total		32	21	27.97

^aValues for April, July, and October are for portions of the month.

Table 2. Analysis of variance on effect of season and in-row spacing on height to first flower and yield components for 'PACE105'.

Source	Ht to 1st flower (cm)	Marketable				Cull			
		Number of fruit per plant	Avg. fruit wt (g)	Number of fruit per ha ($\times 1000$)	Yield ($\text{Mg}\cdot\text{ha}^{-1}$)	Number of fruit per plant	Avg. fruit wt (g)	Number of fruit per ha ($\times 1000$)	Yield ($\text{Mg}\cdot\text{ha}^{-1}$)
Season (S)	**	**	*	*	*	**	**	**	*
In-row spacing (I)	NS	**	NS	**	*	**	**	NS	NS
Linearity	NL	**, L	NL	*, L	NL	*, L	NL	NL	*, L
Interaction									
S $\times$ I	NS	NS	NS	NS	NS	NS	NS	NS	NS
Season									
Spring 2006	13.3 b ^a	11.3 a	42.7 b	519.8 a	24.6 a	8.9 a	28.1 a	251 a	12.8 a
Spring 2007	16.8 a	8.8 b	50.4 a	425.9 b	23.7 a	2.2 b	17.3 b	63 b	2.2 b
Summer 2007	16.7 a	9.5 b	19.1 c	462.2 ab	9.6 b	2.2 b	9.1 b	73 b	1.6 b

^aValues in a column followed by the same letter are not significantly different ($P \leq 0.05$); Ryan-Einot-Gabriel-Welsch multiple F-test.

NS, **Nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.01$, analysis of variance; NL = not linearly distributed.

Fig. 1. Linear distribution of (A) number of marketable fruit per plant, (B) number of marketable fruit/ha, (C) number of cull fruit per plant, and (D) cull yield/ha in relation to in-row spacing.

was significantly less than the spring plantings and may reflect reduced flower and/or fruit retention resulting from elevated nighttime air temperatures (Cochran, 1932; Deli and Tiessen, 1969; Dorland and Went, 1947). Establishing plants at in-row spacings from 8 to 48 cm produced no clear determination of the most beneficial in-row spacing to maximize marketable yield. The distribution of marketable yield was relatively narrow across the range of in-row spacings. The data indicate that plants could be placed closer together than 48 cm without loss to marketable yield. The response to spacing may reflect the influence of the bell pepper portion (Russo, 1991) of the genetic makeup of this cultivar.

Although fruit were of marketable size for the late summer planting, they were not as heavy as for those produced from plants established in the spring. Russo (1996b) found that if bell peppers were left on the plant, fruit size stabilized, but fruit weight continued to increase as a result of added thickness and weight in walls of pods. It may be that if pods of 'Pace 105' were kept on the plant longer, they would have increased in weight, but this would also lead to increased numbers of red fruit, reducing the value of the harvested crop.

Correlations of distance to the first flower and some yield, mostly cull components, although significant, were not strong. This may mean that energy expended before

Table 3. Effect of in-row spacing on marketable yield and average fruit cull weight.

In-row spacing (cm)	Marketable yield (Mg-ha ⁻¹)	Avg. cull fruit wt (g)
8	20.2 ab ^z	14.1 b
16	20.8 ab	16.8 b
24	21.1 ab	15.0 b
32	21.7 a	28.6 a
40	15.9 b	20.4 ab
48	16.8 b	14.1 b

^zValues in a column followed by the same letter are not significantly different ($P \leq 0.05$); Ryan-Einot-Gabriel-Welsch multiple F-test.

flowering was permanently diverted from fruit production. The strong correlation for average marketable fruit weight and marketable yield indicates that individual fruit weight is more important than the number of fruit produced. The similar response for cull fruit weight and cull yield indicates that many of the culled fruit could have likely been marketable except for being rejected as a result of blemishes or red color.

First-formed fruit were mostly culled as a result of blemishes. If, as for the Spring 2006 planting, the distance to the first flower was shorter, the opportunity for blemishing may have been increased for first-formed fruit, which were more likely to be in contact with the soil. This seems to be supported by correlations indicating that as height to the first flower increased, cull yield/ha decreased. This could be interpreted to mean that there was less chance for first-formed fruit to be in contact with the soil. Changing physiological condition of the maturing fruit might make them more susceptible to blemishing. The plants were grown on bare soil. It may be that if mulch was used, amounts of blemishing might be affected because fruit would not be in contact with soil. This needs to be examined, but use of mulch would also incur additional costs. The widest spaced plants had more cull fruit per plant. This may be attributable, in part, to increased penetration of light in to the canopy contributing to discoloration and sun scald on pods.

In-row plant density may affect other management activities such as pesticide spray operations. Derksen et al. (2007) found that for bell pepper, there were no differences in spray coverage resulting from plant density. However, the habit of the nonpungent jalapeño pepper, more upright, is different from bell pepper. There was no necessity of pesticide application at this location, and the distribution of pesticides on foliage is not known.

The distribution of yield over the in-row spacing seems to indicate that 'Pace105' responded more like bell pepper to spacing (Locascio and Stall, 1994; Russo, 1991) than to other types of peppers (Decoteau and Graham, 1994; Kahn et al., 1997; Leskovar and Boales, 1995; Motsenbocker, 1996; Motsenbocker et al., 1993, 1997). The producer, using 'Pace105', has the option of either using fewer plants on the same amount of land or more plants on less land without much reduction of quantity or quality of yield.

Table 4. Pearson correlation coefficient analysis for variables measured for plants established at the various in-row plant spacings over planting seasons.

	Pearson correlation coefficients Prob > r under H ₀ : Rh ₀ = 0				
	Marketable fruit number	Avg. marketable fruit wt	Cull yield	Avg. cull fruit wt	Ht to first flower
Marketable yield	0.49977	0.83601	0.39636	0.48484	-0.27218
	0.0001	<0.0001	0.0030	0.0002	0.0465
Average marketable fruit weight			0.27061	0.40129	
Cull fruit number			0.0478	0.0026	
			0.85945		-0.43375
			<0.0001		0.0011
Cull yield				0.53947	-0.54257
				<0.0001	<0.0001
Average cull fruit weight					-0.39560
					0.0031

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