

## Little heterosis for yield and yield components in hybrids of six cucumber inbreds

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### Summary

Heterosis and inbreeding depression for fruit yield has been reported for pickling cucumber (*Cucumis sativus* L.). However, cucumber inbreds often perform as well as hybrids, and there is little inbreeding depression. The objectives of this study were to reexamine the amount of heterosis and inbreeding depression for fruit yield and yield components in pickling cucumber, and to determine the relationship between yield components and yield for heterosis. Two pickling cucumber inbreds (M 12, M 20) and inbreds from four open-pollinated monoecious cultivars ('Addis', 'Clinton', 'Wisconsin SMR 18', 'Tiny Dill') were hybridized to form four F<sub>1</sub> hybrids ('Addis' × M 20, 'Addis' × 'Wis. SMR 18', 'Clinton' × M 12, M 20 × 'Tiny Dill'). F<sub>1</sub> hybrids were then self-pollinated or backcrossed to generate F<sub>2</sub>, BC<sub>1A</sub>, and BC<sub>1B</sub> progeny. Thirty plants of each generation within each hybrid family were grown in plots 3.1 m long with four replications in each of two seasons. Data were collected from once-over harvest for vegetative, reproductive, yield, and fruit quality traits. Heterosis and inbreeding depression for fruit yield and yield components were not observed in three of the hybrids. Only 'Addis' × 'Wis. SMR 18' exhibited high-parent heterosis and inbreeding depression for total, marketable, and early fruit weight. For 'Addis' × 'Wis. SMR 18', heterosis for fruit yield was associated with a decreased correlation between percentage of fruit set and fruit weight, an increased negative correlation between percentage of fruit set and both the number of branches per plant and the percentage of pistillate nodes, and an increased negative correlation between the number of nodes per branch and total fruit weight. Inbreeding depression was associated with a weakening of the strong negative correlations between percentage of fruit set and the number of branches per plant, and between the number of nodes per branch and total fruit weight. Those correlations were associated with high-parent heterosis and inbreeding depression only for one cross, and do not necessarily apply to future crosses in which heterosis may be observed for yield. We did not observe the heterosis or inbreeding depression for yield in cucumber in most of the crosses as was reported by Ghaderi & Lower (1979a; 1979c).

### Introduction

Heterosis has been utilized in many crops, including cucurbits, to exploit dominance variance through the production of hybrids. In cucumber, Hayes & Jones (1916) first observed heterosis for fruit size and fruit number per plant. Others have reported heterosis for fruit yield in particular crosses of cucumbers (Hutchins, 1938; Singh et al., 1970; Solanki et al., 1982a; 1982b; Rubino & Wehner, 1986; Hormuzdi & More, 1989). Ghaderi & Lower (1979a; 1979c) repor-

ted heterosis for fruit number per plot, fruit weight per plot, and average fruit weight for several crosses of pickling cucumber. However, there was no evidence of inbreeding depression for plants taken randomly from a population (Rubino & Wehner, 1986). In addition, yield of gynoeocious or monoecious pickling cucumber inbreds is often similar to that of gynoeocious hybrids (Wehner, 1989).

In many crops, yield has been partitioned into its various components to better understand the factors which influence yield. However, the number of studies

examining the correlation between yield components and heterosis for yield has been limited. Hayes & Jones (1916) observed no heterosis when plants having similar fruit size and vine type were hybridized. This observation suggested that plants with large differences in their yield components were required for heterosis. Ghaderi & Lower (1978) suggested that heterosis in yield components such as number or weight of leaves, branches, and roots should have a direct effect on fruit yield. They hypothesized that more branches in  $F_1$  hybrids than their parents might result in greater photosynthetic activity and, hence, higher yield. In another study, selection for a vigorous root system resulted in a 23% increase in fruit yield (Yurina & Lebedeva, 1976).

The objectives of this study were 1) to examine the amount of mid-parent and high-parent heterosis, and inbreeding depression for fruit yield and yield components in pickling cucumber, and 2) to correlate changes in relationships between yield and yield components over generations with high-parent heterosis for fruit yield and/or yield components.

## Materials and methods

### *Germplasm*

Our methods and crosses were similar to those used by Ghaderi & Lower (1979c). Inbreds from four open-pollinated monoecious cultivars ('Addis', 'Clinton', 'Wisconsin SMR 18', 'Tiny Dill') and two monoecious inbreds (M 12, M 20) (0% heterozygosity according to Ghaderi & Lower (1979c)) were hybridized in different combinations during the fall of 1995 to form four  $F_1$  hybrids (hybrid 1 – 'Addis' × M 20, hybrid 2 – 'Addis' × 'Wis. SMR 18', hybrid 3 – 'Clinton' × M 12, hybrid 4 – M 20 × 'Tiny Dill'). NCSU 8A referred to by Ghaderi & Lower (1979c) is a close relative of 'Clinton'. In the spring of 1996, random  $F_1$  plants from each hybrid were self-pollinated to generate  $F_2$  progeny, and backcrossed once to parents A (maternal) and B (paternal) to generate  $BC_{1A}$  and  $BC_{1B}$  progeny. Based on the crosses made, three levels of heterozygosity existed over generations, 0% ( $P_A$ ,  $P_B$ ), 50% ( $F_2$ ,  $BC_{1A}$ ,  $BC_{1B}$ ), and 100% ( $F_1$ ) (Ghaderi & Lower, 1979c).

### *Design*

The experiment was a randomized complete block design with four  $F_1$  hybrid families, six generations

( $P_A$ ,  $P_B$ ,  $F_1$ ,  $F_2$ ,  $BC_{1A}$ ,  $BC_{1B}$ ), two seasons (spring, summer), and four replications per season. Seasons were used because they provide more information than locations, and are just as effective as years for cucumber studies conducted in North Carolina (Swallow & Wehner, 1989). The experiment was arranged in a split plot such that families were whole plots and generations were subplots.

Forty seeds were planted in plots 3.1 m long as recommended by Swallow & Wehner (1986) on raised, shaped beds. Plots were planted 29 April 1996 for the spring season, and 8 July 1996 for the summer season. All research was conducted at the Horticultural Crops Research Station in Clinton, North Carolina using standard cultural procedures for growing pickling cucumbers in North Carolina (Schultheis, 1990). There were alleys 1.5 m long separating plot ends. The field was surrounded by 'Sumter' guard rows on the sides, and end plots 1.5 m long in order to provide competition for the outside plots (Wehner, 1988; 1989). Large, multiple-row plots were not used since they are not as efficient as small, single-row plots (Wehner & Miller, 1990).

The soil type was a mixture (through the fields used) of Norfolk, Orangeburg and Rains (fine-loamy, siliceous, thermic, Typic Kandiudults) with some Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults). Plots were thinned to 30 plants (64,500 plants/ha) on 22 May 1996 for the spring season and 22 July 1996 for the summer season. Plots were harvested when 90% of the plots contained fruit at the 10% oversized (> 51 mm in diameter) fruit stage as recommended by Miller and Hughes (1969) for optimum fruit yield in once-over harvest of pickling cucumbers. Harvest dates were 18 June for the spring season, and 20 and 21 August for the summer season.

### *Data collection*

Plots were evaluated for the number of branches per plant, number of nodes per branch, the percentage of flowering nodes that developed pistillate flowers (percentage of pistillate nodes), and the percentage of pistillate flowers which developed into harvestable fruit (percentage fruit set). Number of fruits per plot were counted and weighed to obtain total, early (number of oversized fruits), marketable (total yield minus misshapen fruits), and total yield. In addition, fruit shape was rated to reflect straightness, uniformity, and cylindrical nature per plot. Fruit shape rating was on a scale of 1 to 9, where 1–3 = poor, 4–6 = intermediate,

7–9 = excellent (Strefeler & Wehner, 1986). Plants having fewer than five leaves, only staminate flowers, and vines less than 0.4 m in length were considered weak, and not used in the data analysis for plots. Those plants most likely germinated after plots were thinned, and did not contribute to fruit yield and/or yield component data.

#### *Data analysis*

Plots with fewer than 16 plants were considered missing to prevent bias of the data analysis. In addition, stand was considered as a covariate (Cramer & Wehner, 1998) during the analyses to eliminate differences among plots attributable to stand differences. In order to determine significant mid-parent heterosis for each cross, the data were analyzed separately for each family using the GLM procedure of the SAS statistical package (SAS Institute, Cary, NC). In order to test single degree of freedom contrasts between the  $F_1$  generation and the mid-parent, mid-parent values were included in the analysis. In addition, single degree of freedom contrasts between the  $F_1$  generation and the  $P_A$ ,  $P_B$  and  $F_2$  generations were made.

Since inclusion of mid-parent values in the data likely biased the error mean square values (MSE), a second analysis was conducted on data in which the mid-parent values had been removed. The MSE and its degrees of freedom from the second analysis were used to calculate the F-ratio for the single-degree of freedom contrasts in the initial analysis. A significant contrast between the mid-parent (or high parent) and the  $F_1$  generation was used to determine whether mid-parent (or high parent) heterosis was significant. A significant contrast between the  $F_1$  and  $F_2$  generations was used to determine whether inbreeding depression was significant. Mean and LSD values were calculated from the second analysis for each trait within each family in order to determine differences between generations. PATHSAS (Cramer et al., 1998) was used to calculate Pearson correlation coefficients for yield components and yield factors for each generation within each family.

## **Results and discussion**

### *Fruit yield*

When the generation means for each hybrid family were examined, high-parent heterosis and inbreeding depression for fruit yield in cucumbers was rare

(Table 1). Only one hybrid exhibited high-parent heterosis and inbreeding depression for yield. The lack of high-parent heterosis or inbreeding depression for fruit yield was unexpected since Ghaderi & Lower (1979c) had observed high-parent heterosis for fruit yield. However, previous work by Jenkins (1942) and Rubino & Wehner (1986) reported no inbreeding depression for yield when cucumber lines were self-pollinated for many generations. In addition, gynoeious cucumber inbreds perform as well as gynoeious hybrid cultivars in our trials (unpublished data).

In those cases where we observed heterosis for the 'Addis'  $\times$  'Wis. SMR 18' family, the hybrid exhibited high-parent heterosis and inbreeding depression for total, marketable, and early fruit weight (Table 1). In addition, mid-parent heterosis was observed for total and marketable fruit number for the 'Addis'  $\times$  'Wis. SMR 18' family. Of the remaining three families, only the M 20  $\times$  'Tiny Dill' hybrid exhibited mid-parent heterosis, and that was only for fruit shape rating (Table 1).

Heterosis observed in the 'Addis'  $\times$  'Wis. SMR 18' family might have resulted from heterotic groups based on the adaptation of cultivars to certain regions of the United States. In the mid-20th century, breeding programs for pickling cucumbers existed in both the northern and southern United States. The objective of each program was to develop pickling cucumber cultivars adapted to their particular region. Since the cultural conditions were very different between the two regions, breeders would have relied on different germplasm pools for cultivar development. 'Addis' was developed from SC 19B ('Pixie', PI 197087) and PW ('Pixie', 'Poinsett', Gy 14). In contrast, 'Wis. SMR 18' was developed from 'Wis. SMR 12' ('Chicago Pickling', 'Maine No. 2') and 'Ohio MR17' ('Chinese Long', 'Early Russian', 'National Pickling'). Thus, 'Addis' and 'Wis. SMR 18' did not have any parents in common, and might belong to separate heterotic groups, as implied by Ghaderi & Lower (1979b).

In support of heterotic groups, Ghaderi & Lower (1978) observed high-parent heterosis for top vegetative growth fresh weight at anthesis of 'Liberty' which is the  $F_1$  hybrid of 'Wis. SMR 18' and M 41 (developed from pickling cucumber material adapted for southern U.S. region). High-parent heterosis for the same traits was not observed when the parental inbreds for the hybrids came from breeding programs in the same geographic area. The other inbreds they tested, 'Addis', 'Chipper', Gy 3, and Gy 14, were developed

Table 1. Means<sup>z</sup>, mid-parent<sup>y</sup> and high-parent heterosis<sup>y</sup>, and inbreeding depression<sup>x</sup> (ID) of total, marketable and early fruit yield in terms of number (1000 ha<sup>-1</sup>) and weight (Mg ha<sup>-1</sup>) and fruit shape rating of each generation and F<sub>1</sub> hybrid

Generation	Total yield		Marketable yield		Early yield		Fruit shape
	Number	Weight	Number	Weight	Number	Weight	
‘Addis’ × M 20							
P <sub>A</sub>	103.0	9.7	89.3	17.1	30.9	15.8	6.8
P <sub>B</sub>	62.4	4.3	47.6	10.9	10.8	9.2	6.1
F <sub>1</sub>	91.8	9.4	81.4	16.9	26.2	16.1	6.3
F <sub>2</sub>	112.4	14.3	90.1	25.0	42.2	22.1	6.5
BC <sub>1A</sub>	119.9	12.8	104.2	21.3	46.4	20.0	7.0
BC <sub>1B</sub>	81.5	7.5	60.6	18.9	23.1	15.1	6.0
LSD 5%	30.3	8.7	25.6	7.8	15.4	5.3	0.6
Mid-parent	84.1	7.2	69.9	14.2	21.5	12.7	6.5
High-parent	-11.2	-0.3	-7.9	-0.2	-4.7	0.3	-0.5
ID	7.5	4.9	8.7	8.1	16.0	6.0	0.2
‘Addis’ × ‘Wis. SMR 18’							
P <sub>A</sub>	92.5	8.4	83.9	14.6	29.8	14.1	6.7
P <sub>B</sub>	66.4	5.9	49.0	11.8	25.6	10.3	4.4
F <sub>1</sub>	110.8	13.8	93.9	25.7	42.2	23.6	6.3
F <sub>2</sub>	95.2	8.7	74.2	16.0	28.8	13.7	5.5
BC <sub>1A</sub>	102.7	11.7	87.6	19.3	37.8	18.3	6.1
BC <sub>1B</sub>	89.8	10.3	70.2	18.1	33.6	15.0	5.5
LSD 5%	24.4	6.5**	20.0**	5.9**	15.8	4.8*	1.0***
Mid-parent	78.6*	7.1***	65.3**	13.1***	27.5+	12.1**	5.5
High-parent	18.3	5.4**	10.0	11.1**	12.4	9.5*	-0.4
ID	-15.6	-5.1**	-19.7+	-9.7***	-13.4+	-9.9*	-0.8
‘Clinton’ × M 12							
P <sub>A</sub>	128.0	10.1	118.4	19.9	35.5	19.2	7.5
P <sub>B</sub>	85.5	5.8	74.5	11.5	19.1	10.5	7.0
F <sub>1</sub>	110.8	13.5	104.7	21.8	41.6	21.3	7.0
F <sub>2</sub>	109.2	12.6	97.1	22.2	36.9	20.7	7.3
BC <sub>1A</sub>	100.6	10.1	93.1	18.1	31.5	17.5	7.1
BC <sub>1B</sub>	119.4	17.0	105.4	26.0	51.4	24.6	7.1
LSD 5%	27.2	7.7*	24.9*	7.2*	17.0**	5.2*	0.6
Mid-parent	106.8	7.9	96.4	15.7	27.3	14.9+	7.3
High-parent	-17.2	3.4	-13.7	1.9	6.1	2.1	-0.5
ID	-1.6	-0.9	-7.6	0.4	-4.7	-0.6	0.3
M 20 × ‘Tiny Dill’							
P <sub>A</sub>	68.0	6.9	51.2	14.0	25.0	11.7	5.6
P <sub>B</sub>	117.1	5.8	88.2	12.3	29.3	10.5	4.4
F <sub>1</sub>	84.5	8.7	66.7	15.8	28.0	13.4	6.1
F <sub>2</sub>	101.1	8.7	70.1	19.8	30.7	14.5	5.6
BC <sub>1A</sub>	101.9	11.2	74.5	23.7	33.1	19.3	6.3
BC <sub>1B</sub>	102.7	10.4	67.3	19.6	36.6	14.1	5.9
LSD 5%	25.7	8.3	26.7	7.4	14.3	5.0	0.9*
Mid-parent	92.5	6.4	69.7	13.2	27.1	11.1	5.0*
High-parent	-32.6	1.8	-21.5	1.8	-1.3	1.7	0.5
ID	16.6	0.0	3.4	3.0	2.7	1.1	-0.5

+, \* \*\*, \*\*\* Significant at  $P = 0.10, 0.05, 0.01, 0.001$ , respectively.

<sup>z</sup> Data are means of eight replications of 30 plants per plot.

<sup>y</sup> Mid-parent =  $F_1$  generation -  $(P_A + P_B)/2$ . High-parent heterosis =  $F_1$  generation - high-parent. Significant heterosis determined by single degree of freedom of contrasts between the  $F_1$  generation and mid-parent or high-parent.

<sup>x</sup> Inbreeding depression =  $F_2$  generation -  $F_1$  generation. Significant heterosis determined by single degree of freedom of contrasts between the  $F_1$  and  $F_2$  generation.

Table 2. Means<sup>z</sup>, mid-parent<sup>y</sup> and high-parent heterosis<sup>y</sup>, and inbreeding depression<sup>x</sup> (ID) for number of branches per plant, number of nodes per branch, percentage of pistillate nodes, percentage of fruit set, average weight per fruit (g) and total fruit weight per plot (kg) of each generation and F<sub>1</sub> hybrid

Generation	Branches /plant	Nodes /branch	% pistillate nodes	% fruit set	Average weight/fruit (g)	Total fruit weight (kg)
'Addis' × M 20						
P <sub>A</sub>	3.35	8.26	16.0	40.0	168.5	8.0
P <sub>B</sub>	4.73	6.93	18.0	29.0	167.0	5.1
F <sub>1</sub>	4.68	5.83	13.0	46.0	167.5	7.9
F <sub>2</sub>	4.11	6.68	18.0	40.0	224.8	11.6
BC <sub>1A</sub>	3.79	8.32	12.0	48.0	175.5	9.9
BC <sub>1B</sub>	4.38	6.69	13.0	39.0	208.2	8.8
LSD 5%	1.69	2.13	5.0	7.0*	58.1	4.0
Mid-parent	4.00	7.64	17.0	35.0**	167.8	6.6
High-parent	-0.05	-2.43	-5.0	6.0	-1.0	-0.1
ID	-0.57	0.85	5.0	-6.0	57.3	3.7
'Addis' × 'Wis. SMR 18'						
P <sub>A</sub>	3.41	6.53	15.0	40.0	147.5	6.8
P <sub>B</sub>	2.83	8.82	12.0	32.0	144.7	5.5
F <sub>1</sub>	3.84	9.18	13.0	39.0	230.6	11.9
F <sub>2</sub>	3.44	8.46	13.0	38.0	166.8	7.4
BC <sub>1A</sub>	3.81	8.14	12.0	42.0	188.0	9.0
BC <sub>1B</sub>	3.55	8.89	12.0	38.0	200.6	8.4
LSD 5%	0.94	1.81	4.0	9.0	52.1*	3.0**
Mid-parent	3.10	7.75	13.0	35.0	146.0**	6.1***
High-parent	0.43	0.36	-2.0	-1.0	83.1**	5.1**
ID	-0.40	-0.72	0.0	-1.0	-63.8*	-4.5**
'Clinton' × M 12						
P <sub>A</sub>	4.58	6.48	15.0	46.0	156.5	9.3
P <sub>B</sub>	2.32	8.32	17.0	35.0	122.0	5.3
F <sub>1</sub>	3.34	6.42	17.0	42.0	189.6	10.1
F <sub>2</sub>	3.88	7.56	16.0	38.0	192.8	10.3
BC <sub>1A</sub>	3.92	6.41	15.0	45.0	170.4	8.4
BC <sub>1B</sub>	3.37	8.92	16.0	37.0	220.1	12.1
LSD 5%	1.25*	1.88*	4.0	7.0*	51.4*	3.6*
Mid-parent	3.45	7.40	16.0	40.0	139.3	7.3
High-parent	-1.24	-1.90	0.0	-4.0	33.1	0.8
ID	0.54	1.14	-1.0	-4.0	3.2	0.2
M 20 × 'Tiny Dill'						
P <sub>A</sub>	4.61	6.78	14.0	35.0	203.6	6.5
P <sub>B</sub>	3.77	5.04	90.0	11.0	97.5	5.7
F <sub>1</sub>	3.38	6.04	34.0	23.0	171.4	7.3
F <sub>2</sub>	3.08	6.15	31.0	28.0	203.3	9.2
BC <sub>1A</sub>	3.96	6.45	19.0	36.0	226.3	11.0
BC <sub>1B</sub>	3.48	5.32	49.0	17.0	179.5	9.1
LSD 5%	0.88	1.50	11.0***	7.0***	59.2	3.9
Mid-parent	4.19	5.91	52.0***	23.0	150.6	6.1
High-parent	-1.23	-0.74	-56.0***	-12.0	-32.2	0.8
ID	-0.30	0.11	-3.0	5.0	31.9	1.9

+, \*, \*\*, \*\*\* Significant at  $P = 0.10, 0.05, 0.01, 0.001$ , respectively.

<sup>z</sup> Data are means of eight replications of 30 plants per plot.

<sup>y</sup> Mid-parent =  $F_1$  generation -  $((P_A + P_B)/2)$ . High-parent heterosis =  $F_1$  generation - high-parent. Significant heterosis determined by single degree of freedom of contrasts between the  $F_1$  generation and mid-parent or high-parent.

<sup>x</sup> Inbreeding depression =  $F_2$  generation -  $F_1$  generation. Significant heterosis determined by single degree of freedom of contrasts between the  $F_1$  and  $F_2$  generation.

by breeding programs in the southeastern U.S. for use in that region.

#### *Yield components*

High-parent heterosis and inbreeding depression for yield components was rare for the cucumber hybrids studied, as found for the yield traits themselves (Table 2). The 'Addis' × M 20 hybrid was the only hybrid to exhibit heterosis (mid-parent) for a yield component (percentage of fruit set) (Table 2). Even though the 'Addis' × 'Wis. SMR 18' hybrid exhibited high-parent heterosis and inbreeding depression for fruit yield (weight), heterosis and inbreeding depression was not observed for yield components. Ghaderi & Lower (1979b) also did not observe heterosis or inbreeding depression for the number of nodes per plant and the average internode length for the hybrid, 'Addis' × 'Wis. SMR 18'. The high-parent heterosis and inbreeding depression we observed for average weight per fruit and total fruit weight of the 'Addis' × 'Wis. SMR 18' resulted from the high-parent heterosis and inbreeding depression observed for fruit weight per plot (Tables 1 & 2).

The high-parent heterosis for fruit weight of the hybrid, 'Addis' × 'Wis. SMR 18' may have resulted from more fruits developing at early nodes in comparison to its parents. The F<sub>1</sub> hybrid also exhibited heterosis for both early fruit number and weight (Table 1). Fruit development at early nodes may be expected to alter the percentage of pistillate nodes observed. However, if subsequent nodes produced only staminate flowers, the percentage of pistillate nodes could have been the same as the case where the pistillate nodes were equally distributed along the plant (Table 2). Early fruit development has been shown to delay the development of subsequent pistillate flowers and fruits through a phenomenon referred to as first-fruit inhibition (McCollum, 1934). First fruit inhibition results from a limitation in photosynthate supply permitting only one fruit to grow at a time (Pharr et al., 1985). Hence, high-parent heterosis for fruit weight could be observed with no change in yield components over generations.

#### *Correlation*

In order to understand the relationships between yield components and fruit yield, correlations were calculated for both parents and the F<sub>1</sub> and F<sub>2</sub> generations within each hybrid family (Table 3). The correlations of interest occurred for hybrids in which significant

heterosis or inbreeding depression was measured for fruit yield or yield components. Only the 'Addis' × 'Wis. SMR 18' hybrid exhibited heterosis and inbreeding depression for yield. The correlations between pairs of yield components, and between yield and its components were of interest for this hybrid. The correlations discussed are only applicable to the cross between 'Addis' × 'Wis. SMR 18' and should not be generalized for other crosses in which heterosis or inbreeding depression for fruit yield may occur.

For both parents of the 'Addis' × 'Wis. SMR 18' hybrid, percentage fruit set was positively correlated with both average weight per fruit and total fruit weight per plot (Table 3). The hybrid did not exhibit the same strong positive correlation between percentage fruit set and yield (Table 3). High-parent heterosis for fruit weight in this family was associated with a weakening of the strong, positive correlation between percentage of fruit set and fruit weight. Several strong correlations that were observed among yield components, and between yield and yield components of the hybrid, were not observed for either parent (Table 3). Heterosis for fruit yield was associated with strong, negative correlations between the percentage of fruit set and number of branches per plant, between the percentage of fruit set and the percentage of pistillate nodes per plant, and between the number of nodes per branch and total fruit weight per plot (Table 3). The negative correlation between the percentage of pistillate nodes and percentage fruit set would suggest that first-fruit inhibition is occurring. The presence of strong correlations resulted from an increase in fruit yield (Table 1) rather than from yield components, since yield component means remained similar from the parental to the F<sub>1</sub> generation (Table 2).

The relationship between inbreeding depression and yield component correlations was evaluated by noting the changes in correlations from F<sub>1</sub> to F<sub>2</sub> generations. For the 'Addis' × 'Wis. SMR 18' hybrid, strong negative correlations between the number of branches per plant and percentage of fruit set (-0.66), and between the number of nodes per branch and total fruit weight (-0.65) for the F<sub>1</sub> generation became weak in the F<sub>2</sub> generation (-0.45, -0.16, respectively) (Table 3). In addition, a strong negative correlation between the number of nodes per branch and the percentage of pistillate nodes was observed for the F<sub>2</sub> generation (-0.75), but not for the F<sub>1</sub> generation (-0.55) (Table 3). The inbreeding depression observed for this family was associated with weakening of certain correlations and a strengthening of the correlation

Table 3. Correlation coefficients between number of branches per plant, number of nodes per branch, percentage of pistillate nodes, percentage of fruit set, average weight per fruit, and total fruit weight in each generation and hybrid

Gener- -ation	Yield component	Nodes/ branch	% pistillate nodes	% fruit set	Average fruit weight	Total fruit weight
‘Addis’ × M 20						
P <sub>A</sub>	Branches/plant	-0.27	0.67	-0.54	0.14	0.07
	Nodes/branch		-0.80*	0.31	-0.38	0.06
	% pistillate nodes			-0.59	0.40	0.15
	% fruit set				-0.41	-0.01
	Average fruit weight					0.77*
P <sub>B</sub>	Branches/plant	0.02	-0.29	-0.61	0.46	0.67
	Nodes/branch		-0.80*	0.27	0.01	0.08
	% pistillate nodes			-0.35	0.10	-0.05
	% fruit set				-0.71+	-0.73+
	Average fruit weight					0.92**
F <sub>1</sub>	Branches/plant	-0.53	-0.21	-0.45	0.30	0.26
	Nodes/branch		-0.16	-0.17	0.41	0.50
	% pistillate nodes			-0.19	0.31	0.25
	% fruit set				-0.86*	-0.81+
	Average fruit weight					0.99***
F <sub>2</sub>	Branches/plant	-0.67	0.07	0.21	0.44	0.73*
	Nodes/branch		-0.63	-0.22	0.11	-0.22
	% pistillate nodes			-0.39	-0.48	-0.35
	% fruit set				-0.11	0.32
	Average fruit weight					0.71*
‘Addis’ × ‘Wis. SMR 18’						
P <sub>A</sub>	Branches/plant	0.45	-0.59	-0.04	-0.07	0.33
	Nodes/branch		-0.28	0.03	0.42	0.65
	% pistillate nodes			-0.38	-0.23	-0.31
	% fruit set				0.82*	0.73+
	Average fruit weight					0.85*
P <sub>B</sub>	Branches/plant	0.15	-0.21	0.43	-0.14	-0.19
	Nodes/branch		-0.61	0.15	0.03	0.28
	% pistillate nodes			-0.05	0.32	0.13
	% fruit set				0.73*	0.67+
	Average fruit weight					0.96***
F <sub>1</sub>	Branches/plant	-0.52	0.51	-0.66+	0.36	0.56
	Nodes/branch		-0.55	0.33	-0.36	-0.65+
	% pistillate nodes			-0.91**	-0.27	-0.13
	% fruit set				0.14	0.14
	Average fruit weight					0.80*
F <sub>2</sub>	Branches/plant	-0.09	-0.01	-0.45	0.39	0.45
	Nodes/branch		-0.75*	0.40	0.06	-0.16
	% pistillate nodes			-0.68+	-0.29	0.06
	% fruit set				0.16	-0.11
	Average fruit weight					0.92**

Table 3. (continued)

Gener- -ation	Yield component	Nodes/ branch	% pistillate nodes	% fruit set	Average fruit weight	Total fruit weight
‘Clinton’ × M 12						
P <sub>A</sub>	Branches/plant	-0.86**	0.60	-0.33	0.49	0.40
	Nodes/branch		-0.83**	0.24	-0.65+	-0.62
	% pistillate nodes			-0.29	0.68+	0.77*
	% fruit set				-0.41	0.16
	Average fruit weight					0.73*
P <sub>B</sub>	Branches/plant	0.68+	-0.25	-0.35	0.70+	0.60
	Nodes/branch		-0.43	-0.22	0.88**	0.72*
	% pistillate nodes			-0.25	-0.14	0.20
	% fruit set				-0.57	-0.44
	Average fruit weight					0.89**
F <sub>1</sub>	Branches/plant	-0.92**	0.29	-0.44	0.39	0.35
	Nodes/branch		-0.54	0.45	-0.29	-0.30
	% pistillate nodes			-0.48	-0.30	-0.07
	% fruit set				0.64	0.66
	Average fruit weight					0.95**
F <sub>2</sub>	Branches/plant	-0.30	0.16	-0.33	0.63+	0.74*
	Nodes/branch		-0.91**	0.75*	-0.12	-0.03
	% pistillate nodes			-0.87**	0.13	0.02
	% fruit set				-0.33	-0.20
	Average fruit weight					0.95***
M 20 × ‘Tiny Dill’						
P <sub>A</sub>	Branches/plant	-0.44	0.42	0.01	-0.15	0.24
	Nodes/branch		-0.84+	-0.04	0.79	0.61
	% pistillate nodes			-0.37	-0.79	-0.57
	% fruit set				-0.19	-0.25
	Average fruit weight					0.92*
P <sub>B</sub>	Branches/plant	-0.38	0.38	-0.90*	-0.69	-0.62
	Nodes/branch		-0.54	0.11	-0.34	-0.27
	% pistillate nodes			-0.18	0.25	0.38
	% fruit set				0.85+	0.84+
	Average fruit weight					0.96*
F <sub>1</sub>	Branches/plant	0.55	-0.62	0.49	0.67+	0.69+
	Nodes/branch		-0.40	0.11	0.44	0.40
	% pistillate nodes			-0.76*	-0.51	-0.36
	% fruit set				0.55	0.48
	Average fruit weight					0.98***
F <sub>2</sub>	Branches/plant	0.19	-0.61	0.50	0.78*	0.21
	Nodes/branch		-0.72+	0.86*	0.49	0.95**
	% pistillate nodes			-0.94**	-0.91**	-0.60
	% fruit set				0.76*	0.75+
	Average fruit weight					0.41

+, \*, \*\*, \*\*\* Significant at  $P = 0.10, 0.05, 0.01, 0.001$ , respectively.

Correlations were calculated from eight observations for each family-generation combination except for the P<sub>B</sub> generation from the ‘Addis’ × M20 hybrid, P<sub>A</sub> generation from the ‘Addis’ × ‘Wis. SMR 18’ hybrid, and F<sub>1</sub> and F<sub>2</sub> generations from the M 20 × ‘Tiny Dill’ hybrid (7); the F<sub>1</sub> generation from the ‘Addis’ × M 20 hybrid (6); and the P<sub>A</sub> and P<sub>B</sub> generations from the M 20 × ‘Tiny Dill’ hybrid (5).



between the number of nodes per branch and the percentage of pistillate nodes. Some of the differences in correlations between generations may relate to the uniformity among plants in each generation. Plants of the F<sub>1</sub> generation should be uniform, while plants of the F<sub>2</sub> generation should be segregating for traits in which the parents differed. In our testing, yield component observations for each F<sub>2</sub> generation plot were generated from a sample of 30 plants. By sampling 30 plants for each plot value, some of the variability between plants of the F<sub>2</sub> generation was reduced. As a result, means for the F<sub>1</sub> and F<sub>2</sub> generation were similar for the four yield components measured (Table 2).

Other strong correlations (positive or negative) were observed among yield components and between yield components and yield (Table 3). However, those correlations were not associated with high-parent heterosis, since neither heterosis nor inbreeding depression for yield or yield components was observed in the remaining three hybrids (Table 3). The majority of correlations between yield and its components (other than average fruit weight) were weak for each generation and in each family. Several strong correlations were conserved over generations and among families. For all families and generations, except the F<sub>2</sub> generation of the M 20 × ‘Tiny Dill’, the average weight per fruit was positively correlated with total fruit weight per plot (Table 3). In some instances, the strong positive correlation between these two factors resulted in positive correlation between other yield components and total fruit weight. In addition, positive correlations were observed between average fruit weight and other yield components (Table 3).

As a comparison, means from Ghaderi & Lower (1979a; Tables 3, 4, and 5) were used to calculate high-parent heterosis for four hybrids and three traits (fruit number per plot, fruit weight per plot, average fruit weight) (data not shown). ‘Addis’ × M 20 and ‘Tiny Dill’ × M 20 exhibited high-parent heterosis for average and total fruit weight per plot. High-parent heterosis for fruit number and total weight per plot was observed for ‘Clinton’ × M 12. Ghaderi & Lower (1979a) did not observe high-parent heterosis for ‘Addis’ × ‘Wis. SMR 18’. In our study, only ‘Addis’ × ‘Wis. SMR 18’ exhibited high-parent heterosis for total and average fruit weight.

The differences in results between the two studies might be attributed to the different evaluation methods used in each study. Ghaderi & Lower (1979c) collected data on 25 plants per plot while our study observed 30 plants per plot. The study of Ghaderi &

Lower (1979c) used five replications while our study used four replications. They tested in two different locations, Clinton and Raleigh, within one season. Our study was conducted for two different seasons at one location, Clinton. Ghaderi & Lower (1979c) planted their crop the first week of June and harvested in the third week of July. We planted our spring crop the last week of April and harvested the fourth week of June.

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