# Fruit Yield and Yield Component Means and Correlations of Four Slicing Cucumber Populations Improved through Six to Ten Cycles of Recurrent Selection

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ABSTRACT. Increased fruit yield in slicing cucumber (*Cucumis sativus* L.) has been difficult to achieve since yield is quantitatively inherited with low heritability. From 1981 to 1993, four slicing cucumber populations differing in their genetic diversity (wide, medium, elite, and 'Beit Alpha') were advanced through six to ten cycles of modified half-sib recurrent selection. The objectives of this research were to determine 1) the fruit yield and yield component means; 2) the correlations between yield components, between yield traits, and between components and yield; and 3) the change in means and correlations with selection for improved yield of four slicing cucumber populations. In 1994 and 1995, four families were randomly selected from three cycles (early, intermediate, and late) from each population and self-pollinated. Thirty plants from each $S_1$ family were evaluated in 3.1-m plots in Spring and Summer 1995 and 1996 at the Horticultural Crops Research Station in Clinton, N.C. Plants were harvested and data were collected on number of branches per plant and nodes per branch, proportion of pistillate nodes, fruit set and shape, and total, early, and marketable yield. When averaged over all populations, seasons, and years, fruit yield and quality increased with selection while yield components remained unchanged with selection. Fruit yield and components differed between populations, seasons, and years. Most correlations between yield components and between yield components and fruit yield were weak, and strong correlations varied between populations, seasons, and yield components. Indirect selection of proportion of pistillate nodes has potential for improving yield for certain population–season combinations. Selection weakened many strong correlations between yield components and between yield and components. Changes in correlations often did not correspond with changes in trait means. Based on this research, selection for yield components would not be advantageous for improving fruit yield in all slicing cucumber populations. Additional yield components, yield component heritability, and better component selection methods need to be determined before component selection can be used to improve fruit yield.

North Carolina is the sixth leading state in the production of slicing cucumbers (*Cucumis sativus*), with cucumbers being the second most important vegetable crop in North Carolina (U.S. Dept. of Agriculture, 1996). One of the breeding objectives in cucumber breeding programs is increased fruit yield. However, yield in cucumber is quantitatively inherited with low heritability. Cucumber fruit yield is measured as volume, mass, number, or dollar value. For once-over harvest of cucumbers, fruit number per plot is a more stable measure of yield than fruit mass (Wehner, 1989). In addition, fruit number has higher heritability than fruit mass and is highly correlated with mass (Smith et al., 1978).

Recurrent selection can be used to improve quantitative traits having low heritability, permitting the accumulation of yield gains from each cycle of selection. Recurrent selection has been used in cucumber to improve fruit yield (Lertrat and Lower, 1983; 1984; Nienhuis and Lower, 1988; Wehner and Cramer, 1996a; 1996b). Wehner and Cramer (1996b) observed an average of 45% gain in total, early, and marketable fruit per plot for a middle-eastern ('Beit Alpha' type) slicing cucumber population intercrossed for 10 cycles of recurrent selection. In addition, early yield increased 58% on average for three slicing cucumber populations.

A method to improve yield indirectly is to select for traits that are highly correlated with yield but possess higher heritability. These traits, often referred to as yield components, may include number of plants per hectare, number of harvests per plant, branches per plant, nodes per branch, pistillate flowers, fruit per node or culls, and marketable or early yield. Yield components have been used to study yield in horticultural crops such as blueberry (*Vaccinium corymbosum* L.) (Siefker and Hancock, 1986), cucumber (AbuSaleha and Dutta, 1988; Solanki and Shah, 1989; Prasad and Singh, 1994a; 1994b; Yin and Cui, 1994; Zhang and Cui, 1994; Cramer, 1997), strawberry (*Fragaria* ×*ananassa* Duchesne) (Hancock et al. 1984), and tomato (*Lycopersicon esculentum* Mill.) (McGiffen et al., 1994). Zhang and Cui (1994) suggested that early yield was mainly composed of days from sowing (DFS) to first staminate flowering on 50% of plants, DFS to first pistillate flowering, DFS to first pistillate flowering on 50% of plants, fruiting percentage on the main stem, fruiting branch percentage, fruit harvested in early stage, and mean mass per fruit.

The objectives of this study were to determine 1) fruit yield and yield component means for several populations, cycles and environments; 2) the correlation between yield components, between yield traits, and between yield and its components for four populations and two seasons; 3) yield components for indirect selection of fruit yield; and 4) the change in means and correlations with six to ten cycles of modified intrapopulation half-sib recurrent selection for improved fruit yield and quality.

## Materials and Methods

POPULATION FORMATION AND SELECTION. Four slicing cucumber populations (NCWBS, NCMBS, NCES1, and NCBA1) were developed at North Carolina State Univ. from 1981 to 1984 and were selected using modified intrapopulation half-sib recurrent

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selection to improve fruit yield, earliness, and shape of the population (Wehner and Cramer, 1996b). Families were selected in the spring based on a simple weighted index (SWI), which was weighted 70% yield and 30% quality traits (Wehner and Cramer, 1996b). In addition, populations were indirectly selected for general adaptation to the summer in eastern North Carolina since populations were intercrossed during the summer. The NCWBS population had the widest genetic diversity while the NCES1 population had the narrowest. Also, the NCBA1 population contained genetic material not found in American slicer cultivars (Wehner, 1998a, 1998b).

PROGRESS EVALUATION. Early, intermediate, and late cycles of selection were chosen to represent each population (0, 3, and 6 for NCWBS; 2, 6, and 10 for NCMBS; 1, 5, and 10 for NCES1; and 0, 4, and 8 for NCBA1). Different sets of four families each were taken at random from each population–cycle combination in 1995 and 1996, and self-pollinated in the greenhouse. The experiment was a randomized complete block with four replications of each family in each of two seasons (spring and summer) in each of 2 years (1995, 1996) arranged in a split plot. This combination of environments was used because seasons and years provide more information than locations for North Carolina cucumber yield trials (Swallow and Wehner, 1989). Whole plots were the four slicer populations and subplots were the three cycles of recurrent selection (early, intermediate, and late).

Forty seeds were planted in 3.1-m-long plots on 27 Apr. 1995 and 29 Apr. 1996 (spring) and on 13 July 1995 and 8 July 1996 (summer) at the Horticultural Crops Research Station, Clinton, N.C. Plots were on raised, shaped beds, and were separated at each end by 1.5-m alleys. Guard rows and 1.5-m-long end plots were used around the field to provide competition for plants in the outside plots (Wehner, 1989). The plot size used was optimum for once-over harvest (Swallow and Wehner, 1986). Small, single-row plots were used since they were determined to be more efficient than large, multiple-row plots (Wehner and Miller, 1990). In addition, plot end borders were also not used since they were found unnecessary for cucumber yield trials (Wehner, 1988). 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). Recommended cultural practices were used throughout the experiment (Schultheis, 1990).

Plots were thinned to 30 plants at the first-true-leaf stage. For the spring season, plants were harvested by hand on 30 June and 3 July 1995 and on 21 or 25 June 1996. For the summer season, plots were harvested 5 Sept. 1995 and 23 or 27 Aug. 1996. Plots were harvested when the checks had reached the 10% oversized (>61-mm-diameter) fruit stage. Each plot was evaluated for number of branches, nodes per branch, and total, early (oversized), and marketable (total minus nubbin-shaped and crooked-shaped fruit) fruit per plant; percentage pistillate nodes; percentage fruit set; fruit shape; and a SWI described by Wehner (1982). Fruit shape rating reflected how straight, uniform, and cylindrical the fruit in a plot were based on a scale of 1 to 9, where 1 to 3 = poor, 4 to 6 = intermediate, and 7 to 9 = excellent (Strefeler and Wehner, 1986). The SWI was calculated as follows: SWI = 0.2(total/7) + 0.3(early/3) + 0.2(% marketable/10) + 0.3(shape). Plants that had no flowers, fewer than five leaves, or were <0.4 m long were considered weak and were not used in data collection.

DATA ANALYSIS. Plots were corrected to 30 plants for plots with 14 to 29 plants (plots with <14 plants were considered missing). Fruit yield and yield components were corrected by dividing by plant stand and multiplying by 30. Plots with low stands were eliminated from analysis to prevent extreme biasing during stand correction. Plant stands were corrected to reduce mean differences in yield and components resulting from differences in stand. Currently, a better correction method does not exist for cucumber or other vine crops. The stand correction increased coefficient of determination values and decreased coefficient of variability values for most analyses. Data were analyzed using the GLM procedure of the SAS statistical package (SAS Institute, Cary, N.C.) to determine differences in yield and component means between years, seasons, populations, and cycles. The used model assumed seasons and years as random effects and populations and cycles as fixed effects. Correlations, which were determined using PATHSAS (Cramer et al., 1998), of ≥0.70 (positive or negative) were considered to be strong while correlations between –0.69 and 0.69 were considered weak. Those classifications were made based on a correlation of 0.70, which would have a coefficient of determination of 0.49, and the correlation between the two traits, which would account for ≈50% of the variation observed for the two traits.

## Results and Discussion

YIELD AND YIELD COMPONENT MEANS. When means were calculated over years, seasons, cycles, and replications, the NCES1 population had the highest percentage of marketable fruit per plot and number of marketable fruit per plant (Table 1). Conversely, the NCWBS population had a total fruit yield, fruit shape rating, SWI, and proportion of pistillate nodes that was lower than the other three populations. The explanation for the high marketable yield of the NCES1 population relates back to the cultigens used to form the NCES1 population. Those cultigens would have possessed the highest marketable yield of the cultivars available at the time of population formation. The NCES1 population possessed a higher percentage of those elite cultigens than the other three populations (Wehner, 1998a). In addition, the NCWBS population was formed with a genetically diverse group of cultigens that possessed a range of fruit yield and quality (Wehner, 1998a). Initially, this population had a lower mean yield and poorer fruit quality than the other slicer populations. When fruit yield and quality were averaged over all cycles, the NCWBS population was still inferior to the other slicer populations, even though the latest cycle might be much improved when compared to the earliest cycle.

With regard to yield components, the NCWBS and NCES1 populations had a higher average fruit set than the NCMBS and NCBA1 populations (Table 1). In addition, the NCBA1 population had a higher proportion of pistillate nodes than the NCES1 population. However, there was no difference in branch number, nodes per branch, or early fruit per plot between populations (Table 1). Within each population, those traits are extremely variable between seasons, years, and cycles; this made trait differences between populations difficult to detect. If an unprotected LSD mean separation tested had been conducted, each of those traits would have exhibited significant differences between populations; however, the differences were not significant based on analysis of variance at $P = 0.05$ (Table 1).

All yield traits except total yield increased from early to late selection cycles when averaged over years, seasons, populations, and replications (Table 1). Of the traits measured, early yield had the largest gain (50%) of all traits from early to late cycles averaged over years, seasons, populations, and replications (Table 1). The average gain of percentage marketable yield and marketable yield per plant from early to late cycles was 22% and 34%, respectively, while fruit shape rating and SWI increased an average of 10% to 13% with selection. Wehner and Cramer (1996b) also observed

similar increases from early to late selection cycles in early yield, fruit shape rating, and SWI for three slicer populations. Conversely, the number of nodes per branch decreased 9% from early to late cycles while the number of branches per plant, proportion of pistillate nodes, and fruit set remained constant over selection cycles. Based on those results, selection within the four slicer populations has been successful for increasing the number of high-quality marketable and early fruit per plot without decreasing the total number of fruit per plot. In addition, selection for increased fruit yield has resulted in little change in yield component means.

With regard to the effect of the environment on trait means, early and percentage marketable yield, SWI, the number of nodes per branch, fruit set, and the number of marketable fruit per plant were higher in 1995 than in 1996, while total fruit yield, the number of branches per plant, and proportion of pistillate nodes were higher in 1996 than in 1995 (Table 1). All traits except fruit shape rating, nodes per branch, proportion of pistillate nodes, and fruit set were higher in the summer than in the spring when averaged over years, populations, cycles, and replications. The number of nodes per branch was higher in the spring than in the summer. In a study on pickling cucumber populations, the number of branches per plant was also highly variable between years and seasons (Cramer, 1997). In addition to branches and nodes per branch, the proportion of pistillate nodes and fruit set were variable between years but remained constant over seasons (Table 1).

For most population–season combinations, there were few linear changes in yield components over selection cycles. Selection for improved yield did not change yield component means for most populations. There were no instances in which a linear change in yield component means over selection cycles corresponded with a similar change in yield. In addition, instances in which yield traits changed over selection cycles were not consistent over seasons or populations.

LATEST CYCLE CORRELATIONS. To determine the current relationships among yield components and yield in each population, the correlations between components, between components and yield, and between yield traits were calculated for the latest cycles of each population (Table 2). With regard to the correlations between yield components at the latest cycles, most correlations (85%) ranged from –0.69 to 0.69 and were considered to be weak. In a similar study with pickling cucumbers, 79% of the correlations between yield components were weak for the latest cycle of four populations (Cramer, 1997). Those results suggest that yield components were weakly associated with each other for most populations and seasons and that only certain yield components were correlated depending on the population and season studied. In addition, selection for one component would not affect the mean performance of another component.

However, there were certain yield components that were correlated for certain population–season combinations. Selection for an increased number of branches per plant in the NCMBS or NCES1 population would reduce the number of nodes per branch in the spring (NCMBS) or either (NCES1) season (Table 2). Selection for improved yield in the NCES1 population has already increased the number of branches per plant and decreased the number of nodes per branch in the spring (Cramer, 1997). Also for the NCMBS population, an increase in fruit set during the spring would result in a decrease in the number of branches per plant and an increase in the number of nodes per branch (Table 2). A similar correlation between branches per plant and fruit set was observed for the NCH1 pickle population tested in the spring (Cramer, 1997). Since branches per plant and nodes per branch were negatively correlated, opposite sign correlations would be expected when another yield component (fruit set) was strongly correlated with both traits. Selection for an increased number of nodes per branch in the NCES1 and NCBA1 populations would

Table 1. Mean values[z] of total, early, and percent marketable fruit per plot, fruit shape rating,[y] simple weighted index (SWI[x]), branches per plant, nodes per branch, percentage pistillate nodes, percentage fruit set, and marketable fruit per plant for 30 plants in each population, cycle, and season.

| Effect | Total/ plot | Early/ plot | Percent marketable | Fruit shape[y] | SWI | Branches/ plant | Nodes/ branch | Pistillate nodes (%) | Fruit set (%) | Marketable/ plant |
|---|---|---|---|---|---|---|---|---|---|---|
| Grand | 47.9 | 8.3 | 49.8 | 5.6 | 4.9 | 2.47 | 8.44 | 0.162 | 0.44 | 0.80 |
| **Year** | | | | | | | | | | |
| 1995 | 43.4 | 11.2 | 69.5 | 5.5 | 5.4 | 1.73 | 10.58 | 0.140 | 0.48 | 1.01 |
| 1996 | 51.5 | 5.9 | 33.9 | 5.7 | 4.4 | 3.07 | 6.71 | 0.179 | 0.40 | 0.63 |
| F ratio | **20.9**\*\* | **12.6**\*\* | **197.5**\*\*\* | 0.4 | **13.1**\*\* | **421.35**\*\*\* | **92.54**\*\*\* | **7.65**\* | **16.04**\*\* | **27.39**\*\*\* |
| **Season** | | | | | | | | | | |
| Spring | 39.3 | 5.7 | 45.4 | 5.8 | 4.4 | 1.58 | 9.50 | 0.159 | 0.44 | 0.62 |
| Summer | 55.9 | 10.7 | 53.8 | 5.4 | 5.4 | 3.30 | 7.46 | 0.164 | 0.44 | 0.97 |
| F ratio | **64.9**\*\*\* | **13.6**\*\* | **7.6**\* | 2.5 | **13.7**\*\* | **653.88**\*\*\* | **24.01**\*\*\* | 0.00 | 0.11 | **18.06**\*\* |
| **Cycle** | | | | | | | | | | |
| Early | 47.0 | 6.6 | 45.6 | 5.2 | 4.5 | 2.22 | 9.01 | 0.179 | 0.43 | 0.68 |
| Intermediate | 50.0 | 8.2 | 47.5 | 5.9 | 5.0 | 2.62 | 8.12 | 0.158 | 0.45 | 0.80 |
| Late | 46.6 | 9.9 | 55.7 | 5.7 | 5.2 | 2.56 | 8.23 | 0.149 | 0.44 | 0.91 |
| LSD 5% | 5.2 | **2.3**\*\* | **5.3**\*\* | **0.2**\*\*\* | **0.4**\*\*\* | 0.31 | **0.68**\* | 0.026 | 0.04 | **0.14**\*\* |
| **Population** | | | | | | | | | | |
| NCWBS | 41.2 | 6.7 | 40.4 | 4.3 | 4.0 | 2.41 | 8.60 | 0.112 | 0.51 | 0.53 |
| NCMBS | 51.8 | 8.5 | 44.1 | 5.8 | 4.9 | 2.80 | 8.20 | 0.175 | 0.40 | 0.83 |
| NCES1 | 49.3 | 8.1 | 63.8 | 6.4 | 5.4 | 2.16 | 9.12 | 0.162 | 0.46 | 1.07 |
| NCBA1 | 49.4 | 10.0 | 49.9 | 6.0 | 5.2 | 2.54 | 7.76 | 0.203 | 0.37 | 0.76 |
| LSD 5% | **6.0**\*\* | 2.3 | **6.1**\*\*\* | **0.3**\*\*\* | **0.4**\*\*\* | 0.36 | 0.79 | **0.030**\*\* | **0.05**\*\* | **0.16**\*\*\* |

[z]Data are means of 192 (grand), 96 (year, season), 64 (cycle), or 48 (population) replications of 30 plants per plot.
[y]Fruit shape ratings are 1 to 3 = poor, 4 to 6 = intermediate, 7 to 9 = excellent.
[x]SWI = 0.2(total/7) + 0.3(early/3) + 0.2(% marketable/10) + 0.3(shape).
\*,\*\*,\*\*\*Significant at $P$ = 0.05, 0.01, or 0.001, respectively.

decrease the proportion of pistillate nodes during the summer (Table 2). Cramer (1997) also observed a negative correlation between nodes per branch and proportion of pistillate nodes for the latest cycle of the NCH1 pickle population tested in the summer. With regard to correlations between yield components and fruit yield per plant, most correlations (81%) for the latest cycle were

Table 2. Correlation coefficients[z] between branches per plant, nodes per branch, percentage pistillate nodes, percentage fruit set and total, marketable and early yield per plant for the latest cycle in each population, and season.

| Season | Yield component | Nodes/ branch | Pistillate nodes (%) | Fruit set | Fruit/plant (no.) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Total | Marketable | Early |
| **NCWBS Cycle 6** | | | | | | | |
| Spring | Branches/plant | −0.69 | −0.65 | −0.58 | −0.53 | **−0.89** | **−0.87** |
| | Nodes/branch | | −0.08 | 0.37 | 0.04 | 0.48 | 0.36 |
| | Pistillate nodes | | | 0.42 | **0.74** | 0.67 | **0.77** |
| | Fruit set | | | | **0.80** | **0.70** | 0.37 |
| | Total fruit | | | | | 0.58 | 0.44 |
| | Marketable fruit | | | | | | **0.87** |
| Summer | Branches/plant | −0.18 | −0.15 | −0.15 | **0.76** | −0.03 | −0.47 |
| | Nodes/branch | | −0.20 | −0.66 | −0.17 | **0.73** | 0.67 |
| | Pistillate nodes | | | −0.16 | 0.27 | −0.18 | 0.01 |
| | Fruit set | | | | 0.07 | −0.59 | −0.53 |
| | Total fruit | | | | | 0.05 | 0.49 |
| | Marketable fruit | | | | | | **0.78** |
| **NCMBS Cycle 10** | | | | | | | |
| Spring | Branches/plant | **−0.81** | 0.46 | **−0.92** | −0.35 | −0.35 | −0.14 |
| | Nodes/branch | | −0.59 | **0.93** | 0.68 | 0.65 | 0.50 |
| | Pistillate nodes | | | −0.64 | 0.05 | 0.13 | 0.18 |
| | Fruit set | | | | 0.51 | 0.46 | 0.29 |
| | Total fruit | | | | | **0.97** | **0.91** |
| | Marketable fruit | | | | | | **0.94** |
| Summer | Branches/plant | −0.68 | −0.27 | 0.35 | −0.33 | −0.40 | **−0.72** |
| | Nodes/branch | | −0.20 | −0.47 | 0.10 | **0.77** | **0.97** |
| | Pistillate nodes | | | −0.53 | 0.48 | −0.18 | −0.19 |
| | Fruit set | | | | 0.03 | −0.59 | −0.49 |
| | Total fruit | | | | | −0.19 | −0.06 |
| | Marketable fruit | | | | | | **0.75** |
| **NCES1 Cycle 10** | | | | | | | |
| Spring | Branches/plant | **−0.80** | 0.15 | −0.57 | 0.10 | −0.34 | −0.08 |
| | Nodes/branch | | −0.21 | 0.57 | 0.17 | 0.55 | 0.20 |
| | Pistillate nodes | | | −0.08 | 0.62 | 0.36 | **0.88** |
| | Fruit set | | | | 0.46 | 0.50 | 0.02 |
| | Total fruit | | | | | **0.79** | 0.63 |
| | Marketable fruit | | | | | | 0.48 |
| Summer | Branches/plant | **−0.76** | 0.51 | −0.64 | 0.54 | 0.32 | −0.15 |
| | Nodes/branch | | **−0.70** | 0.44 | −0.40 | −0.17 | 0.43 |
| | Pistillate nodes | | | −0.17 | **0.78** | 0.49 | 0.26 |
| | Fruit set | | | | 0.00 | 0.33 | 0.38 |
| | Total fruit | | | | | **0.88** | 0.55 |
| | Marketable fruit | | | | | | 0.50 |
| **NCBA1 Cycle 8** | | | | | | | |
| Spring | Branches/plant | −0.42 | −0.50 | −0.29 | −0.44 | −0.38 | **0.71** |
| | Nodes/branch | | 0.00 | 0.46 | **0.76** | **0.75** | **−0.74** |
| | Pistillate nodes | | | −0.45 | 0.58 | 0.43 | −0.26 |
| | Fruit set | | | | 0.12 | 0.25 | −0.51 |
| | Total fruit | | | | | **0.91** | −0.64 |
| | Marketable fruit | | | | | | −0.60 |
| Summer | Branches/plant | −0.26 | 0.01 | −0.13 | 0.59 | −0.05 | −0.44 |
| | Nodes/branch | | **−0.73** | −0.39 | **−0.71** | −0.07 | 0.02 |
| | Pistillate nodes | | | −0.21 | 0.43 | 0.53 | 0.55 |
| | Fruit set | | | | 0.12 | −0.34 | −0.46 |
| | Total fruit | | | | | −0.11 | −0.39 |
| | Marketable fruit | | | | | | **0.77** |

[z]Strong correlations (bold) were considered to be 0.7 to 1.0 and −0.7 to −1.0.

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weak with a few exceptions (Table 2). The latest cycles of pickle populations also exhibited a high percentage (78%) of weak correlations between yield components and total yield per plant (Cramer, 1997). Those weak correlations suggest that selection for an increase in yield components would not increase the total yield per plant for most populations in this study. However, there were several instances in which strong correlations were observed between certain yield components and fruit yield.

The correlations between yield components and fruit yield, and between yield components were often influenced by the environment, particularly when strong correlations existed. Of the 18 strong correlations observed between certain yield components and total fruit yield for the latest cycle of selection, only one correlation remained strong over both seasons. In that instance, the sign of the correlation changed from positive to negative from spring to summer. Seasonal differences in correlations between yield components and fruit yield were also observed for pickling cucumber populations with only two strong correlations being maintained over seasons (Cramer, 1997). If yield components are to be used to improve yield, a yield component should be selected that exhibits a strong correlation with yield in both seasons.

Selection for an increase in the number of nodes per branch of the NCBA1 population would increase the total yield in the spring but would decrease yield in the summer (Table 2). The latest cycle of a pickle population (NCH1) also exhibited a negative correlation between nodes per branch and total fruit number per plant in the summer (Cramer, 1997). In addition, the number of branches per plant in the spring for the NCBA1 population was positively correlated with marketable yield and negatively correlated with early yield per plant. For cycle 10 of the NCMBS population tested in the summer, the number of nodes per branch was positively correlated with the number of marketable and early fruit per plant (Table 2). In addition, the number of branches per plant was negatively correlated with early yield.

For the NCWBS population, the correlation between the number of branches and total fruit per plant was positive in the summer. The latest cycle of a pickle population (NCH1) also exhibited a positive correlation of total fruit number per plant with the proportion of pistillate nodes in the spring and with the number of branches per plant in the summer (Cramer, 1997). In addition, the number of branches per plant of the NCWBS population was negatively correlated with marketable and early yield per plant in the spring. In the summer, the number of nodes per branch was positively correlated with marketable fruit number per plant.

An increase in the proportion of pistillate nodes of the NCES1 and NCWBS populations would result in an increase in total yield during the summer for the NCES1 population and an increase in total and early yield during the spring for the NCWBS population (Table 2). In addition, selection for higher fruit set of the NCWBS population would increase total and marketable yield during the spring. Of the four populations studied, the NCWBS population had a significantly lower proportion of pistillate nodes and a significantly higher fruit set than the other three populations when averaged over all cycles (Cramer, 1997). With such differences in the proportion of pistillate nodes and fruit set in the NCWBS population, those differences may account for the strong correlation between those traits and total fruit yield per plant.

With regard to the strong correlations of proportion of pistillate nodes with fruit yield, selection for an increased proportion of pistillate nodes would be beneficial for increasing fruit yield for certain populations and seasons. In addition to a strong positive correlation, the proportion of pistillate nodes would possess higher heritability than fruit yield based on the number of genes control-

ling each trait. Sex expression in cucumbers is controlled by several genes: $F$ and $gy$ (confer gynoecy), $a$ (confers androecy), $m$ and $m$-$2$ (confer andromonoecy), $In$-$F$ ($F$ intensifier), and $Tr$ (for trimonoecy) (Pierce and Wehner, 1990). Fruit yield is controlled by many genes. In addition, the heritability of total fruit yield has been reported to be 0.07 for cycle 0 of the NCES1 population (Strefeler and Wehner, 1986). Based on strong positive correlations and greater heritability, selection for increased proportion of pistillate nodes would be more advantageous than direct selection of yield for certain populations and seasons.

Regarding the correlation between yield traits, most correlations (88%) between total and early yield per plant were weak for the latest cycle of selection (Table 2). Conversely, the correlations between marketable and early yield per plant were positive for all populations except the NCES1 population and the NCBA1 population tested in the spring. Two pickle populations also exhibited strong positive correlations between marketable and early yield (Cramer, 1997). In addition, total and marketable yield were positively correlated for the NCES1 population tested in either season and the NCMBS and NCBA1 populations tested in the spring (Table 2). The correlation between total and marketable yield per plot for this population has been previously reported to be 0.97 (Strefeler and Wehner, 1986). Several pickle populations also exhibited strong correlations between total and marketable fruit number per plant (Cramer, 1997). The lack of correlation between early yield and total or marketable yield of the NCES1 population might relate to a limited amount of variability for early yield in the population. The NCES1 population was formed with cultigens ('Poinsett 76', 'Dasher') that possessed a high marketable yield and late maturity (Wehner, 1997). In addition, the early yield per plot of the NCES1 population has remained constant over 11 cycles of recurrent selection (Wehner and Cramer, 1996b).

CHANGE IN CORRELATIONS WITH SELECTION. In addition to the correlations among yield components for the latest cycle of selection, we were also interested in the change in correlation among components with selection. Most correlations (54%) between pairs of yield components were weak and remained weak from early to late selection cycles (Table 3). In addition, 10% of the correlations were strong (positive or negative) and remained strong with selection. The remaining correlations were weak at the early cycle and became negative at the latest cycle of selection or were strong (positive or negative) initially and then became weak with selection for improved yield. For the NCBA1 population tested in the summer, all correlations among yield components, except the correlation between pistillate nodes and nodes per branch, were strong (positive or negative) at cycle 0 and weakened from cycle 0 to cycle 8 (Table 3). In that population, strong correlations between yield components were a hindrance to yield improvement. As fruit yield improved in the population during the summer (Wehner and Cramer, 1996b), the correlations between components were weakened.

For the NCES1 population, the correlation between pistillate nodes and nodes per branch weakened from cycle 1 to cycle 10 in the spring but became more negative in the summer (Table 3). In addition, the correlation of branches per plant with nodes per branch in the summer became more negative for the NCES1 population and weakened for the NCWBS population from early to late cycles. For the NCES1 population tested in the summer, the number of branches per plant increased while the number of nodes per branch decreased from cycle 1 to cycle 10 (Cramer, 1997). Those changes in trait means over selection cycles may account for the changes in correlations involving branches per plant and/or nodes per branch.

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In many instances, the correlations between components weakened over cycles of selection. The correlation of nodes per branch with branches per plant and pistillate nodes of the NCWBS population tested in the spring and the correlation with pistillate nodes of the NCMBS population tested in the summer weakened from early to late cycles (Table 3). In addition, the correlation of

Table 3. Correlation coefficient strength[z] between branches per plant, nodes per branch, percentage pistillate nodes, percentage fruit set and total, marketable and early yield per plant in four populations and two seasons for early, intermediate and late cycles, respectively.

| Season | Yield component | Nodes/branch | Pistillate nodes (%) | Fruit set (%) | Fruit/plant (no.) Total | Marketable | Early |
|---|---|---|---|---|---|---|---|
| | | | **NCWBS** | | | | |
| Spring | Branches/plant | + + 0 | 0 0 0 | 0 0 0 | 0 0 0 | **0 0 −** | **0 0 −** |
| | Nodes/branch | | **− 0 0** | 0 0 0 | 0 0 0 | 0 0 0 | 0 0 0 |
| | Pistillate nodes | | | 0 − 0 | **0 0 +** | 0 0 0 | **0 0 +** |
| | Fruit set | | | | **+ 0 +** | **0 0 +** | **0 + 0** |
| | Total fruit | | | | | 0 + 0 | 0 + 0 |
| | Marketable fruit | | | | | | **+ + +** |
| Summer | Branches/plant | **− 0 0** | 0 0 0 | **+ 0 0** | **+ 0 +** | 0 0 0 | 0 + 0 |
| | Nodes/branch | | 0 − 0 | **− 0 0** | 0 0 0 | **0 0 +** | 0 0 0 |
| | Pistillate nodes | | | 0 0 0 | 0 + 0 | 0 0 0 | 0 0 0 |
| | Fruit set | | | | **+ 0 0** | 0 − 0 | 0 − 0 |
| | Total fruit | | | | | 0 0 0 | 0 0 0 |
| | Marketable fruit | | | | | | **+ + +** |
| | | | **NCMBS** | | | | |
| Spring | Branches/plant | **− − −** | 0 0 0 | **− − −** | 0 0 0 | 0 0 0 | 0 0 0 |
| | Nodes/branch | | 0 0 0 | **+ + +** | 0 0 0 | **+ 0 0** | 0 0 0 |
| | Pistillate nodes | | | 0 0 0 | 0 0 0 | 0 0 0 | 0 + 0 |
| | Fruit set | | | | **+ 0 0** | **+ 0 0** | 0 0 0 |
| | Total fruit | | | | | **+ 0 +** | **0 0 +** |
| | Marketable fruit | | | | | | **0 + +** |
| Summer | Branches/plant | 0 0 0 | 0 0 0 | 0 0 0 | **+ + 0** | 0 + 0 | **0 0 −** |
| | Nodes/branch | | **− 0 0** | 0 0 0 | **− 0 0** | **0 0 +** | **0 0 +** |
| | Pistillate nodes | | | 0 − 0 | **+ 0 0** | 0 0 0 | 0 0 0 |
| | Fruit set | | | | 0 0 0 | 0 0 0 | 0 0 0 |
| | Total fruit | | | | | 0 + 0 | 0 0 0 |
| | Marketable fruit | | | | | | **0 0 +** |
| | | | **NCES1** | | | | |
| Spring | Branches/plant | **− 0 −** | 0 + 0 | **− − 0** | 0 0 0 | **− 0 0** | **+ 0 0** |
| | Nodes/branch | | **− − 0** | **+ + 0** | 0 0 0 | **++ 0** | 0 0 0 |
| | Pistillate nodes | | | 0 − 0 | 0 0 0 | 0 0 0 | **0 0 +** |
| | Fruit set | | | | 0 0 0 | **+ 0 0** | **− 0 0** |
| | Total fruit | | | | | **0 + +** | 0 0 0 |
| | Marketable fruit | | | | | | 0 0 0 |
| Summer | Branches/plant | **0 0 −** | 0 0 0 | 0 0 0 | **+ 0 0** | 0 0 0 | 0 0 0 |
| | Nodes/branch | | **0 0 −** | 0 0 0 | 0 0 0 | 0 0 0 | 0 0 0 |
| | Pistillate nodes | | | 0 − 0 | **0 0 +** | 0 0 0 | **+ + 0** |
| | Fruit set | | | | 0 0 0 | 0 0 0 | 0 0 0 |
| | Total fruit | | | | | **+ + +** | 0 0 0 |
| | Marketable fruit | | | | | | 0 0 0 |
| | | | **NCBA1** | | | | |
| Spring | Branches/plant | 0 0 0 | 0 0 0 | 0 0 0 | 0 + 0 | 0 0 0 | **0 0 +** |
| | Nodes/branch | | 0 0 0 | **− 0 0** | **− 0 +** | **0 + +** | **− 0 −** |
| | Pistillate nodes | | | 0 0 0 | 0 + 0 | 0 0 0 | 0 0 0 |
| | Fruit set | | | | **+ 0 0** | **− 0 0** | **+ 0 0** |
| | Total fruit | | | | | **− 0 +** | **− + 0** |
| | Marketable fruit | | | | | | 0 0 0 |
| Summer | Branches/plant | **− 0 0** | **+ 0 0** | **− 0 0** | **+ 0 0** | **+ 0 0** | **+ 0 0** |
| | Nodes/branch | | **− 0 −** | **+ 0 0** | **− 0 −** | 0 + 0 | 0 0 0 |
| | Pistillate nodes | | | **− 0 0** | **+ + 0** | 0 0 0 | 0 0 0 |
| | Fruit set | | | | **− 0 0** | 0 0 0 | 0 0 0 |
| | Total fruit | | | | | **+ 0 0** | **+ 0 0** |
| | Marketable fruit | | | | | | **+ 0 +** |

[z]Weak correlation (0) (−0.69 to 0.69), positive correlation (+) (0.70 to 1.00), negative correlation (−) (−0.69 to −1.00).

fruit set with branches per plant and with nodes per branch weakened from early to late cycles for the NCWBS population tested in the summer and the NCES1 population tested in the spring (Table 3). Those observations would suggest that to improve fruit yield, as those populations were doing (Wehner and Cramer, 1996b), strong correlations between yield components must be weakened.

In addition to changes in components with selection, we were also interested in the effect of selection on the correlations between yield and its components. Of the correlations observed, 57% of the correlations were weak and remained weak from early to late selection cycles in both seasons (Table 3). In addition, 38% of the correlations weakened or strengthened with selection. Of those changing correlations, 61% of the correlations between yield components and yield were strong (positive or negative) at the early cycle and became weak by the latest cycle. Some examples of those changing correlations would be the correlations between branches per plant and total yield for the NCMBS and NCES1 populations (summer), the correlations between nodes per branch and marketable yield for the NCMBS and NCES1 populations (spring), and the correlations between fruit set and total yield for the NCMBS population (spring), the NCWBS (summer), and the NCBA1 population (both seasons) (Table 3). Weakening of correlations between yield components and yield has also been observed for pickling cucumber populations (Cramer, 1997). Selection for improved yield in many instances favors the weakening of correlations between yield components and fruit yield. Perhaps those correlations are a hindrance to yield improvement in certain populations.

Several population–component combinations exhibited different responses to selection depending on the season. For the NCES1 population, the correlation between proportion of pistillate nodes and early yield became positive from cycle 1 to cycle 10 in the spring but became weak over the same cycles in the summer (Table 3). The correlation between nodes per branch and marketable yield for the NCMBS population was positive at cycle 2 in the spring and weakened with selection. In the summer, the correlation was initially weak and became positive at cycle 10. In addition, several population–component combinations exhibited changes in response to selection in one season only. For the NCES1 population, the correlation between the proportion of pistillate nodes and total yield remained weak from cycle 1 to cycle 10 in the spring but became positive over cycles in the summer (Table 3). The number of branches per plant of the NCWBS population became negatively correlated with marketable yield with selection in the spring but remained weak over selection cycles in the summer.

In many instances, the correlations between yield components and the correlations between yield and its components changed over cycles of selection (Table 3) even though fruit yield and/or yield component means showed no change over selection cycles for population–season combinations (Cramer, 1997). Many of the yield and yield component means remained constant from early to late cycles of selection for population–season combinations. Pickling cucumber populations also exhibited changes in yield component correlations and correlations between components and yield over selection cycles with no corresponding change in yield or component means over selection cycles (Cramer, 1997). The lack of changes in yield and component means make changes in correlations difficult to explain.

With regard to the correlations between yield traits, 46% of the correlations were weak and remained weak over selection cycles; 21% of the correlations were strong and remained strong with selection; and the remaining correlations were weak initially and

became stronger with selection, or were strong and weakened over selection cycles (Table 3). For the NCWBS population, marketable and early yield were positively correlated at each cycle and in both seasons (Table 3). In addition, total and marketable yield of the NCES1 population were positively correlated at each cycle in the summer. Of those correlations that changed in strength over selection cycles, the correlation between marketable and early yield for the NCMBS population became more positive from cycle 2 to cycle 10 in both seasons. In addition, the positive correlation between total and early yield at cycle 0 of the NCBA1 population weakened from cycle 0 to cycle 8 in both seasons. An elite pickle population tested in both seasons also exhibited a weakening of the correlation between total and early yield over cycles (Cramer, 1997). For the NCBA1 population, the correlation between total and marketable yield became more positive in the spring but weakened in the summer. Several correlations between yield traits changed over selection cycles in only one season.

In conclusion, indirect selection of yield components to improve fruit yield would not be advantageous for all slicing cucumber populations. In most instances, weak correlations existed between components and between yield components and yield. In addition, correlations varied depending on the population and season tested. However, for most populations and seasons, marketable yield was positively correlated with total and early yield. Of the yield components studied, the proportion of pistillate nodes would be the most likely yield component to be used for indirect selection for certain population–season combinations. Many strong correlations between yield components and between yield components and yield weakened with selection for improved yield. In addition, changes in correlations over selection cycles often did not correspond with changes in trait means over cycles. When averaged over all populations, environments, and replications, selection was effective for improving fruit yield and quality but had little effect on yield component means. Populations differed in fruit yield and yield components, and yield and components differed between seasons and years. More work needs to be done to determine heritability of yield components. In addition, other yield components, such as plants per hectare, nodes per plant, average internode length, and number of pistillate flowers per node, and other measures of yield, such as mass and value, should be studied for correlations between yield components and yield. For yield component selection to be used in cultivar development, better evaluation methods for measuring yield components must be developed.

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