Ten Cycles of Recurrent Selection for Fruit Yield, Earliness, and Quality in Three Slicing Cucumber Populations

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Abstract. **Fruit yield, earliness, and quality have low to moderate heritability, but are traits of major importance in cucumber (*Cucumis sativus* L.). The objective of this study was to determine the changes made in those traits using recurrent selection in three slicing cucumber populations (NCMBS, NCES1, and NCBA1). During population improvement, one or two replications of 200 to 335 half-sib families were evaluated in the spring season for five traits: total, early, and marketable fruit per plot, fruit shape rating, and a simple weighted index (SWI = 0.2(total yield)/2 + 0.3(early yield) + 0.2(% marketable)/10 + 0.3(fruit shape). Families from each population were intercrossed in an isolation block during the summer season using remnant seeds of the best 10% selected using the index. Response was evaluated using a split-plot treatment arrangement in a randomized complete block design with 32 replications in each of two seasons (spring and summer). Whole plots were the three populations, and subplots were the 11 cycles (cycles 0 to 9 plus checks). We measured improvement in performance of the populations in a selected (spring) and unselected environment (summer). Significant gains were made for all traits in all populations over the 9 to 10 cycles of recurrent selection. Greatest progress was made for the NCMBS population, with an average of 37% gain from cycle 0 to 9 over all five traits. The trait where most progress was made was early yield, with an average of 63% gain from cycle 0 to 9 over the three populations.**

Cucumber is the second most important horticultural crop in North Carolina (including both pickling and slicing types), and North Carolina is the fourth largest producer of slicing cucumbers in the United States (U.S. Dept. of Agriculture, 1990). Breeding efforts in the United States have concentrated on the incorporation of qualitatively-inherited traits (gynoecy, disease resistance, fruit color) into elite inbreds using backcross or pedigree selection (Wehner, 1988b). The inbreds are then made available directly to growers or used in single-cross hybrids. However, many traits of interest to growers (fruit yield, earliness, and quality) are quantitatively inherited, and have low heritability.

Recurrent selection for population improvement is an effective breeding method for improving quantitative traits with low heritability in cucumber (Wehner, 1989). Recurrent selection involves systematic testing and selection of desirable individuals from a population followed by recombination of the selected individuals to form a new population (Fehr, 1991). The new population should be superior (although performance might also get worse) to the original population, both in average performance and in performance of the best individuals. The accumulation of small gains from each cycle results in significant long-term improvement of the population.

In cucumber, early testing for yield traits is effective (Rubino and Wehner, 1986a), and inbreeding depression is minimal (Rubino and Wehner, 1986b). Thus, the development of advanced populations with improved fruit yield, earliness and quality should result in inbred lines and hybrids with improved performance.

Recurrent selection has been used in cucumber to increase low temperature germination ability (Nienhuis et al., 1983; Staub et al., 1988), herbicide resistance (Staub et al., 1991), and disease resistance (Sloane et al., 1985). Recurrent selection methods such as S_1 line, half-sib family and full-sib family selection have been effective for yield improvement in cucumber (Lertrat and Lower, 1983, 1984; Nienhuis, 1982; Nienhuis and Lower, 1988; Wehner, 1989). On the other hand, convergent-divergent selection was not effective in the Gynoecious Synthetic population for improving yield over several environments in midwestern and southeastern United States (Wehner et al., 1989).

The objective of this study was to determine whether progress was made for fruit yield, earliness and quality using recurrent selection in three slicing cucumber populations.

Materials and Methods

Research on population improvement was done in three general stages: population formation (1981–84), recurrent selection (nine or more cycles), and evaluation of response (a replicated study in two environments in 1993). All work was done at the Horticultural Crops Research Station, Clinton, N.C.

Population formation. Three slicing cucumber populations were developed at North Carolina State Univ. The North Carolina medium base slicer (NCMBS) population consisted of 152 cultigens (cultivars, breeding lines and plant introduction accessions) intercrossed in 1981 and 1982 (Strefeler and Wehner, 1986; Wehner, 1996a). The North Carolina elite slicer 1 (NCES1) population consisted of eight cultigens intercrossed in 1981 and 1982 (Strefeler and Wehner, 1986; Wehner, 1996a). The North Carolina Beit Alpha 1 (NCBA1) population consisted of eight cultigens intercrossed in 1982–84 (Wehner, 1996b). The populations were developed to improve fruit yield, earliness and shape through a program of modified half-sib family recurrent selection.

Recurrent selection. Populations were improved by testing in the spring season followed by intercrossing the best families in isolation blocks in summer for 9 (NCBA1) to 10 (NCMBS,

NCES1) cycles. Half-sib families from each population were planted in 1.5-m-long plots (changed to 1.2 m after selection cycle 4 was completed) on raised, shaped beds 1.5 m apart during the spring season from 1983–92. That plot size was found to be optimum for yield measurement (Swallow and Wehner, 1986). Plot end borders were found to be unnecessary for efficient trialing (Wehner, 1988a), as were multiple-row plots (Wehner and Miller, 1990), so neither was used.

Recommended cultural practices (summarized recently by Schultheis, 1990) were used throughout the experiments. 'Poinsett 76' was planted every eighth row, and in field border rows and end tiers as a pollenizer. Irrigation was applied when needed for a total of 25 to 40 mm per week. Fertilizer was incorporated at a rate of 90N–39P–74 K kg/ha before planting, with an additional 34 kg N/ha applied at the vine-tip-over (four to six true leaf) stage. Herbicide [Curbit, ethalfluralin, N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine] and insecticide (Sevin, carbaryl, 1-naphthyl N-methylcarbamate) were applied at recommended rates (Schultheis, 1990).

The 20-year normals for mean daily air temperature during spring were 23 to 27C day, and 9 to 14C night. The 20-year normals for mean daily air temperature during the summer season were 30 to 37C day, and 18 to 20C night (National Climatic Data Center, Asheville, N.C.).

The experiment was a randomized complete-block design with one replication of 200 half-sib families during the first 6 years of selection, increased to 390 families for 1 year, then increased to two replications the following year, and finally changed to 335 families in 22 sets of 16 each in the last 2 years. In the first 7 years, 24 families were selected for intercrossing; in the last 3 years, 40 families were selected for intercrossing. Changes were made in the test method to reflect current information on testing efficiency (Wehner, 1987; Wehner and Miller, 1984). The selection plots were planted 26 Apr. to 18 May and harvested 12 June to 15 July depending on year.

Once-over harvest was simulated by spraying the foliage with paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at 0.6 kg/ha when the checks had reached the 10% oversized fruit stage (Wehner et al., 1984). Fruit were rated as oversized when they exceeded 60 mm in diameter. Half-sib families were evaluated for five traits: total yield (number of fruit per plot), early yield (number of oversized fruit per plot), marketable yield (total yield minus crooked and nubbin fruit), fruit shape rating (Strefeler and Wehner, 1986), and a simple weighted index (Wehner, 1982). Fruit shape rating reflected how straight, uniform and cylindrical the fruit in a plot were, using a scale of 1–3 = poor, 4–6 = intermediate, 7–9 = excellent. The simple weighted index was heavily weighted (70%) toward yield traits, and was calculated as: SWI = 0.2(total yield)/2 + 0.3(early yield) + 0.2(% marketable yield)/10 + 0.3(fruit shape). Total yield was divided by 2 and percentage marketable yield was divided by 10 to give them the same range (1 to 9) as the other traits. Each trait was then given a weight (20% or 30%) to reflect its importance in the breeding program.

Half-sib families from each population were intercrossed in separate isolation blocks during the summer season using remnant seeds of the best 10% of the families (24 or 40) selected using the SWI. To maximize natural outcrossing (Wehner and Jenkins, 1985), the selected families (24 or 40) were planted in plots with a composite pollenizer (CP) every third row. The CP rows consisted of all selected families (24 or 40) mixed together and sprayed with silver nitrate (2.06 mol·liter^{-1}) at the cotyledon stage to induce monoecious sex expression. Plants of the selected families were planted in plot rows, then sprayed with ethrel [(2-chloroethyl) phosphonic acid] at a rate of 1.0 ml·liter^{-1} (22% a.i.) at the cotyledon stage to induce gynoecious sex expression. Use of that system should increase the amount of intercrossing and sample a maximum number of families from the population.

The intercross blocks were planted from 24 June to 27 July and harvested from 4 Sept. to 27 Oct. depending on year. Bravo

Table 1. Mean squares from analysis of variance for simple weighted index (SWI)[z], total yield (total), and early yield (early) as fruits per plot, percentage marketable yield (marketable), and fruit shape rating (shape) in the three slicing cucumber populations (NCMBS, NCES1, and NCBA1) tested in two seasons (Spring and Summer 1993), and 10 cycles (0 to 9) of recurrent selection at Clinton, N.C.

Source of		Mean squares				
variation	df	SWI	Total	Early	Marketable	Shape
			NCMBS			
Season (S)	1	2.09	0.84	42.96[*]	6.61	2.54
Error A	62	1.77	30.71	8.44	177.60	1.21
Cycle (C)	9	7.16[***]	83.82[***]	31.21[***]	293.34	1.92[*]
S × C	8	1.79	30.66	3.55[***]	97.94	0.87
Error B	435	0.94	19.93	2.75	176.61	0.94
			NCES1			
S	1	155.76[***]	657.30[**]	815.25[***]	71.44	15.52[**]
Error A	62	4.31	72.95	16.31	187.47	1.97
C	9	9.85[***]	143.95[***]	31.37[***]	270.14[***]	4.61[***]
S × C	9	0.90	26.80	4.76	62.61	1.61
Error B	497	1.18	24.57	4.63	71.94	0.87
			NCBA1			
S	1	13.77	3533.20[***]	1313.70[***]	19441.50[***]	27.38[***]
Error A	62	5.28	65.69	15.33	534.70	1.45
C	8	27.06[***]	275.76[***]	31.46[***]	1622.10[***]	18.98[***]
S × C	8	4.83[***]	28.00	21.81[***]	31.23	6.32[***]
Error B	494	1.04	21.08	3.63	158.36	0.93

[z]SWI = 0.2(total yield)/2 + 0.3(early yield) + 0.2(%marketable yield)/10 + 0.3(fruit shape)
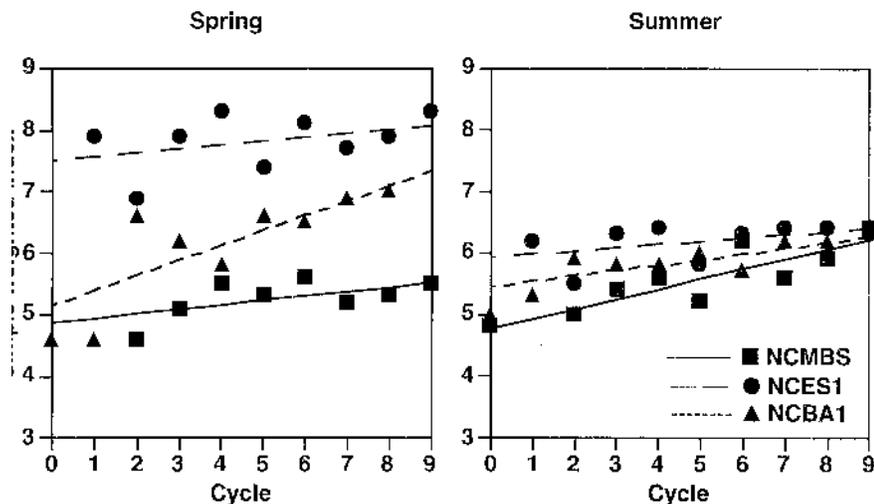[*,**,***]Significant at P = 0.05, 0.01, or 0.001, respectively.

Spring / Summer

(chlorothalonil, tetrachloroisophthalonitrile) and Benlate [benomyl, methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate] were applied at recommended rates (Schultheis, 1990) to control fungal diseases when required to prevent destruction of the plots.

Seeds from each family in each cycle of each population were sampled randomly in 1992, and increased to provide equal-aged material for the evaluation phase.

Response evaluation. Selection response was measured in the spring and summer seasons of 1993 at the Horticultural Crops Research Station. Cultural practices were the same as those described above for the recurrent selection stage. 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).

The experiment was a split-plot treatment arrangement in a randomized complete block design with 32 replications in each of two seasons (spring and summer). In previous North Carolina tests, seasons provided more information than locations, and were just as effective as years (Swallow and Wehner, 1989). Therefore, we used seasons rather than locations to maximize the range of environments represented. Whole plots were the three populations and subplots were the 11 cycles (cycles 0 to 9, with the check 'Dasher II' replicated in each whole plot).

The 1.2-m test plots were planted 24 and 27 May 1993 for spring, and 6 and 9 July 1993 for summer. The test plots were harvested 9 to 19 July 1993 for spring, and 23 Aug. to 7 Sept. 1993 for summer. Data were collected on the traits described above, and were analyzed using regression and analysis of variance procedures from SAS (SAS Institute, Cary, N.C.). Selection response was calculated using predicted values from regression. Checks were excluded from regression analysis, but were included with cycle means to make comparisons for selection response.
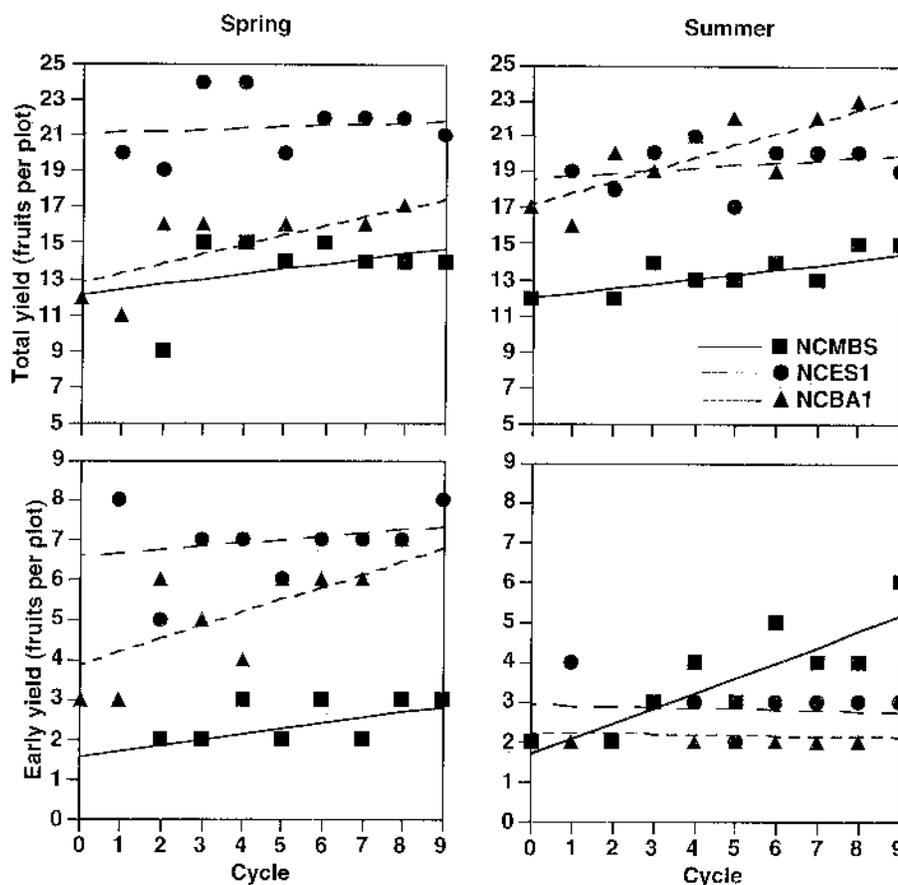
Results

Analysis of variance. The NCES1 and NCBA1 populations exhibited highly significant gains over all five traits measured (total, early, and marketable fruit per plot, fruit shape, and SWI) from cycle 0 to cycle 9 (Table 1). Gains in total and early fruit per plot and SWI

Spring / Summer

from cycle 0 to 9 were observed in the NCMBS population.

There were significant season by cycle interactions (involving changes in magnitude but not rank) for SWI, early yield, and fruit shape in the NCBA1 population (Table 1). Larger gains in magnitude were achieved from cycle 0 to 9 for those traits in the environment for which they were selected (spring) than the unselected environment (summer). Conversely, larger gains were observed from cycle 0 to 9 for early yield of the NCMBS population in summer than in spring (Table 1). There were no season by cycle interactions for the 5 traits in the NCES1 population (Table 1). In addition, there were no season × cycle interactions for SWI, total yield, marketable yield, or fruit shape in the NCMBS population. The season × cycle interactions were not significant for total yield and percentage marketable yield in the NCBA1 population.

Regression analysis. The NCBA1 population had the largest gain (41%) in SWI from cycle 0 to cycle 9 during spring (Fig. 1). The largest gain in SWI for summer was observed in the NCMBS population. The simple weighted index in the NCBA1 population averaged over both seasons increased by 28% from cycle 0 to 9. Gains in the SWI of all populations from cycle 0 to cycle 9 were made in the selected (spring) and unselected (summer) environment.

Total yield increased in spring and summer environments for all populations from cycle 0 to cycle 9 (Fig. 2). The NCBA1 population had the largest gain (35%) in total yield from cycle 0 to 9.

Early yield in the spring environment increased from cycle 0 to cycle 9 for all three populations (Fig. 2). The NCMBS population produced an average of 1 to 3 additional early fruit after 9 cycles of recurrent selection. In the summer environment, early yield of the NCMBS population increased from cycle 0 to 9, while early yield of the NCBA1 and NCES1 populations remained constant over the same number of cycles.

Each population had a 5% to 14% gain in percentage marketable yield from cycle 0 to cycle 9 of selection (Fig. 3). The NCBA1 population had the largest gain (14%) in percentage marketable yield.

Gain from selection for more desirable fruit shape was made in the NCBA1 and NCES1 populations, while the NCMBS population remained constant from cycle 0 to cycle 9 (Fig. 3). The largest gain in fruit shape from cycle 0 to 9 was observed for the NCBA1 population during the spring environment.

Gain from selection. Greatest progress for the three populations was made in NCMBS, with an average of 37% gain from cycle 0 to 9 over all five traits (SWI, total yield, early yield, percentage marketable yield, and fruit shape). NCES1 had the lowest gain with an average of 8%, and NCBA1 was intermediate with an average of 29% over all five traits.

Among the five traits measured, the greatest progress was made for early yield, with an average of 63% gain from cycle 0 to 9 over the three populations. In addition, total fruit yield produced per plot increased an average of 20%; the simple weighted index increased an average of 19%; fruit shape rating increased an average of 12%; and marketable fruit per plot increased an average of 9% from cycle 0 to 9 over all three populations. The average gain from cycle 0 to 9 for the three populations and the five traits was 25%.

Discussion

Comparison of actual yield among populations was not possible in this study. The ordinate intercept of the regression line for each population was a measure of population performance, along with the effect of the field it was tested in, and the slightly different stages of harvest. However, the objective of this study was not to compare mean performance among populations, but rather genetic gains made over 9 cycles of selection for fruit yield and quality.

Gain from selection. In 1986, Strefeler and Wehner predicted gain in total, marketable and early fruit number per plot, as well as fruit shape rating for several populations, using full-sib families and two seasons of two replications each for testing. They predicted a gain from cycle 0 to cycle 9 for the NCES1 and NCMBS populations, respectively, of 88% and 105% for total yield, 0.4% and 0% for marketable yield, 36% and 68% for early yield, 35% and 93% for fruit shape rating, and 47%
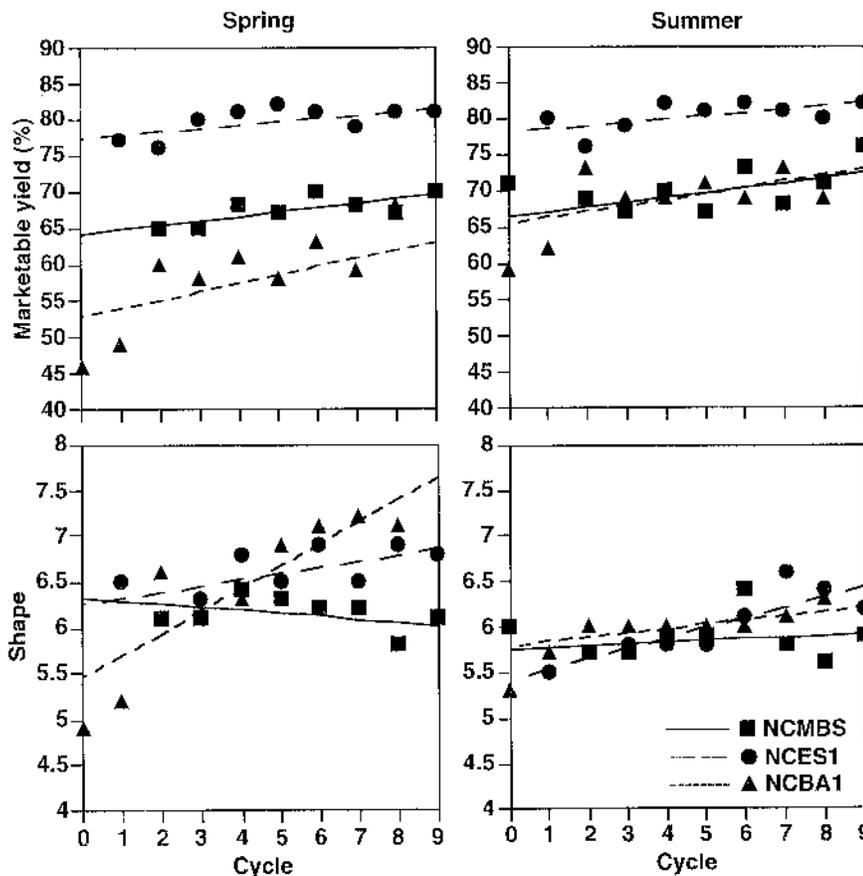

Fig. 3. Means and regression lines of percentage marketable yield and subjective fruit shape (1–10) rating of fruits per plot for three slicing cucumber populations, North Carolina medium base slicer (NCMBS), North Carolina elite slicer 1 (NCES1), and North Carolina beit alpha 1 (NCBA1) tested in two seasons (Spring and Summer 1993), and 10 cycles (0 to 9) of recurrent selection at Clinton, N.C. Regression equations and r^2 values for percentage marketable yield of three populations and two seasons are NCMBS, spring ($y = 64.21 + 0.6x$, $r^2 = 0.53$), NCES1, spring ($y = 77.41 + 0.46x$, $r^2 = 0.38$), NCBA1, spring ($y = 52.92 + 1.14x$, $r^2 = 0.43$), NCMBS, summer ($y = 65.69 + 0.82x$, $r^2 = 0.41$), NCES1, summer ($y = 78.15 + 0.46x$, $r^2 = 0.35$), and NCBA1, summer ($y = 66.46 + 0.67x$, $r^2 = 0.23$). Regression equations and r^2 values for fruit shape of three populations and two seasons are NCMBS, spring ($y = 6.32 - 0.03x$, $r^2 = 0.21$), NCES1, spring ($y = 6.25 + 0.07x$, $r^2 = 0.39$), NCBA1, spring ($y = 5.45 + 0.24x$, $r^2 = 0.63$), NCMBS, summer ($y = 5.75 + 0.02x$, $r^2 = 0.03$), NCES1, summer ($y = 5.43 + 0.11x$, $r^2 = 0.75$), and NCBA1, summer ($y = 5.8 + 0.05x$, $r^2 = 0.75$).

and 72% for SWI (determined from predicted values of fruit shape, total, early, and percentage marketable yield). The actual gain we measured in fruit shape and total and early yield with 10 cycles of recurrent selection was <15% for the NCES1 population and <21% for the NCMBS population except for early yield (135%). Those gains were lower than predicted, but that is not surprising because we used fewer replications, and half-sib rather than full-sib family testing used in Strefeler and Wehner's (1986) estimate. In addition, estimates of genetic variances are only valid for the cycle 0 population where they were measured, so extrapolation through 9 cycles of selection is misleading. It is interesting to note that the prediction by Strefeler and Wehner (1986) of marketable yield was lower than actual gain for marketable yield after 9 cycles of recurrent selection, where we observed 5% and 10% increases for NCES1 and NCMBS, respectively.

Large gains in yield have been reported in cucumber using recurrent selection. Nienhuis and Lower (1988) reported 35%, 64%, and 57% gains in fruit number per plant in the gynoecious synthetic (GS) population, a *C. sativus* var. *hardwickii* semiexotic (HSE) population, and the GS x HSE population hybrids, respectively, in each of three cycles of S_1 line selection.

Yield gains from recurrent selection have also been reported in many agronomic crops. Pomeranke and Stuthman (1992) observed a 38% to 40% gain in grain yield of 140 oat (*Avena sativa* L.) lines improved through five cycles of recurrent selection. In soybean (*Glycine max* (L.) Merr.), Kenworthy and Brim (1979) reported that three cycles of S_1 line selection increased seed yield by 134 kg/ha per cycle. Probably the most successful use of recurrent selection has been in maize (*Zea mays* L.), where significant yield gains have been reported by many investigators (Genter, 1971; Horner et al., 1973; Moll et al., 1978; Mulamba et al., 1983).

Strefeler and Wehner (1986) predicted that the NCMBS population would achieve greater gain per cycle in all traits than the NCES1 population. That prediction was correct, since the actual gain in the NCMBS population averaged over all traits was greater than the average gain of NCES1 for cycles 0 to 9. The difference in average gain for the five traits between populations was probably related to genetic variance. Strefeler and Wehner (1986) estimated that NCMBS had a larger phenotypic variance and a larger additive genetic variance than NCES1 for fruit shape, and total and early yield. Thus, NCMBS probably had a larger gain per cycle because of its wider genetic base.

The selection method used, which changed from one replication of 200 families to two replications of 335 families, did not have any apparent effect on gain. Gains were made for all traits (SWI, total yield, early yield, marketable yield, and fruit shape) at about the same rate regardless of the testing method used.

Population means. Plant breeders are interested in making gains from selection. However, the products of selection must outperform the best cultivars if they are to be useful. In North Carolina trials (Wehner, 1996a, 1996b), the population means for yield of marketable fruit in six harvests of NCMBS, NCES1, and NCBA1 were 23.7, 24.4, and 19.0 Mg/ha, respectively, averaged over 4 years, two seasons, and three replications (or 108%, 111%, and 87% of the 'Dasher II' check cultivar, respectively). Fruit shape rating averaged 86% (NCMBS, NCES1) to 100% (NCBA1) as good as 'Dasher II'.

We were surprised that the populations performed so well against the leading gynoecious hybrid, since the populations were highly heterogeneous and monoecious. However, we have observed that monoecious cultivars perform as well as near-isogenic, gynoecious cultivars in multiple-harvest trials. Monoecious cultivars produce total numbers of fruit similar to gynoecious cultivars,

but not as many early fruit, requiring several harvests to catch up (Wehner and Miller, 1985).

In summary, recurrent selection was successful in improving fruit yield and quality in three cucumber populations. Gains were made in the selected environment (spring), and also in the unselected environment (summer). Total fruit yield, early fruit yield, percentage marketable fruit, and fruit shape rating increased over cycles of recurrent selection in the three populations tested.

Literature Cited

Fehr, W.R. 1991. Principles of cultivar development. vol. 1. Theory and technique. p. 172–174.

Genter, C.F. 1971. Yields of S_1 lines from original and advanced synthetic varieties of maize. Crop Sci. 11:821–824.

Horner, E.S., H.W. Lundy, M.C. Lutrick, and W.H. Chapman. 1973. Comparison of three methods of recurrent selection in maize. Crop Sci. 13:485–489.

Kenworthy, W.J. and C.A. Brim. 1979. Recurrent selection in soybeans: I. Seed yield. Crop Sci. 19:315–318.

Lertrat, L. and R.L. Lower. 1983. Pickling cucumber population improvement for increased fruit yield. Cucurbit Genet. Coop. Rpt. 6:18–19.

Lertrat, L. and R.L. Lower. 1984. Pickling cucumber population improvement for increased fruit yield II. Cucurbit Genet. Coop. Rpt. 7:9.

Moll, R.H., C.C. Cockerham, C.W. Stuber, and W.P. Williams. 1978. Selection responses, genetic-environmental interactions, and heterosis with recurrent selection for yield of maize. Crop Sci. 18:641–645.

Mulamba, N.N., A.R. Hallauer, and O.S. Smith. 1983. Recurrent selection for grain yield in a maize population. Crop Sci. 23:536–540.

Nienhuis, J. 1982. Response to different selection procedures for increased fruit yield in two pickling cucumber populations. PhD diss. Univ. of Wisconsin, Madison.

Nienhuis, J. and R.L. Lower. 1988. Comparison of two recurrent selection procedures for yield in two pickling cucumber populations. J. Amer. Soc. Hort. Sci. 113:272–276.

Nienhuis, J., R.L. Lower, and J.E. Staub. 1983. Selection for improved low temperature germination in cucumber. J. Amer. Soc. Hort. Sci. 108:1040–1043.

Pomeranke, G.J. and D.D. Stuthman. 1992. Recurrent selection for increased grain yield in oat. Crop Sci. 32:1184–1187.

Rubino, D.B. and T.C. Wehner. 1986a. Efficiency of early generation testing in pickling cucumber. Euphytica 35:89–96.

Rubino, D.B. and T.C. Wehner. 1986b. Effect of inbreeding on horticultural performance of lines developed from an open-pollinated pickling cucumber population. Euphytica 35:459–464.

Schultheis, J.R. 1990. Pickling cucumbers. N.C. State Agr. Ext. Hort. Info. Lflt. 14-A.

Sloane, J.T., T.C. Wehner, and S.F. Jenkins, Jr. 1985. Inheritance of resistance to rhizoctonia fruit rot in cucumber. HortScience 20:1119–1120.

Staub, J.E., R.L. Lower, and J. Nienhuis. 1988. Correlated responses to selection for low temperature germination in cucumber. HortScience 23:745–746.

Staub, J.E., L.D. Knerr, and L.A. Weston. 1991. Evaluations and correlated responses to resistance to chloramben herbicide in cucumber. HortScience 26:905–908.

Strefeler, M.S. and T.C. Wehner. 1986. Estimates of heritabilities and genetic variances of three yield and five quality traits in three fresh-market cucumber populations. J. Amer. Soc. Hort. Sci. 111:599–605.

Swallow, W.H. and T.C. Wehner. 1986. Optimum plot size determination and its application to cucumber yield trials. Euphytica 35:421–432.

Swallow, W.H. and T.C. Wehner. 1989. Optimum allocation of plots to years, seasons, locations, and replications, and its application to once-over-harvest cucumber trials. Euphytica 43:59–68.

U.S. Department of Agriculture. 1990. Agricultural statistics. U.S. Govt. Printing Office. Washington, D.C. p. 154.

Wehner, T.C. 1982. Weighted selection indices for trials and segregating populations. Cucurbit Genet. Coop. Rpt. 5:18–20.

Wehner, T.C. 1987. Efficient methods for testing vegetable cultivars. HortScience 22:1220–1223.

Wehner, T.C. 1988a. Effect of end-border condition on small-plot yield of cucumber. Euphytica 38:113–119.

Wehner, T.C. 1988b. Survey of cucumber breeding methods in the U.S.A. Cucurbit Genet. Coop. Rpt. 11: 9–12.

Wehner, T.C. 1989. Breeding for improved yield in cucumber, p. 323–359. In: J. Janick (ed.). Plant breeding reviews. vol. 6.

Wehner, T.C. 1996a. Three slicing cucumber populations: NCWBS, NCMBS, and NCES1. HortScience (In press.)

Wehner, T.C. 1996b. Two special cucumber populations: NCH1 and NCBA1. HortScience (In press.)

Wehner, T.C. and S.F. Jenkins, Jr. 1985. Rate of natural outcrossing in monoecious cucumbers. HortScience 20:211–213.

Wehner, T.C. and C.H. Miller. 1984. Efficiency of single-harvest methods for measurement of yield in fresh-market cucumbers. J. Amer. Soc. Hort. Sci. 109:659–664.

Wehner, T.C. and C.H. Miller. 1985. Effect of gynoecious expression on yield and earliness of a fresh-market cucumber hybrid. J. Amer. Soc. Hort. Sci. 110:464–466.

Wehner, T.C. and C.H. Miller. 1990. Yield of cucumbers in multiple-harvest trials with dissimilar genotypes in border rows. HortScience 25:106–108.

Wehner, T.C., T.J. Monaco, and A.R. Bonanno. 1984. Chemical defoliation of cucumber vines for simulation of once-over harvest in small-plot yield trials. HortScience 19:671–673.

Wehner, T.C., R.L. Lower, J.E. Staub, and G.E. Tolla. 1989. Convergent-divergent selection for cucumber fruit yield. HortScience 24:667–669.

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J. Amer. Soc. Hort. Sci. 121(3):362–366. 1996.