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Gain for Pickling Cucumber Yield and Fruit Shape Using Recurrent Selection

Todd C. Wehner* and Christopher S. Cramer

ABSTRACT

Qualitative traits of cucumbers (*Cucumis sativus* L.) such as disease resistance have been improved significantly during the past 30 yr. On the other hand, quantitative traits such as yield, earliness, and fruit shape have been improved less. The objective of this study was to determine the progress that could be made on such traits with recurrent selection in three pickling cucumber populations (NCMBP, NCEP1, and NCH1). During population improvement, one or two replications of 200 to 335 half-sib families were evaluated in the spring season for total, early, and marketable fruits per plot, a fruit shape rating, and a simple weighted index (SWI = 0.2 × total yield / 2 + 0.3 × Early yield + 0.2 × % marketable yield / 10 + 0.3 × quality). Families from each population were intercrossed in an isolation block during each summer with remnant seeds of the best 12% selected with the index. Progress was evaluated by means of 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 10 to 11 cycles (Cycles 0–9 plus checks). Populations were improved for performance in a selected (spring season) as well as a non-selected environment (summer season). Greatest gains were made for the NCMBP population, with an average of 54% gain from Cycle 0 to 9 over the five traits, and for early yield, with an average of 65% gain from Cycle 0 to 9 over the three populations. In other trials, NCH1 had the best mean performance. Based on those results, modified half-sib recurrent selection can be used to improve fruit yield and quality of NCMBP, NCEP1, and NCH1 populations. Further studies should be made on NCMBP because it had the greatest gain per year, and on NCH1 because it had the highest mean performance.

North Carolina is the second largest producer of pickling cucumbers in the USA, and cucumbers are the second most important horticultural crop in North Carolina (U.S.D.A., 1990). Breeding programs in the USA have used pedigree or backcross methods for improvement of qualitative traits such as gynoecy, disease resistance, and fruit color in the development of elite inbreds (Wehner, 1988b), which are then used by growers or made into single-cross hybrids. However, other traits of interest to growers – yield, earliness, and fruit shape – are inherited quantitatively, and have low heritability.

Recurrent selection is useful for improving quantitative traits with low heritability, providing a new population which is superior to the original population in both mean performance and in performance of the best individuals (Fehr, 1991). Significant long-term improvements of the population result from the accumulation of small gains from each cycle of recurrent selection.

In cucumber, recurrent selection has been used to improve disease resistance (Sloane et al., 1985), herbicide resistance (Staub et al., 1991), and low temperature germination rate (Nienhuis et al., 1983). Recurrent selection using S_1 lines, half-sib families, or full-sib families have been effective for cucumber yield improvement (Lertrat and Lower, 1983, 1984; Nienhuis, 1982; Nienhuis and Lower, 1988; Wehner, 1989). On the other hand, yield of a gynoecious synthetic population was not improved by convergent-divergent selection in several environments in the midwestern and southeastern USA (Wehner et al., 1989).

The objective of this study was to determine whether progress could be made for fruit shape, and for total, marketable, and early fruit yield with recurrent selection in three pickling cucumber populations.

MATERIALS AND METHODS

Population improvement was accomplished in three stages: population formation (1976 through 1982), recurrent selection (9–10 cycles), and progress evaluation (replicated study in two environments in 1993). All research was done at the Horticultural Crops Research Station in Clinton, NC.

Population Formation

Three pickling cucumber populations were developed at North Carolina State University. The North Carolina medium base pickle (NCMBP) population consisted of 69 inbred or hybrid cultivars and breeding lines (hereafter referred to as cultigens) intercrossed from 1976 to 1982 (Wehner, 1997a, in press). The North Carolina elite pickle 1 (NCEP1) population consisted of five cultigens intercrossed from 1981 to 1982 (Wehner, 1997a, in press). The North Carolina hardwickii 1 (NCH1) population consisted of 13 cultigens intercrossed from 1976 to 1982 (Wehner, 1997b, in press). The populations were developed as a way to expand the germplasm base being used for cultivar development in the USA, and to improve fruit yield, earliness, and shape using modified half-sib family selection.

Recurrent Selection

Populations were improved by testing in the spring season followed by intercrossing the best families in isolation blocks in the summer season for nine (NCEP1) to 10 (NCMBP, NCH1) cycles. Half-sib families from each population were planted in 1.2- to 1.5-m-long plots on raised, shaped beds 1.5 m apart during the spring season from 1983 through 1992. That plot size was found to be optimum for yield evaluation (Swallow and Wehner, 1986). Plot end borders were found to be unnecessary for yield trials (Wehner, 1988a), as were multiple-row plots (Wehner and Miller, 1990).

In cucumber, early testing was effective (Rubino and Wehner, 1986a) for predicting characteristics of advanced lines developed from improved populations. Also, inbreeding depression was minimal in six generations of self pollination from a random-mated population (Rubino and Wehner, 1986b), indicating that improved populations could be used to develop inbred lines with high fruit yield for direct use by growers.

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Abbreviations: SWI, simple weighted index; CP, composite pollenizer; GS, gynoecious synthetic; HSE, *C. sativus* var. *hardwickii* semi-exotic.

Recommended cultural practices were used throughout the experiments (Schultheis, 1990). 'Sumter' was planted every 9th row, and in border rows and end-tiers as a pollenizer. The field plot methods in the selection phase were changed as we gained information from research on efficient testing methods (Wehner, 1986; Wehner, 1987). The experiment design during the first 6 yr of selection was one replication of 200 families in 1.5-m plots. The number of families was 390 for 1 yr followed by an increase in the number of replications to two. Finally, the number of families was decreased to 335 in 22 sets of 16 each in 1.2-m plots for the last 2 yr. Twenty-four families were selected for intercrossing in the first 7 yr, and 40 families were selected for intercrossing the final 3 yr. The selection plots were planted 18 April to 24 May and harvested 10 June to 18 July depending on year.

Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at 0.6 kg/ha was sprayed on the foliage when the check cultivar (Calypso, which was in every 20th plot) had reached the stage where 10% of the fruits were oversized (over 51-mm diam) to simulate once-over harvest (Wehner et al., 1984). Half-sib families were evaluated using total yield (number of fruits per plot), early yield (number of oversized fruits per plot), marketable yield (total minus crooked or nubbin fruits per plot), fruit shape, and a simple weighted index (Wehner, 1982). Fruit shape rating reflected how straight, uniform, and cylindrical the fruits in a plot were and was determined by a 1-to-9, where 1 to 3 = poor, 4 to 6 = intermediate, and 7 to 9 = excellent (Strefeler and Wehner, 1986). The simple weighted index (SWI) was calculated as follows: SWI = $0.2 \times$ total yield / $2 + 0.3 \times$ early yield $+ 0.2 \times$ % marketable yield / $10 + 0.3 \times$ shape. Although the index consisted of 70% weighting on yield traits, percentage marketable yield represented some quality aspects (freedom from crooked- and nubbin-shaped fruits).

The best 12% (24 or 40, depending on year) of half-sib families were selected from each population using the SWI. Those elite families were intercrossed in separate isolation blocks during the summer season using remnant seeds. The selected families were planted in plots surrounded by a composite pollenizer (CP), produced by mixing seeds of the selected 24 or 40 families, and planted every third row in order to maximize the amount of outcrossing (Wehner and Jenkins, 1985). In order to increase natural outcrossing, plot rows were sprayed with ethrel [(2-chloroethyl) phosphonic acid] at a rate of 1.0 mL L^{-1} with 22% a.i. at the cotyledon stage to produce gynoecious sex expression, and CP rows were sprayed with silver nitrate (2.06 mol L^{-1}) at the cotyledon stage to induce monoecious sex expression.

The intercross blocks were planted from 17 June to 1 August and harvested from 11 September to 16 October depending on year. If necessary, Bravo (chlorothalonil, tetrachloroisophthalonitrile; Diamond Shamrock Chem. Co., Cleveland OH) and Benlate (benomyl, methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate; E.I. du Pont de Nemours & Co., Inc., Wilmington, DE) were applied at recommended rates (Schultheis, 1990) to control fungal diseases in the intercross blocks to prevent loss of the plants before seed harvest.

The populations were sampled randomly in 1992 and the seeds were increased to ensure 70% or greater germination rate in the progress evaluation phase.

Progress Evaluation

Selection progress was measured in the spring and summer seasons of 1993 at the Horticultural Crops Research Station, Clinton, NC. Cultural practices were the same as those described above for the recurrent selection stage. The soil type was a mixture of Norfolk, Orangeburg, and Rains (fine-loamy, siliceous, thermic, Typic Kandiudults) with some Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults), depending on the field.

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 North Carolina trials, seasons provide more information than locations, and are just as effective as years (Swallow and Wehner, 1989), so we rely on seasons rather than locations for environmental diversity. Whole plots were the three populations and subplots were the 11 cycles (Cycles 0–9, with the check cultivar, Calypso, as the "11th cycle").

The 1.2-m test plots were planted 24 and 27 May 1993 for the spring season, and 6 to 9 July 1993 for the summer season. The test plots were harvested 9 to 19 July 1993 for the spring season, and 23 Aug. to 7 Sept. 1993 for the summer season. Data were collected on the same traits described above, and analyzed using regression and analysis of variance procedures from SAS (SAS Institute, Cary, NC). Regression analysis over cycles was calculated on mean values over 32 replications for each population and trait combination. Gains from Cycle 0 to 9 were calculated by inserting values of 0 and 9 into the regression equation for each trait and population and subtracting the difference. Gains were expressed as a percentage of the value at Cycle 0. The check cultivar was excluded from regression analysis.

RESULTS

Analysis of Variance

Only the NCMBP population had significant effects for cycle in the five traits (total, early, and marketable fruits per plot, fruit shape, and SWI) measured (Table 1). The NCH1 population had significant effects for cycle in all traits except marketable yield. Significant effects for cycle were measured for the SWI, early yield, and fruit shape of the NCEP1 population. Both the NCMBP and the NCH1 population had significant differences between seasons for the five traits measured. Significant season effects were measured for fruit shape, early yield, and marketable yield in the NCEP1 population.

There was significant interaction for season × cycle for SWI, total yield, and early yield in the NCMBP and NCEP1 populations (Table 1). Gains from Cycle 0 to 9 were larger in the spring season for SWI and early yield in the NCMBP population, and also larger for SWI, total yield, and early yield in the NCEP1 population. Larger gains were observed during the summer season than the spring season for total yield in the NCMBP population. There was significant interaction for season by cycle for total yield and marketable yield in the NCH1 population (Table 1). Finally, the change in fruit shape from Cycle 0 to 9 was not influenced by season based on the nonsignificant season by cycle interaction for all populations.

Population Means

Comparisons of actual yield among populations was not possible in this study, but is being investigated in separate performance trials. The ordinate intercept of the regression line should not be used for comparisons

Table 1. Analysis of variance (source, degrees of freedom, and mean squares) for simple weighted index (SWI), total yield, early yield, percentage marketable yield, and fruit shape rating in the three pickling cucumber populations (NCMBP, NCEP1, NCH1) tested in two seasons (spring and summer, 1993), and 10 cycles (0 to 9) of recurrent selection at Clinton, NC.

Source of variation	Degrees of freedom	Mean square				
		SWI	Total	Early	% marketable	Shape
NCMBP						
Season (S)	1	135***	7870***	604***	24 500***	22.1**
Error A	62	2.73	47.7	8.72	155	2.68
Cycle (C)	9	21.5***	216***	44.8***	288*	17.0***
S × C	9	2.56***	42.1***	11.1***	202	0.49
Error B	552	0.77	13.3	2.79	130	0.91
NCEP1						
Season (S)	1	5.71	163	384***	22 300***	35.1***
Error A	62	3.57	67.0	11.4	355	2.37
Cycle (C)	8	2.55**	43.8	16.3***	198	3.94***
S × C	8	4.64***	131***	7.66**	61.5	1.17
Error B	494	1.00	23.2	2.50	102	0.92
NCH1						
Season (S)	1	33.1*	6760***	580***	21 400***	37.3***
Error A	62	7.59	107.3	28.5	258	2.50
Cycle (C)	9	4.70***	85.8***	13.9**	120	7.40***
S × C	9	1.78	108.4***	4.14	216*	0.16
Error B	523	1.28	26.3	4.47	94.2	1.04

*, **, *** Indicates mean square significant at 0.001, 0.01, or 0.05 level, respectively.

among populations since they were harvested from different fields and at different times. The objective of this study was to compare only genetic gain in fruit yield and quality.

Regression Analysis

Of the five traits, greatest progress was made for early yield (65%) from Cycle 0 to 9 averaged over all populations. The SWI, total yield, and fruit shape rating had 11 to 14% gain from Cycle 0 to 9 for all populations. Marketable yield did not increase from Cycle 0 to 9.

The greatest gain for a population from Cycle 0 to 9 averaged over the five traits (54%) was observed for the NCMBP population, while the NCEP1 population gained an average of only 5% from Cycle 0 to 9 averaged over the five traits. On the other hand, the NCH1 population had no gain from Cycle 0 to 9 averaged over the five traits.

When progress for a particular trait was compared among populations, the NCMBP population exhibited the largest gain of the three populations in SWI (30%), total yield (46%), early yield (173%), marketable yield (1%), and fruit shape rating (22%) from Cycle 0 to Cycle 9 averaged over both environments. The NCEP1 population exhibited its largest gain in early yield (21%) while modest gains were achieved for SWI (4%) and fruit shape rating (5%) over 10 cycles of selection. Total and marketable yield of NCEP1 decreased by 2% from Cycle 0 to 9. The NCH1 population made a 16% improvement in fruit shape over 10 cycles of selection. However,

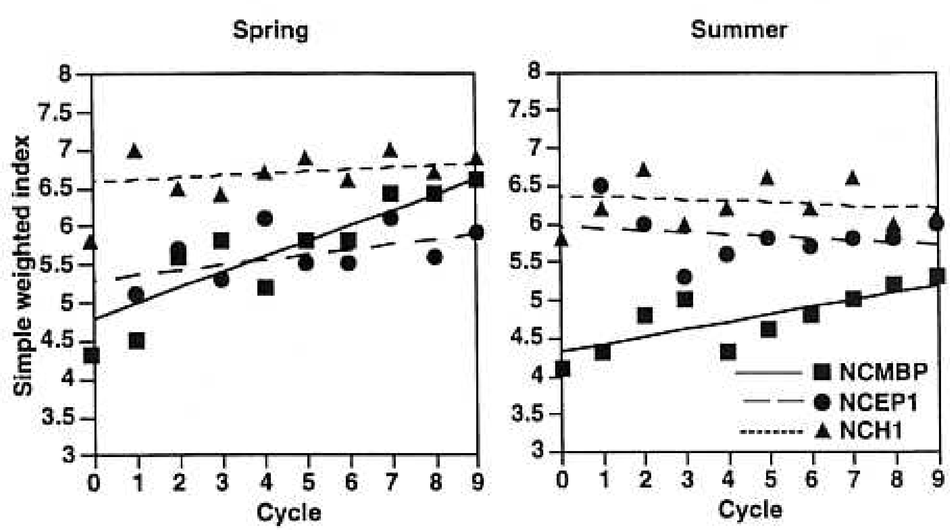

Fig. 1. Means and regression curves of simple weighted index of fruits per plot for three pickling cucumber populations, North Carolina medium base pickle (NCMBP), North Carolina elite pickle 1 (NCEP1), and North Carolina hardwickii 1 (NCH1) tested in two seasons (spring and summer, 1993), and 10 Cycles (0–9) of recurrent selection at Clinton, NC. Each point represents 32 replications. Regression equations and r^2 values for SWI of three populations and two seasons are NCMBP, spring ($y = 4.80 + 0.2x$, $r^2 = 0.75$), NCEP1, spring ($y = 5.30 + 0.07x$, $r^2 = 0.28$), NCH1, spring ($y = 6.60 + 0.03x$, $r^2 = 0.10$), NCMBP, summer ($y = 4.33 + 0.1x$, $r^2 = 0.49$), NCEP1, summer ($y = 5.96 - 0.03x$, $r^2 = 0.05$), and NCH1, summer ($y = 6.38 - 0.02x$, $r^2 = 0.04$).

total, early, and marketable yield decreased over 10 cycles of selection. The SWI remained constant from Cycle 0 to 9.

Testing in the selected environment (spring season) resulted in larger gains over the five traits and three populations than testing in the nonselected environment (summer season). The NCMBP population exhibited the largest gains of the three populations in the spring (62%) and summer (45%) seasons averaging over the five traits from Cycle 0 to 9. During the summer season, the average gain over the five traits decreased from Cycle 0 to Cycle 9 for both the NCEP1 and the NCH1 populations.

The SWI in each population increased from Cycle 0 to 9 when evaluated in the selected environment (spring season) (Fig. 1). The NCMBP population had the largest increase (38%) in SWI from Cycle 0 to 9. The SWI in the NCEP1 and NCH1 populations decreased by 3 to 5% from Cycle 0 to 9 in the nonselected environment (summer season). Conversely, the NCMBP population exhibited a 21% increase in SWI in the nonselected environment (summer season).

Total yield increased 44 and 18% for the NCMBP and NCEP1 populations, respectively, from Cycle 0 to Cycle 9 when populations were evaluated in the selected environment (Fig. 2). However, total yield of the NCH1 population decreased by 4%. Total yield of the NCEP1 and NCH1 populations in the nonselected environment decreased by 17 and 15%, respectively, while the total yield of the NCMBP population increased 49% from Cycle 0 to 9.

The three pickle populations had larger increases in early yield from Cycle 0 to 9 in the selected environment than the nonselected environment (Fig. 2). The NCMBP population exhibited a larger gain in early yield (200%) than either NCEP1 (50%) or NCH1 (13%) when populations were evaluated in the spring season. In addition, NCMBP and NCEP1 had a 133 and 6% increase, respectively, in early yield during the summer environment, while early yield of NCH1 decreased 12%.

The three populations showed no substantial gain in

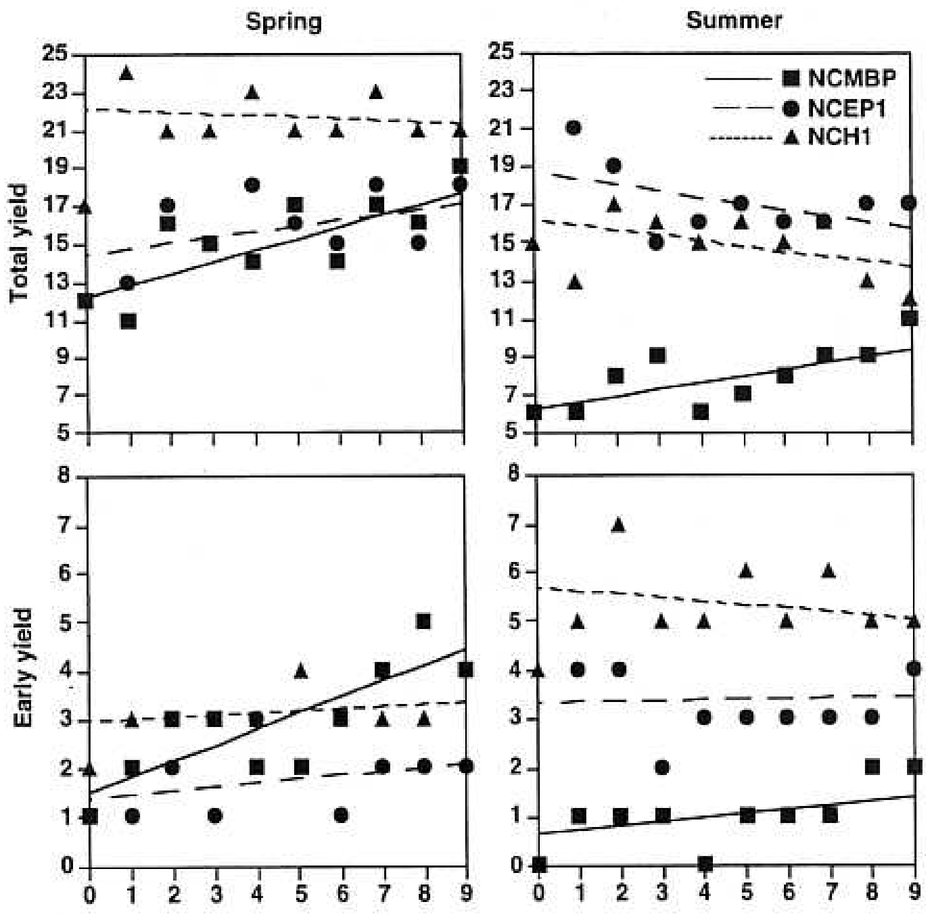

Fig. 2. Means and regression curves of total and early yield of fruits per plot for three pickling cucumber populations, North Carolina medium base pickle (NCMBP), North Carolina elite pickle 1 (NCEP1), and North Carolina hardwickii 1 (NCH1) tested in two seasons (spring and summer, 1993), and 10 cycles (0–9) of recurrent selection at Clinton, NC. Each point represents 32 replications. Regression equations and r^2 values for total yield of three populations and two seasons are NCMBP, spring ($y = 12.2 + 0.59x$, $r^2 = 0.53$), NCEP1, spring ($y = 14.5 + 0.29x$, $r^2 = 0.23$), NCH1, spring ($y = 22.2 - 0.1x$, $r^2 = 0.05$), NCMBP, summer ($y = 6.26 + 0.35x$, $r^2 = 0.40$), NCEP1, summer ($y = 18.7 - 0.34x$, $r^2 = 0.31$), and NCH1, summer ($y = 16.1 - 0.26x$, $r^2 = 0.20$). Regression equations and r^2 values for early yield of three populations and two seasons are NCMBP, spring ($y = 1.51 + 0.33x$, $r^2 = 0.71$), NCEP1, spring ($y = 1.38 + 0.08x$, $r^2 = 0.12$), NCH1, spring ($y = 3.00 + 0.04x$, $r^2 = 0.15$), NCMBP, summer ($y = 0.64 + 0.08x$, $r^2 = 0.27$), NCEP1, summer ($y = 3.35 + 0.01x$, $r^2 = 0.01$), and NCH1, summer ($y = 5.68 - 0.07x$, $r^2 = 0.10$).

the percentage of marketable fruits per plot from Cycle 0 to 9 when evaluated in either the selected or nonselected environments (Fig. 3). In the selected environment, marketable yield increased 3 and 1% for NCMBP and NCEP1, respectively, while marketable yield decreased 3% for NCH1. In the nonselected environment, marketable yield decreased 1 and 5% for NCMBP and NCEP1, respectively, while the marketable yield of NCH1 increased 1%.

Fruit shape rating for the three populations increased from Cycle 0 to Cycle 9 in the selected and nonselected environments (Fig. 3). The NCMBP population exhibited the largest improvement in fruit shape from Cycle 0 to 9 in the selected (23%) and nonselected (21%) environments.

DISCUSSION

Gain from Selection

Substantial gains were made in total yield, early yield, and fruit shape (traits with low heritability) by means of nine to 10 cycles of modified half-sib family recurrent selection. Similar gains in yield using recurrent selection were reported by Nienhuis and Lower (1988). They observed a 35, 64, and 57% gain in fruit number per plant of a gynoecious synthetic (GS) population, a *C. sativus* var. *hardwickii* semi-exotic (HSE) population, and their hybrid population, GS × HSE, respectively, with three cycles of S_1 line selection.

The large average increase in the five traits for the NCMBP population was expected since the NCMBP population had a wider genetic base (69 cultigens) than either NCEP1 (five cultigens) or NCH1 (13 cultigens). Gains predicted by Strefeler and Wehner (1986) also were larger in populations having a wider genetic base.

Changes in the test method from one replication of 200 families to two replications of 335 families in 22 sets of 16 did not have any apparent effect on gain from Cycle 0 to 9. Gains were made in the five traits at about the same rate regardless of the testing method used. The use of additional families and replications may have been

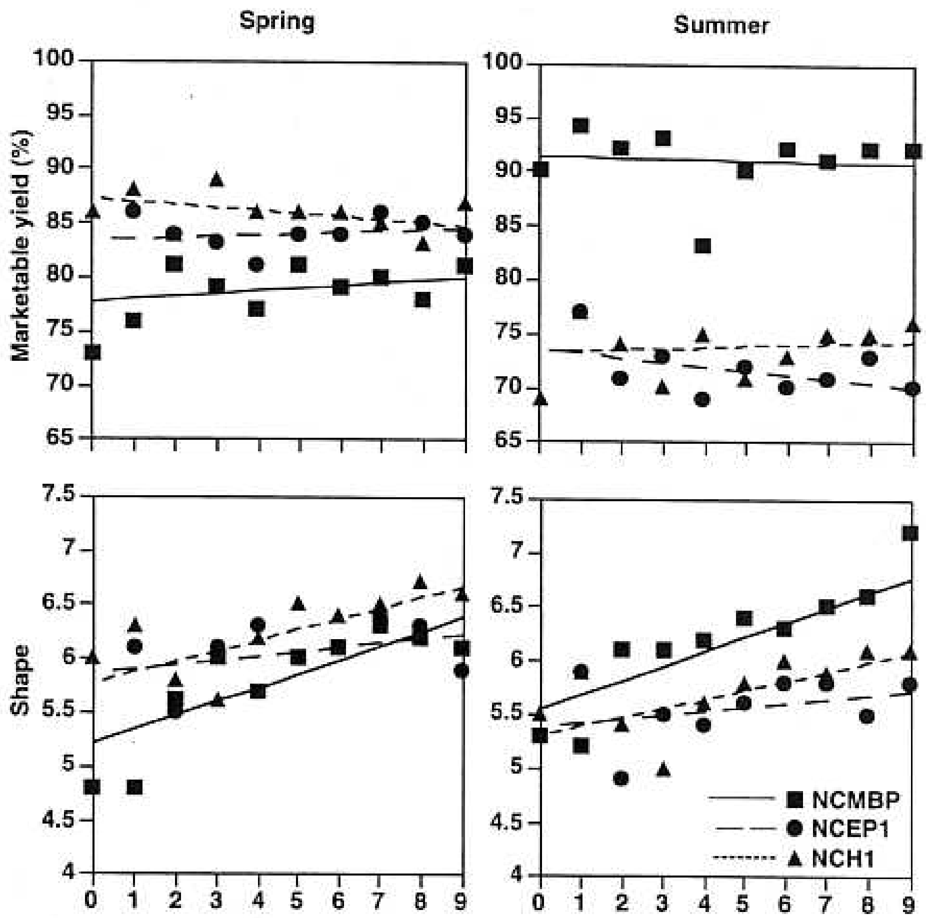

Fig. 3. Means and regression curves of percentage marketable yield and fruit shape rating of fruits per plot for three pickling cucumber populations, North Carolina medium base pickle (NCMBP), North Carolina elite pickle 1 (NCEP1), and North Carolina hardwickii 1 (NCH1) tested in two seasons (spring and summer, 1993), and 10 cycles (0–9) of recurrent selection at Clinton, NC. Each point represents 32 replications. Regression equations and r^2 values for percentage marketable yield of three populations and two seasons are NCMBP, spring ($y = 77.8 + 0.24x$, $r^2 = 0.15$), NCEP1, spring ($y = 83.6 + 0.11x$, $r^2 = 0.04$), NCH1, spring ($y = 87.2 - 0.27x$, $r^2 = 0.15$), NCMBP, summer ($y = 91.4 - 0.07x$, $r^2 = 0.01$), NCEP1, summer ($y = 73.7 - 0.39x$, $r^2 = 0.22$), and NCH1, summer ($y = 73.4 + 0.11x$, $r^2 = 0.02$). Regression equations and r^2 values for fruit shape of three populations and two seasons are NCMBP, spring ($y = 5.22 + 0.13x$, $r^2 = 0.63$), NCEP1, spring ($y = 5.88 + 0.04x$, $r^2 = 0.15$), NCH1, spring ($y = 5.79 + 0.1x$, $r^2 = 0.55$), NCMBP, summer ($y = 5.55 + 0.13x$, $r^2 = 0.73$), NCEP1, summer ($y = 5.39 + 0.04x$, $r^2 = 0.12$), and NCH1, summer ($y = 5.31 + 0.09x$, $r^2 = 0.43$).

useful, but the effects were too small to detect in the cycles of selection evaluated.

In North Carolina, the spring environment is significantly different from the summer environment for cucumber (1988, unpublished data). That environmental variation may account for the differences in progress for a particular trait and population between the selected and nonselected environment. However, fruit shape exhibited progress regardless of environment.

Population Means

Although it was not possible to use the ordinate intercept from the regression analyses to compare population means, data from performance trials is available (Wehner, 1996a,b). Total yield ($/ha), percentage marketable yield, and early yield ($/ha in the first two of six total harvests) over 3 yr, two seasons, three replications, and six harvests in North Carolina trials were 82, 86, and 88% as good as 'Calypso' (the check cultivar) for the NCMBP, NCEP1, and NCH1 populations, respectively. The performance (as percentage of Calypso) ranged from 60% for early yield in the NCMBP population in summer trials to 102% for percentage marketable yield, also in the NCMBP population, in the spring trials. The actual means in grower trials might vary from the data presented here, as a result of the use of different production methods (Wehner, 1995; Wehner and Miller, 1984). However, the relative differences among populations and comparisons with the check should be similar.

We were surprised that the populations performed so well against the leading gynoecious hybrids, since they consisted of genetically diverse, mostly monoecious plants. However, monoecious cultivars perform as well as near-isogenic, gynoecious cultivars in multiple-harvest trials by catching up after the first harvests (Wehner and Miller, 1985). Since the mean of each population was close to the check cultivar, Calypso, which is a predominately gynoecious hybrid, one would expect cultivars developed from the best families of each population to do better than the check. Averaged over 3 yr, two seasons, and three traits, the three populations performed about 85% as well as Calypso, with little difference among the three populations. NCH1 was a little better on the average than the other two populations, and NCMBP had the greatest gain per cycle of the three, so those two populations appear to be the most interesting for further research.

CONCLUSIONS

Of the five traits evaluated, early yield and fruit shape had the largest gains in the three populations from Cycle 0 to 9, while marketable yield had little gain. The NCMBP population had larger gains over the five traits than either NCEP1 or NCH1. Larger gains were observed for NCMBP and NCEP1 when evaluated in the selected environment (spring season) than in the nonselected environment (summer season). However, it is interesting that progress can be made for performance in a stressful environment by selecting in an elite environment. Finally, changes in the testing methods during the selection stage did not affect the gain made over cycles of recurrent selection. Since NCMBP made the greatest gains, and NCH1 had the highest mean performance for the traits evaluated, those two populations are the most interesting for future studies, and for use in developing new cultivars for processing use.

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