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Convergent–Divergent Selection for Cucumber Fruit Yield

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Abstract. **A heterogeneous cucumber (*Cucumis sativus* L.) population (mostly gynoecious) was evaluated at five locations for single-plant fruit yield at the mature-fruit stage in 1981. Seeds from the highest-yielding plants were then harvested, combined, and partitioned into five lots. Seeds were combined such that each location received only the superior genotypes from the other four locations. This procedure was continued for an additional four cycles using two types of selection: single-plant selection for fruit number at the mature-fruit stage (1981–82) and half-sib family selection at the once-over harvest stage (1983–84). In 1985, yield improvement from selection was measured by compositing the seeds of the selected plants or families from each of the four cycles and five locations and planting them at the five locations. No progress was made for total, marketable, or early yield. Percentage of culls was reduced an average of 0.7% per cycle. Genotype by environment interaction among the diverse locations may have prevented progress for yield.**

Lonnquist's convergent–divergent selection has been used successfully in maize (*Zea mays* L.) to improve yield when exercised over several production environments (Lonnquist et al., 1979). This selection scheme is intended to produce a population that is widely adapted. Although selection for fruit yield has been practiced in cucumber for more than half a century, much of the improvement in cucumber yield can be attributed to improved cultural practices and the incorporation of better levels of disease resistance. Early yield was improved by the introduction of gynoecious flowering habit (Peterson, 1960), but total multiple-harvest yield was not (Wehner and Miller, 1985). The lack of progress for increased fruiting ability in cucumber might be partially due to the small breeding effort in cucumber relative to crops such as maize or to a lack of variability for yield. Heritability for yield has been measured in several cucumber populations and is in the range of 0.17 to 0.25 (Smith et al., 1978; Strefeler and Wehner, 1986). Those results indicate that genetic variability for yield exists and is sufficient to permit progress by recurrent selection. The methods used in this study were later shown to be effective and efficient in selecting for yield. For example, single-harvest trials can be used to estimate efficiently the multiple-harvest yield in pickling (Wehner, 1986) and fresh-market (Wehner and Miller, 1984) cucumbers.

The objective of this study was to determine whether progress could be made in distinct production locations using convergent–divergent selection to improve the yield of cucumber.

Research was conducted at five locations (in order of planting time): Horticultural Crops Res. Sta., Clinton, N.C.; Campbell Inst. for Research and Technology, Napoleon, Ohio; Univ. of Wisconsin Expt. Sta., Hancock and Arlington; and Central Crops Res. Sta., Clayton, N.C.

Population tested. The population used was the Gynoecious Synthetic (Gyn. Syn.), developed by intercrossing all gynoecious pickling cucumber lines available from the United States and the Netherlands in 1978. The population was intercrossed twice before it was divided into five lots for testing and selection.

Cultural practices. The population was selected and tested in five location–season combinations: Clinton, Napoleon, Hancock, and Arlington in the spring, and Clayton in the summer. Plots were 1.5 m long in rows 0.75 to 1.5 m apart (center to center), with 30 or 40 plants each. Plots were separated at each end by alleys, and guard rows were used to surround trials. The preceding practices were shown to be optimal for these kinds of tests (Smith and Lower, 1978; Swallow and Wehner, 1986; Wehner, 1988; Wehner and Miller, 1989). Recommended cultural practices were used at the five selection and test locations (Hughes et al., 1983). Planting dates for the 4 years of selection and 1 year of testing were 13–25 May at Clinton, 24–29 May Napoleon, 29 May–11 June at Hancock, 4–14 June at Arlington, and 1–12 July at Clayton. Harvest dates were 12 June–7 Aug. at Clinton, 15 July–10 Aug. at Napoleon, 1–25 Aug. at Hancock, 8–20 Aug. at Arlington, and 19 Aug.–7 Sept. at Clayton.

The majority of plots were harvested when the 'Claypso' check plots had ≈10% oversized fruits (>51 mm in diameter), as recommended by Miller and Hughes (1969) for optimum yield in once-over harvest systems. Differences in the timing of harvest over locations resulted in absolute differences in yield over test locations, but the relative differences among families within locations were of primary interest in this study. At harvest, the number of total and cull (crooks and nubs, but not oversized) fruits was counted, as well as the number of plants in the harvested area. Total fruit number was used to estimate yield rather than fruit weight or value because of its greater stability and independence from maturity effects (Ells and McSay, 1981).

Table 1. Fruit yield of the Gynoecious Synthetic population over five selection cycles at five locations.[z]

Selection cycle	Yield (fruits per plot)			Culls (%)	Fruits per plant
	Total	Marketable	Early[y]		
0	51	38	8	37	1.4
1	50	37	8	35	1.5
2	49	38	9	34	1.4
3	49	37	9	33	1.4
4	48	37	9	33	1.4
Calypso	53	43	7	27	1.6
LSD (5%)	3	2	1	3	0.1
b values[x]	−0.5	−0.1	0.3	−0.7	0.0

[z] Data are means over five test locations, five selection locations, and five replications.
[y] Early yield is the number of oversized fruits per plot at once-over harvest (made when the check plot had ≈10% oversized fruits).
[x] Mean regressed on cycles of selection.

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Table 2. Fruit yield of the Gynoecious Synthetic population over five selection cycles at five locations.[z]

Selection location	Selection cycle	Yield (fruits per plot)			Culls (%)	Fruits per plant
		Total	Marketable	Early[y]		
Clinton	0	85	77	24	9	2.1
	1	83	75	21	9	2.1
	2	80	75	26	7	2.1
	3	81	74	25	7	2.0
	4	80	75	25	7	2.0
	Calypso	92	87	17	6	2.3
Napoleon	0	28	6	1	77	0.9
	1	27	7	2	73	0.9
	2	27	7	2	73	0.9
	3	26	8	2	71	0.9
	4	23	7	2	69	1.0
	Calypso	24	10	2	56	1.0
Hancock	0	59	49	7	17	1.6
	1	59	46	7	22	1.5
	2	53	44	7	18	1.4
	3	54	45	7	18	1.4
	4	53	44	7	18	1.3
	Calypso	64	56	6	13	1.7
Arlington	0	57	44	6	23	1.8
	1	55	43	6	22	2.2
	2	61	48	7	21	2.0
	3	57	45	6	21	1.9
	4	59	45	6	24	1.8
	Calypso	54	45	5	16	1.9
Clayton	0	26	13	3	57	0.6
	1	25	14	3	49	0.7
	2	24	14	3	51	0.6
	3	27	15	3	48	0.7
	4	25	14	3	48	0.7
	Calypso	31	19	3	43	0.8
LSD (5%)		6	5	2	6	0.2

[z] Data are means over five selection locations and five replications. Differences among treatments were not significant, $P = 0.05$.

[y] Early yield is the number of oversized fruits per plot at once-over harvest (made when the check plot had =10% oversized fruits).

Number of marketable fruits, percentage of culls, and total number of fruits per plant were calculated from the harvest data.

Population evaluation. The population was selected in each of the five locations based on single-plant performance in 1981 and 1982 and on half-sib family performance in 1983 and 1984. The selection intensity was 0.2%, 1.25%, 25%, and 25% for cycles 1 through 4, respectively. Gardner's grid selection (Gardner, 1961), which provides for increased control of field variability, was used to select single plants. Each field was divided into a grid of 250 and 100 selection blocks for selection in 1981 and 1982, respectively.

The population was tested in 1985 in the five locations by bulking the seeds from each of the cycles and locations to make 20 lots, one for each location–cycle combination. The C_0 (the original, unselected population) and a commonly grown cultivar (Calypso, a gynoecious x monoecious hybrid) were also included as checks.

Experimental design. A split-plot treatment arrangement in a randomized complete block design with five replications was used for the final evaluation of progress in selection. Whole-plots were the five test locations, and sub-plots were the 22 genotypes (4 cycles × 5 selection locations + Gyn. Syn. C_0 + 'Calypso'). Analysis of variance was used to test treatment effects. Linear regression analysis of yield on selection cycle was used to evaluate progress in selection at each location.

Selection progress. No progress was made during the four cycles of selection for total, marketable, or early yield in the Gyn. Syn. cucumber population (Table 1). Regression analysis showed a nearly zero slope for progress curves of the yield variables. We had hoped to make significant gains from the third and fourth cycles of selection because the selection techniques had been improved using experimental data gathered during the first part of the study. However, neither single-plant (cycles 1 and 2) nor small-plot (cycles 3 and 4) selection had any effect on yield. Some progress was made for percentage of culls, with an average decrease in culls of 0.7% per cycle over all locations (Table 1). However, the improvement in percentage of culls was expressed only at the North Carolina and Ohio test locations, ranging from 2% to 9% over the four cycles of selection (Table 2).

There were large differences in yield among test locations. These differences seemed to depend on the production environment (stress, temperature, soil moisture, and fertility) and the differences in harvest stage at the different locations. Harvest stage ranged from 2% oversized fruits on 'Calypso' check plots at Napoleon, Ohio, to 17% oversized fruits at Clinton, N.C. (Table 2). As a result of these differences, the mean squares for location were large compared to all other sources of variation (Table 3).

Explanations. There are at least three possible explanations for the lack of response to selection for yield: 1) the initial population lacked genetic variation for yield, 2) the method of evaluation of yield was not effective, or 3) genotype × environment interaction was significant and confounded progress for yield at one selection location with progress made at the other locations.

Explanation 1 is unlikely because increased yield through recurrent selection at one location has been reported using Gyn. Syn. C_0 as a base population (Lertrat and Lower, 1984; Nienhuis, 1982).

Explanation 2 is possible because effective yield measurement during the first 2 years may not have occurred. Single-plant selection at mature fruit stage has been shown to be of little value in estimating green stage yield in pickling cucumbers (Wehner, 1986). However, the 3rd and 4th years of selection used methods that are effective (Wehner and Miller, 1984; Wehner, 1986). Thus, although explanation 2 can be used to explain the lack of response in the first two cycles, it does not explain a lack of response in the last two cycles of selection.

The effect of genotype × environment interaction is the most attractive explanation for the observed lack of progress. Genotype × environment interaction has been found to be an important source of variation in other crops, such as maize (Comstock and Moll, 1963). In maize, progress was reported for yield when a population was selected simultaneously over different locations. However, the locations were all in the north central United States and could be considered the same climatic zone (Lonnquist et al., 1979). In contrast, locations in our study represent at least two distinct climatic zones (southeastern and north central United States). If genotype × environment interactions were an important source of variation in cucumber, it could make inter-regional selection progress difficult. In that case, progress made at one location could be offset by selection at another location.

In a North Carolina study, the genotype × environment interaction component of variance was important in total fruit number of pickling and fresh-market cucumbers grown for once-over harvest in 2 years, three seasons, and four locations (Wehner, 1987). The genotype × environment component ranged from 58% to 112% as large as the genotype component.

The existence of cultivars known as "generalists" in the United States does not indicate a lack of genotype × environment interaction. For example, 'Calypso' pickling cucumber is grown in several regions, but is not necessarily the highest-yielding cultivar in each region. Its general success relates to other superior characteristics, such as disease resistance and fruit quality.

Conclusions. Rapid progress in selecting for high yield in cucumber may depend on developing "specialists" that are adapted to

Table 3. Mean squares for test location, selection location, and cycle for the Gynoecious Synthetic population.

Source of variation	Degrees of freedom	Yield (fruits per plot)			Culls (%)	Fruits per plant
		Total	Marketable	Early[z]		
Whole plot						
Replication	4	97^{NS}	265^{NS}	44^{NS}	953^{NS}	0.11^{NS}
Test location (T)	4	55,604**	73,112**	8065**	66,988**	37.44**
Error	16	229	146	47	535	0.37
Sub-plot						
Selection location (S)	4	108^{NS}	98^{NS}	2^{NS}	135^{NS}	0.27^{NS}
Cycle (C)	3	57^{NS}	10^{NS}	32^{NS}	122^{NS}	0.28^{NS}
S × C	12	170^{NS}	100^{NS}	32**	151^{NS}	0.26^{NS}
T × S	16	116^{NS}	74^{NS}	5^{NS}	110^{NS}	0.14^{NS}
T × C	12	113^{NS}	36^{NS}	21^{NS}	47^{NS}	0.16^{NS}
T × S × C	48	115^{NS}	84^{NS}	20*	92^{NS}	0.22^{NS}
Error	395	114	85	13	111	0.19

[z] Early yield is the number of oversized fruits per plot at once-over harvest (made when the check plot had ≈10% oversized fruits).

**,*,NS Mean square significant at $P = 0.01$, 0.05, or not significant, respectively.

a particular region of the United States, rather than trying to develop "generalists" using methods like convergent–divergent selection. Neither approach is presently being taken, because most cucumber breeding programs in the United States are regional in their methods of selection, but their goals are to develop "generalists". In order to achieve maximum yield at a particular location, which locations can be covered (constituting an efficient selection region) by each breeding program working at its selection location needs to be determined.

Literature Cited

Comstock, R.E. and R.H. Moll. 1963. Genotype–environment interactions, p. 164–196. In: W.D. Hanson and H.F. Robinson (eds.). Statistical genetics and plant breeding. NAS–NRC Publ. 982.

Ells, J.E. and A.E. McSay. 1981. Yield comparisons of pickling cucumber cultivar trials for once-over harvesting. HortScience 16:187–189.

Gardner, C.O. 1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Sci. 1:241–245.

Hughes, G.R., C.W. Averre, and K.A. Sorensen. 1983. Growing pickling cucumbers in North Carolina. North Carolina Agr. Ext. Serv. AG-315.

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

Lonnquist, J.H., W.A. Compton, J.L. Geadelmann, F.A. Loeffel, B. Shank, and A.F. Troyer. 1979. Convergent-divergent selection for area improvement in maize. Crop Sci. 19:602–604.

Miller, C.H. and G.R. Hughes. 1969. Harvest indices for pickling cucumbers in once-over harvest systems. J. Amer. Soc. Hort. Sci. 94:485–487.

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

Peterson, C.E. 1960. A gynoecious inbred line of cucumbers. Michigan Agr. Expt. Sta. Quart. Bul. 43:40–42.

Smith, O.S. and R.L. Lower. 1978. Field plot techniques for selecting increased once-over harvest yields in pickling cucumbers. J. Amer. Soc. Hort. Sci. 103:92–94.

Smith, O.S., R.L. Lower, and R.H. Moll. 1978. Estimates of heritabilities and variance components in pickling cucumbers. J. Amer. Soc. Hort. Sci. 103:222–225.

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.

Wehner, T.C. 1986. Efficiency of 3 single-harvest trials for evaluation of yield in pickling cucumber. Euphytica 35:493–501.

Wehner, T.C. 1987. Genotype–environment interaction for cucumber yield in 23 North Carolina environments. Cucurbit Genet. Coop. Rpt. 10:25–26.

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

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. 1989. Effect of different genotypes in border rows on yield of pickling and fresh-market cucumbers in multiple-harvest trials. HortScience (In press.)