Euphytica 35 (1986) 89–96

EFFICIENCY OF EARLY GENERATION TESTING IN PICKLING CUCUMBER

DAVID B. RUBINO and TODD C. WEHNER

Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695–7609, USA

Received 1 March 1985

INDEX WORDS

Cucumis sativus, pickling cucumber, selection methods, yield, earliness, early testing, fruit quality, vegetable breeding.

SUMMARY

Early testing was evaluated for efficiency as a procedure for selecting among lines for yield (total and marketable fruit number), earliness and fruit quality (shape, color and seedcell size) in 24 sets of lines developed at random from a pickling cucumber (*Cucumis sativus* L.) population. The advantage of early testing was calculated using the regression of S_6 on S_1 performance. The amount of effort required in worker-hours and the theoretical gain from selection were also considered in estimating the advantage of early testing. Early testing for specific combining ability and for general combining ability was up to 2.05 times as efficient as late testing for total yield, and up to 2.29 times as efficient as late testing for earliness. Early testing was not efficient for selection for the fruit quality traits measured, nor for inbred performance *per se*.

INTRODUCTION

The optimum stage for testing lines during the inbreeding process for yield has been investigated extensively for several important crops. However, cucumber (*Cucumis sativus* L.) has not been among those studied. Cucumber lines are sometimes inbred to the S_6 generation or further without testing before they are evaluated for inbred and hybrid performance. Since those lines arise from the entire distribution of the S_0 population, many poor lines must be discarded following testing. With early testing, lines are evaluated after just 1 generation of inbreeding. Therefore, if the performance of lines could be predicted accurately in an early generation, time, space, money and labor would be saved by concentrating only on those lines with the potential for a high level of performance.

The early testing procedure was first suggested by JENKINS (1935), who reported that early testing of maize (*Zea mays* L.) lines would be effective after the second generation of inbreeding. He found that, for 9 out of 11 'Iodent' lines, yields in progenies from top crosses after the sixth and eighth generation of inbreeding did not differ significantly from those after 2 generations of inbreeding. Other research has also supported the use of early testing in maize. SPRAGUE (1946) reported that S_0 plants

Paper No. 9505 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC 27695–7601.

with high combining ability transmitted the characteristic to their S_1 progeny. LONNQUIST (1950) found that S_1 lines, with high combining ability resulted in S_4 lines with high combining ability, and that S_1 lines with low combining ability resulted in S_4 lines with low combining ability. In another study of maize, HALLAUER & LOPEZ-PEREZ (1979) reported that, although correlations between S_1 and S_8 testcrosses were too small for predictive purposes, the highest yielding S_8 testcrosses generally came from the same lines as the higher yielding S_1 testcrosses.

Some maize researchers have expressed doubt about the usefulness of early testing. RICHEY (1945, 1947) suggested that testing and selection for combining ability in the S_2 and S_3 generations of maize lines would eliminate potentially valuable lines and that the expenditure of considerable effort outweighed the very small gain from early testing. It has been suggested (HALLAUER & MIRANDA, 1981), however, that some form of early testing is included in most maize breeding programs regardless of the intention of the plant breeder.

The objective of this experiment was to determine the value of early testing in the detection of potentially superior cucumber lines. Accuracy of prediction of S_6 performance from S_1 performance using regression, theoretical gain from selection, and labor requirement for each method were considered in estimating the efficiency of early (S_1) vs. late (S_6) testing.

MATERIALS AND METHODS

Line development. The reference population for this study was the North Carolina Medium Base Pickle (NCMBP) population, which was formed by intercrossing several hundred pickling cucumber lines (adapted cultivars, breeding lines, large-fruited lines, compact- and determinate-vined lines, multiple-fruiting *Cucumis sativus* var. *hardwickii* (ROYLE) KITAMURA lines, and several hundred lines from the USDA plant introduction collection held at Ames, Iowa). The initial lines were crossed in various combinations for different experiments before compositing and intercrossing in 1977, 1978 and 1980 to form the NCMBP population. The NCMBP population was chosen because it represents diverse, but adapted pickling cucumber germplasm.

Fifty open-pollinated plants from NCMBP were self-pollinated for 6 generations to produce 24 sets of inbred lines. Generations S_1 and S_6 of each set were then cross-pollinated with 2 testers, NCMBP and Gy 14. Plants from the original population (NCMBP) were used as one tester to evaluate early testing for testcross performance (general combining ability) of the lines. The other tester (Gy 14, a gynoecious inbred) was included to evaluate early testing for hybrid performance (specific combining ability). Early testing for inbred performance per se was also evaluated using all 6 generations (S_1, S_2, ..., S_6).

Field work. Seeds of the hybrid and inbred sets were planted 11 May (spring test) and 13 July 1983 (summer test) at the Horticultural Crops Research Station near Clinton, N.C. using a split-plot design with 2 replications. Whole plots were the 3 testers (crosses with NCMBP, crosses with Gy 14, and the inbreds per se), subplots were the 24 sets, and sub-subplots were the 6 generations (S_1 to S_6). Thus, one whole plot consisted of 24 sets with the 6 generations crossed to the original population (S_1 ×

NCMBP, $S_2 \times$ NCMBP, ..., $S_6 \times$ NCMBP). The second whole plot was similar, but with Gy 14 as a parent in the cross instead of NCMBP. The third whole plot consisted of the 24 sets of the 6 generations tested directly as lines per se. A stand of 15 plants per 1.5 m plot (61750 plants/ha) was maintained with standard cultural practices.

Plots were evaluated in the spring test 49 to 63 days after planting, as they reached the stage where about 75% of the fruits were oversized. All plots in the summer test were evaluated 48 days after planting, when 'Calypso' check plots reached the stage where about 75% of the fruits were oversized. MILLER & HUGHES (1969) recommended that pickling cucumbers be harvested when at least 10% of the fruits were oversized, for optimum yield in a once-over harvest system. However, we wanted to wait long enough that most of the plots would have some oversized fruits, even if they were late-maturing. Total fruit number and marketable fruit number (total fruit number minus number of culls) per plot were measured. Thus, marketable fruit number included oversized fruits that were not culls. Technically, oversized fruits are not marketable, but we were maily interested in those that were free of defects, since oversized fruits could be harvested earlier to make them marketable. Earliness was estimated as the number of days to harvest for the spring test, and by counting the number of oversized (over 51 mm diameter) fruits per plot for the summer test. Fruit shape, seed cell size, and color were rated on a 1 to 9 scale with 1 = poor, 5 = average, and 9 = excellent.

Data analysis. In order to measure the efficiency of early testing for each trait, S_6 testcross performance was regressed on S_1 testcross performance, S_6 hybrid performance was regressed on S_1 hybrid performance, and S_6 inbred performance was regressed on the performance of S_1 through S_5 inbred generations. All generations of S_1 through S_5 inbreds were tested for ability to predict S_6 line performance. That was done to determine how far to inbreed before testing in order to provide for efficient development of high yielding S_6 lines. Also, the advantage of S_1 line testing over testing the S_6 generation was calculated using a modified equation for gain from selection. In order to account for differences in gain from selection (Gs_1/Gs_6), amount of effort required for each of the testing methods (worker-hrs$_6$/ worker-hrs$_1$) and the ability of early testing to predict results of late testing ($b_{6.1}$), the advantage of S_1 over S_6 line testing ($A_{1/6}$) was estimated as follows.

$$A_{1/6} = \frac{Gs_1}{Gs_6} \times b_{6.1} \times \frac{\text{worker-hrs}_6}{\text{worker-hrs}_1}$$

where Gs = the gain from selection, $Gs_1 = k_1\, \sigma^2_{G1}/\sigma_{P1}$, and $Gs_6 = k_6\, \sigma^2_{G6}/\sigma_{P6}$, k_1 and k_6 = the standardized selection differentials for S_1 and S_6 line testing, respectively ($k_1 = k_6$), σ^2_{G1} and σ^2_{G6} = the genetic variances among S_1 and S_6 lines, respectively, σ_{P1} and σ_{P6} = the phenotypic standard deviations for S_1 and S_6 lines, respectively, $b_{6.1}$ = the coefficient for the regression of the S_6 on the S_1 generation, and worker-hrs$_1$ and worker-hrs$_6$ = the estimated labor (in worker-hrs) required for S_1 and S_6 line testing, respectively.

Advantages were estimated for a selection intensity of 10%, and for once-over harvest using Paraquat to defoliate the plants. The Paraquat method was recommended

Table 1. Coefficients (b) for the regressions of S_6 on S_1 through S_5 inbred performance per se for fruit yield and fruit quality traits in cucumber tested in 2 seasons (spring and summer, 1983).

Regression[1]	Yield (number of fruit/plot)			Fruit quality score[3]		
	total	marketable	earliness[2]	shape	seedcell size	color
			spring test			
$b_{6.1}$	0.15	0.43	0.09	0.22	0.00	0.82**
$b_{6.2}$	0.05	0.16	0.48	0.58**	0.39	0.67**
$b_{6.3}$	0.66**	0.60**	0.91*	0.77**	0.66**	0.69**
$b_{6.4}$	0.78**	0.58	0.29	0.59**	0.63*	0.61**
$b_{6.5}$	0.54	0.67	0.51	0.74**	0.66**	0.73**
			summer test			
$b_{6.1}$	0.52	0.36	0.76**	0.26	0.17	0.21
$b_{6.2}$	0.26	0.21	0.44*	0.45	0.33	0.22
$b_{6.3}$	0.69**	0.41	0.60**	0.45	0.00	0.09
$b_{6.4}$	0.70**	0.48*	0.62**	0.38	0.12	0.14
$b_{6.5}$	0.82**	0.70**	0.74**	0.95**	0.00	0.26

[1] Notation: $b_{6.1}$ is the regression of S_6 line performance on S_1 line performance, etc.
[2] Earliness is the number of days to harvest (spring), or the number of oversized fruits (over 51 mm diameter) per plot at harvest (summer).
[3] Quality scored 1 to 9 (1 = poor, 5 = average, 9 = excellent).
*, ** b significantly different from zero at the 5 and 1% levels, respectively.

by WEHNER et al., 1984 to reduce the labor requirement for evaluating fruit yield in plots harvested once-over.

For this study, it was assumed that both S_1 and S_6 line testing required 6 generations of self-pollination for each one retained in the breeding program (since S_1 lines must be advanced to S_6 before final testing). Further, S_1 line testing requires an additional field test for the early test in the S_1 generation. We estimated that a single generation of self-pollination required 0.1223 worker-hours per line from planting through harvest. To that was added 0.1443 worker-hours for field testing, harvesting and data handling (WEHNER & SWALLOW, 1984).

RESULTS AND DISCUSSION

The ability to predict S_6 performance per se for the fruit yield generally increased as testing was performed in later generations, starting with S_1 and ending with S_5 (Table 1). Clear exceptions to that trend were total and marketable yield in the S_2 generation for both spring and summer tests, where the regression coefficients were lower than expected. It may have been the result of poor seed production conditions for that generation, since each generation for the inbred test was produced together at one time in the greenhouse. Also, earliness and the 3 fruit quality traits did not fit the trend for total and marketable yield. For the spring test, the regression coefficient for earliness was significant (5% level) only for the S_3 generation, but nearly all regression coefficients were significant for fruit quality. However, for the summer test, the regression coefficients for earliness were greater than 0.40 for all generations, whereas shape was the only fruit quality trait with a significant regression coefficient.

Table 2. Coefficients (b) for the regressions of S_6 data on S_1 data for inbred, hybrid, and testcross performance for fruit yield and fruit quality traits in cucumber tested in 2 seasons (spring and summer, 1983).

Trait	Inbred	Hybrid	Testcross
	spring test		
Yield			
Total (number of fruits/plot)	0.15	0.32	0.16
Marketable (total-cull fruits/plot)	0.43	0.32*	0.14
Earliness (number of days to harvest)	0.09	0.25	0.28
Quality[1]			
Shape	0.22	0.12	0.00
Seedcell size	0.00	0.22	0.18
Color	0.82**	0.00	0.01
	summer test		
Yield			
Total	0.52	0.41**	0.22
Marketable	0.36	0.45**	0.18
Earliness (number of oversized fruits/plot)	0.76**	0.43**	0.59**
Quality			
Shape	0.26	0.29	0.00
Seedcell size	0.17	0.22	0.02
Color	0.21	0.23	0.00

[1] Quality scored 1 to 9 (1 = poor, 5 = average, 9 = excellent).
*, ** b significantly different from zero at the 5 and 1% levels, respectively.

The regression coefficients for S_6 on S_1 inbred line performance per se were not significant for any trait measured except fruit color in the spring test and earliness in the summer test (Table 2). Thus, there was no significant ability to predict S_6 performance from S_1 performance for total and marketable fruit yield and for fruit shape and seedcell size. The regression coefficients indicated that, in the summer test, early testing for specific combining ability (hybrid performance) was good for yield (total and marketable) and earliness, but not for fruit quality (shape, color, and seedcell size). For general combining ability (testcross performance), the regression coefficients indicated good prediction ability only for earliness in the summer test.

In all cases but one, the results of early testing (S_1 line testing) failed to predict those of late testing (S_6 line testing) for the fruit quality traits (shape, color, and seedcell size). In fact, the ability to predict S_6 performance from early generations for the fruit quality traits was extremely poor. The efficiency of early testing will depend somewhat on the magnitude of the heritability for the trait being considered. Heritabilities of 0.17 for fruit number, 0.25 for fruit color, and 0.49 for carpel wall thickness (similar to seedcell size) were reported for a monoecious pickling cucumber population (SMITH et al., 1978). It is puzzling that the traits with low heritability were the ones where early testing was most efficient.

Early testing for the yield traits was most efficient when lines were tested as hybrids made by crossing with Gy 14. A similar trend resulted when the advantage of S_1 line testing over S_6 line testing was calculated (Table 3). There was little or no advantage of early testing for inbred performance per se for any of the traits measured except

Table 3. Advantages[1] of S_1 over S_6 line testing for inbred, hybrid and testcross performance for fruit yield traits and fruit quality traits in cucumber tested in 2 seasons (spring and summer, 1983).

Trait	Inbred	Hybrid	Testcross
	spring test		
Yield			
Total (number of fruits/plot)	0.00	2.05	0.00
Marketable (total-cull fruits/plot)	0.00	2.48	0.17
Earliness (number of days to harvest)	0.04	0.47	1.11
Quality[2]			
Shape	0.26	0.00	0.00
Seedcell size	0.00	0.10	0.10
Color	1.81	0.00	0.05
	summer test		
Yield			
Total	0.00	1.44	1.61
Marketable	0.24	1.80	1.40
Earliness (number of oversized fruits/plot)	1.10	1.04	2.29
Quality			
Shape	0.34	0.00	0.00
Seedcell size	0.36	0.38	0.04
Color	0.00	0.79	0.00

[1] Advantage = $(Gs_1 \times b_{6.1} \times \text{worker-hrs}_6)/(Gs_6 \times \text{worker-hrs}_1)$ for a selection intensity of 10% of lines retained, and once-over harvest using Paraquat to defoliate the plants (see text for explanation of terms).
[2] Scored 1 to 9 (1 = poor, 5 = average, 9 = excellent).

for fruit color in the spring test, where there was an 81% advantage, and for earliness in the summer test, where there was a 10% advantage.

Early testing for specific combining ability (hybrid performance) was advantageous for total and marketable yield, but not for earliness. For total and marketable yield, early testing was about 2 (spring) or 1.5 (summer) times as efficient as S_6 line testing, respectively. Early testing for the fruit quality traits was not efficient when testing hybrids made with Gy 14. For the testcrosses, early testing was advantageous for the yield traits (total and marketable) and for earliness in the summer test, being 1.4 to 2.3 times as efficient as late testing. However, early testing for general combining ability was not efficient for the fruit quality traits.

The data were used to determine how many elite S_6 lines would be retained using early testing at several selection intensities (Table 4). Actual selection among the 24 sets of lines provided encouraging results. In this case, early testing for inbred performance was effective for all of the yield and quality traits, providing 19 to 30% success in identifying the top lines. Early testing for hybrid performance was about as effective as inbred testing, with 16 to 29% success, and early testing for testcross performance was less useful with 14 to 27% success. This does not match the results for advantages calculated for early testing (Table 3) because they included measures of heritability which tended to have low values in this study.

Thus, early testing can be used effectively in some cases to evaluate lines in the S_1 generation for performance in the S_6 generation. Early testing was best for evaluating hybrid (specific combining ability) performance for yield traits. It was not as effec-

Table 4. The number of the best S_6 cucumber lines retained by selection of the best 2, 4 or 8 S_1 lines of the 24 tested using performance of the inbred, hybrid or testcross tested in 2 seasons (spring and summer, 1983).

	Inbred			Hybrid			Testcross		
Trait	2	4	8	2	4	8	2	4	8
			spring test						
Yield									
Total[1]	0.0	1.0	2.0	0.0	1.0	2.0	1.0	1.0	4.0
Marketable[2]	0.0	1.0	1.0	0.0	0.0	2.7	1.0	1.0	3.0
Earliness[3]	1.0	1.5	2.7	0.5	1.0	2.5	1.0	1.5	4.0
Quality[4]									
Shape[4]	0.0	0.0	2.3	0.0	0.5	2.0	0.0	1.0	3.0
Seedcell size	0.0	1.0	2.3	0.0	1.0	2.0	0.0	1.0	1.5
Color	0.0	1.0	2.5	0.0	1.0	1.5	0.0	0.0	1.5
Mean & Success[5]		19			16			27	
			summer test						
Yield									
Total	0.0	1.0	6.0	0.0	1.0	3.0	0.0	0.0	1.0
Marketable	0.0	1.0	5.0	0.0	1.0	4.0	0.0	0.0	0.7
Earliness	0.0	2.0	4.0	0.0	1.0	3.0	0.0	0.0	2.5
Quality									
Shape	1.0	1.0	3.0	0.0	1.0	4.1	0.0	0.0	0.7
Seedcell size	1.0	1.0	2.7	1.0	1.0	2.0	1.0	2.0	3.1
Color	0.0	0.0	1.8	2.0	2.0	3.6	0.0	1.0	1.4
Mean & Success		30			29			14	

[1] Number of fruits/plot.
[2] Total-cull fruits/plot.
[3] Number of days to harvest (spring), or number of oversized fruits/plot (summer).
[4] Scored 1 to 9 (1 = poor, 5 = average, 9 = excellent).
[5] Average % of lines retained by S_1 line testing that were also retained by S_6 line testing over the 3 selection intensities (2, 4 and 8 out of 24) for all traits tested.

tive in evaluating fruit quality traits. In summary, a program can be designed that makes effective use of early testing for improving yield and quality traits of cucumber lines. But late testing can also be used effectively, making it a choice of convenience for the plant breeder.

ACKNOWLEDGEMENTS

Thanks to Rufus R. Horton, Jr. for technical assistance.

REFERENCES

HALLAUER, A. R. & E. LOPEZ-PEREZ, 1979. Comparisons among testers for evaluating lines of corn. Proc. Annu. Hybrid Corn Ind. Res. Conf. 34: 57–75.

HALLAUER, A. R. & J. B. MIRANDA, 1981. Quantitative genetics in maize breeding. Iowa State University Press, Ames, Iowa.

JENKINS, M. T., 1935. The effect of inbreeding and of selection within inbred lines of maize upon the hybrids made after successive generations of selfing. Iowa State College J. Sci. 3: 429–450.

LONNQUIST, J. H., 1950. The effect of selection for combining ability within segregating lines of corn. Agron. J. 42: 503–508.

MILLER, C. H. & G. R. HUGHES, 1969. Harvest indices for pickling cucumbers in once-over harvested systems. J. Amer. Soc. Hort. Sci. 94: 485–487.

RICHEY, F. D., 1945. Isolating better foundation inbreds for use in corn hybrids. Genetics 30: 455–471.

RICHEY, F. D., 1947. Corn breeding: gamete selection, the Oenothera method, and related miscellany. J. Amer. Soc. Agron. 39: 403–412.

SMITH, O. S., R. L. LOWER & R. H. MOLL, 1978. Estimates of heritabilities and variance components in pickling cucumber. J. Amer. Soc. Hort. Sci. 103: 222–225.

SPRAGUE, G. F., 1946. Early testing of inbred lines of corn. J. Amer. Soc. Agron. 38: 108–117.

WEHNER, T. C., T. J. MONACO & A. R. BONNANO, 1984. Chemical defoliation of cucumber vines for simulation of once-over harvest in small-plot yield trials. HortScience 19: 671–673.

WEHNER, T. C. & W. H. SWALLOW, 1984. Optimum plot size for once-over harvest of pickling and fresh-market cucumbers. Cucurbit Genet. Coop. Rpt. 7: 35–36.