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SINGLE AND 3-WAY CROSS HYBRIDS OF PICKLING CUCUMBER

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SINGLE AND 3-WAY CROSS HYBRIDS OF PICKLING CUCUMBER

By

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ABSTRACT

SINGLE AND 3-WAY CROSSES OF PICKLING CUCUMBER

By

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Development of high-yielding cucumber cultivars adapted to once-over mechanical harvest has received considerable attention in breeding programs. A highly female F_1 with uniform sex expression is desirable because of the concentration of fruit set necessary for once-over mechanical harvest. However, commercial hybrid cultivars are generally termed predominantly female (PF), with variable percentages of staminate and female flowers. The present research was undertaken to compare single with 3-way cross hybrids; and also, androecious with monoecious pollen parents for their effects on sex expression and subsequent yield; and finally, to estimate the genetic variance components in pickling cucumbers under open-field conditions for sex expression and yield.

The significant correlations between percent female nodes and marketable yield were 0.34 for single cross and 0.45 for 3-way cross hybrids. The use of androecious pollen parents for hybrid cultivars resulted in superior yielding hybrids as compared to the monoecious lines currently being used as pollen parents for commercial hybrid seed production. It was speculated that 3-way cross

might be used in place of single cross hybrid cultivars for the production of pickling cucumbers for once-over harvest.

Additive effects of genes (general combining ability) were found to be relatively more important than non-additive effects (specific combining ability) for both percent female nodes and yield. It may be possible to predict the best 3-way combination for yield from the general performance of the parents in single cross combinations. Therefore, cucumber breeders might develop high yielding cultivars based on high general combining ability for yield in parental arrays.

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Guidance Committee:

This thesis has been condensed into the format suited and intended for publication in the Journal of the American Society for Horticultural Science.

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SINGLE AND 3-WAY CROSSES OF PICKLING CUCUMBER

I. COMPARISON OF SINGLE AND 3-WAY CROSSES OF HYBRID PICKLING CUCUMBER FOR FEMALE EXPRESSION AND YIELD IN ONCE-OVER HARVEST.

ABSTRACT

An array of single and 3-way cross hybrids of pickling cucumbers were evaluated over two years under open-field conditions for female expression and yield. The significant correlations between percent female nodes and marketable yield were 0.34 for single cross and 0.45 for 3-way cross hybrids. Highest yields were obtained from the gynoecious by androecious, gynoecious by hermaphrodite, and gynoecious by hermaphrodite by androecious parental combinations, in that order, on the basis of either total or marketable fruits per plant. Androecious and monoecious pollen parents were compared for their influence on the yield and female expression of their hybrid combinations. Androecious lines were superior pollen parents as their hybrids were more female and produced higher yields than those with monoecious pollen parents. The possible use of any of the above mentioned parental sex combinations; and the use of 3-way crosses as hybrid cultivars in place of conventional single crosses of gynoecious by monoecious, for the production of pickling cucumbers for once-over mechanical harvest is suggested.

INTRODUCTION

Pickling cucumber production in Michigan was estimated at an on-farm value of $15 million for 1978 (USDA Statistical Reporting Service). Most of the crop is produced for once-over mechanical harvest (USDA Statistical Reporting Service). Production of pickling cucumbers for mechanical harvest differs greatly from that for hand-harvest (8). The entire crop is harvested when the greatest number of fruits is judged marketable (6). Thus, the success of once-over mechanical harvest is based on inherent yield potential and uniformity which in turn depends upon many factors including the cultivar, environment and management (7, 8). The average yield of pickling cucumber by once-over mechanical harvest is respectable at 193 bu/A (USDA Statistical Reporting Service), but the yield potential is likely higher. An arbitrary goal of 400 to 600 bu/A of seeded pickling cucumber by once-over harvesting has been speculated by various researchers.

Female expression of hybrid varieties is an important economic trait, as a high concentrated fruit-set is needed for once-over mechanical harvest. Commercial hybrid cultivars are predominantly female (PF) with various percentages of staminate and pistillate flowers. Improvement in the percentage and stability of pistillate flowering (femaleness) of these hybrids under field conditions should subsequently improve the uniformity of fruit-set and yield for once-over harvest. Two possibilities have been put forward to enhance the "femaleness" of cultivars as compared to the current PF hybrid cultivars. Recent attention focused on the use of hermaphroditic, bisexual flowers only, (9, 13) and androecious, only male flowers, (14) lines, in place of the commonly used monoecious lines (10, 12), for hybrid seed production of pickling cucumber. Compared to monoecious, androecious pollen parents usually produced hybrids with a higher percent of gynoecious (female) plants (14). It is not known whether all-female, gynoecious cultivars would yield higher than the PF cultivars used for once-over harvest, or if increased femaleness would be necessarily associated with subsequent increased yield.

The objectives of this study were to compare single and 3-way cross hybrids of pickling cucumbers; to evaluate androecious and monoecious pollen parents for their effects upon hybrid sex expression and subsequent yield; and to determine the association of sex with yields from a hybrid array for once-over harvest.

MATERIALS AND METHODS

Plant materials

An array of parental lines was selected from publically released and Michigan State University (MSU) germplasm (Table 1). In January 1978, appropriate stock seeds were sent to Linda Vista near Cartago, Costa Rico, to produce all the hybrid seeds (Table 2) for experimental purposes. Plants were grown using standard cultural practices in plastic houses with screened sides to exclude pollinating insects; seeds were produced by hand-pollination.

Field trials

Seeds were sown at the Clarksville Horticultural Experiment Station (near Grand Rapids, MI.) in a sandy loam soil during the 1978 and 1979 growing seasons. The plots were arranged in a partially balanced triple lattice design. Each plot was 6 m long on a 4-row flat bed with 45 cm between rows. The seedlings were blocked to 30 cm between plants in the row, which approximated 65,000 plants per hectare. Standard cultural practices (8) were used including sprinkler irrigation and bees for pollination. The seed lots of single crosses with '5804A', germinated very poorly; and therefore, these plots were eliminated from the data analysis.

A random sample of 12 plants per plot was classified for sex expression by recording the sex of individual flowers on the first

TABLE 1.--Parental lines of pickling cucumber used to produce an array of single and 3-way cross hybrids.

Sex phenotype	Parental line	Source	Status	Origin
Gynoecious	Gy14	Clemson Univ.	Released	Gy3 x SMR18
	368G	MSU	Experimental	Gy3 x (713-5 x(35G x "Spotvrige"))
	551F	Cornell Univ.	Released	MSU713-5 x SR551
Hermaphrodite	661H	MSU	Experimental	SC40A x MSU7154H
	669H	MSU	Experimental	MSU844G x MSU4108H
	319H	MSU	Experimental	SC40A x MSU7172H
	581H	MSU	Experimental	(MSU394G x 4108H)
Monoecious	SC36A	Clemson Univ.	Experimental	Unknown
	SC38A	Clemson Univ.	Released	(Gy3 x SMR18) x SC587
	316M	MSU	Experimental	MSU9402 x SC 23
Androecious	5802A	MSU	Experimental	MSU394G x 1A2
	5803A	MSU	Experimental	MSU394G x 1A1
	5804A	MSU	Experimental	Tablegreen 68G x 1A3

TABLE 2.--Hybridization for single and 3-way cross hybrids of pickling cucumber to test for femaleness and yield in once-over harvest system.

Parental sexes of crosses	Type of cross	Sex of hybrid	No. hybrids
Single cross hybrids			
Gynoecious x Hermaphrodite	G x H	Gynoecious	12
Gynoecious x Androecious	G x A	Predominantly female	9
Gynoecious x Monoecious	G x M	Predominantly female	9
Three-way cross hybrids			
(Gynoecious x Hermaphrodite) x Androecious	(G x H) x A	Predominantly female	36
(Gynoecious x Hermaphrodite) x Monoecious	(G x H) x M	Predominantly female	36
		GRAND TOTAL	102

10 nodes of the main runner. Nodes were classified as females when they developed either pistillate flowers or mixed pistillate and staminate flowers (functionally female) on the same node. The other two classes were male or blind nodes which have no potential to bear fruit.

Individual plots were hand-harvested when approximately 10% of the fruits by weight were judged over-sized (> 5.1 cm diameter) to estimate once-over harvest yields. This grade size distribution was suggested to be the optimum harvest-time for once-over harvest (6, 7). Since the time required for 10% over-sized was not uniform, each plot for a given hybrid entry was harvested individually.

The fruits were then size-graded according to PCIC[3/] standards as follows:

Grade No.	1	2	3	4
Fruit diam. (cm)	< 2.7	2.7-3.8	3.8-5.1	> 5.1

The number and weight of each grade were recorded for each plot.

The data were statistically analyzed using plot yields adjusted to a per plant basis. Homogeneity of the variances over years was tested by using a two-tailed F test (16) and found homogeneous; therefore, data were pooled over the two years.

[3/]Pickling Cucumber International Committee, St. Charls, IL 60174.

RESULTS AND DISCUSSION

The interaction of year with many of the parental lines and hybrids was significant (Table 3) for sex expression and for total and marketable number of fruits per plant. The test of homogeneity for variances was not significantly different; therefore, the data were averaged over the two years of study. The hybrids of gynoecious (G) by hermaphroditic (H) crosses were stable from year to year for sex expression as measured by percent female nodes. This agreed with previous works (2, 5, 9, 13) which concluded that the use of hermaphroditic pollen parents improved and stabilized the gynoecious expression of hybrids with gynoecious seed parents. The parental gynoecious and hermaphroditic lines were also stable across years, although more variation was observed for gynoecious parents as compared to their hybrids with hermaphroditic pollen parents (Table 3).

Estimation of yield by weight is biased by the time-of-harvest due to rapid changes in fruit size and weight; and most strongly by the proportion of over-sized, unmarketable fruits. Accordingly, yield was estimated by the number of fruits per plant as suggested previously (15) for once-over harvest yields. However, we did find a correlation of 0.74 between total fruit number and total weight of fruits per plant and 0.77 between marketable fruit number and marketable weight of fruits per plant. These correlations were highly significant, probably due to the timeliness of the harvest

TABLE 3.--ANOVA for the effect of year on femaleness and yield of pickling cucumber for once-over harvest.

Source of variation[z/]	d.f.	Mean square[y/] Sex expression	Total fruit/plant (No)	Marketable fruits/plant (No)
G x H F_1's	11	10.832	1.483**	1.434**
Year	1	78.648	0.332	1.456**
G x H F_1's x Year	11	10.627	1.514**	1.391**
G x A F_1's	5	643.635**	4.930**	4.082**
Year	1	11392.921**	8.054**	12.005**
G x F_1's x Year	5	768.460**	1.430**	1.445**
G x M F_1's	8	1346.053**	0.527**	0.443*
Year	1	24257.266**	2.279**	6.468**
G x M F_1's x Year	8	1234.158**	0.879**	0.910**
(G x H) x A F_1's	35	1018.885**	0.934**	0.948**
Year	1	16079.595**	6.222**	10.700**
(G x H) x A F_1's x Year	35	549.262**	0.844**	0.685**
(G x H) x M F_1's	35	1295.076**	0.791**	0.969**
Year	1	67478.479**	32.321**	45.426**
(G x H) x M F_1's x Year	35	836.852**	0.366**	0.428**
G	2	112.287	0.098	0.264
Year	1	2.571	1.939**	1.475**
G x Year	2	1.926	1.208**	0.858**
H	3	14.071	15.754**	28.033**
Year	1	2.299	2.991**	10.147**
H x Year	3	22.582	3.165**	1.169**
M	2	215.083**	1.900**	0.970**
Year	1	7.661	2.534**	0.739**
M x Year	2	219.493**	1.003**	0.108**
Pooled error	450	41.955	0.207	0.175

z/ G = gynoecious; H = hermaphrodite; A = androecious; M = monoecious
y/ * = significant at 5% level; ** = significant at 1% level.

of individual plots according to their size grade distribution; i.e., 10% over-sized by weight (6).

Among the array of parental means for yield and associated traits (Table 5) gynoecious lines exhibited the highest percent female nodes (94%) as compared to monoecious, M, (12%) and hermaphroditic (0%, only bisexual nodes) parental lines. Of course, androecious (A) lines bear only staminate flowers with no pistillate flowers. The means of gynoecious and monoecious parental lines did not differ for total yield, but there was a significant difference for marketable number of fruits per plant (Table 4).

Single cross hybrids

Hybrids of G x H crosses produced the highest percent female nodes (Table 5) and were phenotypically stable for gynoecious expression as the difference between years was not significant. However, all other parental sex combinations used for hybrids were significantly different over years for percent of female nodes. The differences for yield between the hybrids made by the parental crosses of G x H, G x A, and G x M were significant (Table 4). The first years means for yield, both total and marketable, were highest for G x H hybrids. However, the G x A hybrids outyielded the other two sets of single cross hybrids in the second year. Overall, the G x A hybrids were higher yielding than either G x H or G x M hybrids. Regression analysis calculated a significant correlation coefficient of 0.25 between percent pistillate nodes and total yield and of 0.34 between the former and marketable yield. The higher correlation of

TABLE 4.--ANOVA for effect of hybrid cross on femaleness and yield of pickling cucumber for once-over harvest.

Source of variation[z]	df	Mean square[y] Female nodes (%)	Total fruit/plant (No)	Marketable fruit/plant (No)
Between				
G parents	2	224.58	0.20	0.53
M Parents	2	430.17**	3.80**	1.94**
Single crosses	2	25100.24**	21.80**	17.21**
3-way crosses	1	9111.65**	32.29**	46.10**
G vs. M	1	369396.10**	0.02	1.40*
G vs. G x H	1	402.18**	23.36**	27.42**
G vs. G x A	1	7649.24**	48.93**	34.12**
G vs. G x M	1	14195.59**	5.94**	3.83**
G vs. (G x H) x A	1	6280.46**	22.89**	22.05**
G vs. (G x H) x M	1	13616.39**	6.53**	4.13**
M vs. G x H	1	311135.48**	14.96**	22.59**
M vs. G x A	1	215768.63**	25.46**	26.61**
M vs. G x M	1	190912.56**	6.28**	11.64**
M vs. (G x H) x A	1	278677.87**	12.20**	19.90**
M vs. (G x H) x M	1	202853.68**	7.35**	13.28**
G x H vs. G x A	1	26109.19**	7.73**	1.41*
G x H vs. G x M	1	43884.73**	17.80**	21.90**
G x H vs. (G x H) x A	1	8450.63**	0.68	0.62
G x H vs. (G x H) x M	1	15609.48**	16.28**	20.75**
G x A vs. G x M	1	2007.87**	42.88**	30.16**
G x A vs. (G x H) x A	1	321.74**	23.04**	8.28**
G x A vs. (G x H) x M	1	1004.60**	70.45**	51.42**
G x M vs. (G x H) x A	1	7285.11**	12.13**	16.56**
G x M vs. (G x H) x M	1	624.33**	0.01	0.05
Error	540	93.43	0.26	0.22

z/ G = gynoecious; H = hermaphrodite; A = androecious; M = monoecious.
y/ *: significant at 5% level; **: significant at 1% level.

TABLE 5.--Means of parental lines and different hybrid crosses for sex expression and yield of pickling cucumber for once-over harvest.[z]

Line/hybrid cross	Pistillate nodes (%)	Total fruit/plant (No)	Marketable fruit/plant (No)
Gynoecious	94	1.7	1.6
Monoecious	12	1.7	1.4
Hermaphrodite	0[y]	4.0[w]	3.2[w]
Gynoecious x Hermaphrodite	97	2.3	2.2
Gynoecious x Androecious	85	2.5	2.3
Gynoecious x Monoecious	81	2.0	1.8
(Gynoecious x Hermaphrodite) x Androecious	86	2.2	2.1
(Gynoecious x Hermaphrodite) x Monoecious	83	2.0	1.8
Grand mean of hybrids	85	2.1	2.0

z/ See Table 4 for the separation of the means.
y/ All bisexual flowers on nodes.
w/ Fruits were round to oblong shape, typical of hermaphrodites.

marketable yield with pistillate nodes indicates that there may be more differences between the hybrids for marketable yield than for total yield.

Three-way cross hybrids

The androecious pollen parent crosses of (G x H) x A, produced more female nodes and yielded more than those utilizing monoecious pollen parents, (G x H) x M, over the two years of testing (Table 5). The correlation coefficient of 0.35 between pistillate nodes (%) and total yield and of 0.45 between the former and marketable yield for the 3-way cross hybrids were highly significant at the 1% level. These values are higher than those calculated for single cross hybrids which indicated more variation among 3-way cross hybrids for yield. The correlations between the same traits for single and 3-way cross hybrids were less for the second year than the first year, but in both years 3-way crosses displayed higher correlation coefficients than single cross hybrids. Moreover, marketable yields were more closely correlated with percent pistillate nodes than total yield. This high correlation between percent pistillate nodes and marketable yield indicated that hybrids with more pistillate flowers would be more likely to produce the highest marketable yields.

Single versus 3-way cross hybrids

The ranking for sex expression (Table 5) among single and 3-way crosses was somewhat consistent over both years. The G x H crosses produced the highest percent pistillate nodes. The other combinations of parental sexes produced hybrids in the following descending order; (G x H) x A, G x A, (G x H) x M, and G x M for % pistillate nodes which agreed with earlier work (14). The various hybrid combinations displayed a comparable ranking for yield as measured by total and marketable fruit counts per plant. By observation, the descending order of parental sex combinations was G x A, G x H, (G x H) x A, (G x H) x M, and G x M hybrids for yield. The difference between (G x H) x M and G x M hybrids for yield was not significant and neither was G x H from (G x H) x A hybrids (Table 4). By observation, the average mean for marketable number of fruits of G x A was some 9% higher than (G x H) x A hybrids (Table 5). On a 1-year basis, however, the mean of (G x H) x A was slightly higher than G x A in 1978; the converse was observed in 1979. As expected, hybrid vigor for yield was expressed, as measured by the grand mean of all hybrids for total (2.1) and marketable (2.0) numbers of fruits per plant, when compared to the gynoecious and monoecious parental lines (Table 5). Previous researchers found similar hybrid vigor for yield of F_1 hybrids over parental means in cucumber (3, 4). Of course, the all-male, androecious lines do not produce fruit due to the absence of pistillate flowers.

Based on these data, the use of androecious lines as pollen parents for single and 3-way crosses resulted in more female and superior yielding hybrid cultivars as compared to the monoecious lines currently being used as pollen parents for commercial hybrid seed production (1, 11, 12). Therefore, we would suggest the use of androecious pollen parents for 3-way cross hybrids in place of single and 3-way cross hybrid cultivars with monoecious pollen parents for the production of pickling cucumbers for once-over harvest. However, the eventual adoption of androecious in place of monoecious pollen parents for hybrid seed production can only be proposed as was suggested previously (14). The parental combinations giving more female expression did result in a higher yield potentials than the current G x M hybrid cultivars. High female expression contributes to both more and uniform, concentrated fruit-set necessary for maximum yields in once-over mechanical harvest as exhibited by the G x A, G x H, and (G x H) x A experimental hybrid crosses.

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SINGLE AND 3-WAY CROSSES OF PICKLING CUCUMBER

II. GENERAL AND SPECIFIC COMBINING ABILITY IN SINGLE
AND 3-WAY CROSSES OF HYBRID PICKLING
CUCUMBER FOR FEMALE EXPRESSION AND
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SINGLE AND 3-WAY CROSSES OF PICKLING CUCUMBER

II. GENERAL AND SPECIFIC COMBINING ABILITY IN SINGLE AND 3-WAY CROSSES OF HYBRID PICKLING CUCUMBER FOR FEMALE EXPRESSION AND YIELD INTENDED FOR ONCE-OVER HARVEST

ABSTRACT

Single and 3-way cross hybrids of 13 parental lines of pickling cucumber were used to estimate general and specific combining ability for percent female nodes and yield. Parental lines '551F', '368G', '581H', and '5802A' exhibited the highest general combining ability effects in both single and 3-way crosses for total yield and marketable yield. Additive effects of genes were found to be relatively more important than nonadditive effects for both percent female nodes and yield. Cucumber breeders might develop high yielding cultivars based on high general combining ability for yield in parental arrays; moreover the general performance of the parental lines in single crosses might be used to predict high yielding 3-way hybrid crosses.

INTRODUCTION

Information on the relative importance of general (GCA) and specific combining ability (SCA) is of value in breeding programs for species which are amenable to the development of F_1 hybrid cultivars. Such basic information on combining ability in cucumber would aid the breeder in developing improved hybrid cultivars.

Sprague and Tatum (26) used the term "general combining ability" to designate the average performance of a line in hybrid combinations. They used "specific combining ability" to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Genetically, GCA is associated with additive genetic variance and SCA is generally considered to be a function of dominance variance and epistatic variance (22). The relative importance of GCA and SCA have been reported by several workers in cross-pollinated (2, 8, 9, 13, 14, 22, 26) and self-pollinated (4, 7, 12, 21) crops. The GCA is relatively more important than SCA in previously unselected materials, but SCA, on the other hand, is relatively more important in populations previously subjected to testing and selection for GCA (22).

Only limited data have been reported from combining ability studies on cucumber. El-Shawaf and Baker (5) made a combining ability study involving 4 gynoecious lines crossed with 5 hermaphroditic

cucumber lines. They reported that additive genetic variance was greater and more important than that for nonadditive effects for parthenocarpic yield and associated traits, except for gynoecious expression where nonadditive effects were most important.

The objective of the research reported herein was to estimate the GCA and SCA from a group of 13 parental lines of pickling cucumber for female expression, total yield and marketable yield in single and 3-way cross combinations.

MATERIALS AND METHODS

Three gynoecious (G), 4 hermaphroditic (H), 3 monoecious (M), and 3 androecious (A) lines (Table 1) were used to produce an array of 30 single cross and 72 3-way cross hybrids of pickling cucumber. The seed lots of single crosses with '5804A', germinated very poorly; and therefore, these plots were eliminated from the data analysis. The parental lines were considered genetically diverse as they represented breeding lines from Cornell University, Clemson University, and Michigan State University. The single cross hybrids were produced by methods described earlier (18, 19) and the 3-way crosses by methods already reported (20, 24).

The hybrids and parental lines, excluding the androecious parental lines, were grown in 1978 and 1979 growing seasons on the Clarksville Horticultural Experiment Station (near Grand Rapids, Mich). A partially balanced triple lattice design was used. The plantings were made in 4-row, 6 m beds with 45 cm between rows. After emergence, the seedlings were thinned to a spacing of 30 cm between plants. The following traits were studied:

Sex expression

The flower sexes on the first 10 nodes of the main runner were recorded from a random sample of 12 plants from each plot. Nodes with either pistillate and/or pistillate and staminate flowers

TABLE 1.--Parental lines of pickling cucumber used to produce an array of single and 3-way cross hybrids.

Sex phenotype	Parental line	Source	Status	Origin
Gynoecious	Gy14	Clemson Univ.	Released	Gy3 x SMR18
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	669H	MSU	Experimental	MSU844G x MSU4108H
	319H	MSU	Experimental	SC40A x MSU7172H
	581H	MSU	Experimental	(MSU394G x 4108H)
Monoecious	SC36A	Clemson Univ.	Experimental	Unknown
	SC38A	Clemson Univ.	Released	(Gy3 x SMR18) x SC587
	316M	MSU	Experimental	MSU9402 x SC 23
Androecious	5802A	MSU	Experimental	MSU394G x 1A2
	5803A	MSU	Experimental	MSU394G x 1A1
	5804A	MSU	Experimental	Tablegreen 68G x 1A3

were classified as female nodes. Other nodes were classified as either male or blind having no potential to bear fruit.

Yield

The total and marketable (< 5.1 cm diameter) number of fruits per plant were obtained for each plot. Plots were harvested once-over by-hand when approximately 10% of the fruits were judged over-sized by weight (> 5.1 cm diameter) to estimate mechanical harvest yeilds (15, 17).

The analysis of variance for each year and for the pooled data were computed. The variances for years were homogenous; therefore, the data were pooled. The mathematical model used for the analysis of variance was;

$$Y_{ijkp} = \mu + g_i + g_j + s_{ij} + y_k + r_{kp} + (gy)_{ik} + (gy)_{jk} + (sy)_{ijk} + e_{ijkp}$$

where,

Y_{ijkp} = the observation on the hybrid between the i^{th} female and the j^{th} male in the p^{th} replication of the experiment conducted in the k^{th} year.

μ = an effect common to all hybrids in all replications,

g_i = an effect common to all progenies of the i^{th} female line,

g_j = an effect common to all progenies of the j^{th} male line,

s_{ij} = an effect common to the progeny of mating the i^{th} female and the j^{th} male line.

y_k = the effect of the k^{th} year,

r_{kp} = the effect of the p^{th} replication in the k^{th} year,

$(gy)_{ik}$ = the interaction effect of the i^{th} female and the k^{th} year,

$(gy)_{jk}$ = the interaction effect of the j^{th} male and the k^{th} year,

$(sy)_{ijk}$ = the effect of the second interaction of the i^{th} female and the j^{th} male and the k^{th} year,

e_{ijkp} = the effect of the plot which had the hybrid between the i^{th} female and the j^{th} male in the p^{th} replication conducted in the k^{th} year.

The analysis of variances were calculated for both single and 3-way cross hybrids (Table 2). The $\sigma^2_{j_i}$ estimates the genetic variance component of the female lines; and $\sigma^2_{g_j}$, the genetic variance component of the male parents. Hence, small values of $\sigma^2_{g_i}$ or $\sigma^2_{g_j}$ indicate genetically similar female or male parents, respectively. Similarly, $\sigma^2_{s_{ij}}$ is a measure of SCA variance where low values indicate a performance as expected on the basis of their GCA. The model description and the assumptions involved have been reported (3, 6).

TABLE 2.--ANOVA model used to study combining ability in single and 3-way cross hybrids of pickling cucumber grown over two years under open-field conditions for once-over harvest.

Source of variation[z]	Degrees freedom		Expectation of mean squares[y]
	Single	3-way	
g_i's (GCA of females)	2	11	$\sigma^2 + r\sigma^2_{sy} + rm\sigma^2_{g_iy} + ry\sigma^2_s + rym\sigma^2_{g_i}$
g_j's (GCA of males)	8	5	$\sigma^2 + r\sigma^2_{sy} + rf\sigma^2_{g_jy} + ry\sigma^2_s + ryf\sigma^2_{g_j}$
s_{ij}'s (SCA)	16	55	$\sigma^2 + r\sigma^2_{sy} + ry\sigma^2_s$
g_i's x year	2	11	$\sigma^2 + r\sigma^2_{sy} + rm\sigma^2_{g_iy}$
g_j's x year	8	5	$\sigma^2 + r\sigma^2_{sy} + rf\sigma^2_{g_jy}$
s_{ij}'s x year	16	55	$\sigma^2 + r\sigma^2_{sy}$
Error	540		σ^2

z/ GCA = general combining ability; SCA = specific combining ability.

y/ r = 1, 2, 3.; y = 1, 2.; f = no. of females; m = no. of males.

RESULTS AND DISCUSSION

The F test from the analysis of variance showed highly significant differences for percent pistillate nodes, total yield, and marketable yields for the adjusted means of the entries. The means for total and marketable yields in both single and 3-way cross hybrids significantly exceeded the means of the common parents (Tables 3, 4). A more detailed analysis of these differences was reported separately (27).

Single crosses

Among the parental lines, the highest GCA effects for % pistillate nodes was observed for the parent 'Gy14' among females; and for '661H' among the male lines (Table 5). The next highest value for GCA effects of this trait among the male parents was obtained for '669H'. These two hermaphroditic lines were previously found by El-Shawaf and Baker to be good combiners for gynoecious expression as pollen parents with gynoecious seed parents (5). Among the females, '368G', and among the males, 'SC36A', had the lowest GCA effects for female expression. The highest value for SCA effects was obtained from the single cross of 'Gy14 x SC38A' which is the pedigree for the hybrid cultivar, 'Carolina'. The female parent of this cross yielded the highest value for GCA among the female parents which suggested that the relatively high SCA for female expression

TABLE 3.--Femaleness and yield of single cross hybrids of pickling cucumber with one parent in common in 1978 and 1979 field trials for once-over harvest.

	Female nodes(%)		Total fruit/ plant (no.)		Mkt fruit/ plant (no.)	
Parents	Hybrid ($\bar{X}$)	Parent ($\bar{X}$)	Hybrid ($\bar{X}$)	Parent ($\bar{X}$)	Hybrid ($\bar{X}$)	Parent ($\bar{X}$)
Females						
Gy14	89	98	2.0	1.6	1.8	1.5
368G	87	93	2.3	1.8	2.1	1.8
551F	87	92	2.3	1.6	2.2	1.5
Grand mean	88	94	2.2	1.7	2.0	1.6
Males						
661H	98	-[z]	2.3	3.2[w]	2.1	1.8[w]
669H	97	-[z]	2.3	3.2[w]	2.2	2.6[w]
319H	96	-[z]	2.1	4.3[w]	1.9	3.6[w]
581H	96	-[z]	2.5	5.2[w]	2.4	4.8[w]
5802A	86	0[y]	2.4	-[y]	2.3	-[yy]
5803A	75	0[y]	2.4	-[y]	2.2	-[y]
SC36A	74	10	1.8	1.8	1.7	1.6
SC38A	78	9	1.9	1.6	1.8	1.4
316M	91	15	2.1	1.3	1.9	1.2
Grand mean	88	11	2.2	1.6[v]	2.0	1.4[v]

z/ all bisexual flowers.
y/ all staminate flowers.
w/ typical short, round hermaphroditic fruits graded by diam only.
v/ hermaphroditic fruits are excluded from this mean as their relatively high numbers would bias this estimate.

TABLE 4.--Femaleness and yield of 3-way cross hybrids of pickling cucumber with two parents in common and of common parents in 1978 and 1979 field trials for once-over harvest.

Parents	Female nodes(%) Hybrids ($\overline{X}$)	Female nodes(%) Parents ($\overline{X}$)	Total fruit/ plant (no.) Hybrids ($\overline{X}$)	Total fruit/ plant (no.) Parents ($\overline{X}$)	Mkt fruit/ plant (no.) Hybrid ($\overline{X}$)	Mkt fruit/ plant (no.) Parents ($\overline{X}$)
Females						
Gy14 x 661H	86	98	2.0	1.9	1.9	1.8
Gy14 x 669H	89	96	2.0	2.0	2.0	1.9
Gy14 x 319H	80	95	2.0	1.9	1.9	1.8
Gy14 x 581H	80	95	2.1	2.3	1.9	2.2
368G x 661H	83	98	2.1	2.7	1.9	2.5
368G x 669H	89	97	2.0	2.5	1.9	2.4
368G x 319H	80	97	2.0	2.3	2.0	2.2
368G x 581H	86	96	2.2	2.5	2.1	2.4
551F x 661H	84	97	2.0	2.1	1.9	2.0
551F x 669H	92	97	2.1	2.3	2.0	2.3
551F x 319H	79	96	2.2	2.0	2.1	1.9
551F x 581H	86	96	2.2	2.7	2.1	2.6
Grand mean	85	96	2.1	2.3	2.0	2.2
Males						
5802A	90	0^z	2.4	0	2.3	0
5803A	79	0^z	2.1	0	2.0	0
5804A	90	0^z	2.2	0	2.1	0
SC36A	79	10	1.8	1.8	1.7	1.8
SC38A	78	9	1.9	1.6	1.7	1.4
316M	92	15	2.2	1.3	2.0	1.2
Grand mean	85	11	2.1	1.6	2.0	1.5

z/ all staminate flowers.

TABLE 5.--Estimates of relative GCA and SCA effects for femaleness and yield based on single cross hybrids of pickling cucumbers grown over 2 years in open-field conditions for once-over harvest.

Parents	Specific effects (SCA)									General effects of females(GCA)
Females	Males									
	661H	669H	319H	581H	5802A	5803A	SC36A	SC38A	316M	
					Female nodes (%)					
Gy14	-1.25	-1.60	-1.94	-1.88	+1.15	-0.05	+0.33	+7.69	-2.51	+1.23
368G	+1.18	+0.92	+1.11	+1.22	-1.10	+0.50	-1.27	-3.30	+0.70	-0.65
551F	+0.60	+0.67	+0.81	+0.65	-0.05	-0.46	+0.93	-4.40	+1.78	-0.58
General effects of males										
(GCA)	+9.96	+8.75	+8.22	+7.80	-2.28	-12.45	-13.40	-10.02	+3.42	
					Total frt./plant (no.)					
Gy14	-0.12	-0.01	+0.07	-0.03	-0.25	-0.30	+0.11	+0.23	+0.23	-0.23
368G	+0.57	+0.30	+0.31	+0.08	-0.17	+0.55	+0.04	-0.02	+0.15	+0.10
551F	-0.25	-0.10	-0.18	+0.06	+0.61	-0.05	+0.06	-0.01	-0.18	+0.13
General effects of males										
(GCA)	+0.06	+0.08	-0.13	+0.29	+0.25	+0.17	-0.37	-0.26	-0.09	
					Mkt frt/plant (no.)					
Gy14	-0.07	-0.09	+0.03	+0.05	-0.29	-0.34	+0.18	+0.28	+0.15	-0.22
368G	+0.31	+0.08	+0.13	-0.10	-0.32	+0.31	-0.20	-0.21	-0.02	+0.09
551F	-0.24	-0.07	-0.15	+0.05	+0.50	+0.02	+0.02	-0.06	-0.13	+0.13
General effects of males										
(GCA)	+0.07	+0.15	-0.11	+0.33	+0.20	+0.13	-0.35	-0.30	-0.11	

was partially a result of high GCA of the female parent. This was in agreement with earlier work (5) which concluded that the female parents were responsible for most of the additive effects for gynoecious expression.

For the total number of fruits per plant (Table 5), '551F' and '368G' among the females; and, '581H' and '5802A' among the males, showed the highest values for GCA effects. The single crosses of '551F x 5802A', '368G x 661H', and '368G x 5803A' had the highest observed values for SCA effects. Both parents of the former cross and the female parent of the second and third crosses were among the better general combiners. Presumably, increased yield of these hybrids was largely the result of GCA effects.

Parental line, '551F', demonstrated the largest GCA effect among the female lines for marketable number of fruits per plant (Table 5). This female parent also gave the highest value for SCA effects when crossed with '5802A'. The '5802A' male parent was the second best general combiner among the male parents after '581H' for marketable yield.

3-way crosses

Among the F_1 hybrids and the parental lines used for 3-way cross hybrids, the highest value for GCA effects on % female nodes (Table 6) was obtained among the F_1 female lines for '(551F x 669H)' and among the male lines for '316M'. The next highest values for GCA effects were observed for '(Gy14 x 669H)' and '(368G x 669H)' among F_1 female parents; and for '5804A' and '5802A' among the males.

TABLE 6.--Estimates of relative GCA and SCA effects for femaleness and yield based on 3-way cross hybrids of of pickling cucumbers grown over 2 years in open-field conditions for once-over harvest.

Parents	Specific effects (SCA)												
	Males												General effects of males (GCA)
Females	(Gy14x 661H)	(Gy14x 669H)	(Gy14x 319H)	(Gy14x 581H)	(368Gx 661H)	(368Gx 669H)	(368Gx 319H)	(368Gx 581H)	(551Fx 661H)	(551Fx 669H)	(551Fx 319H)	(551Fx 581H)	
						Female nodes (%)							
5802A	+2.03	-3.35	+1.65	-1.03	-1.14	+0.90	+2.92	+3.33	+4.17	-2.68	-0.40	+0.25	+5.64
5803A	+2.45	+4.28	-4.96	+3.08	-1.09	+5.00	-4.00	+1.25	-3.81	+0.09	+0.29	-3.57	-5.92
5804A	-1.20	-3.23	+4.89	-9.67	-2.64	-0.10	+7.36	+0.49	+0.65	-3.58	+6.64	+0.39	+5.74
SC36A	-1.44	+1.25	-2.41	+0.32	-1.26	+0.80	-1.40	+0.91	-1.34	+4.47	+0.21	-0.20	-5.92
SC38A	-2.56	+2.38	+0.94	+4.27	+1.25	-5.63	-6.82	+0.42	+1.84	+7.05	-7.10	+3.94	-6.76
316M	+0.72	-1.34	-0.14	+3.01	+4.36	-0.99	+1.92	+0.22	-1.53	-6.24	+0.33	-0.82	+7.22
General effects of females													
(GCA)	+1.95	+4.74	-4.38	-4.20	-1.71	+4.08	-4.38	+1.30	-0.48	+7.47	-5.40	+1.00	
						Total fruit/plant (no.)							
5802A	-0.06	+0.15	+0.01	-0.01	-0.24	+0.02	+0.15	-0.08	-0.25	+0.04	+0.33	-0.05	+0.17
5803A	+0.05	-0.08	-0.19	+0.36	-0.24	+0.17	-0.17	+0.36	0.00	-0.08	-0.12	0.00	+0.02
5804A	+0.16	+0.13	+0.04	-0.35	+0.47	-0.20	-0.12	+0.12	0.00	-0.15	+0.12	-0.15	+0.15
SC36A	-0.23	-0.01	-0.06	-0.03	+0.15	+0.17	+0.20	-0.12	+0.10	+0.10	-0.14	-0.30	-0.26
SC38A	+0.01	-0.01	-0.09	+0.09	-0.10	+0.01	-0.14	-0.04	+0.08	+0.18	-0.04	+0.16	-0.22
316M	+0.08	-0.13	+0.30	-0.06	-0.03	-0.08	+0.09	-0.15	+0.08	-0.08	-0.14	-0.09	+0.10
General effects of females													
(GCA)	-0.11	-0.04	-0.04	-0.02	+0.01	-0.03	-0.09	+0.16	-0.10	+0.02	+0.10	+0.14	
						Marketable fruit/plant (no.)							
5802A	-0.02	+0.16	+0.02	+0.01	-0.21	+0.05	+0.12	-0.04	-0.24	-0.01	+0.27	-0.07	+0.13
5803A	+0.07	-0.07	-0.24	+0.40	-0.23	+0.17	-0.17	+0.28	-0.01	-0.06	-0.01	-0.02	+0.04
5804A	+0.12	-0.06	+0.06	-0.38	+0.46	-0.13	-0.06	+0.18	+0.01	-0.12	+0.09	-0.13	+0.17
SC36A	-0.24	+0.04	-0.09	-0.01	+0.09	+0.07	+0.08	-0.06	+0.17	+0.09	-0.06	-0.04	-0.28
SC38A	+0.05	+0.02	-0.06	+0.04	-0.05	-0.05	-0.06	-0.14	-0.04	+0.22	-0.06	+0.15	-0.23
316M	-0.02	-0.09	+0.33	-0.06	-0.06	-0.09	+0.10	-0.20	+-.12	-0.10	-0.12	-0.11	-0.11
General effects of females													
(GCA)	-0.13	-0.02	-0.04	-0.01	-0.04	-0.04	-0.11	+0.18	-0.13	+0.04	+0.11	+0.19	

All the aforementioend F_1 females had the '669H' parental hermaphroditic line in common. This indicated that the relatively high values for GCA effects for female expression were largely due to the additive gene effects of parental line '669H' which was also a good combiner in single crosses. Highest values for SCA effects for female expression were observed for hybrid crosses '(368G x 319H) x 5804A' and '(551F x 669H) x SC38A'. Each of these hybrids had one parent, male in the case of the former and female in the latter cross, among the best general combiners for femaleness. This suggested again that the % female nodes for these hybrids was at least partially due to the additive effects of the parental lines.

The highest GCA effects for total yield (Table 6) were observed for '(368G x 581H)' and '(551F x 581H)' among the F_1 females, and for '5802A', among the male lines. Hybrids of '(368G x 661H) x 5804A', '(368G x 581H) x 5803A', and '(Gy14 x 581H) x 5803A' demonstrated the best SCA effects for total number of fruits per plant. Neither parents of the latter hybrid showed a high value for GCA, which indicated the total yield differences for this hybrid were mainly a result of SCA effects.

The highest values for general effects or GCA for marketable number of fruits per plant were exhibited by '(551F x 581H)' and '(368G x 581H)' among the F_1 females and '5802A' and '5804A' among the male parents (Table 6). Parental line '5804A' also gave the highest value for specific effects or SCA when crossed with '(368G x 661H)'. Parental lines '551F', '368G', '581H', and '5802A', which

had the better general effects for total and marketable yields in single crosses, performed in the same manner in 3-way crosses too. This would suggest that additive effects of genes contributed much to yield. This is analogous to early findings with corn (1) and later with tomato (16, 21), which suggested that single crosses could be used to predict the performance of inbreds in three-way and double cross combinations.

It was assumed that differences in general performance of the parental lines in our study were primarily due to differences in additive effects of the genes; and that, differences in specific effects were due to differences in nonadditive gene effects. Caution should be used in generalizing this information to other cucumber populations because the genetic variance components of this population (σ^2_m, σ^2_f, σ^2_{mf}) could be over-estimated due to linkage disequilibrium and/or epistasis (11, 23). The model and genetic materials used did not allow estimation of the variance components for linkage and epistasis; therefore, estimation of additive and nonadditive components of genetic variance might be biased to an unknown extent (10, 11).

Variance components for most of the interactions with years were significant (Table 7). Thus, estimates obtained from a given year are largely an expression of the conditions particular to that year, and interpretations should be made in that context. However, the variance components for the interactions involving SCA and years were consistently larger than the corresponding estimates involving GCA for both total and marketable yields, in both single and 3-way

TABLE 7.--Estimates of the components of variance for GCA and SCA and their interaction with year calculated for the 1978 and 1979 combined F_1 data of single and 3-way crosses of pickling cucumber[z].

Components	Female nodes(%)		Total frt/plant(no)		Mkt frt/plant(no)	
	Single cross F_1	3-way cross F_1	Single cross F_1	3-way cross F_1	Single cross F_1	3-way cross F_1
f_i(GCA of females)	-3.56	19.87	0.11	0.01	0.08	-0.01
m_j(GCA of males)	84.29	41.98	0.07	0.07	0.01	0.11
$(fm)_{ij}$ (SCA)	0.58	12.32	-0.09	-0.01	0.06	-0.05
f_i x year	8.90	47.64**	-0.03	-0.01	0.01	0.06*
m_j x year	379.09**	191.93**	0.01	0.03**	0.15	0.03
$(fm)_{ij}$ x year	16.75	31.60**	0.60**	0.13**	0.22**	0.20**

z/ *significant at 5% level; **significant at 1% level.

cross combinations. This suggested that the variance of SCA includes not only the nonadditive deviations due to dominance and epistasis, but also a considerable portion of genotype-environment interaction (22). Hence, information on GCA variation over years could be of more value than information on SCA variation over years.

Estimates of the relative importance of additive (GCA) and nonadditive (SCA) effects can be obtained from the ratio σ_g^2/σ_s^2. Although not significantly different from zero, the GCA variance estimates were greater than those for SCA in nearly every case. The variance components for GCA of male parents were larger than those for female parents, in most cases, which indicated a greater variability among the male than among the female parents. The unequal variance components of GCA for males and females could be explained by maternal effects (cytoplasmic inheritance) or linkage disequilibrium (3, 23) or the effects of particular lines chosen for males and females. Reciprocal crosses would be the best estimate of maternal effects, especially for characters that showed differences in magnitude between GCA variance components for males and females, but such crosses are not possible from a practical standpoint.

In our study, additive effects (GCA) were found to be relatively more important than nonadditive effects (SCA) for female expression and yield. This agreed with results obtained in agronomic crops (*Zea mays*, (26; 28) *Medicago sativa*, (2)) and horticultural crops (*Lycopersicon esculentum* (4, 7, 21); *Cucumis melo* (13, 14); *Cucumis sativus* (25); *Brassica oleracea* (8); *Pisum sativum*, (12)) in the situation where inbred parental lines had not been previously subjected to selection for GCA. However, pickling cucumber lines previously selected for yield displayed lower SCA than GCA for yield, probably due to the lack of genetic diversity in the parental population (5). From our results, it might be speculated that it is possible to predict the best hybrid combination for yield from the GCA of the parental lines; at least in this population. Moreover, it may be possible to predict the best 3-way combination for yield from the general performance of the parents in single cross combinations. Therefore, we propose that cucumber breeders might develop high yielding hybrid cultivars based on high GCA for yield in parental arrays; and that single cross performance can be used to predict high yielding 3-way hybrid crosses.

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