3. Boonen, P. and C. Backus. 1986. Verslag aspergeproeven 1985. Horst Stichting Proeftuin "Noord-Limburg" (Netherlands).
4. Cassini, R., L. Corriols-Thévenin, C. Doré and R. Cassini. 1979. Trying a new approach to *Fusarium* and *Rhizoctonia* diseases in asparagus culture. EUCARPIA, Section Vegetables. Proc. 5th Intl. Asparagus Symp. 28 Aug.–1 Sept. 1979. Geisenheim, West Germany. p. 205–210.
5. Chin, C.K. 1982. Promotion of shoot and root formation in asparagus *in vitro* by ancymidol. HortScience 17:590–591.
6. Corriols-Thévenin, L. 1979. Different methods in asparagus breeding. EUCARPIA, Section Vegetables. Proc. 5th Intl. Asparagus Symp. 28 Aug.–1 Sept. 1979. Geisenheim, West Germany. p. 8–20.
7. Corriols, L. 1985. Behaviour of several hybrid schemes towards asparagus breeding tests. EUCARPIA Vegetable Section. Proc. 6th Intl. Asparagus Symp. 5–9 Aug. 1985. Guelph, Ont., Canada. p. 8–21.
8. Desjardins, Y., H. Tiessen, and P.M. Harney. 1987. The effect of sucrose and ancymidol on the in vitro rooting of nodal sections of asparagus. Hortscience 22:131–133.
9. Doré, C. 1974. Production de plantes homozygotes mâles et femelles à partir d'anthères d'asperge. Compt. Rend. Acad. Sci. Paris 278:2135–2138.
10. Doré, C. 1975. La multiplication clonale de l'asperge (*Asparagus officinalis*) par culture *in vitro* : son utilisation en sélection. Ann. Amélior. Plantes 25:201–204.
11. Doré, C. 1989. Asparagus anther culture. In: Y.P.S. Bajaj (ed.). Biotechnology in agriculture and forestry, Springer-Verlag, Berlin. (In press.)
12. Doré, C. 1988. Nouveau regard sur le comportement de l'asperge multipliée *in vitro*. Agronomie 8(10). (In press.)
13. Ellison, H. 1984. Release of Jersey Giant and Greenwich. Asparagus Res. Nwslt. 2(1):23.
14. Huyskes, J.A. 1959. A method for selecting asparagus varieties with a long fibreless top. Euphytica 8:21–28.
15. Lhérault, L. 1867. Traité sur la culture des asperges d'Argenteuil. Ed. Louis Lhérault, Argenteuil, France.
16. Peirce, L.C. 1982. 'Emerald' asparagus. Hortscience 17:981.
17. Sneep, J. 1953. The significance of andromonoecy for the breeding of *Asparagus officinalis*. Euphytica 2:89–95; 224–228.
18. Spath, H.W. 1984. Réflexions sur la méthode d'obtention d'asperge mâle pour les variétés Lucullus. P.H.M. Revue Hort. 243:34.
19. Thévenin, L. 1967. Les problèmes d'amélioration chez *Asparagus officinalis* L.: I.Biologie et Amélioration. Ann. Amélior. Plantes 17:33–36.
20. Thévenin, L. 1968. Les problèmes d'amélioration chez *Asparagus officinalis* L.: II. Haploïdie et amélioration. Ann. Amélior. Plantes 18:327–365.
21. Thévenin, L. 1968–1971. Asperge. Rapport d'activité. Station de Génétique et d'Amélioration des Plantes de Versailles, INRA, J1–J30.
22. Thévenin, L. 1973. Les divers aspects de la sélection de l'asperge en France. EUCARPIA, Section Horticole, 4ème réunion sur la sélection de l'Asperge, 13–15 June 1973. C.N.R.A., Versailles, France. p. 55–70.
23. Thévenin, L. and C. Doré, 1976. L'amélioration de l'asperge (*Asparagus officinalis* L.) et son atout majeur, la culture *in vitro*. Ann. Amélior. Plantes 26:655–674.
24. Tiedjens, V.A. 1924. Some physiological aspects of asparagus. Proc. Amer. Soc. Hort. Sci. 21:129–140.

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Combining Ability Analyses of Fruit Yield and Quality in Near-homozygous Lines Derived from Cucumber

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Abstract. **Combining ability estimates for characters relating to yield and fruit quality were undertaken to determine if lines derived from *Cucumis sativus* var. *hardwickii* (R.) Alef. (*hardwickii*) could be used in the development of higher-yielding commercial cucumbers. General and specific combining ability estimates were obtained in a North Carolina Design II experiment for nine near-homozygous processing cucumber (*Cucumis sativus* L.) lines, five of which were derived from *hardwickii* germplasm. Lines were evaluated under two planting densities (29,000 and 58,000 plants/ha) for three harvests, and environments sampled were two planting times (2 weeks apart within the same year). Traits evaluated included fruit number per plant, primary lateral branch number, percentage of pistillate flowers, days to anthesis, fruit length, and fruit length : diameter (L:D) ratio. General combining ability (GCA) mean squares were significant at both planting densities for all traits when combined over planting times, except for fruit L:D ratio at the higher density. Specific combining ability mean squares were significant for days to anthesis. Of the lines evaluated, WI 2963 and 4H261 produced the greatest GCA female and male effects, respectively, for three harvest yield and primary lateral branch number, but the lowest effects for fruit size. Our results suggest that further selection within these high-performance *hardwickii* derivatives for fruit shape will produce lines that perform well at a high planting density when crossed with *sativus* lines having good general combining ability.**

Low fruit-setting ability is a major factor limiting fruit yield of processing cucumber cultivars during once-over mechanical or multiple harvesting. An effective way to increase genetic variability and response to selection for quantitatively inherited characters, such as yield, is the incorporation of exotic germplasm into commercially adapted cultivars (2). Several *Cucumis sativus* var. *hardwickii* (R.) Alef. lines (hereafter referred to as *hardwickii*) have been used as a germplasm source for increasing the genetic variability for fruit yield in commercial cucumber (hereafter referred to as *sativus*) (15, 16, 24). Although *hardwickii* plants have the ability to simultaneously set a large

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number of seeded fruit, these fruit are small, ellipsoid, bitter, and have a large interior seed cavity. To use *hardwickii* germplasm, these negative quality attributes and *hardwickii*'s susceptibility to many economically important cucumber diseases must be overcome.

Breeding strategies designed to incorporate the simultaneous fruiting ability of *hardwickii* into commercially acceptable cultivars have been initiated. We used two *hardwickii* plant introductions (PI 183967 and PI 215589) along with several *sativus* inbred lines to develop populations segregating for high fruiting capacity (24). After initial *hardwickii* x *sativus* matings, progeny were screened for diseases in advanced breeding generations during inbred line development. These extracted lines were allowed to random-mate, and the resulting population was subjected to two cycles of recurrent selection for fruit length and fruit number. The inbred lines derived from these populations are resistant to six diseases and have non-bitter, white-spined fruits. Although the derived lines are acceptable for most horticultural traits, the fruit length : diameter (L:D) ratio is short and the interior seed cavity of the fruit is large. Researchers in Wisconsin used three cycles of S_1 progeny selection to increase fruit number per plant in a population derived from a cross between a gynoecious inbred *savitus* line, 'GY-14', and a *hardwickii* line derived from PI 183967 (13–15, 20). Inbred lines with improved once-over harvest fruit per plant were developed with two cycles of family selection.

An increase in planting density has been reported to significantly decrease the number of lateral branches (10) and fruit per plant (6, 24) in *hardwickii* germplasm. When *savitus* x *hardwickii* F_1 hybrids were backcrossed to *sativus*, they did not differ significantly from the recurrent parent for yield at a plant density of 60,000 plants/ha (24). Consequently, planting density effects are a consideration in evaluating yield potential of *hardwickii* derivatives. The present study was undertaken to evaluate the combining ability of the *hardwickii* derivatives in hybrid combinations with *sativus* to determine: a) the general and specific combining ability of the lines, and b) if yielding ability can be maintained at a high planting density without sacrificing fruit quality.

Materials and Methods

Plant material. Nine genetically distinct cucumber populations that had been maintained by self-pollination for several generations were evaluated (Table 1). Cucumber has a narrow genetic base in terms of variability (19); however, the parents used in the study represented germplasm having diverse ancestory and fruit characteristics. Five of the lines evaluated contained *hardwickii* germplasm. The USDA gynoecious indeterminate breeding lines WI 1701, WI 2712, and WI 2963 were used as females. The latter inbred line, WI 2963, resulted from self-pollination of an F_1 progeny from a cross between a *hardwickii* accession (PI 215589) and an inbred processing cucumber line (WI 1606). Two *sativus* inbred lines (WI 1983 and 13M), along with four lines derived from initial *hardwickii* x *sativus* matings (WI 5098, WI 5551, 2H1853, and 4H261), were used as males.

To obtain information about combining ability, a North Carolina Design II mating scheme (4) was used to produce 18 F_1 families (three females crossed to six males). Seeds of the F_1 progeny were produced in a greenhouse in Madison, Wis. during Spring 1985. Eighteen plants were grown for each female parent line, and eight plants were grown for each male parent line. Reciprocal cross-progeny were not included since the results of previous studies indicated no influence of cytoplasmic and/or maternal factors on the quantitative traits evaluated in this study (6, 24).

Experimental design. The parents and F_1 progenies plus control cucumber ('Calypso') were grown in the field at the Univ. of Wisconsin Experimental Farm at Hancock during Summer 1985 on a Plainfield loamy sand (Typic Udipsamment; sandy, mixed, mesic). To evaluate the effects of environments on the traits studied, the experiment was planted on two dates during the growing season (4 and 18 June).

The experimental design in each planting environment was a split-plot, with genotypes randomized within two replications. Single-row plots of 30 plants on 1.52-m row centers were used in each replication. All plots were overseeded and thinned to 30 plants/plot, or ≈29,000 plants/ha at a 23-cm plant spacing and ≈58,000 plants/ha at a 11.5-cm plant spacing, thus providing plot lengths of 7 m and 3.5 m, respectively, for each planting density tested. All plots were bordered by plants of the monoecious cultivar Wautoma to ensure an adequate source of pollen.

Data collection. Data were collected for the following traits: number of fruit per plant at first harvest (simulated once-over mechanical harvest), three-harvest average yield (fruit per plant per harvest), days to anthesis, percentage of pistillate flowers, number of primary lateral branches, fruit length, and fruit length : diameter ratio. Fruits >19 mm in diameter were hand-harvested from 25 competitive plants when two fruit >51 mm in diameter were observed within a plot, as suggested for the optimum time for a once-over harvest (23). Two additional harvests were conducted in the same manner to provide data for a multiple harvest. The mean yields of three harvests were determined by summing the three harvests and calculating average fruit number per plant per harvest. Mean fruit lengths and L:D ratios were obtained by measuring 10 fruit (27 to 38 mm in diameter) randomly chosen from each plot at the third harvest. Days to anthesis were specified as the number of days from sowing to the appearance of at least three fully expanded corollas per plot. Data for percentage of pistillate flowers were taken during harvesting from the first 10 nodes of the first 10 consecutive plants in a plot. Nodes with both staminate and pistillate flowers were counted as staminate. Primary lateral branch number per plant was also calculated from these 10 consecutive plants at the time of third harvest.

Statistical analysis. Analyses of variance were computed for planting times and planting densities using the plot means (see Table 2). Since there were no statistical differences between planting times, and data were normally distributed with homogeneous error variances within planting times, data were combined over planting times. Parental means and half-sib family means were calculated at each planting density for all traits examined (see Table 3). To obtain a measure of the degree of associated changes among the traits, simple correlations were computed on plot means at each planting density (see Table 4).

Since the main interest in these analyses was to examine general and specific combining ability effects at each planting density, the genotype sum of squares was partitioned into parents and crosses (male, female, and male × female) sums of squares (see Table 5). Residuals were checked for random distribution of data for each trait, and transformations were not required.

The general combining ability (GCA) effect of each parent, the specific combining ability (SCA) effect of each cross, and the variation among crosses due to statistically additive features

Table 1. Characteristics of parental lines of cucumber used in the production of F_1 progeny for combining ability analaysis.

	Parental lines								
	sativus[z]				*sativus* x *hardwickii* derivatives[z]				
Traits	WI 1701	WI 2712	WI 1983	13M	WI 5098	WI 5551	WI 2963	2H1853	4H261
Sex type[y]	G	G	PG	M	PG	M	G	PG	M
Bitterfree	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Disease resistances[x]	AL,AN,S CMV,D,P	AL,AN,S CMV,D,P TL	AL,AN,S CMV,D,P	CMV,S	AL,AN,S CMV,D,P	AL,AN,S CMV,D,P	AL,AN,S CMV,D,P	---	---
Fruit length : diameter ratio[w] LSD (0.05) = 0.3	2.6	3.0	2.4	2.6	2.1	2.2	2.6	2.2	1.9
Yield[v] (fruit/plant) LSD (0.05) = 0.6	1.6	1.9	1.5	1.2	2.7	2.7	2.3	2.4	3.0

[z] *sativus* = *C. sativus* L.; *hardwickii* = *C. sativus* var. *harwickii* (R.) Alef.

[y] G = gynoecious, PG = predominantly gynoecious, M = monoecious.

[x] AL = angular leaf spot, AN = anthracnose, S = scab, CMV = cucumber mosaic virus, D = downey mildew, P = powdery mildew, TL = target leaf spot.

[w] Means of four 10-fruit (2.7–3.8 cm in diameter) replications at third harvest.

[v] Means of four 25-plant replications averaged over three harvests. Measurements taken at Hancock, Wis., in 1985; grown at 58,000 plants/ha.

Table 2. Mean squares from analyses of variance for morphological traits of cucumber combined over two planting dates and two planting densities for nine parents and their F_1 progenies.

		Mean squares						
		Fruit/plant					Fruit[y]	
Source of variation	df	First harvest (no.)	Three harvests[z] (no.)	Lateral branch (no.)	Pistillate flowers (%)	Days to anthesis (no.)	Length (cm)	L:D ratio
Planting time (PT)	1	0.33	1.45	2.36	0.024	212.01	11.16	0.453
Error a	2	0.07	0.93	1.65	0.017	113.37	74.21	0.327
Planting density (PD)	1	12.04**	66.19**	38.00*	0.296	13.50	100.04**	1.178
PD × PT	1	0.04	0.18*	0.00	0.086	25.35	27.45	0.088
Error b	2	0.03	0.01	0.64	0.042	25.18	3.69	0.177
Genotype (G)	26	1.90**	3.09**	4.75**	0.281**	67.25**	125.34**	0.673**
G × PT	26	0.45*	0.15	0.35	0.018	6.32	5.90	0.108
G × PD	26	0.24	0.38	0.53	0.013	16.32**	6.33	0.092
G × PT × PD	26	0.29	0.19	0.37	0.014	6.38	3.41	0.113
Error c	104	0.24	0.26	0.38	0.018	5.44	23.80	0.088
CV (%)		26.3	20.3	21.5	16.4	5.1	7.0	11.6

[z] Averaged over three harvests.

[y] Length and length : diameter (L:D) ratio of fruits 2.7–3.8 cm in diameter.

*,**Significant at the 5% and 1% probability levels, respectively.

of the parents (GCA : SCA) were estimated as described by Simmonds (22). The SE of the effects were estimated as described by Owens et al. (20). The effects of genotypes, plant spacings, and planting times were fixed in the analyses of variance; hence, the conclusions drawn from these data pertain only to the parents and environments used in the study (9).

Results

Except for genotype × planting time (G × PT) interactions for the first harvest yield, initial analyses of variance indicated that variations among planting times and (G × PT) interactions were nonsignificant for all traits examined (Table 2). The three-way interaction, genotype × planting time × planting density, was nonsignificant for all traits; hence, data were combined over planting times for further analyses. Highly significant variation was detected among genotypes for all traits and among planting densities for first harvest yield, three-harvest yield, lateral branch number, and fruit length. The genotype × planting density interaction was highly significant for days to anthesis. The nonsignificant planting density influence on fruit L:D ratio indicates that fruit length and fruit diameter were similarly influenced by planting density.

To examine the breeding worth of each line, parameter means and combining ability effects were calculated within each planting density. Except for fruit L:D ratio at the high density (58,000 plants/ha), the mean comparisons of F_1 progenies having a common parent indicated significant differences among the parental lines for all traits examined (Table 3). Although the relative ranking of the parental means was generally consistent over both planting densities for all traits, mean yields were significantly lower at the 58,000 plants/ha density for the first harvest yield, three-harvest average yield, and lateral branch number traits.

Table 3. Means by planting density of morphological traits of F_1 progeny with one common parent for crosses between near-homozygous cucumber lines.[z]

Parent	Fruit/plant					Fruit[y]	
	First harvest (no.)	Three harvests[x] (no.)	Lateral branch (no.)	Pistillate flowers (%)	Days to anthesis (no.)	Length (cm)	L:D ratio
Low plant density (29,000 plants ha)							
Females							
WI 1701	1.78	2.68	2.98	0.83	43.3	9.22	2.67
WI 2712	2.07	2.82	2.98	0.87	42.5	9.63	2.85
WI 2963	2.04	3.41	3.63	0.90	46.4	8.60	2.45
Males							
13M	1.26	2.04	2.80	0.95	42.5	10.29	2.94
WI 1983	1.59	2.38	2.83	0.98	43.5	9.51	2.80
WI 5098	2.14	2.96	3.13	1.00	46.8	9.08	2.55
WI 5551	2.35	3.34	3.73	0.84	46.0	8.91	2.55
2H1853	2.16	3.36	2.80	0.82	41.8	8.80	2.63
4H261	2.27	3.74	3.90	0.61	44.1	8.31	2.46
LSD (0.05)	0.74	0.76	0.84	0.17	3.4	0.76	0.26
Calypso[z]	1.68	2.64	2.90	0.78	40.2	10.19	2.84
High plant density (58,000 plants/ha)							
Females							
WI 1701	1.40	1.67	2.52	0.74	45.7	8.71	2.40
WI 2712	1.67	1.92	1.93	0.77	44.4	9.08	2.58
WI 2963	1.34	1.97	2.95	0.86	46.0	8.67	2.40
Males							
13M	1.09	1.40	1.83	0.90	45.0	9.71	2.53
WI 1983	1.41	1.64	2.17	0.95	45.5	8.92	2.76
WI 5098	1.38	1.83	2.37	0.98	45.6	8.72	2.34
WI 5551	1.69	2.01	2.97	0.76	45.6	8.97	2.52
2H1853	1.66	2.03	2.50	0.62	43.6	8.54	2.28
4H261	1.63	2.22	2.97	0.53	47.1	8.06	2.32
LSD (0.05)	0.56	0.48	0.89	0.21	3.1	0.93	0.65
Calypso[w]	1.13	1.47	2.20	0.63	42.7	10.45	2.59

[z] Mean separation within columns by LSD at 0.05.

[y] Length and length : diameter (L:D) ratio from four 10-fruit (2.7–3.8 cm in diameter) replications.

[x] Averaged over three harvests from four, 25-plant replications.

[w] Control cultivar.

These findings are in agreement with other reports regarding planting density effects (3, 5, 17, 24).

Phenotypic correlations were estimated for all pairs of characters (Table 4). In general, there was good agreement between planting densities with regard to the value of the coefficients. Coefficients were moderate to large between three-harvest yield and first harvest yield, as well as lateral branch number. A high, positive correlation was detected between fruit length and fruit L:D ratio. Negative correlations of intermediate range were detected between fruit shape (length and L:D ratio) and first and three-harvest yields, as well as lateral branch number. These negative correlations had higher value coefficients at the lower planting density. There was no evidence of strong associations between fruit yield and the percentage of pistillate flowers or early flowering.

Except for fruit L:D ratio at the high planting density (58,000 plants/ha), GCA mean squares of the male parents were significant for all traits at both planting densities (Table 5). The mean squares of the female parents were significant for lateral branch number and fruit length at both planting densities. The only significant specific combining ability (male × female interaction) mean square was number of days to anthesis. The relative ranking and direction of the GCA effects were consistent over both planting densities with respect to all traits examined, although the magnitude of GCA effects tended to be greater at the lower planting density (Table 6). These results suggest that lower-density plantings may be more discriminating for certain traits.

The most positive GCA effects for first harvest (Table 6) and three-harvest average yields were noted for the female parents, WI 2712 and WI 2963, respectively, and for the male parents, WI 5551 and 4H261, respectively. In contrast, the parents with the poorest combining ability for both first harvest and three-harvest yields were the female parent WI 1701 and the male parent 13M. In general, the specific combining ability estimates among the hybrids approached zero for the yield traits, although large SCA estimates were obtained for WI 2963 × WI 5551 at both planting densities for first harvest yield and for WI 2963 × WI 5551 and WI 2712 × WI 5551 at the high density for three-harvest average yield (data not shown).

The highest GCA effects for primary lateral branch number were displayed by female parent parent WI 2963 and male parent 4H261; however, these parental lines displayed the lowest GCA values for fruit length and fruit L:D ratio. In contrast, the female and male parents with the highest GCA values for both fruit length and fruit L:D ratio were WI 2712 and 13M, respectively.

High GCA effects for percentage of pistillate flowers were displayed by female parent WI 2963 and male parents 13M, WI 1983, and WI 5098. Male line 4H261 did not combine well with the other parents for female flowers. The SCA effects among hybrids approached zero, except for WI 2963 × 2H1853, which was high. The highest GCA effects for early flowering was displayed by WI 2712 and 2H1853 among the female and male lines, respectively. Six of 18 F_1 hybrids displayed significant SCA effects for early flowering. The hybrids WI 2963 × 4H261 displayed high SCA effects for late flowering.

Although line 13M had the highest GCA for maximum fruit length and L:D ratio among the male parents, it transmitted poor yielding ability to its progeny. Conversely, line 4H261 had the highest GCA among male parents for fruit yield for three harvests, but its offspring tended to have the shortest fruit and lowest L:D ratio among the progenies in the study. Based on its high GCA, line WI 2712 was the preferred female parent for transmitting the maximum first harvest yield, maximum fruit length, and L:D ratio, and minimum days to flowering to its progeny. Line WI 2963 was the most favorable female parent for transmitting maximum three-harvest yield, maximum proportion of female flowers, and maximum number of lateral branches to its progeny.

The ratio of GCA : total variance of the crosses (GCA : SCA, Table 5) ranged from 0.69 to 0.99, depending on the trait examined, indicating the gene action was primarily additive in nature. When GCA : SCA has a value of unity, the parental performance in a cross is predictable based on GCA alone (1). Others have reported similar findings regarding the additive gene action of cucumber (7, 11, 15).

Discussion

The average number of fruits per plant per harvest for all crosses examined was greater after three harvests than after the first harvest. This, and the fact that there was a relatively high correlation between lateral branch number and three-harvest yield but not first harvest yield, suggests that, as the plant grows and

Table 4. Correlation coefficients by planting density of morphological traits of 18 F_2 progenies derived from nine nearly homozygous cucumber lines.

Trait	Planting density^z	First harvest yield (no.)	Three-harvest yield^y (no.)	Lateral branch (no.)	Days to anthesis (no.)	Fruit^x Length (cm)	Fruit^x L:D ratio
Three-harvest yield	L	0.76*					
	H	0.78*					
Later branch number	L	0.36	0.60*				
	H	0.26	0.53*				
Days to anthesis	L	0.23	0.27	0.35			
	H	0.20	0.26	0.33			
Fruit length	L	−0.45*	−0.64*	−0.53*	−0.31		
	H	−0.27	−0.44	−0.52*	−0.29		
Fruit L:D ratio	L	−0.46*	−0.65*	−0.56*	−0.33	0.83*	
	H	−0.19	−0.31	−0.43	−0.29	0.46*	
Pistillate flowers (%)	L	−0.02	−0.13	−0.24	−0.06	0.21	0.18
	H	−0.20	−0.24	−0.24	−0.04	0.22	0.11

^{z}L = 29,000 plants/ha; H = 58,000 plants/ha.

^{y}Averaged over three harvests.

^{x}Length and length : diameter (L:D) ratio of fruits 2.7–3.8 cm in diameter.

*Significant at the 5% probability level.

Table 5. Analyses of variance of combining ability by planting density for morphological traits of F_1 progenies derived from nearly homozygous cucumber lines.

		Mean squares						
		Fruit/plant					Fruit	
Source of variation^z	df	First harvest (no.)	Three harvests (no.)	Lateral branch (no.)	Pistillate flowers (%)	Days to anthesis (no.)	Length (cm)	L:D ratio
				Low plant density (29,000 plants/ha)				
Block	3	0.04	0.64	0.72	0.06**	80.92**	27.38**	0.20**
Males (GCA_M)	5	2.29**	5.04**	3.00**	0.25**	46.86**	83.40**	0.43**
Females (GCA_F)	2	0.54	3.66**	3.56**	0.03	97.72**	105.55**	1.09**
M × F (SCA)	10	0.42	0.30	0.35	0.02	15.73**	4.81	0.01
Error	51	0.27	0.29	0.35	0.73	5.75	4.48	0.03
GCA : SCA^y		0.87	0.97	0.95	0.93	0.90	0.98	0.99
CV (%)		26.60	18.09	18.57	13.36	5.44	5.92	6.97
				High plant density (58,000 plants/ha)				
Block	3	0.04	0.20	0.70	0.01	60.85**	24.12**	0.45
Males (GCA_M)	5	0.65**	1.06**	2.35**	0.40**	15.29**	53.05**	0.32
Females (GCA_F)	2	0.85*	0.63	5.93**	0.09	17.68	21.50**	0.28
M × F (SCA)	10	0.25	0.01	0.22	0.01	15.08**	9.38	0.18
Error	51	0.15	0.12	0.40	0.02	4.63	6.65	0.21
GCA : SCA^y		0.86	0.99	0.97	0.98	0.69	0.89	0.77
CV (%)		26.61	18.30	25.81	18.47	4.49	7.49	18.21

^{z}Male and female mean squares estimate general combining ability effects while the male × female (M × F) mean squares estimates specific combining ability effects.

^{y}GCA : SCA = GCA_M + GCA_F/GCA_M + GCA_F + SCA.

*,**Significant at the 5% and 1% probability levels, respectively.

produces more laterals, it is capable of supporting more fruits per plant.

The experimental objective to bring the fruit quality traits of the *hardwickii*-derived lines up to commercially acceptable limits through F_1 hybrid production while maintaining high yields was generally unsuccessful. At the high planting density (58,000 plants/ha), the F_1 progeny having either 4H261 or WI 5551 as a common parent produced 37% to 51% more fruit per plant for first and three-harvest yields than the control 'Calypso'. However, fruits of these F_1 progenies ranged from 14% to 23% smaller in length and 3% to 10% smaller in L:D ratio than 'Calypso'.

Table 6. GCA effects by planting density for morphological traits of male and female cucumber lines used in an interpopulation Design II mating system.

	Fruit/plant					Fruit[y]	
Parent	First harvest (no.)	Three harvests[z] (no.)	Lateral branch (no.)	Pistillate flowers (%)	Days to anthesis (no.)	Length (cm)	L:D (ratio)
			Low plant density (29,000 plants/ha)				
Females							
WI 1701	−0.18	−0.29*	−0.22*	−0.04*	−0.86	0.07	0.02
WI 2712	0.11	−0.15	−0.22*	0.00	−1.61*	0.48*	0.20*
WI 2963	0.08	0.44*	0.45*	0.03	2.31*	−0.55*	−0.20*
SE	0.10	0.10	0.11	0.02	0.45	0.13	0.03
Males							
13M	−0.70*	−0.93*	−0.39*	0.08*	−1.61*	1.14*	0.29*
WI 1983	−0.37*	−0.59*	−0.37*	0.11*	−0.61	0.36	0.15*
WI 5098	0.18	−0.01	−0.05	0.13*	2.72*	−0.07	−0.10*
WI 5551	0.39*	0.37*	0.55*	−0.03	1.89*	−0.24	−0.10*
2H1853	0.20	0.39*	−0.42*	−0.05	−2.36*	−0.35	−0.02
4H261	0.31*	0.77*	0.70*	−0.26*	−0.03	−0.84*	−0.19*
SE	0.12	0.13	0.14	0.03	0.56	0.21	0.04
			High plant density (58,000 plants/ha)				
Females							
WI 1701	−0.08	−0.18*	0.10	−0.05	0.32	−0.10	−0.06
WI 2712	0.21*	0.07	−0.45*	−0.02	−0.97*	0.26*	0.12
WI 2963	−0.14*	0.12*	0.35*	0.07*	0.65	−0.16	−0.06
SE	0.07	0.06	0.12	0.03	0.40	0.10	0.08
Males							
13M	−0.39*	−0.45*	−0.56*	0.11*	−0.39	0.89*	0.30*
WI 1983	−0.07	−0.21*	−0.18	0.16*	0.11	0.10	0.07
WI 5098	−0.10	−0.02	−0.18	0.19*	0.19	−0.10	−0.12
WI 5551	0.21*	0.16*	0.25	−0.03	0.19	0.15	−0.06
2H1853	0.18*	0.18*	0.10	−0.17*	−1.81*	−0.28	−0.18
4H261	0.15	0.37*	0.55*	−0.26*	1.69*	−0.76*	−0.14
SE	0.09	0.08	0.15	0.03	0.51	0.16	0.11

[z] Averaged over three harvests.

[y] Length and length : diameter (L:D) ratio of fruits 2.7–3.8 cm in diameter.

*Significant at the 5% probability level.

Since most of the variation among lines for the traits examined can be explained by differences in GCA effects, genetic improvement for fruit yield could best be realized by selection among the high-performing parental lines (WI 2963, WI 5551, and 4H261). Further selection for fruit shape, while maintaining high selection pressure for yield, should produce lines that will perform well when crossed with *sativus* lines having good GCA for fruit shape, such as WI 2712. Since genes exhibiting nonadditive effects (dominance and/or epistasis) were also evident for days to anthesis and for other traits in several specific crosses, improvement could be achieved by testing selected parents for SCA in hybrid combination. Studies to determine optimum planting densities for fruit yield of *hardwickii*-derived lines would be advisable.

Literature Cited

1. Baker, L.R. 1978. Issues in diallel analysis. Crop Sci. 18:533–536.
2. Bliss, F.A. 1981. Utilization of vegetable germplasm. HortScience 16(2):129–132.
3. Cantliffe, D.J. and S.C. Phatak. 1975. Plant population studies with pickling cucumbers grown for once-over harvest. J. Amer. Soc. Hort. Sci. 100(5):464–466.
4. Comstock, R.E. and H.F. Robinson. 1948. The components of genetic variance in populations of biparental progenies and their use in estimating the average degree of dominance. Biometrics 4:254–266.
5. Delaney, D.E., R.L. Lower, and M.D. Edwards. 1983. Effect of within row spacing on mature fruit yield of three *C. sativus* var. *hardwickii* derivatives and a gynoecious inbred of *C. sativus*. Cucurbit Genet. Coop. Rpt. 6:3–4.
6. Della Vecchia, P.T. 1982. Inheritance of short-day response to flowering and of some fruit characteristics in crosses between *Cucumis sativus* var. *hardwickii* (R.) Alef. and *Cucumis sativus* L. lines. PhD Diss., Univ. of Wisconsin, Madison.
7. El-Shawaf, I.I.S. and L.R. Baker. 1981. Combining ability and genetic variances of G x H F_1 hybrids for parthenocarpic yield in gynoceious pickling cucumber for once-over mechanical harvest. J. Amer. Soc. Hort. Sci. 106(3):365–370.
8. Griffing, B. 1956. Concepts of general and specific combining ability in relation to diallel crossing systems. Austral. J. Biol. Sci. 9:463–493.
9. Hallauer, A.R. and J.B. Miranda. 1981. Quantitative genetics in maize breeding. Iowa State Univ. Press, Ames. p. 64–116.
10. Horst, E.K. and R.L. Lower. 1978. *Cucumis hardwickii*: a source of germplasm for the cucumber breeder. Cucurbit Genet. Coop. Rpt. 1:5.
11. Kupper, R. 1984. Evaluation of combining ability between lines of *Cucumis sativus* L. and *Cucumis sativus* var. *hardwickii* (R.) Alef. MS Thesis, Univ. of Wisconsin, Madison.
12. Lertrat, K. 1984. Improving fruit yield in two pickling cucumber

populations for a once-over emchanical harvesting system. PhD Diss., Univ. of Wisconsin, Madison.
13. Lertrat, K. and R.L. Lower. 1983. Pickling cucumber inbred line development by full-sib family selection. Cucurbit Genet. Coop. Rpt. 6:16–17.
14. Lertrat, K. and R.L. Lower. 1984. Pickling cucumber inbred line development by full-sib family selection II. Cucurbit Genet. Coop. Rpt. 7:8.
15. Lower, R.L., J.Nienhuis, and C.H. Miller. 1982. Gene action and heterosis for yield and vegetative characteristics in a cross between a gynoecious pickling cucumber inbred and a *Cucumis sativus* var. *hardwickii* line. J. Amer. Soc. Hort. Sci. 107(1):75–78.
16. Lower, R.L. and M.D. Edwards. 1986. Cucumber breeding, p. 173–207. In: M. Bassett (ed.). Breeding vegetable crops. AVI, Westport, Conn.
17. Lower, R.L., O.S. Smith, and A. Ghaderi. 1983. Effects of plant density, arrangement, and genotype on stability of sex expression. HortScience 18(5):737–738.
18. National Academy of Sciences. 1972. Genetic vulnerability of major crops. NAS, Washington, D.C.
19. Nienhuis, J. 1982. Response to different selection procedures for increased fruit yield in two pickling cucumber populations. PhD Diss., Univ. of Wisconsin, Madison.
20. Owens, K.W., F.A. Bliss, and C.E. Peterson. 1985. Genetic variation within and between two cucumber populations derived via the inbred backcross line method. J. Amer. Soc. Hort. Sci. 110(3):437–441.
21. Simmonds, N.W. 1979. Principles of crop improvement. Longman Group, London. p. 110–116.
22. 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(1):92–94.
23. Staub, J.E. 1985. Preliminary yield evaluation of inbred lines derived from *C. sativus* var. *hardwickii* (Royle) Kitamura. Cucurbit Genet. Coop. Rpt. 8:18–21.
24. Staub, J.E. and R.S. Kupper. 1985. Use of *Cucumis sativus* var. *hardwickii* germplasm in backcrosses with *Cucumis sativus* var. *sativus*. HortScience 20(3):436–438.

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Germination and Seedling Growth of Perennial Ryegrasses in Soluble Salts

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Abstract. **A laboratory experiment was conducted with seeds of perennial ryegrass (*Lolium perenne* L.) cultivars germinating and growing on floating mats in saline hydroponic solutions. This study was done to determine the relative intraspecific salt resistances of 48 perennial ryegrasses during germination and seedling growth in saline solutions. Total germination, germination rate, leaf blade length, root length, and total seedling fresh and dry weight were measured after 21 days. Test solutions prepared from deionized water and equal quantities of NaCl and $CaCl_2$ by weight consisted of 11.6 (low), 19.5 (medium), and 23.5 $dS\cdot m^{-1}$ (high) salinity. Cultivars had highly significant total germination and germination rate responses to salt stress. Seedling growth responses as measured by blade and root length and weights were also significant. A hydroponic medium with a salt concentration of 23.4 $dS\cdot m^{-1}$ should provide a suitable stress level for screening ryegrass genotypes for improved germination and seedling salt resistance. At the high salinity level, cultivars that average less than a 50% reduction in growth parameters relative to high-yielding cultivars should be considered. Broad-sense heritability estimates indicate that seedling dry and fresh weight and germination rate would be valuable criteria for use in selection of perennial ryegrasses for salt resistance.**

Perennial ryegrasses are widely used in the southern and southwestern United States for overseeding dormant warm-season turfgrasses. However, saline conditions often limit the establishment and quality of perennial ryegrasses for turf use. Salts concentrate in the soil from use of poor-quality water; soil solutions can reach harmful concentrations. Comparisons characterizing several turf and forage grasses (1, 2, 8, 9, 11) indicate that cool-season grasses are sensitive to salinity. A significant range of intraspecies responses to soluble salts on germination and seedling growth of Kentucky bluegrass (*Poa pratensis* L.) (6) and tall fescue (*Festuca arundinacea* Schreb.) cultivars (5) had been reported. Younger et al. (12) reported a wide range

Table 1. Mean squares for salt resistance sources of variation for perennial ryegrass, calculated as a percentage of the control for three salt levels and 48 cultivars.

		Mean squares					
		Germination		Weight		Growth	
Source of variation	df	Total	Rate	Dry	Wet	Blade	Root
Salt level	2	386**	11,007**	55,931**	63,017**	49,200**	161,210**
Cultivars	47	150	259**	2,084**	1,369**	428**	1,026**
Salt level × cultivar	94	49	92	301**	287**	68	206

**Significant at 0.01 level of probability.

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