Screening the Cucumber Germplasm Collection for Fruit Yield and Quality

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ABSTRACT

Yield of cucumber (*Cucumis sativus* L.) in the United States has not been significantly increased during the last two decades. Our objective was to evaluate the USDA cucumber germplasm collection for fruit yield and quality. All cucumber plant introduction accessions from the USDA National Plant Germplasm System collection plus check cultivars and breeding lines (hereafter collectively referred to as cultigens) were evaluated for early, total, and marketable yield (number and weight), fruit quality rating, and days to harvest in small plots harvested once. All plants were treated with ethephon (2-chloroethyl phosphonic acid) to make them gynoecious. Highly significant differences were observed among cultigens for all traits evaluated in the study. Pickling type cultigens with the highest yield (fruit weight) were PI 209065, PI 326598, PI 137848, PI 285610, and PI 264666. Slicing type cultigens with the highest yield were PI 234517, PI 118279, PI 304085, and PI 512614. Beit Alpha type cultigens with the highest yield were PI 167050, PI 163213, PI 532519, PI 211978, PI 357864, PI 183231, and PI 211117. Trellis type cultigens with the highest yield were PI 264228, PI 478366, PI 390262, PI 532524, PI 390267, and PI 532520. The USDA collection also exhibited a wide range in diversity for marketable fruit number, fruit weight, percentage of culled fruit at harvest, fruit quality, and days to harvest. High yielding cultigens identified in the study could be used to develop high yielding cultivars.

Cucumber is thought to have originated in India or China (Harlan, 1975), with domestication occurring later throughout Europe. Cucumber is a member of the Cucurbitaceae family, which comprises 90 genera and 750 species (Sitterly, 1972). Cucumber is thought to be one of the oldest vegetable crops, being grown for at least five thousand years. Cucumber is a thermophilic and frost-susceptible crop, growing best at temperatures >20°C. The crop is grown throughout the world and is the fourth most important vegetable crop after tomato (*Lycopersicon esculentum* Mill.), cabbage (*Brassica oleracea* var. *capitata* L.), and onion (*Allium cepa* L.) (Tatlioglu, 1993).

Cucumber is grown as a number of different types and is used as either a fresh or processed vegetable. Some of the types of cucumber grown throughout the world are American pickling, European pickling, American slicing (fresh market), European greenhouse (parthenocarpic), oriental trellis, middle-eastern (Beit Alpha), and schalgurken. Cucumber types differ based on the type of use (fresh market or processed), fruit length, diameter, color, color uniformity, skin thickness, and skin surface protrusions. In the United States in 1998, 17 264 ha were planted to pickling cucumber with a total production of 615 310 Mg of fruit (USDA, 1998). The total area and production of slicing cucumber for 1997 was 9760 ha with a production of 202 514 Mg (USDA, 1998). Cucumber is the second most important vegetable crop in North Carolina, with a production area of ≈9717 ha (USDA, 1997). Nationally, North Carolina was ranked third in pickling cucumber production after Michigan and Florida, and fifth in slicing cucumber production after Georgia, Florida, Michigan, and California during 1997 (USDA, 1997).

Breeding for yield in cucumber has been one of the important objectives of many cucumber breeding programs since the 1900s (Wehner, 1989). Yield of pickling cucumber has been improved by breeding for disease resistance (Peterson, 1975), as well as through the use of improved cultural practices (Cargill et al., 1975). Increased yield of cucumber cultivars has been due also to the improvement of qualitative traits such as gynoecious sex expression, improved fruit color (improved percentage marketable fruit), and direct yield improvement (Wehner, 1989).

The average yield of pickling cucumber in the United States (USDA, 1959–1998) has increased by 100% across the last four decades due to improved cultural practices, and selection for yield and disease resistance. Most of the productivity increase was during the first two decades, with a plateau in the last two decades. Thus, there is a need to focus more on yield improvement. To identify new sources of high yield in the cucumber germplasm collection for use in breeding, we are using a three-stage process: First, all available plant introduction accessions, cultivars, and breeding lines (hereafter collectively referred to as cultigens) are tested for combining ability with a gynoecious tester; second, all available cultigens are tested for yield per se; and third, the best cultigens are evaluated using larger trials with multiple harvests, seasons, and years.

Measurement of the yield of a large and diverse set of cucumber cultigens is costly. Previous research has provided some guidelines for the design of efficient yield trials. Fruit number was found to be a more stable measure of productivity than fruit weight or value in a once-over harvest trial for cucumber (Ells and McSay, 1981). Fruit number was more highly heritable (0.17) than fruit weight (0.02) (Smith et al., 1978). Evaluation of yield in single-plant hills was poorly correlated with multiple-harvest yield in replicated field trials, indicating the necessity for testing in row plots (Wehner and Miller, 1984; Wehner, 1986). In addition, greenhouse evaluation for yield based on fruit number on single plants was not correlated (r = 0.09 to 0.15) with yield at two field locations (Nerson et al., 1987).

Once-over harvest trials having three replications were recommended for maximum efficiency to determine which cucumber lines should be tested further in multiple-harvest trials (Wehner and Miller, 1984; Weh-

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The research was funded in part by the North Carolina Agricultural Research Service (NCARS). Received 25 June 2001. *Corresponding author (todd_wehner@ncsu.edu).

Published in Crop Sci. 42:2174–2183 (2002).

ner, 1986). A plot size of 1.2 × 1.5 m was found to be optimum for yield evaluation for once-over harvest of pickling cucumber cultigens harvested using paraquat (1,1′-dimethyl-4,4′-bipyridinium ion; Swallow and Wehner, 1986). In cucumber, small-plot, single-harvest trials were found to be more efficient than large-plot, multiple-harvest trials (Wehner, 1986, 1989). Wehner et al. (1984) recommended the use of paraquat to defoliate plots for efficient yield measurement in once-over harvest trials.

Swallow and Wehner (1989) calculated that maximum efficiency was achieved by allocating test plots of cucumber cultigens to different seasons and years rather than locations and replications. Another study showed that yield evaluation at the Clinton location was more efficient (information relative to cost) than three other North Carolina locations tested (Wehner, 1987).

Miller and Hughes (1969) reported that harvesting at 14 to 31% oversized fruit stage in a plot was found to be optimum for maximum value in once-over harvest for 'Piccadilly' and 'Southern Cross' gynoecious pickling hybrids in North Carolina. Oversize is >51-mm diameter for pickling and >60-mm diameter for slicing cucumber. Chen et al. (1975) used a computer simulation and reported that plots harvested at 10% oversized fruit stage gave an optimum yield for Piccadilly hybrid under North Carolina conditions. Colwell and O'Sullivan (1981) reported that the optimum harvest stage to maximize yield for 'Femcap' and 'Greenstar' gynoecious hybrids occurred when 5 to 15% of fruit in a plot were oversized. Studies using a diverse array of pickling and slicing cucumber cultigens revealed no effect on fruit yield and quality traits (with the exception of early yield of pickling type) between harvesting cucumber when fruit in a plot reached 10 or 50% oversized fruit stage (Shetty, 1999).

Cucumber plants produce one or more of three types of flowers: staminate, pistillate, and perfect. Exogenous application of ethylene is known to promote the production of pistillate flowers in monoecious cucumber lines, resulting in increased fruit yield (McMurray and Miller, 1968; Robinson et al., 1968; Miller et al., 1970; Rudich et al., 1972; Hogue and Heeney, 1974; Cantliffe and Phatak, 1975). Ethephon treatments significantly improved the total yield, percentage of culled fruit, and fruit quality traits evaluated in pickling cucumbers (Shetty, 1999). Shetty (1999) observed higher total yields with a single ethephon application and did not observe an additional benefit beyond a single application at the first-true-leaf stage.

Ethephon also was found to have an effect on vegetative and floral traits (days to first flower set, days to 50% flower set, days to first fruit set, days to 50% fruit set, and fruit quality in a group of cucumber cultigens which differed in their sex expression. This study also concluded that one application of ethephon was optimum. More ethephon applications usually increased the number of days to reach a particular growth stage (days to first flower set, days to 50% flower set, days to first fruit set, and days to 50% fruit set). However, ethephon did not have an effect on fruit yield and quality traits on a set of slicing cucumber cultigens (Shetty, 1999). Ethephon treatment of isogenic lines of cucumber differing in sex expression improved gynoecious rating, fruit number (total, early, and marketable), and fruit weight (total, early, and marketable) compared with the untreated control. Ethephon was effective in increasing pistillate flower number on monoecious inbreds, but had little effect on gynoecious inbreds.

The objective of this experiment was to evaluate all available cucumber cultigens in the USDA germplasm collection for fruit yield and quality under field conditions in North Carolina.

MATERIALS AND METHODS

All experiments were conducted at the Horticultural Crops Research Station, Clinton, NC, during the spring and summer seasons of 1997 and 1998. For this experiment, 817 cultigens were evaluated (810 plant introduction accessions and seven check cultivars and breeding lines). Plant introduction accessions were obtained from the USDA North Central Regional Plant Introduction Station at Ames, Iowa. The cultigens originated in 50 different countries, with the greatest number coming from Turkey, People's Republic of China, the former Yugoslavia, Iran, the former USSR, Japan, India, and Spain (Table 1).

Seeds were planted on raised, shaped beds in rows 1.5 m apart. The soil type in the study was a mixture of Norfolk (fine-loamy, kaolinitic, thermic Typic Kandiudults), Orangeburg (fine-loamy, kaolinitic, thermic Typic Kandiudults), and Rains (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults), with some Goldsboro (fine-loamy, siliceous, subactive, thermic, Aquic Paleudults).

Plots were 1.2-m long and 1.5-m wide with 1.2-m alleys at each end. Plots were planted with 16 seeds and thinned to a uniform stand of 12 plants per plot. Recommended horticultural practices (Schultheis, 1990) were used for all experiments. Fertilizer was incorporated before planting at a rate

Table 1. Seed source for 817 cucumber cultigens tested for fruit yield in North Carolina.

Seed source	No. of cultigens	Seed source	No. of cultigens
Afghanistan	15	Indonesia	1
Australia	1	Iran	59
Bhutan	3	Iraq	1
Brazil	2	Israel	6
Burma	2	Italy	3
Canada	3	Japan	47
Former Czechoslovakia	29	Kenya	2
Denmark	3	Korea	17
Egypt	19	Lebanon	4
Ethiopia	2	Malaysia	2
France	6	Mauritius	1
Georgia	1	New Zealand	2
Germany	4	The Netherlands	15
Great Britain	2	Oman	3
Greece	1	Pakistan	7
Hong Kong	2	The Philippines	3
Hungary	21	Poland	13
India	45	P.R. China	111
Puerto Rico	3	USSR	49
Spain	43	Uzbekistan	4
Sweden	4	Former Yugoslavia	62
Syria	11	Zambia	1
Taiwan	10	Zimbabwe	2
Thailand	2		
Turkey	149	Cultivars (checks)	7
Ukraine	3		
USA	19		

of 90-39-74 kg ha^{-1} (N-P-K), with an additional 34 kg ha^{-1} N applied at the vine tip-over stage. Curbit [ethalfluralin N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine] was applied for weed control. Irrigation was applied when needed for a total (irrigation plus rainfall) of 25 to 40 mm per week. 'Sumter' pollenizer was planted in side rows and end plots to provide additional pollen and border competition for the test plots.

No disease problems were observed in the spring season of either year. Some foliar diseases were observed in the plots during the summer season, but symptoms were mild due to the routine spray program followed as part of recommended cultural practices (Schultheis, 1990). Each plot was harvested once-over when the plants had 15% oversized fruit. Although the usual index for yield evaluation for testing populations in our breeding program is 10%, we used a 15% index in this study to avoid penalizing low yielding or late-maturing cultigens.

Ethephon was applied at the first to second true leaf stage (approximately one month after planting). A backpack sprayer at 100 to 140 kPa (15 to 20 psi) was used to spray the ethephon on the leaves until run-off. Ethephon was prepared using Florel (3.9% ethephon, Southern Agricultural Insecticides, Inc., Palmetto, FL)[1] at the rate of 2.5 mL L^{-1}.

Data were collected as plot means, and consisted of number of total, early, and cull fruit per plot. Early fruit were the number of oversized fruit at harvest. The number of marketable fruit was calculated as total − cull. Percentage of culls was calculated as 100 × cull fruit number/total fruit number. Similar formulas were used to compute percentage of early (by weight and by number) fruit and percentage (by weight and by number) of marketable fruit. Fruit weight was recorded for all grades (early, marketable, cull, and total) during the spring season of 1997. In all other environments, only total fruit weight was recorded. In those environments, early, marketable, and cull fruit weights were estimated from early, marketable, and cull fruit number along with total fruit weight using regression relationships from the spring season (Shetty, 1999).

Fruit quality was rated, based on fruit color and shape, on a 1 to 9 scale (1–3 = poor overall with curved and tapered shape and nonuniform light green color; 4–6 = intermediate; 7–9 = excellent overall with straight, cylindrical, and blocky shape and uniform dark green color). Thus, the scale has three main levels, with three sublevels in each, resembling a +/− system (7 = excellent−, 8 = excellent, 9 = excellent+). Days to harvest and fruit quality rating were also recorded. All cultigens were grouped into one of four types: pickling, slicing, middle-eastern (Beit Alpha), and oriental trellis. Digital photographs of fruit of all cultigens used in the study were recorded to verify fruit type.

The experiment was a randomized complete block design with 817 cultigens, two seasons (spring, summer), two years (1997, 1998), and three replications. The two years and two seasons were considered to be four environments to simplify the statistical analysis. Data were analyzed using GLM procedures of SAS 6.12 (SAS Institute, Inc., Cary, NC). Yield was expressed as thousands of fruit ha^{-1} for fruit number, and Mg ha^{-1} for fruit weight to make comparisons with other studies easier. Plots with a stand count (plant number) of <50% were eliminated from the statistical analysis, and plots with stand count ranging from 50 to 75% of target stand (12 plants) were corrected using the formula:

$$\text{corrected yield} = 12 \times (\text{total yield/stand}),$$

according to the method of Cramer and Wehner (1998).

[1] Use of trade names in this publication does not imply endorsement by the NCARS of the products named, or criticism of similar ones not mentioned.

RESULTS AND DISCUSSION

Data collected in spring and summer seasons of 1997 and spring 1998 were excellent. However, poor stand establishment conditions occurred in summer 1998, and data were obtained for only 70% of the plots in one replication, and 30% in the other two replications. Thus, we used only the data from three environments (eliminating data for summer 1998).

The main effect of environment was not significant for any traits except percentage marketable fruit weight (Table 2). There were significant differences among the 817 cultigens for fruit yield and quality, and for days to harvest. The interaction of cultigen and environment was significant for all traits, except percentage of culls. However, the effect of cultigen was much larger than that of cultigen × environment for all the traits (Table 2). Therefore, fruit yield and quality traits are presented as averages across the three environments.

The complete dataset for yield of 817 cultigens was submitted to the Germplasm Resources Information Network (http://www.ars-grin.gov/) for those interested in particular cultigens. The cultigens evaluated were grouped into four distinct categories based on the fruit type data. There were 249 pickling, 116 slicing, 265 middle-eastern (Beit Alpha types), and 187 oriental trellis cucumber cultigens (Tables 3, 4, 5, and 6).

Because some cultigens produce a large number of fruit with a small fruit weight, and because breeders and growers are most interested in fruit weight, we presented the data for cultigens ranked by total fruit weight. The most interesting cultigens would be those with highest fruit weight and number within a particular fruit type. Also of interest are early and marketable fruit weight and number, percentage of culls, fruit quality rating, and days to harvest (Tables 3, 4, 5, and 6).

Pickling Cucumber

Forty-seven cultigens produced higher yields (total fruit number) than the highest yielding check Calypso. The cultigens with the highest fruit number were PI 215589, PI 344440, PI 356809, PI 370643, PI 249561, PI 209065, PI 288992, PI 179678, PI 531314, and PI 422191. PI 215589 produced 267 thousand fruit ha^{-1}, compared with Calypso, with 105 thousand fruit ha^{-1}. PI 209065 (USA OH) and PI 531314 (Hungary) were the only two cultigens with both a higher fruit number and fruit weight than Calypso (Table 3).

Cultigens with the highest early fruit weight were PI 209065, PI 285610, PI 175111, PI 137848, PI 264666, PI 269481, PI 306180, PI 370019, PI 482463, PI 211728, and PI 163216. All yielded more than 20 Mg ha^{-1}. Only 21 cultigens had higher early yield than the best check, Calypso. A total of 68 cultigens had a higher early yield percentage (by weight) than the best check cultivar, Sumter. PI accessions of pickling type that had the highest early yield percentage (by weight) were PI 211728,

Table 2. *F* ratios for mean squares of yield, quality, and harvest traits for the cucumber cultigens evaluated during 1997–1998 at Clinton, NC.

Source of variation	df	Total		Early		Marketable		% cull		Fruit quality†	Harvest days‡
		Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.		
		Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}		
Environment	2	0.8	1.28	0.8	1.6	2.1	1.5	3.5	0.2	2.3	2.2
Rep (Environment)	6	147	152	132	45.6	52	117	76	42	1115	140
Cultigen	816	2.3**	5.5**	1.9**	2.9**	1.7**	3.5**	3.0**	2.1**	8.6**	8.7**
Cultigen × Environment	1521	1.3**	1.3**	1.3**	1.2**	1.1**	1.3**	1.0	1.2**	1.3**	1.4**

** Significant at the 0.01 probability level.
† Fruit quality ratings were based on fruit shape and color (1–3 = poor, 4–6 = intermediate, 7–9 = excellent).
‡ Harvest days is the number of days from planting to harvest.

PI 512336, PI 175121, PI 500359, PI 344432, PI 370447, PI 163218, PI 163216, PI 212896, and PI 512607. Cultigens with higher early fruit weight and higher early yield percentage (by weight) than the best checks were PI 174160, PI 175111, PI 175121, PI 209065, PI 269481, PI 285610, PI 344432, and PI 370019.

Thirty PI accessions had higher early yields (by number), and 111 PI accessions had higher early yield percentage (by number) than the best check, Calypso. PI accessions with the highest early yield (by number) were PI 209065, PI 422191, PI 531314, PI 169397, PI 215589, PI 379278, and PI 269480. All were estimated to produce more than 66 thousand fruit ha^{-1}. Cultigens with the highest early yield percentage (by number) were PI 500359, PI 222986, PI 370447, PI 175120, PI 175121, PI 217946, PI 512607, and PI 221440. All had >70% of yield in numbers as early yield. Cultigens with both high early fruit yield and high early yield (by number)

Table 3. Yield, quality, and harvest traits for the three checks, 20 highest, and 10 lowest yielding (out of 249 total) pickling cucumber cultigens evaluated during 1997–1998 at Clinton, NC.

Cultigen	Seed source	Total		Early		Marketable		% cull		Fruit quality†	Harvest days‡
		Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.		
		Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}		
'Calypso'	Check-USA	26	105	18	55	5	33	7	16	7.4	55
'Sumter'	Check-USA	19	98	15	47	3	28	7	21	7.2	58
WI 2757	Check-USA	15	79	10	33	3	27	7	24	6.8	64
					Highest yielding 20						
PI 209065	USA OH	33	146	24	92	5	19	6	20	5.7	57
PI 326598	Hungary	30	92	16	52	1	31	5	10	6.8	64
PI 137848	Iran	30	123	22	65	5	36	7	20	5.0	52
PI 285610	Poland	29	80	23	48	5	21	4	17	5.9	61
PI 264666	Germany	29	84	21	45	5	18	9	25	5.9	58
PI 175111	India	28	73	22	40	4	19	5	19	3.8	55
PI 169397	Turkey	28	116	20	69	6	27	7	16	5.4	55
PI 306180	Poland	28	85	21	44	5	24	7	19	5.7	61
PI 379278	Yugoslavia	27	104	20	67	6	28	7	11	5.4	59
PI 426169	The Philippines	27	89	20	50	5	18	8	22	4.7	56
PI 370019	India	26	99	20	65	4	16	8	19	3.1	56
PI 531314	Hungary	26	135	18	72	5	35	13	22	5.3	58
PI 269481	Pakistan	26	99	21	66	3	20	6	15	2.9	58
PI 326597	Hungary	26	102	19	58	4	25	10	18	7.1	63
PI 174160	Turkey	26	73	20	39	5	22	4	18	6.0	60
PI 264665	Germany	25	75	19	50	4	9	8	22	6.0	59
PI 206043	USA PR	25	105	17	39	7	50	5	14	6.9	63
PI 379285	Yugoslavia	25	81	19	40	4	17	9	28	5.1	60
PI 163216	India	25	50	20	31	3	8	4	19	5.0	78
PI 482463	Zimbabwe	25	21	20	11	4	10	3	0	6.0	73
					Lowest yielding 10						
PI 267087	USSR	9	120	5	44	3	63	3	12	2.6	55
PI 179678	India	9	137	5	42	3	96	5	0	2.0	80
PI 512336	Hong Kong	9	14	9	12	0	1	5	13	4.8	83
PI 357857	Yugoslavia	9	8	9	3	1	3	35	38	5.7	73
PI 512634	Spain	9	23	7	11	3	10	3	4	6.0	76
PI 179921	India	8	27	7	13	1	11	6	21	4.6	75
PI 163222	India	8	26	6	15	1	7	8	14	4.1	72
PI 222986	Iran	7	18	5	11	1	3	10	8	5.5	64
PI 164465	India	4	15	3	6	1	2	7	48	3.8	78
PI 481612	Bhutan	3	12	3	5	0	6	4	17	3.2	80
Mean		18	82	13	40	3	27	8	18	4.8	60
Range		30	260	21	89	12	183	33	48	5.9	31
LSD, 5%		8	30	6	21	2	19	6	14	0.9	4
CV, %		49	40	54	56	77	79	86	83	20	7

† Fruit quality ratings were based on fruit shape and color (1–3 = poor, 4–6 = intermediate, 7–9 = excellent).
‡ Harvest days is the number of days from planting to harvest.

Table 4. Yield, quality, and harvest traits for the four checks, 20 highest, and 10 lowest yielding (out of 116 total) slicing cucumber cultigens evaluated during 1997–1998 at Clinton, NC.

Cultigen	Seed source	Total		Early		Marketable		% cull		Fruit quality†	Harvest days‡
		Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.		
		Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}		
'Sprint 440'	Check-USA	28	88	22	42	4	35	6	14	7.9	61
'Dasher II'	Check-USA	27	101	21	43	3	37	6	20	7.8	61
'Poinset76'	Check-USA	25	106	19	41	4	44	6	20	7.6	64
'Marketmore76'	Check-USA	13	39	9	25	3	14	4	0	7.7	55
				Highest yielding 20							
PI 234517	USA SC	35	105	28	55	5	33	5	16	6.9	63
PI 118279	Brazil	35	148	27	80	5	45	7	15	5.3	57
PI 304805	USA NY	32	114	21	43	9	46	6	23	6.5	69
PI 368560	Yugoslavia	32	55	27	37	3	13	3	9	4.9	69
PI 173893	India	31	80	26	55	2	8	7	20	3.9	59
PI 512614	Spain	30	102	23	48	5	40	5	20	5.6	59
PI 512615	Spain	28	69	23	41	3	19	6	9	5.2	62
PI 165499	India	28	64	24	30	2	18	8	25	4.3	59
PI 414159	USA HW	27	87	20	36	4	36	9	18	6.9	63
PI 288238	Egypt	26	79	21	37	2	14	13	34	5.9	62
PI 288996	Hungary	26	82	20	50	4	18	9	16	4.7	60
PI 512623	Spain	26	95	20	39	3	30	9	27	5.6	60
PI 406473	The Netherlands	26	94	20	40	3	25	10	29	7.0	63
PI 561145	USA NY	26	109	17	41	5	39	10	27	7.4	65
PI 401733	Puerto Rico	25	87	18	35	5	31	9	23	5.4	62
PI 357860	Yugoslavia	25	54	21	36	2	9	4	15	5.0	66
PI 283901	Czech Rep.	25	71	19	34	3	11	19	37	4.6	61
PI 561148	USA NY	25	95	18	47	6	34	4	16	7.4	68
PI 390246	Japan	24	65	18	29	4	20	8	25	6.0	70
PI 422177	Czech Rep.	24	85	18	43	4	25	9	21	6.4	63
				Lowest yielding 10							
PI 357856	Yugoslavia	9	27	7	12	1	8	9	19	5.8	64
PI 267743	PR China	9	26	6	16	2	5	7	14	5.3	66
PI 422192	Czech Rep.	8	19	8	9	2	4	4	29	7.3	71
PI 512619	Spain	8	23	6	9	1	8	6	23	5.4	68
PI 390238	Japan	8	31	6	15	1	11	4	11	5.6	72
PI 321009	Taiwan	7	18	5	9	1	7	6	17	5.3	71
PI 512625	Spain	6	23	6	8	2	11	3	21	5.0	69
PI 379280	Yugoslavia	6	15	6	8	2	5	4	18	4.8	69
PI 368559	Yugoslavia	6	16	5	12	0	3	5	5	4.4	70
PI 481616	Bhutan	2	3	0	0	2	3	0	0	3.0	81
Mean		19	64	14	28	3	22	7	21	5.5	64
Range		33	145	28	80	9	53	33	47	4.9	26
LSD, 5%		10	27	8	18	2	15	6	15	0.9	4
CV, %		55	45	62	70	92	72	90	77	17	8

† Fruit quality ratings were based on fruit shape and color (1–3 = poor, 4–6 = intermediate, 7–9 = excellent).
‡ Harvest days is the number of days from planting to harvest.

compared with the checks were PI 169397, PI 209065, PI 212985, PI 263047, PI 263079, PI 269480, PI 269481, PI 326597, PI 330628, PI 370019, PI 379278, PI 390954, PI 422191, PI 458855, PI 458856, PI 504567, and PI 512620. PI 269481 was the only cultigen that had high early yield (number and weight) and had a high percentage of early yield (number and weight) (Table 3).

There were cultigens with marketable yields (by weight) higher than the best check, Calypso. Cultigens producing >5 Mg ha^{-1} marketable fruit were PI 326598, PI 197087, PI 478367, PI 206043, PI 326596, PI 512597, PI 531312, PI 169397, PI 379278, PI 209065, PI 531309, PI 271753, and PI 531314. There were 88 cultigens with a higher marketable yield percentage (by weight) than the best check, Calypso. Cultigens with both high marketable weight and high marketable yield percentage (by weight) were PI 197087, PI 206043, PI 271753, PI 326596, PI 326598, PI 379278, PI 478367, PI 512597, PI 531309, and PI 531312 (Table 3).

There were 72 cultigens with higher marketable yield (by number) and 101 cultigens with higher marketable yield percentage (by number) than the best check, Calypso (33 thousand fruit ha^{-1}). Cultigens with high marketable fruit number were PI 215589, PI 179678, PI 288992, PI 249561, PI 267087, PI 356809, PI 205995, PI 344440, PI 292012, PI 390953 (all >53 thousand fruit ha^{-1}). Those with high marketable yield percentage (by number) were PI 179678, PI 215589, PI 200815, PI 164734, PI 532162, PI 288992, PI 135122, PI 267087, PI 264226, and PI 482463 (all >50%). Pickling cultigens ranked in the top 10% category for high marketable fruit number and high marketable yield percentage (by number) were PI 179678, PI 215589, PI 267087, and PI 288992 (Table 3).

A total of 100 pickling PI accessions had a lower culled fruit percentage (by weight) than the best check Calypso. Calypso had lower cull weight than the other pickling check, Sumter, for total cull fruit weight but had the same culled fruit percentage (by number). There were 114 cultigens with a lower percentage of culled fruit than Calypso. Cultigens which ranked in the top 10% for fewest number and weight of culls were PI

Table 5. Yield, quality, and harvest traits for the three checks, 20 highest, and 10 lowest yielding (out of 265 total) middle-eastern (Beit-alpha) cucumber cultigens evaluated during 1997–1998 at Clinton, NC.

Cultigen	Seed source	Total		Early		Marketable		% cull		Fruit quality†	Harvest days‡
		Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.		
		Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}		
'Calypso'	Check-USA	26	105	18	55	5	33	7	16	7.4	55
'Sumter'	Check-USA	19	98	15	47	3	28	7	21	7.2	58
WI 2757	Check-USA	15	79	10	33	3	27	7	24	6.8	64
					Highest yielding 20						
PI 167050	Turkey	34	69	26	36	5	18	6	18	6.3	64
PI 163213	India	33	78	24	40	8	35	4	6	5.5	65
PI 532519	USSR	33	131	23	40	5	50	8	30	7.7	59
PI 211978	Iran	33	66	26	45	5	13	5	14	6.0	59
PI 357864	Yugoslavia	31	85	22	32	5	34	9	23	5.7	62
PI 183231	Egypt	30	99	19	53	4	20	13	25	6.2	61
PI 211117	Israel	30	97	20	44	7	39	7	13	7.0	65
PI 292010	Israel	30	127	20	49	6	55	8	21	7.3	62
PI 172852	Turkey	30	87	24	58	4	26	3	3	6.0	64
PI 169401	Turkey	29	86	22	42	4	25	6	19	7.0	63
PI 181755	Lebanon	29	111	21	52	4	42	10	19	6.3	57
PI 169385	Turkey	29	88	20	38	6	45	4	6	6.3	54
PI 167079	Turkey	28	105	21	61	4	29	7	15	6.2	60
PI 534543	Syria	28	155	17	56	8	68	13	22	6.2	56
PI 169388	Turkey	28	55	22	37	3	11	5	10	5.8	62
PI 218036	Iran	28	72	22	49	4	12	7	15	6.0	61
PI 535881	Poland	28	115	20	49	5	37	7	24	7.9	57
PI 137856	Iran	28	111	19	57	5	23	13	25	4.8	55
PI 211988	Iran	28	88	19	49	4	18	12	26	5.8	59
PI 204569	Turkey	28	92	19	49	5	25	7	20	5.5	57
PI 344437	Iran	28	78	18	38	6	21	10	25	5.9	58
					Lowest yielding 10						
PI 248778	Iran	12	56	8	27	2	21	10	12	5.3	57
PI 172839	Turkey	11	38	8	15	2	15	8	21	6.2	66
PI 368556	Yugoslavia	11	32	8	15	2	8	7	30	5.1	67
PI 357867	Yugoslavia	11	22	8	14	2	6	6	15	6.0	73
PI 344433	Iran	11	25	9	17	1	6	5	11	5.6	70
PI 357853	Yugoslavia	10	10	10	9	2	0	7	50	3.3	77
PI 211980	Iran	9	42	6	23	2	12	13	19	5.2	59
PI 171604	Turkey	9	29	6	10	2	17	5	5	5.0	72
PI 379287	Yugoslavia	6	17	5	7	0	6	6	22	4.7	75
PI 357849	Yugoslavia	6	13	5	11	1	2	2	0	5.5	72
Mean		20	73	14	35	4	24	8	19	5.9	60
Range		28	145	21	62	9	68	18	50	4.6	24
LSD, 5%		8	25	6	17	2	16	6	13	0.9	3
CV, %		46	37	51	52	75	74	73	77	17	6

† Fruit quality ratings were based on fruit shape and color (1–3 = poor, 4–6 = intermediate, 7–9 = excellent).
‡ Harvest days is the number of days from planting to harvest.

135122, PI 175121, PI 283902, PI 289698, PI 370447, PI 504570, PI 512634, PI 512637, PI 512640, and PI 532162 (Table 3). In general, the PI accessions evaluated had poor fruit quality ratings compared with the standard checks used in the study. Four pickling cultigens had similar or better ratings for fruit quality: PI 422180, PI 422182, PI 506461, and PI 435947 (Table 3).

There were 36 cultigens that required fewer days to harvest than Calypso. The best one (PI 343452) was 4 d earlier than Calypso. The latest one (PI 512336) required 28 d more than Calypso to harvest. The earliest cultigens were PI 205995, PI 271334, PI 164816, PI 531309, PI 342950, PI 257486, PI 351139, PI 164819, PI 264226, PI 267746, PI 137848, and PI 343452 (Table 3).

The cultigens with the highest total yield in terms of fruit weight among the pickling cucumber cultigens evaluated in the study were PI 209065, PI 326598, PI 137848, PI 285610, and PI 264666. There were 17 cultigens that produced higher total fruit weight than the check cultivar Calypso. In general, all 17 cultigens identified had higher or similar early and marketable fruit weight and number than Calypso. However, fruit quality ratings were lower for the 17 cultigens. In general, the number of days to harvest for the 17 cultigens also was higher than for Calypso. The lowest yielding cultigens in the study were PI 179921, PI 163222, PI 222986, PI 164465, and PI 481612, which also showed low fruit quality rating and high number of days to harvest (Table 3).

Slicing Cucumber

Nine cultigens had more fruit weight than the high yielding slicing check 'Sprint 440'. Four cultigens, PI 234517, PI 118279, PI 304085, and PI 512614, also had higher total fruit number than the check. The nine cultigens were similar for early, marketable, and cull fruit weight. However, PI 118279 from Brazil had a high number of total, early, and marketable fruits with fruit weight similar to the other eight PI accessions identified, but had smaller size. The nine cultigens identified were similar for days to harvest with the exception of PI

Table 6. Yield, quality, and harvest traits for the four checks, 20 highest, and 10 lowest yielding (out of 187 total) trellis cucumber cultigens evaluated during 1997–1997 at Clinton, NC.

Cultigen	Seed source	Total		Early		Marketable		% cull		Fruit quality†	Harvest days‡
		Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.		
		Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}	Mg ha^{-1}	1000 fruit ha^{-1}		
'Sprint 440'	Check-USA	28	88	22	42	4	35	6	14	7.9	61
'Dasher II'	Check-USA	27	101	21	43	3	37	6	20	7.8	61
'Ponsett75'	Check-USA	25	106	19	41	4	44	6	20	7.6	64
'Marketmore76'	Check-USA	13	39	9	25	3	14	4	0	7.7	55
				Highest yielding 20							
PI 264228	France	40	127	24	61	7	18	13	26	5.8	62
PI 478366	PR China	40	99	26	41	6	20	12	39	6.5	67
PI 390262	Japan	36	105	21	35	6	32	17	33	7.0	66
PI 532524	Japan	34	85	23	34	5	30	14	25	6.3	67
PI 390267	Japan	34	95	21	42	6	29	15	22	6.8	64
PI 532520	USSR	33	115	18	35	8	40	19	35	6.6	66
PI 275411	The Netherlands	33	116	20	48	6	39	15	24	5.3	58
PI 419010	PR China	33	80	20	36	6	24	14	27	6.1	62
PI 518851	PR China	32	89	23	45	4	18	14	28	6.3	64
PI 511820	Taiwan	32	93	18	46	6	24	22	26	6.6	61
PI 422167	Czech Rep.	32	84	21	30	5	26	11	31	7.3	66
PI 432884	PR China	31	89	19	29	7	36	14	25	6.4	69
PI 419009	PR China	31	74	16	31	7	23	21	25	6.4	66
PI 418964	PR China	31	72	19	36	5	20	15	22	5.9	67
PI 263085	PR China	31	92	19	34	4	23	18	37	4.8	61
PI 432887	PR China	30	65	18	22	5	16	17	42	6.0	68
PI 257487	PR China	30	90	17	32	6	26	17	35	6.8	61
PI 432873	PR China	30	85	17	25	5	23	22	40	6.3	70
PI 419136	PR China	30	91	17	33	5	22	21	40	6.0	62
PI 419040	PR China	30	82	16	34	5	26	26	34	5.3	65
				Lowest yielding 10							
PI 263082	PR China	14	51	8	18	2	15	23	41	5.1	63
PI 267935	Japan	13	50	6	14	3	11	28	44	4.4	68
PI 451973	PR China	13	63	7	17	3	24	15	38	5.9	61
PI 504572	PR China	12	47	6	21	3	13	17	29	4.8	63
PI 105340	PR China	11	54	6	22	4	22	11	20	3.0	73
PI 470254	Indonesia	9	29	7	15	1	9	9	25	3.4	78
PI 357830	Yugoslavia	9	41	3	5	5	32	8	17	7.0	79
PI 167223	Turkey	8	38	4	9	2	16	14	24	6.0	61
PI 368555	Yugoslavia	8	26	5	11	2	12	5	15	5.8	71
PI 368554	Yugoslavia	5	5	4	5	1	0	8	0	5.6	75
Mean		23	71	14	28	4	22	17	29	5.9	64
Range		35	134	23	56	8	48	27	49	4.9	26
LSD, 5%		10	25	7	15	3	15	9	16	0.9	5
CV, %		49	38	58	58	69	72	57	61	16	8

† Fruit quality ratings were based on fruit shape and color (1–3 = poor, 4–6 = intermediate, 7–9 = excellent).
‡ Harvest days is the number of days from planting to harvest.

304805 and PI 368560, which took 8 d longer. The fruit quality ratings for the nine cultigens were lower than the checks, Sprint 440 and 'Dasher II'. Of the check cultivars, Sprint 440 and Dasher II had similar fruit yield, quality rating, and days to harvest. Sprint 440 and Dasher II had the highest yields in terms of total fruit weight, followed by the remaining two slicing checks used in the study 'Poinsett 76' and 'Marketmore 76' (Table 4).

There were 16 cultigens with a higher number of total fruit than the check cultivar Sprint 440, three cultigens (PI 118279, PI 304805, PI 561145) with a higher total fruit number than Poinsett 76, and five cultigens (PI 118279, PI 304805, PI 561145, PI 234517, PI 512614) with a higher total fruit number than Dasher II. Cultigens with both high fruit weight and number were PI 118279 (Brazil), PI 234517 (USA SC), PI 304805 (USA NY), and PI 512614 (Spain). The four cultigens produced higher total, early, and marketable fruit weight and number than the check cultivars of the same type. Their percentage of cull fruit weight was higher than Sprint 440, but their percentage of cull fruit number was lower. Fruit quality ratings were lower than the check, and PI 234517 had the best fruit quality rating of the four. The four PI accessions had similar days to harvest. However, PI 304805 took 8 d longer than the check (Table 4).

Seven cultigens produced higher early yields (by weight) (PI 234517, PI 118279, PI 368560, PI 173893, PI 165499, PI 512614, and PI 512615) and by fruit number (PI 118279, PI 234517, PI 173893, PI 288996, PI 390259, PI 512614, and PI 561148) than the best check, Dasher II. Forty PI accessions had a higher early yield percentage (by weight) than the best check, Dasher II. Cultigens with the highest early yield percentage (by weight) were PI 338234, PI 368551, PI 368559, PI 173893, PI 368560, PI 379283, PI 250147, PI 357860, PI 561144, PI 267745, and PI 391570. Cultigens with both high early yield and high early yield percentage (by weight) were PI 173893 and PI 288996. Thirteen cultigens had a higher early yield percentage (by number) compared with the highest yielding check Sprint 440. PI 118279 was the only

cultigen with a high early fruit yield and high early yield percentage (by weight) compared with the high check (Table 4).

Eighteen cultigens produced higher marketable yields (by weight) while 11 cultigens had a higher marketable yield percentage (by weight) compared with the best performing slicing cucumber check, Poinsett 76. Cultigens with both high marketable yield and higher marketable yield percentage (by weight) compared with the checks were PI 304805, PI 369717, PI 390244, PI 504815, and PI 512598. Five cultigens (PI 504816, PI 401732, PI 304805, PI 432864, and PI 118279) had high marketable yield (by number) compared with the best check, Sprint 440. Eleven cultigens (PI 481616, PI 504816, PI 432864, PI 390244, PI 401732, PI 525075, PI 561146, PI 390260, PI 512633, PI 344347, and PI 512639) had a higher marketable yield percentage (by number) compared with the high check, Poinsett 76. PI 401732, PI 432864, and PI 504816 had both high marketable yield and high marketable yield percentage compared with the best checks (Table 4).

Of the four slicing cultigens used as checks in this study, Marketmore 76 had the lowest culled fruit percentage (by weight) followed by Sprint 440, Poinsett 76, and Dasher II. Two cultigens (PI 338234 and PI 481616) had a lower culled fruit percentage (by weight) than Marketmore 76. The check cultigens with the lowest culled fruit percentage (by number) were Marketmore 76, Sprint 440, Dasher II, and Poinsett 76. Eight cultigens (PI 390238, PI 481614, PI 250147, PI 379280, PI 368560, PI 512625, PI 338234, and PI 481616) had a lower culled fruit percentage (by number) than Marketmore 76 (Table 4).

The four slicing cucumber checks had the highest fruit quality ratings of the four cucumber types. PI 306785 from Canada was the only PI accession that had a similar fruit quality rating compared with the checks. Slicing cultigens that ranked just below the checks for fruit quality were PI 561148, PI 561145, PI 512633, PI 422192, PI 451976, and PI 406473 (Table 4). PI 176519 was the only slicing cultigen that was harvested as early (55 d) as Marketmore 76, the earliest slicing check. The latest cultigen was PI 481616, which took 81 d to harvest (Table 4).

Middle-Eastern (Beit Alpha) Cucumber

WI 2757 was included as a check representing late-maturing, low-yielding, gynoecious inbreds. A total of 229 middle-eastern (Beit Alpha) cultigens produced higher total fruit weight than the check WI 2757, while 32 cultigens produced higher fruit weight than the standard pickling cucumber check, Calypso. The cultigens with the highest total fruit weight were PI 167050, PI 163213, PI 532519, PI 211978, PI 357864, PI 183231, and PI 211117. Nine cultigens had twice the total fruit weight of WI 2757. There were 97 cultigens with a higher fruit number than WI 2757, while 25 cultigens produced higher fruit number than Calypso (Table 5). Cultigens with highest total fruit number were PI 175693, PI 532519, PI 292010, PI 176956, PI 171601, PI 181910, PI 293923, PI 175690, PI 535881, and PI 525152. The cultigens which were ranked in the top 10% for both total fruit number and total fruit weight were PI 137856, PI 169391, PI 171601, PI 175693, PI 181755, PI 292010, PI 525152, PI 532519, PI 534540, PI 534543, and PI 535881 (Table 5).

There were 164 cultigens with higher early yield and higher early yield percentage (by weight) compared with the check WI 2757, while 32 cultigens were higher in early yield compared with the standard pickling check, Calypso. Cultigens with the highest early yield and highest early yield percentage (by weight) were PI 357849, PI 512628, PI 379287, PI 169384, PI 344433, PI 211589, PI 182188, PI 172852, PI 357859, and PI 357834. Of the cultigens with high early yield, 147 had higher early yield (by number) than WI 2757, while 225 had a higher early yield percentage (by number) than WI 2757. PI 172852 was the only cultigen common to both groups (Table 5).

A total of 164 middle-eastern PI accessions had a higher marketable yield (by weight) than the best check. Cultigens in the top 10% category that had >6 Mg ha^{-1} marketable yield were PI 171601, PI 176924, PI 534543, PI 163213, PI 211117, PI 176951, PI 175693, PI 169380, and PI 344437. There were 72 cultigens with a higher marketable yield percentage (by weight) than the best check. Cultigens with the best performance for marketable yield percentage (by number) were PI 172844, PI 176924, PI 174173, PI 357843, PI 176522, and 176951. PI 171601, PI 176924, PI 176951, and PI 357843 were in the top 10% group for both high marketable weight and high marketable yield percentage (by weight) (Table 5).

There were 87 cultigens with a higher marketable yield (by number) than the check, WI 2757, while 76 cultigens had a high marketable yield percentage (by number). Cultigens in the top category for marketable yield, which also produced $>50\,000$ marketable fruit ha^{-1}, were PI 534543, PI 293923, PI 181910, PI 292010, and PI 171601. Cultigens in the top 10% for marketable yield percentage (by number) were PI 171604, PI 357843, PI 176924, PI 169385, PI 169380, PI 357854, and PI 169383 (Table 5).

There were 214 and 89 cultigens, respectively, having a lower percentage of culls (by weight and number) than the check, WI 2757. The PI accessions that were in the top 10% for lowest percentage of culled fruit (by weight and number) were PI 169385, PI 172852, PI 176924, PI 222243, PI 357843, PI 357849, and PI 512628 (Table 5). There were 30 PI accessions with fruit quality ratings better than the middle-eastern (Beit Alpha) check, WI 2757. Some of the PI accessions with high fruit quality ratings were PI 535881, PI 532519, PI 525153, PI 534539, PI 534541, PI 525154, PI 422197, PI 292010, PI 525155, and PI 525165 (Table 5).

There were 222 PI accessions with earlier yield than WI 2757, which took 64 d to harvest. The earliest middle-eastern (Beit Alpha) cultigen took 52 d to harvest. Some of the other cultigens that took fewer days to harvest were PI 226509, PI 175694, PI 174177, PI 344439, and PI 211975, which all took between 52 and 54 d to harvest.

PI 357853 took the longest to produce fruit (77 d) (Table 5).

Trellis Cucumber

Trellis type cultigens with the highest total fruit weight were PI 264228, PI 478366, PI 390262, PI 532524, PI 390267, and PI 532520 (Table 6). Cultigens with high total fruit number were PI 432849, PI 264228, PI 275411, PI 532520, PI 390262, PI 489754, PI 518854, PI 478364, PI 478366, and PI 532523. Eight cultigens (PI 263085, PI 264228, PI 275411, PI 390262, PI 390267, PI 478366, PI 511820, and PI 532520) were in both lists of the top 10% for fruit weight and number. Cultigens of the trellis type that had high early yield (by weight) and high early yield percentage (by weight) were PI 357837, PI 418963, PI 422167, and PI 432889. Cultigens with high early yield and high early yield percentage (by number) were PI 192940, PI 193497, PI 212233, PI 264228, PI 275412, PI 432851, and PI 432889 (Table 6).

Cultigens with the highest yields for marketable fruit weight were PI 478366, PI 264228, PI 532524, PI 518851, PI 390262, PI 390267, PI 422167, PI 275411, PI 419182, and PI 419010 (all greater than 20 Mg ha^{-1}). PI accessions of the trellis type with high marketable yield percentage (by weight) were PI 192940, PI 357841, PI 390263, PI 368554, PI 267742, PI 470254, PI 357837, PI 418963, and PI 193497. PI accessions ranked in the top 10% for marketable fruit weight and marketable yield percentage (by weight) were PI 264228, PI 357837, PI 422167, PI 432889, and PI 518851. PI accessions with high marketable fruit number were PI 264228, PI 275411, PI 511820, PI 518851, PI 390267, and PI 478366 (all greater than 40,000 fruit ha^{-1}). PI 368554 from Yugoslavia had 100% marketable fruit in all replications in all environments of the study. Cultigens that ranked in the top category for both marketable fruit number and marketable yield percentage (by number) were PI 192940, PI 193497, PI 212233, PI 264228, PI 275412, PI 432851, and PI 432889. PI 264228 and PI 432889 were in the top group for marketable fruit (number and weight) and percentage of marketable fruit (number and weight) (Table 6).

PI accessions with the lowest percentage of culls in the trellis type (by weight and number) were PI 192940, PI 212233, PI 255938, PI 357830, PI 368554, and PI 368555 (Table 6). Cultigens with the highest fruit quality ratings among the trellis type cultigens were PI 422184, PI 255935, PI 285608, PI 422167, PI 372893, PI 356833, PI 511821, PI 255933, PI 390262, PI 508460, and PI 275410 (Table 6). The earliest of the trellis cultigens were PI 263081, PI 419183, PI 518854, PI 432849, PI 267742, and PI 275411 (Table 6).

CONCLUSIONS

The USDA cucumber germplasm collection was screened for fruit yield, earliness, and quality. Digital photographs of the germplasm collection for fruits also have been recorded to verify fruit type of each accession. Several high yielding cultigens were identified in each of the four cucumber types. The cultigens outyielded the check cultivars in the study. The high yielding cultigens evaluated in the study should be tested in multiple-harvest trials to evaluate their performance further. High yielding cultigens identified could be used to develop breeding populations of each of the four cucumber types. These populations could be improved using recurrent selection and directly in cultivar development. Finally, high-yielding cultigens with poor qualitative traits (some aspects of fruit quality) could be improved using backcross breeding.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical assistance of Christopher Cramer, Tammy Ellington, Fred McCuistion, Joel Shuman, Ronghao Song, Bruton Strange, Alan Walters, and Jiahua Xie. The authors thank the USDA North Central Regional Plant Introduction Station at Ames, IA, for kindly providing seeds for the study.

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