Euphytica **79:** 39–43, 1994.

Evaluation of the U.S. cucumber germplasm collection for root size using a subjective rating technique

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Received 8 March 1994; accepted 20 July 1994

Key words: Cucumis sativus, roots, vegetable breeding, cucumber, root size

Summary

Root size in cucumber (*Cucumis sativus* L.) has received little research attention until recently. However, a large root system could improve nutrient and water uptake, and ultimately yield. Knowledge of root size could help cucumber breeders develop cultivars with improved performance. A study was conducted in the greenhouse to evaluate 857 cultigens (827 plant introduction accessions, 22 breeding lines, and 8 cultivars) of cucumber for root length. Complete data were obtained for 794 cultigens. Plants were grown from seeds in 2 replications in the greenhouse. Plants were rated for root length using a 1 to 9 scale (1–3 = small, 4–6 = medium 7–9 = large). Also, root length was measured from soil surface to the tip of the longest main root. In addition, all cultigens were evaluated for root length and dry weight to provide meaning to the subjective rating. Root rating was highly correlated with both root length (r = 0.92) and dry weight (r = 0.64) of roots. Root length averaged 74 mm and most cultigens (579, or 68%) had roots 40 to 110 mm long. The cultigen with the longest roots was PI 183056 (193 mm), and the shortest was PI 176954 (2 mm). The subjective rating technique provided a simple, accurate and rapid method to estimate root growth in the greenhouse.

Introduction

The importance of root system development in relation to plant growth is often overlooked since roots are below ground and are not directly observed. However, a vigorous, well-developed root system is needed for optimal plant growth. The larger the size of the roots, the greater is the potential for water absorption and nutrient uptake; a large root system (capable of deep rooting) is thought to improve use of sub optimal plant nutrient levels in the soil as well as water in all soil profiles (Pearson, 1971).

Breeding to increase root system size of cucumber (*Cucumis sativus* L.) could significantly improve fruit yield since the potential for water and nutrient uptake is greater with an increased root surface area. Roots are often ignored in breeding programs even though a well-developed and vigorous root system is needed for optimal plant growth (Zobel, 1986). Measurement of roots is too expensive for most breeders since the work is difficult and labor intensive (Taylor, 1986). Even though root size is an important trait of cucumber, few genetics or breeding studies have dealt with roots. Ghaderi and Lower (1978) reported midparent heterosis for root fresh weight in 3 cucumber families grown at 30/20 or 27/14° C (day/night) temperatures, with high midparent heterosis occurring mainly in one family. Large heterosis effects for root dry and fresh weight were explained by significant dominance gene effects in an additive-dominance model and by significant d × d effects in a 6-parameter model (m, a, d, aa, ad, dd) (Gadheri and Lower, 1979). Yurina and Lebedeva (1974) reported that higher cucumber fruit yield was obtained by selecting for a more vigorous root system.

Water is essential for plant growth, and the amount of water available in a given environment has an impact on cucumber fruit yield (Randall and Locascio, 1988; Tan et al., 1983). Furthermore, cucumbers having restricted root growth have small shoots, small fruits, and few seeds per fruit (Wehner and Horton, 1986). Plants with restricted root systems are more vulner-

able to water stress than those with well-developed root systems (Miller, 1986) and water-stressed cucumbers have lower fruit growth rates than on non-stressed plants (Ortega and Kretchman, 1982). Grumet et al. (1992) evaluated 96 *Cucumis sativus* plant introduction (PI) accessions and cultivars for rate of root growth using simazine herbicide bands and found 'Flurry', PI 209069 and PI 267747 to have the fastest root growth rates of those tested.

Our study was undertaken to screen the USDA and NCSU cucumber germplasm collections, consisting of 857 accessions, breeding lines and cultivars (hereafter referred to as cultigens), for root length. Our intent was to identify cultigens with large or small root systems for use in genetic studies of roots for ultimate improvement of the crop.

Materials and methods

A greenhouse experiment was designed to evaluate the available USDA and NCSU cucumber germplasm, consisting of a collection of 857 cultigens (827 accessions, 22 breeding lines, and 8 new or obsolete cultivars) for root size.

Cultural practices. Plants were grown from seed in 150-mm diameter (145 mm height; 1.75 liter volume) clay pots on benches in the greenhouse. The medium was a loamy sand soil (85% sand, 10% silt, and 5% clay). Five seeds were sown in each pot. Plants were thinned to two per pot at the 2-leaf stage, and to one at the 3-leaf stage.

Plants were trained on a trellis 1.8 m high, and were not pruned. Irrigation with fertilizer (200 ppm N) was supplied twice daily using drip tubes. Plants were allowed to grow 15 weeks before evaluating the root system. Greenhouse temperatures averaged 30° C (days) and 22° C (nights).

Experiment design. A randomized complete block design with 2 replications was used, with 1-plant plots. In order to facilitate pollination, plants in one replication were sprayed with ethrel (2-chloroethyl phosphonic acid) to induce pistillate flowers and the other with silver nitrate to induce staminate flowers. Pollination was done to increase the seeds of the cultigens tested.

Traits measured. Roots were evaluated approximately 3 months after planting. Roots were washed free of soil using tap water and all plants were subjectively rated for root system size on a scale of 1 to 9 (1 = extra small, 2 = very small, 3 = small, 4 = medium small, 5 = medium, 6 = medium large, 7 = large, 8 = very large, and 9 = extra large). Root lengths were measured, and root dry weight was later determined on a subsample of the cultigens. Root size (presented as length, but could also represent area or volume) was obtained by stretching roots to the same width (150 mm) and height (5 mm), and then measuring the length of the root system in mm. Area would be estimated as width × length × 0.5 (assuming a shape like a triangle). Root volume would be area × height (5 mm).

Data analysis. Data were subjected to analysis of variance (ANOVA), regression (REG) and correlation (CORR) procedures of SAS (SAS Institute, Cary, NC). Regression models were used to determine the relationships for root length with rating, root length with dry weight, and rating with dry weight. Cultigen means for root lengths were compared using Fisher's protected LSD test ($P = 0.05$).

Results and discussion

Significant differences existed among cultigens for root length, with a range of 2 mm to 193 mm and an LSD of 60 mm. However, most cultigens fell into the 40 to 110 mm (579, or 68%). The average root length was 74 mm. Data for 63 cultigens was not collected due to poor seed germination or plant growth.

Root length of the largest and smallest cucumber cultigens along with five standard checks are shown in Table 1. The complete data set will be available from GRIN (Germplasm Resources Information Network, USDA/ARS, Washington, DC). PI 183056 had the largest root size of all cultigens evaluated (193 mm root length). It was not significantly different from 21 other cultigens, however. The cultigen with the smallest root length was PI 176954 (2 mm root length). We compared the 10 cultigens with largest root size listed by Grumet et al. (1992) with our results. According to our measurements, none of the 10 had small roots (< 40 mm in length), and most had medium-sized roots ($\geq$ 40 and $\leq$ 110 mm in length). One cultigen, PI 385968, had large roots (> 110 mm in length). However, three of the top 10 were not evaluated in this

Table 1. Root system length (mm) of the largest 59 and smallest 55 cultigens (along with 5 standard checks) of 857 evaluated (63 missing)†.

Rank	Cultigen	Seed source	Root length
Large			
1	PI 183056	India	193
2	PI 271327	India	180
3	PI 163217	India	178
4	PI 379282	Former Yugoslavia	175
5	PI 164465	India	168
6	PI 271328	India	163
7	PI 164679	India	160
8	PI 188807	Philippines	160
9	PI 504573	India	158
10	PI 357848	Former Yugoslavia	145
11	PI 271326	India	143
12	PI 173892	India	140
13	PI 391573	PR China	140
14	PI 512628	Spain	140
15	PI 314426	Former Soviet Union	138
16	PI 164670	India	135
17	PI 385968	Kenya	135
18	PI 506465	Former Soviet Union	135
19	PI 164284	India	133
20	PI 209066	USA-Iowa	133
21	PI 209068	USA-Iowa	133
22	PI 430585	PR China	133
23	PI 109481	Turkey	130
24	PI 163214	India	130
25	PI 175121	India	130
26	PI 214049	India	130
27	PI 370450	Former Yugoslavia	130
28	PI 525075	Mauritius	130
29	PI 163222	India	128
30	PI 175120	India	128
31	PI 267942	Japan	128
32	PI 338234	Turkey	128
33	PI 512336	Hong Kong	128
34	PI 135123	New Zealand	125
35	PI 163218	India	125
36	PI 249562	Thailand	125
37	PI 355053	Iran	125
38	PI 357860	Former Yugoslavia	125
39	PI 390267	Japan	125
40	PI 432885	PR China	125
41	PI 432888	PR China	125
42	PI 512604	Spain	125
43	PI 512609	Spain	125
44	PI 163223	India	123
45	PI 197086	India	120
46	PI 205996	Sweden	120
47	PI 220171	Afghanistan	120
48	PI 481612	Bhutan	120
49	PI 483340	Korea	120
50	PI 500365	Zambia	120
51	PI 508454	R Korea	120
52	PI 512625	Spain	120
53	PI 512631	Spain	120
54	PI 179678	India	118
55	PI 288238	Egypt	118
56	PI 379285	Former Yugoslavia	118
57	PI 422197	Former Czechoslovakia	118
58	PI 512616	Spain	118
59	LJ 90430	USDA, La Jolla	118
Checks			
97	Wis. SMR 18	Wis.-AES	110
539	Ashley	Clemson Univ.	58
711	Marketmore 76	Cornell Univ.	30
732	Poinsett 76	Cornell Univ.	25
739	M 21	NCSU	23
Small			
740	PI 504815	PR China	20
741	PI 504572	PR China	20
742	PI 483343	Korea	20
743	PI 458851	Former Soviet Union	20
744	PI 436649	PR China	20
745	PI 436610	PR China	20
746	PI 422182	Former Czechoslovakia	20
747	PI 418962	PR China	20
748	PI 344438	Iran	20
749	PI 344435	Iran	20
750	PI 321006	Taiwan	20
751	PI 284699	Sweden	20
752	PI 211982	Iran	20
753	PI 202801	Syria	20
754	PI 188749	Egypt	20
755	PI 178887	Turkey	20
756	PI 177359	Turkey	20
757	PI 169385	Turkey	20
758	PI 137856	Iran	20
759	PI 489753	PR China	18
760	PI 478364	PR China	18
761	PI 390268	Japan	18
762	PI 355052	Israel	18
763	PI 183677	Turkey	18

Table 1. continued

Table 1. continued

Rank	Cultigen	Seed source	Root length
764	Sumter	Clemson Univ.	15
765	PI 506463	Former Soviet Union	15
766	PI 466922	Former Soviet Union	15
767	PI 458855	Former Soviet Union	15
768	PI 432897	PR China	15
769	PI 432891	PR China	15
770	PI 432869	PR China	15
771	PI 419136	PR China	15
772	PI 390249	Japan	15
773	PI 390247	Japan	15
774	PI 344442	Iran	15
775	PI 326598	Hungary	15
776	PI 308916	Former Soviet Union	15
777	PI 304803	USA-New York	15
778	PI 264226	France	15
779	PI 220791	Afghanistan	15
780	PI 183224	Egypt	15
781	PI 182189	Turkey	15
782	PI 178888	Turkey	15
783	PI 176957	Turkey	15
784	PI 137851	Iran	15
785	PI 502331	Former Soviet Union	14
786	PI 308915	Former Soviet Union	13
787	PI 508456	R Korea	10
788	PI 432853	PR China	10
789	PI 344445	Iran	10
790	PI 285610	Poland	10
791	PI 174167	Turkey	10
792	PI 432892	PR China	5
793	PI 419017	PR China	5
794	PI 176954	Turkey	2

† Data are means of 2 replications of 1-plant plots.
LSD (P = 0.05) for comparison of root length = 60.

study ('Flurry', PI 263048, and PI 376063). Thus, our data support the conclusion of Grumet et al. (1992) that root size can be estimated using the herbicide technique they developed.

Root length and our subjective rating were highly correlated (r = 0.92, $P = 0.0001$), indicating that root length of cucumber can be accurately predicted from a subjective rating. Rating increased as root length increased and was best described by the linear relationship, y = 7.81 + 18.22 (rating), $r^2 = 0.85$, $P = 0.0001$, n = 1317 (Fig. 1). Dry weight of roots were positively correlated with both root length (r = 0.64, $P = 0.0001$) and rating (r = 0.70, $P = 0.0001$). Dry

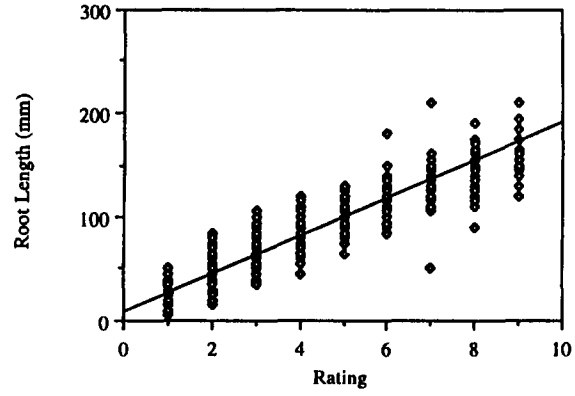

Fig. 1. Relationship between root length and rating. Root length = 7.8 + 18.2 (rating), $r^2 = 0.85$, P = 0.0001, n = 1317.

weights of roots were quadratically related to both rating [y =3.75 - 2.59 (rating) + 0.95 (rating)^2, $R^2 = 0.57$, P = 0.0001, n = 1317] and root length [y = 2.15 - 0.09 (root length) + 0.002 (root length)^2, $R^2 = 0.48$, P = 0.0001, n = 1317).

Rating was shown to be a useful, simple, and accurate method for determining cucumber root growth in the greenhouse. Rating is a subjective measurement, and the person rating must first understand how to accurately rate the size of the root system. Before rating can be used as an accurate measurement of root system size, the rater must determine which root systems go into each of the nine categories; to accomplish this task, the rater should lay out root systems, one for each of the nine categories, so the rating scale can be referred to when a judgment is made. This method of evaluating roots of cucumbers showed that significant genotypic differences for root size existed among the cultigens tested.

Even though the method was easy to use, the process of washing the soil medium from the roots was time consuming. However, cultigens with large roots were identified in this initial screening. Knowledge of root size will allow cucumber breeders to develop cultivars that have larger root systems than current cultivars. That may help in maximizing nutrient and water uptake, thus leading to improved drought tolerance and yield.

We would emphasize that this study was a rough approximation since only two replications were used. It provides a starting point for additional work on inheritance, drought tolerance, and cultivar development. However, our study was useful, since we identified cultigens having root lengths of 2 to 193 mm (more than 3 LSD units in range).

We have initiated additional studies using the cultigens having the largest and smallest root systems from this screening study. Preliminary analysis (data not presented) indicates that the results from the screening are useful in identifying cultigens with small or large root systems. For example, PI 271328, 504573, 379282 and 271327 had large root systems, and PI 344445, 502331 and 432853 had small root systems in a retest that is currently being run. Additional work is needed to select cultigens with large or small root systems, stabilize the best selections using self pollination, and use the selections to evaluate the inheritance of root size.

Acknowledgements

The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned.

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