

Downy Mildew Resistance of the Cucumber Germplasm Collection in North Carolina Field Tests

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ABSTRACT

Downy mildew [*Pseudoperonospora cubensis* (Berk. & Curt.) Rostov] is an important disease in most cucumber (*Cucumis sativus* L.) production areas of the world. Resistant cultivars are available, but higher levels of resistance are needed if yield losses are to be avoided. The objective of this experiment was to evaluate all available plant introduction accessions (from the U.S. National Plant Germplasm System), cultivars, and breeding lines (hereafter collectively referred to as cultigens) of cucumber for downy mildew resistance under field conditions in North Carolina. All available cultigens were tested in four blocks (2 yr and two replications) under natural field epidemics of the disease. Mean ratings for downy mildew leaf damage ranged from 1.3 to 9.0 on a 0 to 9 scale. The most resistant nine cultigens originated from the USA, and were primarily adapted cultivars or breeding lines. The most resistant cultigens, for which multiple-year data were available, were Gy 4, 'Clinton', PI 234517, 'Poinsett 76', Gy 5, 'Addis', M 21, M 27, and 'Galaxy'. The most susceptible cultigens for which multiple year data were available, were PI 288995, PI 176952, PI 178886, and PI 211985. We classified 17 cultigens as highly resistant (1.3–3.0), 87 as moderately resistant (3.3–5.0), 311 as moderately susceptible (5.3–7.0), and 248 as highly susceptible (7.3–9.0) for the 663 cultigens with multiple-year data. No plant introduction accessions were found to be more resistant than the most resistant elite cultivars and breeding lines tested.

DOWNY MILDEW is a major foliar disease of cucumber in humid production areas of the world (Palti and Cohen, 1980). Downy mildew on the genus *Cucumis* has been reported from 70 countries worldwide (Cohen, 1981; Palti, 1974). Palti and Cohen (1980) studied the host range of *P. cubensis* and reported 40 species of approximately 20 genera in the Cucurbitaceae to be hosts, 10 of which are in *Cucumis*. Nine new *Cucumis* species recently were identified as hosts of *P. cubensis*, with reports that all *Cucumis* species are probably hosts of *P. cubensis* (Lebeda, 1992a). Some of the important economic hosts of *P. cubensis* are cucumber, melon (*C. melo* L.), watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai], and squash (*Cucurbita* spp.) (Whitaker and Davis, 1962). Van Vliet and Meysing (1974) suggested that *P. cubensis* could be spread by both cucumber beetles (*Diabrotica undecimpunctata howardi* Barber, *Acalymma vittata* Fabricius, and *Diabrotica*

balteata LeConte) and wind. The primary source of inoculum in the field is through air borne sporangia, which also serve as a secondary source of inoculum (Thomas, 1996).

In North Carolina, the estimated annual incidence of downy mildew is 30%, and the average annual dollar loss is 2.9% based on yield and quality reduction of slicing and pickling cucumbers (St. Amand and Wehner, 1991). Those losses make it the fifth most important disease of cucumber in North Carolina. Fungicides decrease the impact of the disease, but are ineffective under environmental conditions which are highly favorable to the pathogen, such as prolonged periods of high humidity in combination with high day and low night temperatures. Dew is a major factor in the initiation, development, and spread of the disease. Duvdevani et al. (1946) reported that the prevention of dew formation precluded downy mildew development. Therefore, resistant cultivars offer the grower a safe and cost-effective method of disease management.

Several races of *P. cubensis* have been reported (Bains and Jhooty, 1976b; Palti and Cohen, 1980). Five pathotypes of *P. cubensis* were reported based on their compatibility with specific hosts (Thomas et al., 1987). The pathogen overwinters in areas with mild winter temperatures, such as the southern USA, as active mycelium on either cultivated or wild species of cucurbits (Bains and Jhooty, 1976a).

Early research on resistance to downy mildew showed that there was at least one single recessive gene, *dm*, controlling resistance in 'Poinsett' (Van Vliet and Meysing, 1977). Although *dm* was reported in the review of cucumber genes, it was noted that there were probably several genes controlling the trait (Pierce and Wehner, 1990). Doruchowski and Lakowska-Ryk (1992) reported that inheritance of resistance to downy mildew in an inbred line from WI 4783 was controlled by three recessive genes (*dm-1*, *dm-2*, and *dm-3*). Van Vliet and Meysing (1974) reported an inseparable association between the genes for downy mildew (*dm*) and powdery mildew (*pm*) resistance. The recessive gene *dm* was found to be linked or pleiotropic to one of the three powdery mildew resistant genes (*pm-1*, *pm-2*, *pm-3*) (Doruchowski and Lakowska-Ryk, 1992). Lebeda (1992a) reported that there was limited variation in resistance to *P. cubensis* among *Cucumis* species and accessions, except for *C. melo* (Cohen and Eyal, 1987; Lebeda, 1991; Thomas, 1986). Kupper and Staub (1988) reported that the genetic diversity of *C. sativus* was low. Barczynska et al. (1988) reported that there was limited variability for some disease traits. The interspecific vari-

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Table 1. Mean downy mildew rating for 663 cultigens of *Cucumis sativus* field tested in four blocks in North Carolina during 1988 and 1989.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
Gy 4	NC State Univ.	1.3	PI 390247	Japan	4.8
Clinton	NC State Univ.	1.5	PI 390260	Japan	4.8
PI 234517	USA, SC	1.5	PI 390264	Japan	4.8
Poinsett 76	Cornell Univ.	1.5	PI 432855	PR China	4.8
Gy 5	NC State Univ.	1.7	PI 432856	PR China	4.8
Addis	NC State Univ.	1.8	PI 470254	Indonesia	4.8
M 21	NC State Univ.	1.8	PI 482464	Zimbabwe	4.8
M 27	NC State Univ.	1.8	PI 164465	India	5.0
Galaxy	Clemson Univ.	2.0	PI 183056	India	5.0
PI 249562	Thailand	2.5	PI 227209	Japan	5.0
PI 279463	Japan	2.7	PI 255933	Netherlands	5.0
PI 390243	Japan	2.7	PI 265887	Netherlands	5.0
Magnolia	NSSL	2.8	PI 267942	Japan	5.0
PI 426169	Philippines	2.8	PI 279466	Japan	5.0
Chipper	Clemson Univ.	3.0	PI 357857	Yugoslavia	5.0
Gy 3	Clemson Univ.	3.0	PI 390241	Japan	5.0
Gy 14	Clemson Univ.	3.0	PI 390257	Japan	5.0
Gy 6	NC State Univ.	3.3	PI 390259	Japan	5.0
PI 227207	Japan	3.3	PI 418989	PR China	5.0
Calypso	NC State Univ.	3.5	PI 419214	Hong Kong	5.0
PI 432864	PR China	3.5	PI 422191	Czechoslovakia	5.0
PI 432868	PR China	3.5	PI 432892	PR China	5.0
PI 432879	PR China	3.5	PI 432894	PR China	5.0
PI 435946	USSR	3.5	PI 478365	PR China	5.0
Wantoma	USDA-Wis	3.5	PI 483340	Korea	5.0
PI 200815	Burma	3.7	PI 489754	PR China	5.0
PI 478367	PR China	3.7	Brice	NSSL	5.3
Polaris	Clemson Univ.	3.7	Cubit	NSSL	5.3
Tablegreen 72	Cornell Univ.	3.7	PI 163223	India	5.3
PI 390266	Japan	3.8	PI 164670	India	5.3
PI 483342	Korea	3.8	PI 164816	India	5.3
PI 487424	PR China	3.8	PI 188807	Philippines	5.3
PI 489752	PR China	3.8	PI 263049	USSR	5.3
Dasher II	Petoseed	4.0	PI 271327	India	5.3
PI 105340	PR China	4.0	PI 279467	Japan	5.3
PI 227210	Japan	4.0	PI 288332	India	5.3
PI 271326	India	4.0	PI 306180	Poland	5.3
PI 279468	Japan	4.0	PI 321008	Taiwan	5.3
PI 330628	Pakistan	4.0	PI 390246	Japan	5.3
PI 358813	Malaysia	4.0	PI 390256	Japan	5.3
PI 385967	Kenya	4.0	PI 390262	Japan	5.3
PI 390238	Japan	4.0	PI 390267	Japan	5.3
PI 422182	Czechoslovakia	4.0	PI 426629	Pakistan	5.3
PI 432851	PR China	4.0	PI 432862	PR China	5.3
PI 436672	PR China	4.0	PI 432865	PR China	5.3
Pixie	Clemson Univ.	4.0	PI 432867	PR China	5.3
PI 164433	India	4.3	PI 432893	PR China	5.3
PI 267746	India	4.3	PI 436649	PR China	5.3
PI 306785	Canada	4.3	Sprint 440	Asgrow Seed	5.3
PI 390239	Japan	4.3	PI 109063	Turkey	5.5
PI 430585	PR China	4.3	PI 164679	India	5.5
PI 432863	PR China	4.3	PI 175121	India	5.5
PI 432870	PR China	4.3	PI 179678	India	5.5
PI 432871	PR China	4.3	PI 197086	India	5.5
PI 432887	PR China	4.3	PI 211984	Iran	5.5
PI 436648	PR China	4.3	PI 262990	Netherlands	5.5
Boston Pickling	NSSL	4.5	PI 263046	USSR	5.5
Gy 2	NC State Univ.	4.5	PI 263080	USSR	5.5
Marketmore 76	Cornell Univ.	4.5	PI 267743	PR China	5.5
PI 163216	India	4.5	PI 267745	Brazil	5.5
PI 183127	India	4.5	PI 271331	India	5.5
PI 197088	India	4.5	PI 321011	Taiwan	5.5
PI 209066	USA, Ohio	4.5	PI 326596	Hungary	5.5
PI 212896	India	4.5	PI 343451	USSR	5.5
PI 391568	PR China	4.5	PI 344445	Iran	5.5
PI 427089	PR China	4.5	PI 401734	USA, Puerto Rico	5.5
PI 432858	PR China	4.5	PI 406473	Netherlands	5.5
PI 164734	India	4.7	PI 435947	USSR	5.5
PI 288238	Egypt	4.7	PI 436608	PR China	5.5
PI 302443	PR China	4.7	PI 466922	USSR	5.5
PI 163222	India	4.8	PI 169395	Turkey	5.7
PI 197085	India	4.8	PI 183224	Egypt	5.7
PI 197087	India	4.8	PI 255938	Netherlands	5.7
PI 209069	USA, Ohio	4.8	PI 279465	Japan	5.7
PI 220860	Korea	4.8	PI 308916	USSR	5.7
PI 267197	PR China	4.8	PI 113334	PR China	5.8
PI 321007	Taiwan	4.8	PI 163214	India	5.8
PI 321009	Taiwan	4.8	PI 163217	India	5.8

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Table 1. Continued.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
PI 163218	India	5.8	PI 271328	India	6.3
PI 167358	Turkey	5.8	PI 283900	Czechoslovakia	6.3
PI 171606	Turkey	5.8	PI 285610	Poland	6.3
PI 172846	Turkey	5.8	PI 326594	Hungary	6.3
PI 173889	India	5.8	PI 326595	Hungary	6.3
PI 173893	India	5.8	PI 339243	Turkey	6.3
PI 175686	Turkey	5.8	PI 339246	Turkey	6.3
PI 217644	India	5.8	PI 339248	Turkey	6.3
PI 222720	Iran	5.8	PI 344352	Turkey	6.3
PI 227208	Japan	5.8	PI 357836	Yugoslavia	6.3
PI 263082	PR China	5.8	PI 357849	Yugoslavia	6.3
PI 267744	PR China	5.8	PI 357853	Yugoslavia	6.3
PI 267935	Japan	5.8	PI 390245	Japan	6.3
PI 269481	Pakistan	5.8	PI 390253	Japan	6.3
PI 326597	Hungary	5.8	PI 391569	PR China	6.3
PI 385968	Kenya	5.8	PI 418962	PR China	6.3
PI 390953	USSR	5.8	PI 419040	PR China	6.3
PI 401732	USA, Puerto Rico	5.8	PI 422180	Czechoslovakia	6.3
PI 414158	USA, Hawaii	5.8	PI 432854	PR China	6.3
PI 414159	USA, Hawaii	5.8	PI 432860	PR China	6.3
PI 418963	PR China	5.8	PI 458849	USSR	6.3
PI 419017	PR China	5.8	PMR 551	Cornell Univ.	6.3
PI 422174	Czechoslovakia	5.8	Extra Early Mjst	NSSL	6.5
PI 422183	Czechoslovakia	5.8	Gnt Wt Arnstadt	NSSL	6.5
PI 422190	Czechoslovakia	5.8	Packer	Asgrow Seed	6.5
PI 451976	Japan	5.8	PI 103049	PR China	6.5
PI 483339	Korea	5.8	PI 165029	Turkey	6.5
PI 109483	Turkey	6.0	PI 165509	India	6.5
PI 137844	Iran	6.0	PI 174172	Turkey	6.5
PI 164819	India	6.0	PI 177360	Turkey	6.5
PI 164950	Turkey	6.0	PI 178884	Turkey	6.5
PI 165506	India	6.0	PI 179676	India	6.5
PI 167043	Turkey	6.0	PI 179921	India	6.5
PI 169319	Turkey	6.0	PI 181910	Syria	6.5
PI 169352	Turkey	6.0	PI 200818	Burma	6.5
PI 171608	Turkey	6.0	PI 205996	Sweden	6.5
PI 212233	Japan	6.0	PI 206953	Turkey	6.5
PI 249561	Thailand	6.0	PI 222985	Iran	6.5
PI 250147	Pakistan	6.0	PI 224668	Korea	6.5
PI 255935	Netherlands	6.0	PI 263081	PR China	6.5
PI 263084	PR China	6.0	PI 264229	France	6.5
PI 279464	Japan	6.0	PI 264667	Germany	6.5
PI 321010	Taiwan	6.0	PI 285607	Poland	6.5
PI 342951	Denmark	6.0	PI 288996	Hungary	6.5
PI 351140	USSR	6.0	PI 357837	Yugoslavia	6.5
PI 357830	Yugoslavia	6.0	PI 357846	Yugoslavia	6.5
PI 357839	Yugoslavia	6.0	PI 358814	Malaysia	6.5
PI 357844	Yugoslavia	6.0	PI 379285	Yugoslavia	6.5
PI 357845	Yugoslavia	6.0	PI 390261	Japan	6.5
PI 370022	India	6.0	PI 419041	PR China	6.5
PI 400270	Japan	6.0	PI 419136	PR China	6.5
PI 401733	USA, Puerto Rico	6.0	PI 422172	Czechoslovakia	6.5
PI 418964	PR China	6.0	PI 432852	PR China	6.5
PI 422173	Czechoslovakia	6.0	PI 432896	PR China	6.5
PI 432850	PR China	6.0	PI 458852	USSR	6.5
PI 436609	PR China	6.0	Shamrock Resistant	Iowa AES	6.5
PI 451975	Canada	6.0	Muronium	NSSL	6.7
PI 458846	USSR	6.0	PI 164952	Turkey	6.7
PI 458856	USSR	6.0	PI 167198	Turkey	6.7
Danish Mustard	NSSL	6.3	PI 169380	Turkey	6.7
Delicatessen	NSSL	6.3	PI 169381	Turkey	6.7
PI 169385	Turkey	6.3	PI 172845	Turkey	6.7
PI 171604	Turkey	6.3	PI 176516	Turkey	6.7
PI 174160	Turkey	6.3	PI 182188	Turkey	6.7
PI 175120	India	6.3	PI 206954	Turkey	6.7
PI 175681	Turkey	6.3	PI 275412	Netherlands	6.7
PI 177363	Syria	6.3	PI 292011	Israel	6.7
PI 179259	Turkey	6.3	PI 357861	Yugoslavia	6.7
PI 183445	India	6.3	PI 483341	Korea	6.7
PI 188749	Egypt	6.3	Arlington WS	NSSL	6.8
PI 193496	Ethiopia	6.3	Chicago Pickling	NSSL	6.8
PI 209065	USA, Ohio	6.3	Davis Perfect	NSSL	6.8
PI 220791	Afghanistan	6.3	Earliest Of All	NSSL	6.8
PI 257486	PR China	6.3	Everbearing	NSSL	6.8
PI 263079	USSR	6.3	Pacer	Harris-Moran	6.8
PI 264226	France	6.3	PI 109275	Turkey	6.8
PI 267088	USSR	6.3	PI 167134	Turkey	6.8
PI 267741	Japan	6.3	PI 169398	Turkey	6.8

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Table 1. Continued.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
PI 171602	Turkey	6.8	PI 288990	Hungary	7.0
PI 172840	Turkey	6.8	PI 292010	Israel	7.0
PI 172842	Turkey	6.8	PI 296120	Egypt	7.0
PI 175679	Turkey	6.8	PI 314425	USSR	7.0
PI 176520	Turkey	6.8	PI 314426	USSR	7.0
PI 176525	Turkey	6.8	PI 319216	Egypt	7.0
PI 177359	Turkey	6.8	PI 321006	Taiwan	7.0
PI 192940	PR China	6.8	PI 355055	Iran	7.0
PI 206043	USA, Puerto Rico	6.8	PI 357834	Yugoslavia	7.0
PI 214049	India	6.8	PI 357854	Yugoslavia	7.0
PI 222099	Afghanistan	6.8	PI 357855	Yugoslavia	7.0
PI 261608	Spain	6.8	PI 357858	Yugoslavia	7.0
PI 264665	Germany	6.8	PI 357859	Yugoslavia	7.0
PI 271754	Netherlands	6.8	PI 357862	Yugoslavia	7.0
PI 281448	Korea	6.8	PI 419010	PR China	7.0
PI 283902	Czechoslovakia	6.8	PI 422171	Czechoslovakia	7.0
PI 288992	Hungary	6.8	PI 422177	Czechoslovakia	7.0
PI 289698	Australia	6.8	PI 422179	Czechoslovakia	7.0
PI 306179	Poland	6.8	PI 422218	Israel	7.0
PI 339245	Turkey	6.8	PI 432857	PR China	7.0
PI 344347	Turkey	6.8	PI 458850	USSR	7.0
PI 344437	Iran	6.8	PI 478366	PR China	7.0
PI 344444	Iran	6.8	PI 483344	Korea	7.0
PI 357840	Yugoslavia	6.8	Straight 8	NSSL	7.0
PI 357847	Yugoslavia	6.8	Double Yield	NSSL	7.3
PI 357852	Yugoslavia	6.8	Nappa 63	NSSL	7.3
PI 360939	Netherlands	6.8	PI 109481	Turkey	7.3
PI 368558	Yugoslavia	6.8	PI 114339	Japan	7.3
PI 390954	USSR	6.8	PI 135122	New Zealand	7.3
PI 422170	Czechoslovakia	6.8	PI 137835	Iran	7.3
PI 422186	Czechoslovakia	6.8	PI 137836	Iran	7.3
PI 427090	PR China	6.8	PI 137839	Iran	7.3
Sunny South	NSSL	6.8	PI 137853	Iran	7.3
White Wonder	NSSL	6.8	PI 169328	Turkey	7.3
Favor II	NSSL	7.0	PI 169377	Turkey	7.3
Model	NSSL	7.0	PI 169397	Turkey	7.3
PI 109484	Turkey	7.0	PI 169400	Turkey	7.3
PI 118279	Brazil	7.0	PI 169401	Turkey	7.3
PI 137846	Iran	7.0	PI 172839	Turkey	7.3
PI 163213	India	7.0	PI 172843	Turkey	7.3
PI 164284	India	7.0	PI 172848	Turkey	7.3
PI 164743	India	7.0	PI 172851	Turkey	7.3
PI 167197	Turkey	7.0	PI 174170	Turkey	7.3
PI 169350	Turkey	7.0	PI 175688	Turkey	7.3
PI 169351	Turkey	7.0	PI 175694	Turkey	7.3
PI 169378	Turkey	7.0	PI 176521	Turkey	7.3
PI 171600	Turkey	7.0	PI 176522	Turkey	7.3
PI 172841	Turkey	7.0	PI 176524	Turkey	7.3
PI 174173	Turkey	7.0	PI 176957	Turkey	7.3
PI 175683	Turkey	7.0	PI 178887	Turkey	7.3
PI 175690	Turkey	7.0	PI 179260	Turkey	7.3
PI 175691	Turkey	7.0	PI 181755	Lebanon	7.3
PI 175692	Turkey	7.0	PI 182192	Turkey	7.3
PI 176924	Turkey	7.0	PI 204690	Turkey	7.3
PI 176950	Turkey	7.0	PI 209067	USA, Ohio	7.3
PI 178885	Turkey	7.0	PI 211589	Afghanistan	7.3
PI 181752	Syria	7.0	PI 211728	Afghanistan	7.3
PI 181753	Syria	7.0	PI 211978	Iran	7.3
PI 181756	Lebanon	7.0	PI 211983	Iran	7.3
PI 181942	Syria	7.0	PI 218199	Lebanon	7.3
PI 182189	Turkey	7.0	PI 220790	Afghanistan	7.3
PI 182190	Turkey	7.0	PI 222783	Iran	7.3
PI 183231	Egypt	7.0	PI 222987	Iran	7.3
PI 202801	Syria	7.0	PI 223437	Afghanistan	7.3
PI 206425	Turkey	7.0	PI 249550	Iran	7.3
PI 209064	USA, Ohio	7.0	PI 255934	Netherlands	7.3
PI 211975	Iran	7.0	PI 255936	Netherlands	7.3
PI 211982	Iran	7.0	PI 261609	Spain	7.3
PI 212985	India	7.0	PI 263078	USSR	7.3
PI 226509	Iran	7.0	PI 263085	PR China	7.3
PI 229808	Canada	7.0	PI 267087	USSR	7.3
PI 257487	PR China	7.0	PI 267742	PR China	7.3
PI 263083	PR China	7.0	PI 275411	Netherlands	7.3
PI 264231	France	7.0	PI 283901	Czechoslovakia	7.3
PI 264664	Germany	7.0	PI 285603	Poland	7.3
PI 269482	Pakistan	7.0	PI 285606	Poland	7.3
PI 271334	India	7.0	PI 293923	USA, SC	7.3
PI 275410	Netherlands	7.0	PI 304803	USA, New York	7.3
PI 285604	Poland	7.0	PI 308915	USSR	7.3

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Table 1. Continued.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
PI 339244	Turkey	7.3	PI 248778	Iran	7.7
PI 342950	Denmark	7.3	PI 263047	USSR	7.7
PI 344067	Turkey	7.3	PI 288991	Hungary	7.7
PI 344433	Iran	7.3	PI 288994	Hungary	7.7
PI 344438	Iran	7.3	PI 343452	USSR	7.7
PI 354952	Denmark	7.3	PI 344353	Turkey	7.7
PI 356809	USSR	7.3	PI 355053	Iran	7.7
PI 357831	Yugoslavia	7.3	PI 357865	Yugoslavia	7.7
PI 357833	Yugoslavia	7.3	PI 092806	PR China	7.8
PI 357851	Yugoslavia	7.3	PI 109482	Turkey	7.8
PI 357856	Yugoslavia	7.3	PI 164951	Turkey	7.8
PI 357860	Yugoslavia	7.3	PI 169383	Turkey	7.8
PI 357869	Yugoslavia	7.3	PI 169388	Turkey	7.8
PI 392292	USSR	7.3	PI 169394	Turkey	7.8
PI 414157	USA, Oregon	7.3	PI 171603	Turkey	7.8
PI 422167	Czechoslovakia	7.3	PI 171607	Turkey	7.8
PI 432848	PR China	7.3	PI 171611	Turkey	7.8
PI 432861	PR China	7.3	PI 172838	Turkey	7.8
PI 458851	USSR	7.3	PI 174167	Turkey	7.8
PI 137848	Iran	7.5	PI 177364	Iraq	7.8
PI 165046	Turkey	7.5	PI 181940	Syria	7.8
PI 167050	Turkey	7.5	PI 193497	Ethiopia	7.8
PI 167079	Turkey	7.5	PI 204692	Turkey	7.8
PI 169304	Turkey	7.5	PI 206952	Turkey	7.8
PI 169315	Turkey	7.5	PI 211117	Israel	7.8
PI 169334	Turkey	7.5	PI 212599	Afghanistan	7.8
PI 169353	Turkey	7.5	PI 220169	Afghanistan	7.8
PI 169382	Turkey	7.5	PI 221440	Afghanistan	7.8
PI 169384	Turkey	7.5	PI 222782	Iran	7.8
PI 169386	Turkey	7.5	PI 223841	Philippines	7.8
PI 169391	Turkey	7.5	PI 226510	Iran	7.8
PI 169403	Turkey	7.5	PI 228344	Iran	7.8
PI 171609	Turkey	7.5	PI 257494	Iran	7.8
PI 175693	Turkey	7.5	PI 263048	USSR	7.8
PI 175697	Turkey	7.5	PI 264228	France	7.8
PI 179263	Turkey	7.5	PI 267086	USSR	7.8
PI 204569	Turkey	7.5	PI 271753	Netherlands	7.8
PI 211986	Iran	7.5	PI 283899	Czechoslovakia	7.8
PI 212059	Greece	7.5	PI 284699	Sweden	7.8
PI 217946	Pakistan	7.5	PI 288237	Egypt	7.8
PI 222244	Iran	7.5	PI 324239	Sweden	7.8
PI 227664	Iran	7.5	PI 338236	Turkey	7.8
PI 233932	Canada	7.5	PI 339247	Turkey	7.8
PI 255937	Netherlands	7.5	PI 344434	Iran	7.8
PI 264227	France	7.5	PI 351139	USSR	7.8
PI 264666	Germany	7.5	PI 355052	Israel	7.8
PI 264668	Germany	7.5	PI 356832	Netherlands	7.8
PI 267747	USA, Oklahoma	7.5	PI 357868	Yugoslavia	7.8
PI 280096	USSR	7.5	PI 368550	Yugoslavia	7.8
PI 285605	Poland	7.5	PI 458848	USSR	7.8
PI 285608	Poland	7.5	PI 466921	USSR	7.8
PI 285609	Poland	7.5	PI 135123	New Zealand	8.0
PI 293432	Lebanon	7.5	PI 135345	Afghanistan	8.0
PI 338234	Turkey	7.5	PI 169393	Turkey	8.0
PI 338235	Turkey	7.5	PI 169399	Turkey	8.0
PI 339250	Turkey	7.5	PI 169402	Turkey	8.0
PI 344350	Turkey	7.5	PI 172844	Turkey	8.0
PI 344432	Iran	7.5	PI 172847	Turkey	8.0
PI 344435	Iran	7.5	PI 172852	Turkey	8.0
PI 344440	Iran	7.5	PI 174166	Turkey	8.0
PI 357841	Yugoslavia	7.5	PI 174177	Turkey	8.0
PI 357842	Yugoslavia	7.5	PI 176523	Turkey	8.0
PI 357843	Yugoslavia	7.5	PI 176526	Turkey	8.0
PI 357863	Yugoslavia	7.5	PI 178888	Turkey	8.0
PI 372587	Netherlands	7.5	PI 204568	Turkey	8.0
PI 422169	Czechoslovakia	7.5	PI 209068	USA, Ohio	8.0
PI 422198	Czechoslovakia	7.5	PI 211943	Iran	8.0
Producer	NSSL	7.5	PI 222243	Iran	8.0
Early Grn Cluster	NSSL	7.7	PI 222986	Iran	8.0
PI 137851	Iran	7.7	PI 246930	Afghanistan	8.0
PI 169389	Turkey	7.7	PI 251519	Iran	8.0
PI 171601	Turkey	7.7	PI 257286	Spain	8.0
PI 172849	Turkey	7.7	PI 292012	Israel	8.0
PI 174164	Turkey	7.7	PI 296387	Iran	8.0
PI 175689	Turkey	7.7	PI 304805	USA, New York	8.0
PI 206955	Turkey	7.7	PI 344348	Turkey	8.0
PI 211977	Iran	7.7	PI 344439	Iran	8.0
PI 226461	Iran	7.7	PI 344441	Iran	8.0

Continued next page

Table 1. Continued.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
PI 344442	Iran	8.0	PI 183677	Turkey	8.3
PI 356833	Great Britain	8.0	PI 204567	Turkey	8.3
PI 357848	Yugoslavia	8.0	PI 227235	Iran	8.3
PI 357866	Yugoslavia	8.0	PI 251028	Afghanistan	8.3
PI 422168	Czechoslovakia	8.0	PI 274902	Great Britain	8.3
PI 422176	Czechoslovakia	8.0	PI 288993	Hungary	8.3
PI 105263	Turkey	8.3	PI 296121	Egypt	8.3
PI 137847	Iran	8.3	PI 339241	Turkey	8.3
PI 167052	Turkey	8.3	PI 344351	Turkey	8.3
PI 167389	Turkey	8.3	PI 357867	Yugoslavia	8.3
PI 169390	Turkey	8.3	PI 137856	Iran	8.5
PI 171613	Turkey	8.3	PI 169392	Turkey	8.5
PI 175695	Turkey	8.3	PI 176954	Turkey	8.5
PI 175696	Turkey	8.3	PI 357835	Yugoslavia	8.5
PI 176517	Turkey	8.3	PI 288995	Hungary	8.7
PI 176951	Turkey	8.3	PI 176952	Turkey	9.0
PI 176953	Turkey	8.3	PI 178886	Turkey	9.0
PI 177361	Turkey	8.3	PI 211985	Iran	9.0
PI 181874	Syria	8.3			

† LSD (0.05) = 2.0. Some countries listed as the origin of some accessions now no longer exist as political units (Czechoslovakia, U.S.S.R., Yugoslavia). Rating assessed visually one and two weeks after inoculation, and is based on the percentage leaf area affected using a 0 to 9 scale (0 = no damage, 9 = plant dead).

ation of some Cucurbitaceae for resistance to *P. cubensis* is low (Lebeda, 1992a). Den Nijs and Custers (1990) suggested the use of wild *Cucumis* species to broaden the genetic base for selection of resistance in cucumber. However, Lebeda (1992a) reported that there was little chance of producing cucumber cultivars carrying resistance to *P. cubensis* based on interspecific crosses except with *C. melo*.

Cucumber cultivars resistant to downy mildew have been developed (Sitterly, 1973). However, we were interested in identifying higher levels of resistance to downy mildew in the germplasm collection of all available cultivars, breeding lines, land races, feral accessions, and plant introduction accessions (hereafter referred to collectively as cultigens). The objective of this experiment was to evaluate all available cultigens of cucumber for downy mildew resistance under field conditions in North Carolina.

MATERIALS AND METHODS

All experiments were conducted at the Horticultural Crops Research Station at Clinton, NC, using recommended horticultural practices as summarized by Schultheis (1990). Most cultigens were tested in four blocks (two replications in each of 2 yr). However, 218 cultigens were tested in only one replication, so those data should be considered preliminary until they are verified.

Fertilizer was incorporated before planting at a rate of 90–39–74 kg/ha (N-P-K) with an additional 34 kg N/ha applied at the vine-tip-over stage (four to six true leaves). Seeds were planted on raised, shaped beds with centers 1.5 m apart. Plots 1.5 m long were seeded, and later thinned to five plants at the first true leaf stage. The soil was an Onslow loamy fine sand (fine-loamy, siliceous, thermic, Spodic Paleudults) with a 6.4 pH. Irrigation was applied when needed to provide a total of 25 to 40 mm per week, and a tank mix of 2.2 kg/ha of naptalam (2-[(1-naphthalenylamino) carbonyl] benzoic acid) and 4.4 kg/ha of bensulide (*O,O*-bis(1-methylethyl)-S-[2-[(phenylsulfonyl) amino] ethyl] phosphorodithioate) was applied preplant for weed control.

All available (749) plant introduction accessions (PIs) from the U.S. National Plant Germplasm System were tested in

1988 and 1989, along with 26 breeding lines and 106 cultivars from the NCSU collection for a total of 881 cultigens originating from 44 countries (Tables 1 and 2). The majority of cultigens tested were from the USA, Turkey, People's Republic of China, former Yugoslavia, Iran, India, Japan, former USSR, former Czechoslovakia, and the Netherlands. The PI accessions were obtained from the North Central Regional Plant Introduction Station in Ames, IA. Other cultigens were obtained from commercial sources, public breeding programs, or the National Seed Storage Laboratory in Fort Collins, CO. An additional 53 cultigens were tested, but data will not be presented in this paper because of poor emergence or growth in the field.

No artificial inoculum was used. Fields were exposed to natural epidemics in the course of the growing season. Epidemics were encouraged by means of a row of susceptible 'Wisconsin SMR 18' every fourth row in each field to help monitor and spread the inoculum, and by overhead irrigation (applied twice weekly). Plants usually showed significant symptoms of downy mildew by the vine tip-over stage (approximately 3 wk after planting).

Field plots were rated 2 and 4 wk after inoculation for foliar lesions with a 0 to 9 visual rating scale (0 = no foliar symptoms, 1 to 2 = trace, 3 to 4 = slight, 5 to 6 = moderate, 7 to 8 = advanced, 9 = plant dead) (Jenkins and Wehner, 1983). We standardized the amount of leaf damage in ratings 1 through 8 from the eight levels described pictorially for anthracnose [*Colletotrichum orbiculare* (Pass.) Ellis and Halst.] leaf damage by Thompson and Jenkins (1985), which corresponded to rating units 1 through 8 (0 and 9 being obvious endpoints).

The experiment was a randomized complete block with 2 yr, two replications, and 934 cultigens. Prior to analysis, data were checked for normality, error variance homogeneity, and additivity by residual plot analysis. Residual plots had a random distribution, indicating that the statistical model was valid and its assumptions were met (Fernandez, 1992). Rating scale data were not transformed because assumptions for the analysis of variance were met (Little, 1985). Data for some cultigens were not available for all environments, so data were analyzed separately for cultigens with all four environments and cultigens with only two environments. Data were analyzed by the General Linear Models procedure of the Statistical Analysis System (SAS, 1988).

The multiple comparison procedures for mean separation

Table 2. Mean downy mildew rating for 218 cultigens of *Cucumis sativus* field tested in North Carolina in two blocks in 1988 and 1989.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
Garden	Clemson Univ.	1.0	Dharampur-I	Nepal	5.5
Transamerica	Ferry-Morse	1.0	Heinz Pickling	NSSL	5.5
AR 79-75	Univ. Arkansas	2.0	Marketmore 80F	Cornell Univ.	5.5
Centurion	Northrup King	2.0	Medalist	Harris-Moran	5.5
Gy 54	Clemson Univ.	2.0	PI 171612	Turkey	5.5
H-19	Univ. Arkansas	2.0	PI 175111	India	5.5
PI 432886	PR China	2.0	PI 419183	PR China	5.5
PI 481617	Bhutan	2.0	PI 432873	PR China	5.5
Poinsett	Clemson Univ.	2.0	PI 432878	PR China	5.5
SC 57M	Clemson Univ.	2.0	PI 436673	PR China	5.5
Gy 57u	Cornell Univ.	2.5	PI 478364	PR China	5.5
PI 262974	India	2.5	Poinmarket	Clemson Univ.	5.5
PI 279469	Japan	2.5	PSI	NSSL	5.5
Picarow	Agway Inc.	2.5	Royal	Harris-Moran	5.5
PI 500365	Zambia	2.8	Shogoin	NSSL	5.5
M 41	NC State Univ.	3.0	Early Cluster	NSSL	6.0
PI 432877	PR China	3.0	Early White Spine	NSSL	6.0
Pick	Clemson Univ.	3.0	PI 164173	India	6.0
WI 2757	USDA-Wis	3.0	PI 171605	Turkey	6.0
AC 1811	Abbott & Cobb	3.5	PI 357864	Yugoslavia	6.0
General Lee	Ferry Morse	3.5	PI 368555	Yugoslavia	6.0
Green Thumb	Harris Seed	3.5	PI 368560	Yugoslavia	6.0
Homegreen 2	USDA-Wis	3.5	PI 391571	PR China	6.0
Marketsett	Clemson Univ.	3.5	PI 422188	Czechoslovakia	6.0
MR 200	NSSL	3.5	PI 432874	PR China	6.0
PI 173892	India	3.5	PI 432883	PR China	6.0
PI 196289	India	3.5	PI 432889	PR China	6.0
PI 390952	USSR	3.5	Coolgreen	Asgrow Seed	6.5
Redlands Lng Wht	New World Seeds	3.5	Danish Common	NSSL	6.5
Stono	NSSL	3.5	Delcrow	NSSL	6.5
Carolina	Clemson Univ.	4.0	Early Fortune	NSSL	6.5
Cross Country	Ferry-Morse	4.0	Mandarin	Vaughan	6.5
Fancipak	Asgrow Seed	4.0	PI 171610	Turkey	6.5
Gy 1	NC State Univ.	4.0	PI 175680	Turkey	6.5
MSU 9429M	Michigan State	4.0	PI 264230	France	6.5
Olympian	Hollar Seed	4.0	PI 277741	Netherlands	6.5
PI 269480	Pakistan	4.0	PI 357832	Yugoslavia	6.5
PI 3090255	Japan	4.0	PI 368556	Yugoslavia	6.5
PI 390258	Japan	4.0	PI 368559	Yugoslavia	6.5
PI 390268	Japan	4.0	PI 370019	India	6.5
PI 419182	PR China	4.0	PI 370449	Yugoslavia	6.5
PI 426170	Philippines	4.0	PI 379282	Yugoslavia	6.5
PI 432885	PR China	4.0	PI 390240	Japan	6.5
PI 464873	PR China	4.0	PI 390263	Japan	6.5
Prolific	Sakata Seed	4.0	PI 390951	USSR	6.5
PI 419135	PR China	4.1	PI 391572	PR China	6.5
Aodai-Nazare	Asgrow Seed	4.5	PI 391573	PR China	6.5
HMX 4490	Harris-Moran	4.5	PI 422199	Czechoslovakia	6.5
Maximore 102	Abbott & Cobb	4.5	PI 422200	Czechoslovakia	6.5
PI 419108	PR China	4.5	PI 432853	PR China	6.5
PI 432876	PR China	4.5	PI 432869	PR China	6.5
PI 432880	PR China	4.5	PI 432872	PR China	6.5
PI 432888	PR China	4.5	PI 432882	PR China	6.5
PI 432891	PR China	4.5	PI 458847	USSR	6.5
Regal	NC State Univ.	4.5	WS Davis Perfect	NSSL	6.5
Staygreen	NSSL	4.5	Alpha Green	NSSL	7.0
Snows Pickling	NSSL	4.6	Armstrg Erly Clstr	SunSeeds	7.0
PI 422185	Czechoslovakia	4.8	Ashley	Clemson Univ.	7.0
Balam Model	Nepal	5.0	Crystal Salad	NSSL	7.0
Burpless 33	Hastings	5.0	Early Michigan	Burgess Seed	7.0
Discover	Asgrow Seed	5.0	Long Green	Northrup King	7.0
Dublin	Stokes Seed	5.0	M 22	NC State Univ.	7.0
EC 128264	NSSL	5.0	Monopol	Wageningen	7.0
Palmetto	NSSL	5.0	MR 25	NSSL	7.0
PI 167223	Turkey	5.0	National Pickling	NSSL	7.0
PI 220338	Afghanistan	5.0	PI 137845	Iran	7.0
PI 368553	Yugoslavia	5.0	PI 176518	Turkey	7.0
PI 370643	USSR	5.0	PI 176956	Turkey	7.0
PI 390250	Japan	5.0	PI 207476	Afghanistan	7.0
PI 390251	Japan	5.0	PI 211979	Iran	7.0
PI 419078	PR China	5.0	PI 220171	Afghanistan	7.0
PI 432859	PR China	5.0	PI 267943	Japan	7.0
PI 432881	PR China	5.0	PI 326598	Hungary	7.0
PI 432897	PR China	5.0	PI 357850	Yugoslavia	7.0
Pickalot	Burpee Seed	5.0	PI 368548	Yugoslavia	7.0
Slice Max	Sakata Seed	5.0	PI 368554	Yugoslavia	7.0
Balam Khira	Nepal	5.5	PI 368557	Yugoslavia	7.0

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Table 2. continued.

Cultigen	Origin	Rating	Cultigen	Origin	Rating
PI 369717	Poland	7.0	PI 357838	Yugoslavia	7.5
PI 370447	Yugoslavia	7.0	PI 368552	Yugoslavia	7.5
PI 370450	Yugoslavia	7.0	PI 372903	Netherlands	7.5
PI 372893	Netherlands	7.0	PI 379279	Yugoslavia	7.5
PI 372905	Netherlands	7.0	PI 390248	Japan	7.5
PI 379283	Yugoslavia	7.0	PI 390249	Japan	7.5
PI 379284	Yugoslavia	7.0	PI 422181	Czechoslovakia	7.5
PI 379286	Yugoslavia	7.0	PI 422189	Czechoslovakia	7.5
PI 390265	Japan	7.0	PI 422191	Czechoslovakia	7.5
PI 419009	PR China	7.0	PI 432866	PR China	7.5
PI 422197	Czechoslovakia	7.0	PI 436610	PR China	7.5
PI 432875	PR China	7.0	PI 458855	USSR	7.5
PI 458853	USSR	7.0	Poona Khira	Nepal	7.5
PI 458854	USSR	7.0	Snake	Clemson Univ.	7.5
PI 489753	PR China	7.0	SR 551F	Cornell Univ.	7.5
PR 27	NSSL	7.0	Yorkstate Pickling	NSSL	7.5
SMR 58	Asgrow Seed	7.0	Klondike	NSSL	8.0
Spacemaster	Cornell Univ.	7.0	Longfellow	NSSL	8.0
Beit Alpha MR	SunSeeds	7.5	PI 211967	Iran	8.0
Burpee Pickler	Burpee Seed	7.5	PI 220789	Afghanistan	8.0
Chinese Long Grn	Oris	7.5	PI 251520	Iran	8.0
Early Russian	NSSL	7.5	PI 344349	Turkey	8.0
Marketer	Asgrow Seed	7.5	PI 368551	Yugoslavia	8.0
Minn Dwf Cuke II	Minnesota AES	7.5	PI 370448	Yugoslavia	8.0
PI 137857	Iran	7.5	PI 376063	Israel	8.0
PI 173674	Turkey	7.5	PI 390244	Japan	8.0
PI 174174	Turkey	7.5	PI 432849	PR China	8.0
PI 176519	Turkey	7.5	PI 211988	Iran	8.5
PI 205181	Turkey	7.5	PI 344443	Iran	8.5
PI 211962	Iran	7.5	PI 379278	Yugoslavia	8.5
PI 218036	Iran	7.5	PI 379281	Yugoslavia	8.5
PI 229309	Iran	7.5	PI 211980	Iran	9.0

† LSD (0.05) = 4.1. Some countries listed as the origin of some accessions now no longer exist as political units (Czechoslovakia, U.S.S.R., Yugoslavia). Rating assessed visually one and two weeks after inoculation, and is based on the percentage leaf area affected using a 0 to 9 scale (0 = no damage, 9 = plant dead).

of unstructured qualitative treatments for cultigens and germplasm screening is valid statistically and makes means listed in a table simple for presentation (Petersen, 1977; Steel and Torrie, 1980). Single degree of freedom contrasts are not appropriate if no logical a priori structure exists among the treatments of a test (Steel and Torrie, 1980). The LSD method was used for mean separations because it controls the comparison-wise error rate better than do other methods (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The two replications from 1988 were more closely correlated with each other than with the replications from 1989. However, since the correlation was low ($R^2 = 0.29$), the treatment of the two replications in 2 yr as four blocks was not likely to violate the assumptions of the analysis of variance. The mean of each of the four environments was significantly different from all other environments in the test ($P = 0.001$). The means for environments ranged from 5.2 to 8.1. The large range of environment means indicated that cultigens not tested in all four environments (1988, 1989) would be greatly affected because of the lack of data for a specific environment.

No implications could be made concerning the resistance of feral accessions for a given country because the assortment of cultigens for a given country included any combination of improved cultivars, breeding lines, land races, and feral cucumbers. A comparison among countries for only feral cucumbers was not possible because information available from the Germplasm Re-

sources Information Network (GRIN) or from the North Central Regional Plant Introduction Station did not indicate if most accessions were feral or not.

The cultigens were ranked based on the mean downy mildew leaf rating averaged over environments and rating dates (Tables 1 and 2). The most resistant nine cultigens, for which multiple-year data were available (Table 1), were all of U.S. origin and were primarily elite cultivars or elite breeding lines. Those were Gy 4, Clinton, PI 234517, Poinsett 76, Gy 5, Addis, M 21, M 27, and Galaxy. Of all 881 cultigens tested, the two with the lowest ratings were 'Garden' (sometimes referred to as 'Dual') and 'Transamerica' (Table 2). However, since they were tested in only two environments, ratings for those cultigens should be interpreted with caution. The most susceptible cultigens for which multiple-year data were available, were PI 288995, PI 176952, PI 178886, and PI 211985.

It is difficult to separate cultigens into classes such as resistant and susceptible when rating for resistance on a continuous scale. However, plant breeders often use those terms for quantitative traits. In keeping with that practice, cultigens evaluated in multiple environments and having ratings of 1.3 and 3.0 were classified highly resistant, from 3.3 to 5.0 moderately resistant, from 5.3 to 7.0 moderately susceptible, and from 7.3 to 9.0 highly susceptible. The categories were somewhat arbitrary, but resulted from the fact that the LSD was 2.0. Based on those classifications, 17 cultigens were highly resistant, 87 moderately resistant, 311 moderately susceptible, and 248 were susceptible (Table 1). For cultigens

evaluated in only two environments, we classified them as resistant if they had ratings of 1.0 to 5.0, and susceptible if they had ratings of 5.5 to 9.0. Of the 218 cultigens tested in 2 replications, 76 cultigens were classified as resistant and 142 were susceptible (Table 2).

The degree of heterozygosity for most of the cultigens tested was unknown. However, heterozygosity for most of the PI accessions can be high. The PI accessions found to be resistant in this study are likely to have useful genes for resistance. However, those accessions found to be susceptible may still carry recessive alleles for resistance which were not discovered because of small sample size and possible heterozygosity.

No plant introductions were more resistant than the most resistant cultivars or breeding lines tested in this study. Some cultigens found to be resistant in other studies were moderately resistant or susceptible in this study. PI 234517 was highly resistant in our test, and was reported susceptible (Lebeda, 1992b) or resistant (Staub et al., 1989) in other studies. PI 197087 was the major source of resistance for development of downy mildew resistant cultivars in the USA, but was only moderately resistant in our test (Barnes, 1969). Van Vliet and Meysing (1977) reported that PI 197087 was in the ancestry of PI 234517. Since plant introduction accessions are not uniform in resistance, there may be plants within the accession that are highly resistant, or it may be that the accession has lost resistance as it went through seed increase operations in the germplasm system. Van Vliet and Meysing (1977) observed the PI accession they used in their inheritance studies to be uniformly resistant. In addition, they reported that heterozygotes were intermediate to the dominant and recessive homozygotes for the *dm* gene. It would be useful to test many plants of PI 197087 to determine whether high resistance to downy mildew is still present in the accession.

Staub et al. (1989) evaluated the National Plant Germplasm System collection of cucumber consisting of 753 accessions for downy mildew resistance, and reported that 6.2% of the accessions were uniformly resistant, 7.2% were uniformly susceptible, and the remainder (86.6%) were segregating with at least some resistant plants in a 10-plant row. The number of accessions with one or more resistant plants seemed high to us, and may have been due to escapes. However, the 22 PI accessions they mentioned as having resistance to downy mildew were all highly or moderately resistant in our study, except three that were rated moderately or highly susceptible (PI 163217, PI 451976, and PI 390244). The PI accessions that were resistant in both studies were PI 167223, PI 197088, PI 234517, PI 267942, PI 279466, PI 279468, PI 288238, PI 321009, PI 358813, PI 390255, PI 390259, PI 422182, PI 432865, PI 432870, PI 432876, PI 436672, PI 483342, and PI 489754.

The most resistant cultigens should be retested to determine whether plants with even higher resistance can be selected from within each of them. Plant breeders may be able to improve resistance to downy mildew by combining genes from the most resistant plants in the most resistant cultigens if unrelated gene loci are in-

involved. Use of different sources of resistance may also improve the performance of cultivars in different production areas of the world.

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