Greenhouse Evaluation of *Capsicum* Accessions for Resistance to European Corn Borer (*Ostrinia nubilalis*)

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Additional index words. insect resistance, pepper, pungency, vegetable breeding, integrated pest management

Abstract. A replicated greenhouse evaluation of a range of commercial and noncommercial (*Capsicum* spp.) accessions for resistance to European corn borer (ECB) [*Ostrinia nubilalis* (Hubner)] was conducted. Percentage of fruit damaged was observed among 29 accessions four weeks after plants were artificially infested with ECB egg masses. Small-fruited peppers generally showed lower levels of damage, while large-fruited peppers were the most susceptible. Genotypes with elongate fruit were less damaged than those with bell-shaped fruit. Resistance to fruit damage was also associated with increasing pungency level, with two notable exceptions. The pungent genotype ‘Large Red Thick Cayenne’ was significantly more susceptible than many of the other pungent accessions tested. The relative susceptibility of this accession may be related to large fruit size. The nonpungent pepper ‘Corno di Toro’ showed significantly lower percent fruit damage than other nonpungent peppers including ‘Banana Supreme’ with roughly similar fruit size, ranking amidst highly pungent peppers such as ‘Red Scotch Bonnet’. These results confirm that resistance to ECB can be identified in nonpungent *Capsicum* genotypes and demonstrate that pungency is not always correlated with ECB damage. Reported sources of aphid resistance or tolerance showed good levels of ECB resistance, but interpretation of these results was confounded by the presence of pungency.

The European corn borer (ECB) has an extremely wide host range, which has resulted in its status as a significant pest of many different agronomic and vegetable crops. Since being introduced from Europe in the early 1900s, ECB has spread to all but the seven most western states of the continental U.S. In many parts of its host range, ECB has become the most important insect pest of peppers, including vegetable growing regions of New York, New England, the Midwest and southern Canada. In New York, all pepper acreage is annually affected by ECB, with up to 50% yield losses in severely infected fields.

The life history of ECB on pepper has been reviewed. While maize is the preferred host for ECB, female moths will also lay eggs on leaves of pepper plants. Economic damage results when oviposition occurs during periods of fruiting, a regular occurrence. Larvae hatch in 1 to 2 weeks and disperse onto fruit, where they enter by boring under the calyx, leaving a

small amount of sawdust-like frass as the only indication of fruit infestation. ECB develop through five larval instars before they pupate and become adults; a process which in maize is ≈30 d in duration. Within infested pepper fruit, first and second larval instars feed primarily on calyx and placental tissues, while later instars continue development in the primary fruit or move to bore into secondary fruit or stems. Wounds produced by ECB entry holes promote bacterial infection of the fruit by *Erwinia carotovora*. As fruit progressively deteriorate due to soft rot, larvae move into uninfected fruit, spreading the disease. In southern New England and comparable environments, the second flight of bivoltine ECB strains coincides with pepper fruit set in production fields.

Integrated pest management control recom-

mendations for ECB include locating pepper fields away from corn fields, plowing down crop residue to destroy over-wintering larvae, and clearing field perimeters of weedy habitat. However, growers face stringent standards regarding ECB contamination, and rejection of processing pepper lots is common at infestation levels as low as 5% to 10%. Thus, there is a very low tolerance for corn borer in pepper fields, and weekly insecticide applications are recommended to protect fruit from the onset of second flight moth activity until harvest. Heavy dependence on regular insecticide use for control of ECB in pepper is expensive and poses risks in terms of toxicity, development of resistance in the pest and shifting regulatory restrictions on pesticides registered for use in vegetable crops.

Genetic resistance to ECB in commercial pepper varieties could help alleviate some of these problems. There is a great deal of variability in *Capsicum* with regard to response to ECB damage, largely associated with pungency level. Two studies have reported ECB resistance evaluations in pepper. Jarvis and Guthrie (1972) evaluated 120 *Capsicum* plant introductions and 4 cultivars for resistance to corn borer infestation. They examined susceptibility to ECB damage with respect to commercial type, fruit shape, fruit size, and pungency level. Their results indicated that pimiento and bell were the most susceptible market types, followed by paprika, chile, cayenne, tabasco, and ornamental. Genotypes with bell and conical fruit shapes were the most susceptible, followed by elongate, round, and oblate. Larger pods were more susceptible to damage than smaller pods. Nonpungent peppers were the most damaged, followed by pungent and very pungent peppers. An accompanying feeding study demonstrated that even low concentrations of capsaicin were effective in reducing larval growth and development. The authors concluded that capsaicin was an important factor determining resistance. A later study compared ECB damage among two commercial nonpungent peppers and six breeding lines after artificial infestation. Resistance was once again associated with pungency, although one nonpungent pepper breeding line showed a fair level of resistance compared to commercial bell peppers. This breeding line had smaller fruit, more fruit per plant, smaller leaves and less compact habit relative to bell peppers. Feeding studies confirmed that increasing capsaicin levels reduced larval survival, while reduced survival to pupation was observed after

Table 1. Sources of *Capsicum* accessions evaluated for resistance to European corn borer.

Source and Location	Accession
Asgrow Seed Co., San Juan Bautista, CA	NuMex RNaky
AVRDC, Taiwan	PBC 18, PBC 30, PBC 84, PBC 345 (Serrano Vera Cruz), PBC 681 (Early Jalapeno), PBC 750 (Szege 40017), PBC 1351
CalCompack Foods, King City, CA	CalCompack
Cornell University, Ithaca, NY (T. Thorup)	Red Scotch Bonnet
INRA, France	Perennial
Stokes Seeds, Buffalo, NY	Ace, Camelot, Merlin
Tomato Growers Supply Co., Fort Myers, FL	Banana Supreme, Big Bertha, Commandant, Corno di Toro, Gypsy, Large Red Thick Cayenne, NuMex Joe E. Parker, Paprika Supreme, Pasilla Bajio, Pepperoncini, Peto Wonder, Pimento L, Serrano, Super Cayenne II, Super Red Pimento

Received for publication 6 May 2003. Accepted for publication 19 Nov. 2003. We would like to thank Margaret Smith for laboratory-produced European corn borer egg masses and the Asian Vegetable Research and Development Center for cotton aphid resistant germplasm. This study was funded in part by the Cornell University Vegetable Breeding Institute, a consortium of companies that support plant breeding research at Cornell, along with funding from USDA IFAFS Award No. 2001-52100-11347.

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feeding larvae a diet containing 20% ground fruit from the most resistant pungent accessions when compared to similar treatment using a nonpungent pepper breeding line.

Although resistance to ECB has been linked to capsaicin content, pungency is clearly undesirable in nonpungent peppers, therefore potential sources of resistance are required that are independent of pungency. One strategy to locate useful germplasm is to search accessions with tolerance or resistance to other insect pests. Pepper accessions that have been identified for resistance or tolerance to cotton aphid (CA) infestation could potentially provide pleiotropic resistance to ECB. Precedence for this has been noted in maize with resistance to both corn leaf aphid and ECB leaf feeding associated with the presence of the hydroxamic acid DIMBOA [2,4-dihydroxy-7-methoxy-(2*H*)-1,4-benzoxazin-3(4*H*)-one]. In tomato, resistance to both the nematode *Meloidogyne incognita* and potato aphid are controlled by the *Mi* gene. Leaf pubescence, in the form of glandular trichomes that exude acylsugars, has been associated with resistance to a wide range of pests in tomato including both aphids and lepidopterans.

One objective of our study was to test an array of pepper accessions with several potentially important characteristics, including those with resistance to CA, for their relative resistance to ECB. A second objective was to observe whether leaf pubescence provides protection from ECB damage. The final objective was to evaluate additional pepper accessions with a range of pungency levels, fruit shapes and

sizes for resistance to ECB damage, both to confirm the general relationship of these traits to resistance and to see if ECB resistance could be recovered in nonpungent genotypes.

Materials and methods

Plant materials and market types. Sources of pepper germplasm evaluated in this study are listed in Table 1. Market types used in this study are as follows. Ornamental peppers (*C. annuum*) are small-fruited, generally thin-fleshed, and pungent. Chili peppers (*C. annuum*) are elongate, thick-fleshed, and pungent. Aji peppers (*C. baccatum*) are elongate, thin-fleshed, and pungent. Caribbean peppers (*C. chinense*) are blocky, thin-fleshed, and extremely pungent. Pasilla peppers (*C. annuum*) are large, elongate, and thin-fleshed with low pungency. Paprika peppers (*C. annuum*) are elongate and thin-fleshed with low pungency. Cayenne peppers (*C. annuum*) are elongate, slightly curved, thin-fleshed and pungent. Chile peppers (*C. annuum*) are large, elongate peppers with thick flesh and mild pungency. Italian sweet peppers (*C. annuum*) are large, elongate peppers with thick, sweet flesh. Pepperoncini peppers (*C. annuum*) are thin-fleshed, elongate and mildly pungent. Bell peppers (*C. annuum*) are nonpungent with thick flesh and blocky shape with three to four lobes. Pimentos (*C. annuum*) are nonpungent peppers with thick flesh and conical or oblate shape.

Plant culture. Plants were seeded on 21 Apr. 1999 into commercial peat potting mix

(Premier ProMix, Dorval, Quebec) and grown under halogen lights in the Cornell University Insectary greenhouse. Six-week-old seedlings were transplanted on 2 June into 200-mm pots (Kord Products, Toronto, Ont.) and grown in the greenhouse without supplemental lighting. Greenhouse temperatures were maintained between 22 and 32 °C. Plants were fertilized with Peters 20–20–20 plant food (Scotts, Marysville, Ohio) once every week.

ECB infestation and damage evaluation. The evaluation study was arranged as a randomized complete block design with one plant per replication and six replications. Each block consisted of a greenhouse bench with plants arranged 33 cm inches apart within rows and 54 cm between rows. Plants were infested on two dates, 16 and 25 Aug., after most accessions had set several fruit. Artificial infestation was accomplished by pinning two ECB egg masses containing ≈20 eggs each onto stems near fruit. Laboratory produced ECB egg masses were provided by M. Smith, Cornell University. Four weeks after the second infestation, fruit were examined for signs of ECB damage. Any fruit with signs of ECB damage or presence of larvae were counted as infested.

Percentage of fruit infested was determined based on the number of infested fruit out of the total number of fruit at harvest. Expected survivorship of ECB larvae before boring into maize plants is 20% to 50% depending on environmental conditions. Given relatively protected conditions in the greenhouse, expected survivorship to the boring stage on pepper fruit was set at 50%. Based

Table 2. Percentage of fruits damaged among *Capsicum* accessions artificially infested with European corn borer egg masses.

Accession	Type ^a	Pungency ^b	Size ^c	Shape	Damaged fruit (%)	
					Rank	Mean
Perennial	Ornamental	Pungent	Small	Elongate	1	0.00 a ^w
PBC 30 ^v	Cayenne	Pungent	Medium	Elongate	1	0.00 a
PBC 1351 ^v	Aji	Pungent	Small	Elongate	3	0.83 a
PBC 18 ^v	Cayenne	Pungent	Medium	Elongate	4	1.85 ab
Serrano	Chili	Pungent	Small	Elongate	5	2.08 ab
Serrano Vera Cruz	Chili	Pungent	Small	Elongate	6	2.94 ab
Red Scotch Bonnet	Caribbean	High	Medium	Blocky	7	4.44 abc
Super Cayenne II	Cayenne	Pungent	Medium	Elongate	8	8.65 abcd
Early Jalapeno ^v	Chili	Pungent	Medium	Elongate	9	9.93 abcd
Pasilla Bajio	Pasilla	Mild	Large	Elongate	10	16.67 abcde
Paprika Supreme	Paprika	Mild	Large	Elongate	11	18.71 abcdef
Szeged 40017	Paprika	Mild	Large	Elongate	12	21.69 bcdef
Corno di Toro	Italian sweet	Sweet	Large	Elongate	13	24.20 cdef
Large Red Thick Cayenne	Cayenne	Pungent	Large	Elongate	14	28.07 defg
Cal Compack	Paprika	Mild	Large	Elongate	15	32.04 efg
NuMex RNaky	Chile	Mild	Large	Elongate	16	35.75 efgh
NuMex Joe E. Parker	Chile	Mild	Large	Elongate	17	37.18 fgh
Banana Supreme	Italian sweet	Sweet	Large	Elongate	18	46.79 gh
Pepperoncini	Pepperoncini	Mild	Medium	Elongate	19	52.75 h
Gypsy	Bell	Sweet	Large	Conical	20	75.13 i
PBC 84 ^v	Bell	Sweet	Large	Bell	21	76.39 ij
Camelot	Bell	Sweet	Large	Bell	22	80.56 ij
Commandant	Bell	Sweet	Large	Bell	23	82.18 ij
Peto Wonder	Bell	Sweet	Large	Bell	24	82.78 ij
Pimento L	Pimento	Sweet	Large	Conical	25	83.47 ij
Ace	Bell	Sweet	Large	Bell	26	84.26 ij
Super Red Pimento	Pimento	Sweet	Large	Oblate	27	85.52 ij
Merlin	Bell	Sweet	Large	Bell	28	87.78 ij
Big Bertha	Bell	Sweet	Large	Bell	29	95.83 j

^aSee description of market types in Materials and Methods.

^bPungency ratings: sweet (no pungency), mild (<1000 Scoville Units), pungent (2000 to 50,000 Scoville Units), high (>100,000 Scoville Units).

^cSmall = average width <2.5 cm and average length <5 cm, medium = average width 2.5 cm to 5 cm and average length 5 cm to 10 cm, large = average width >5 cm and average length >10 cm.

^wMean separation by Fisher's protected LSD test, *P* = 0.05.

^vShows tolerance to cotton aphid (Frantz et al., in press).

on initial infestation of 80 eggs and expected survivorship of 40 larvae per plant, the upper limit of total fruit (infestable) per plant was adjusted to 40 when calculating the percent of fruit infested. This adjustment was only required for two plants of 'Perennial', four plants of PBC 1351, and one plant of 'Red Scotch Bonnet'. Analysis of variance and Fisher's protected LSD test ($P=0.05$) was performed using Minitab Version 13 (Minitab, State College, Pa.).

Results

Ranks, assigned to accessions based on resistance to fruit damage, ranged from the top ranking (1) for 'Perennial' and PBC 30 with the least amount of damage (0%) to the lowest ranking (29) for 'Big Bertha' with the highest amount of damage (95.83%) (Table 2). Pungent to highly pungent accessions comprised the top nine resistance rankings for percent fruit damage. Mildly pungent peppers comprised 7 out of the next 10 most resistant rankings. The lowest ranked ten accessions were all nonpungent.

Small-fruited accessions comprised four of the top six rankings and large-fruited accessions comprised the 19 out of the 20 lowest rankings. Elongate shaped peppers comprised 19 of the 20 top resistance rankings for percentage of fruit damaged, while bell shaped peppers comprised 7 out of the 9 lowest ranked accessions. These results are consistent with previous studies.

One of the objectives of the study was to determine whether resistance to ECB could be found among accessions rated resistant to CA. CA-resistant accessions PBC 30, PBC 1351, and PBC 18 were three of the four top ranked accessions for percent fruit damage, and the CA-tolerant line 'Early Jalapeno' was also in the top resistance grouping. All four of these accessions are pungent, therefore ECB resistance in these accessions cannot be separated from pungency without performing segregation analysis by making genetic crosses to nonpungent types. However, the CA-resistant nonpungent bell pepper PBC 84 was very susceptible to ECB damage. Assuming that the mechanism of resistance is consistent among the CA-resistant accessions, ECB susceptibility in PBC 84 indicates no evidence of pleiotropy between CA resistance and ECB resistance.

The pubescent pepper accessions 'Serrano' and 'Serrano Vera Cruz' were highly resistant to fruit damage, ranking fourth and fifth overall. Fruit of these accessions are small and pungent, so again, further characterization is required to separate the effects of pubescence from the effects of pungency level and fruit size.

All bell pepper entries evaluated were highly susceptible, with >75% infestation. Pimiento types were also highly infested, with >80% infestation. The Italian sweet types 'Corno di Toro' and 'Banana Supreme' showed significantly less ECB damage than bell and pimiento types. They grouped instead with other large-fruited elongate peppers in the study, most of which have mild pungency. It is striking that 'Corno di Toro' was significantly more resistant than 'Banana Supreme', and actually ranked above the pungent pepper 'Large Red Thick Cayenne'. Fruit damage to 'Corno di Toro'

was not significantly different from the highly pungent 'Red Scotch Bonnet'. Mildly pungent accessions Pasilla Bajio, Paprika Supreme and Szeged 40017 also performed well, ranking slightly better than 'Corno di Toro'.

Discussion

The most pressing need for ECB resistance is in highly susceptible bell and pimiento types, therefore useful resistance sources must be independent of pungency. A nonpungent source of reduced damage such as 'Corno di Toro' could be useful in an attempt to improve levels of damage in bell and pimiento types. It is possible that reduced damage in this accession could be related to a character such as a tightly sealed calyx architecture that excludes first instar larvae. Based on the fact that we recovered this source in an evaluation of a limited number of nonpungent accessions, further evaluation of nonpungent pepper germplasm could reveal better sources of resistance for breeding programs. Segregation analysis of crosses made between 'Corno di Toro' and highly susceptible peppers will be required to determine the mode of inheritance and to examine in further detail the relationship between thickness of fruit walls, fruit shape and other characters with resistance to ECB.

The mildly pungent accessions Pasilla Bajio, Paprika Supreme and Szeged 40017 may also represent possible sources of resistance for introgression into bell and pimiento peppers, if the resistance can be introgressed with a minimal amount of pungency. The surprising level of susceptibility in pungent genotype 'Large Red Thick Cayenne' may be related to large fruit size. It suffered nearly 20% more fruit damaged than the medium-sized commercial cayenne 'Super Cayenne II', and >25% more fruit damage than medium-sized cayenne peppers PBC 30 and PBC 18.

Evaluation of resistance under greenhouse conditions provides a stable environment for infestation, but there are clear and possibly significant phenotypic differences between greenhouse and field-grown pepper plants. Field grown plants tend to be more compact with more leaf cover, which could favor dispersal of first instar ECB larvae, resulting in higher levels of overall infestation. On the other hand, in unprotected conditions, predation by natural enemies and losses to abiotic stresses could mitigate ECB infestation pressure. Further testing will be required to determine the extent to which results from greenhouse evaluations predict field performance.

Since there is a very low tolerance for ECB damage in commercial pepper crops, high levels of resistance would be required to curb regular insecticide use. Further evaluation should continue for resistance to ECB, although the limited amount of genetic variability within nonpungent peppers suggests it may be difficult to find highly resistant sources for improvement of bell and pimiento accessions. Even an intermediate level of resistance, as observed in 'Corno di Toro', would be useful if it reduced the number of sprays required to produce a crop. Host plant resistance might be most likely to provide complementary control of ECB when combined with with inoculative releases of biological con-

trol agents, e.g., parasitoid wasps, or chemical agents. Among the highly resistant hot peppers, the next step will involve segregation analysis to determine whether there is any independence between ECB resistance and pungency. If so, it would open up a much larger germplasm base for resistance breeding.

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