Evaluation of Vegetable Soybean Genotypes for Resistance to Mexican Bean Beetle (Coleoptera: Coccinellidae)

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ABSTRACT One hundred vegetable-type soybean, *Glycine max* [L.] Merrill, accessions from maturity groups III through VIII plus 70 grain-type cultivars and plant introductions (PIs) resistant and susceptible to Mexican bean beetle, *Epilachna varivestis* Mulsant, were evaluated in a randomized block design with three replications for resistance to Mexican bean beetle foliar feeding in a 3-yr field study. Vegetable-type soybean cultivars ranged from moderate susceptibility ('Camp'), similar to many grain-type cultivars, to highly susceptible ('Sato', 'Hahto'). PIs with desirable vegetable-type traits and good to average resistance to Mexican bean beetle (PIs 417061, 417288, and 417310 and FC 31732) were identified, as was highly susceptible germplasm (PI 416771).

KEY WORDS *Epilachna varivestis*, soybeans, insect resistance

SOYBEANS, *Glycine max* (L.) Merrill, long an important nutritional component of Asian diets, are now gaining acceptance in western cultures largely because of the health benefits associated with diets low in saturated animal fats. Traditional vegetable-type uses provide both an export market opportunity and a domestic niche market; the new technologies utilizing texturized soybean protein for meat substitutes may increase the demand for specialty soybeans greatly. Small-seeded cultivars are used for sprouts, natto (fermented whole beans), or tofu (a high-protein meat substitute). Large-seeded types are used for miso (fermented soup base), roasted, or eaten as a green garden vegetable. These specialty soybean cultivars have flavor, texture, and appearance characteristics that often differ from those of cultivars grown for edible vegetable oil or for high-protein feed supplements for livestock. Although seed size and appearance are important factors in developing vegetable-type cultivars, increasing attention is being paid to taste, flavor, and nutritional factors (Mohamed & Rangappa 1992b). Knowledge of disease and insect pest resistance in cultivars, breeding lines, and germplasm sources will assist in the development of economically successful cultivars.

We selected vegetable-type soybean germplasm from maturity groups (MGs) III through VIII for field evaluation of resistance to Mexican bean beetle, *Epilachna varivestis* Mulsant, defoliation. Although the Mexican bean beetle has not been a serious threat to soybean production recently, it was a major pest in the eastern United States from the late 1960s through the mid-1980s. The subsequent decline in Mexican bean beetle populations was associated with a series of years, from the mid-1980s through the early 1990s, with periods of severe summer drought. A return to a more humid summer climate may result in the return of this insect to major pest status. Hot and dry conditions often have been reported as unfavorable to Mexican bean beetle. Kitayama et al. (1979) reviewed these reports and confirmed their conclusions in a greenhouse study using soybeans as the host plant; fecundity was greatest under conditions of moderate temperature (no eggs were laid at 32°C) and high humidity, and longevity increased with humidity.

Resistance to Mexican bean beetle defoliation often indicates resistance to other insect species. The three soybean PIs identified by Van Duyn et al. (1971) as most resistant to Mexican bean beetle (PIs 171451, 229358, and 227687) later were found to be resistant to corn earworm, *Helicoverpa zea* (Boddie), and other insect pests (Clark et al. 1972, Hatchett et al. 1976, Turnipseed & Sullivan 1976).

Materials and Methods

Soybean Selections. This study contained 140 soybean genotypes, including 34 vegetable-type cultivars and 59 vegetable-type PIs and breeding lines. They were selected based on seed size (<10 g/100 or >20 g/100 seeds) and seed-coat color or based on inclusion in other vegetable soybean studies and breeding programs. The seed coats of these selections were predominantly light yellow but also included green, black, and a few brown types. Although a yellow seed coat and light-colored hilum often are desired for vegetable-type soybeans, large green-seeded cultivars have also been developed, and breeding programs in the Republic of China (Taiwan) and the People's Republic of China are selecting for black- and green-seeded cultivars.

Controls in our field evaluations included 25 grain-type cultivars and three breeding lines developed for Mexican bean beetle resistance: HC83-46-1, HC83-123-9 (Cooper & Hammond 1988), and L76-0049 (Rufener et al. 1986). Resistant and susceptible PIs selected from previous Mexican bean beetle resistance studies (Kraemer et al. 1988, 1990) also were included. Some of these selections had vegetable-type characteristics. Seed size data for PIs were obtained from published USDA–ARS sources (Technical Bulletins 1718, 1726, 1760, and 1802; RSLM 238 rev.; Hartwig & Edwards [1986]) and are referred to as grams per 100 seeds. We determined the seed weight for cultivars, breeding lines, and some PIs from soybeans planted for seed increase. In cases where our seed weights differed greatly (>10%) from the published weights, they are noted in the text.

Field Tests. Selected soybean accessions were planted in 2-m rows, 25 seeds per meter, with 1-m spacings, and 0.9-m width between furrows. A mixture of 'Contender' snap beans, *Phaseolus vulgaris* L., and 'Henderson' bush lima beans, *Phaseolus lunatus* L., was planted in every third furrow 3 wk before the soybeans were planted to attract local populations of Mexican bean beetle. In addition, ≈100,000 neonate larvae from greenhouse-reared beetles were transferred to the bean foliage in the experimental plots. A microclimate favorable to beetle development was maintained by using overhead irrigation during periods of high temperature and water stress (Sweetman 1929).

Each maturity group was planted in a separate block to allow comparisons within the same growth stage. The earlier maturity groups were planted later to allow beetle populations time to develop before plant maturity (i.e., MGs VII and VIII were planted in early June, MGs V and VI in mid-June, and MGs III and IV in late June). Defoliation was determined visually by estimating the percentage, in increments of 5%, of total leaf area consumed by beetles in each 2-m row plot. Defoliation not showing the network of veins or feeding marks typical of Mexican bean beetles was disregarded. All defoliation estimates were determined by the same observer.

Statistical Analysis. Selections were evaluated in a randomized block design with three replicates and repeated over three growing seasons (1989, 1990, and 1991). General linear model procedures (GLM procedure [SAS Institute 1990]) were used to analyze the data for each maturity group separately, combined over years.

Table 1. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group III soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt	T[a]
PI 416868-B	16 (5–28)	12	R
PI 404182	20 (12–35)	10	V
PI 476922	21 (5–34)	10	R
'Willomi'	21 (10–35)	25	V
'Pyramid'	21 (12–28)	14	G
'Kanrich'	22 (12–37)	26	V
'Pella'	23 (7–39)	21	V
PI 60296-2	23 (13–35)	21	V
'Williams'	26 (15–31)	19	V
'Wolverine'	26 (15–46)	26	V
'Jogun'	27 (18–43)	25	V
'Williams 79'	30 (15–46)	19	V
'Guelp'	30 (15–50)	14	G
'Columbia'	32 (17–50)	16	G
'Miles'	32 (17–56)	19	V
'Kim'	33 (12–55)	29	V
'Oakland'	34 (18–60)	20	V
'Fuji'	35 (17–58)	18	V
PI 437794	36 (25–51)	20	S
'Kura'	42 (22–79)	31	V
Mean % defoliation		28	
LSD (0.05)		8	

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

Missing values were estimated by GLM, in cases in which only 2-yr data were available, to allow a meaningful comparison of 3-yr means; field populations of beetles varied greatly from year to year. Least significant differences (LSD) between mean percentage defoliation of soybean accessions were determined for each maturity group at the 5% probability level.

Results and Discussion

Mean percentage defoliation was highest in 1989 (38%), followed by 1990 (21%) and 1991 (12%). The low mean defoliation in 1991 was attributed to loss of large numbers of beetle adults in August to nearby fields of very late-planted (July) soybeans. Average defoliation of maturity groups was greatest in the earlier maturity groups and ranged from 28% in MG III to 21% in MGs VII and VIII (Tables 1–6), despite the later maturity groups being present in the field for longer periods of time, especially later in the season when beetle populations peaked. These results support the earlier observation (Kraemer et al. 1990) that Mexican bean beetle resistance tends to be greater in the later maturity groups. Breeding lines HC83-46-1 and HC83-123-9 were significantly more resistant to beetle defoliation than any cultivar or PI selection in MG IV (Table 2). The resistant parent, PI 229358 ('Soden-daizu'), of these two breeding lines comes from MG VII and was shown to be highly resistant to Mexican bean beetle by Van Duyn et al. (1971).

Table 2. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group IV soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt T[a]
HC83-46-1	4 (2– 7)	16 R
HC83-123-9	5 (0– 8)	16 R
PI 360847	14 (7–22)	20 V
PI 248511	15 (8–26)	19 V
'Kailua'	17 (7–30)	20 V
'Kahala'	18 (5–32)	22 V
'Emerald'	19 (8–32)	31 V
'Green and Black'	21 (10–39)	24 V
'Peking'	21 (8–34)	8 V
'Emperor'	22 (5–38)	25 V
'Shiro'	22 (8–39)	27 V
PI 84751	22 (10–37)	7 V
'Douglas'	23 (12–38)	20 G
'Kent'	23 (12–38)	19 G
PI 85505	24 (10–41)	7 V
'Funk Delicious'	24 (10–40)	25 V
'Sparks'	25 (10–42)	18 G
'Mokapu Summer'	25 (10–47)	18 G
'Ware'	26 (13–34)	19 G
'Pixie'	26 (10–42)	16 G
PI 82264	26 (12–42)	7 V
'Custer'	28 (8–50)	13 G
PI 339984	29 (12–44)	7 S
'Wilson-5'	30 (10–54)	9 V
'Hahto [Michigan]'	30 (18–39)	22 V
'Kaikoo'	31 (7–58)	22 V
'Verde'	31 (12–51)	35 V
'Aoda'	32 (13–51)	25 V
'Norredo'	33 (12–53)	7 V
'Jefferson'	34 (12–55)	33 V
'Sanga'	34 (17–57)	28 V
'Kingston'	36 (12–66)	8 V
'Imperial'	37 (20–65)	32 V
'Sato'	43 (13–60)	24 V
Mean % defoliation		25
LSD (0.05)		7

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

Table 3. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group V soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt T[a]
L76-0049	12 (8–13)	14 R
PI 417141	12 (5–19)	19 R
PI 423901-2	14 (12–18)	17 R
PI 417235	15 (8–25)	20 V
PI 416814	15 (10–23)	26 V
PI 416981	18 (12–28)	23 V
PI 423758	19 (7–31)	30 V
'Bedford'	22 (5–34)	14 G
'Pershing'	22 (8–38)	18 G
PI 416982	25 (13–42)	34 V
'Forrest'	25 (15–41)	14 G
PI 417288	26 (10–39)	30 V
'Camp'	26 (12–41)	10 V
PI 408155	26 (13–41)	5 V
PI 423827-B	27 (12–42)	8 V
G9053	27 (12–52)	27 V
'Bay'	27 (10–52)	17 G
'Vance'	28 (12–44)	6 V
PI 417359	33 (13–62)	32 V
G6852	34 (15–54)	20 V
'Essex'	35 (22–46)	14 G
PI 417440	36 (17–64)	30 V
G10134	39 (25–55)	29 V
PI 417467	42 (10–72)	35 V
PI 417193	45 (27–68)	6 V
PI 196177	46 (17–72)	6 V
PI 416771	51 (17–78)	7 V
PI 399055	52 (12–74)	21 S
Mean % defoliation		26
LSD (0.05)		8

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

No vegetable-type cultivar showed exceptional resistance to Mexican bean beetle defoliation, and many were highly susceptible. 'Kura' had 42% defoliation and was one of six vegetable-type genotypes in MG III not significantly different from the susceptible standard, PI 437794 (36%; Table 1). Two vegetable-type cultivars from MG IV, 'Imperial' (37%) and 'Sato' (43%), had defoliation ratings significantly greater than that of the susceptible control, PI 339984 (29%; Table 2); a dozen others were not significantly different. 'Verde' (31%; Table 2) is a MG III cultivar that was misplaced in MG IV and may show somewhat greater comparative resistance if evaluated with other MG III accessions. Cultivars with significantly less defoliation than the susceptible controls included 'Willomi', 'Kanrich', and 'Pella' in MG III and 'Kailua', 'Kahala', 'Emerald', 'Green & Black', 'Emperor', and 'Shiro' in MG IV.

The later maturity groups (V through VIII) contained fewer vegetable-type cultivars than MGs III and IV; however, the same trend prevailed. 'Hahto' (MG VI) had 42% defoliation, not significantly different than that of the susceptible control, PI 201422 (48%; Table 4). Several cultivars had levels of defoliation similar to the maturity group mean and significantly less than that of the susceptible controls: 'Camp' (MG5), 'Late Giant' (MG VI), 'Rokusum' (MG VI), and 'Tokyo' (MG VII) (Tables 3–5). 'Camp', grown for specialty use (natto) and export to Japan, averaged 26% defoliation, similar to 'Forrest' (25%) and significantly less than 'Essex' (35%), both grain-types cultivars.

Soybean PIs from the USDA germplasm collection provide a diverse genetic pool for the improvement of vegetable-type cultivars in both large- and small-seeded types. Large-seeded genotypes with significantly less defoliation than the mean for their maturity group were PIs 360847 ('Shiromeyutaka') and 248511 ('Hakuho No. 1') in MG IV, PIs 417235 and 416814 ('Bansei Shi Mame') in MG V, FC 31665 in MG VI, PI 393550 in MG VII, and PI 417136 ('Manshuu Konpo Daizu') in MG VIII (Tables 1–6). This group included genotypes with seed weights up to 26 g/100 count (i.e., moderately large-seeded). Several of the very large-seeded

Table 4. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group VI soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt T[a]
PI 379621	9 (5–14)	19 R
PI 416937	11 (7–19)	17 R
PI 36906	12 (5–19)	14 R
FC 31665	12 (8–16)	23 V
PI 222397	14 (8–24)	5 V
PI 417310	15 (10–20)	26 V
PI 417422	15 (7–28)	23 V
PI 423907	18 (8–23)	17 R
PI 416925	18 (13–27)	22 V
PI 417213	19 (12–28)	25 V
'Tracy-M'	19 (15–28)	15 G
D71-V89	21 (17–30)	36 V
PI 417427	22 (14–29)	23 V
'Late Giant'	23 (14–38)	25 V
D74-9806	24 (13–38)	27 V
PI 86490	24 (12–40)	4 V
PI 423965	25 (17–37)	22 V
'Larredo'	25 (17–36)	18 G
'Rokusum'	28 (17–39)	45 V
FC 31745	28 (15–50)	21 V
PI 171437	30 (21–41)	7 V
'Centennial'	31 (17–49)	15 G
PI 423852	42 (22–61)	6 V
'Hahto'	42 (23–72)	30 V
PI 201422	48 (24–70)	14 S
Mean % defoliation		22
LSD (0.05)		7

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

genotypes (30 g or greater) included in this study had defoliation averages similar to the maturity group mean. The most notable of these was PI 417288 ('Shibahara Mame') in MG V, reported by Mebrahtu et al. (1991) to have the desirable traits of light-colored pubescence, clear hilum, good standability, and high green pod yield.

Table 5. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group VII soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt T[a]
PI 229358	7 (2–13)	11 R
PI 171451	8 (5–12)	18 R
PI 393550	12 (7–19)	7 V
PI 200523	12 (7–19)	12 R
PI 393547	14 (12–17)	7 V
FC 31732	16 (7–21)	21 V
PI 200456	17 (8–22)	24 V
FC 31927	18 (8–25)	10 V
PI 189402	19 (10–25)	18 V
PI 200492	19 (8–29)	23 V
PI 208788	20 (12–28)	22 V
PI 416900	21 (10–34)	8 V
'Tokyo'	26 (18–41)	26 V
PI 417128	26 (17–42)	23 V
PI 230972	28 (20–42)	26 V
'Bragg'	31 (12–51)	15 G
'Gordon'	32 (15–53)	15 G
PI 200506	32 (17–57)	24 V
PI 416893	33 (18–56)	26 V
PI 181565	47 (25–86)	27 S
Mean % defoliation		21
LSD (0.05)		8

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

Table 6. Mean percentage defoliation (Def%) by Mexican bean beetles of maturity group VIII soybean germplasm averaged over 3 yr (1989, 1990, and 1991) and seed weight (Wt) (g/100)

Accession	Def% (range)	Wt T[a]
PI 417061	8 (3–14)	12 R
PI 417136	13 (8–17)	22 V
PI 194773	14 (8–23)	6 V
PI 374186	17 (10–31)	9 V
PI 227687	17 (7–23)	6 R
PI 374178	19 (10–29)	9 V
PI 374184	20 (12–31)	9 V
PI 374183	21 (12–23)	9 V
PI 416806	22 (15–32)	9 V
PI 381657	24 (15–34)	9 V
'Hutton'	28 (17–42)	14 G
'Foster'	34 (15–50)	11 G
PI 417134	41 (17–62)	13 S
Mean % defoliation		21
LSD (0.05)		7

[a] Type: vegetable-type (V), grain-type (G), resistant control (R), susceptible control (S).

The small-seeded PIs, 222397 (MG VI), 229358, 393550 (MG VII), and 417061 (MG VIII), had significantly less defoliation than the maturity group means. PI 229358 ('Soden-daizu') has been a major source of insect pest resistance for soybean breeders since the 1970s, as has PI 171451 ('Kosamame') (Turnipseed & Sullivan 1976). PI 417061 ('Kosa Mame') was shown more recently to have exceptional insect resistance (Kraemer et al. 1988). Kilen (1990) found that this PI had levels of resistance to leaf-feeding by velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, and soybean looper, *Pseudoplusia includens* (Walker), that were equivalent to those of PIs 171451 and 229358. Although these accessions were included primarily as resistant controls in the study reported here, the seed weights listed by Hartwig & Edwards (1986) for PIs 229358 and 417061 indicate small seed size (8.2 and 8.6 g/100 seeds, respectively); our field harvests averaged somewhat higher for both (11 and 12 g/100 seeds, respectively). In addition, light yellow seed coats are desired in small-seeded specialty soybeans, and the seed-coat color is light green in these two highly insect-resistant PIs.

Flavor, texture, cookability, and nutritional factors are as important as the external appearance of the seed in vegetable-type soybeans (Carter 1985). Although there is no evidence that these qualities affect insect resistance, perhaps it is possible. The high sugar content desired in some vegetable-type soybeans, especially those used for miso, tofu, natto, and sprouts, could act as an insect feeding stimulant. Furthermore, attempts to reduce trypsin inhibitors or other anti-nutritional components could affect resistance to seed-feeding pests. Effects on foliage feeders such as Mexican bean beetle seem less likely. Trypsin inhibitors, found at high levels in soybean seeds, have negative nutritional effects on humans if these proteins are not deactivated, usually by cooking. Mohamed & Rangappa (1992a) evaluated 73 soybean genotypes, including 17 vegetable types, for trypsin inhibitor and lipoxygenase activity and found a number of genotypes that could be used in a breeding program to improve the nutritional quality of soybeans. Trypsin inhibitor activity was lowest in FC 31732, whereas lipoxygenase activity, contributing to an undesirable flavor, was lowest in PI 417310 ('Shiro Aki Daizu'). Both of these genotypes are large-seeded types that also had relatively low Mexican bean beetle defoliation averages in our study, 16% and 15%, respectively. PI 417310 was reported earlier to be most resistant to Mexican bean beetle defoliation in MG VI (Kraemer et al. 1988). Additional characteristics of this accession include high green pod yield (Mebrahtu et al. 1991) and tolerance to ozone exposure, along with 'Kahala', 'Green & Black', 'Verde', and 'Aoda' (Mebrahtu & Mersie 1992).

Levels of phytate, another antinutritional compound, were determined in the seeds of 17 vegetable-type soybeans by Mohamed et al. (1991). Although PI 416771 had the lowest levels of phytate of the germplasm tested, our results indicated this PI is highly susceptible to Mexican bean beetle defoliation (51%; Table 3) and probably would not be a good parental choice for breeders.

Improvement of the aesthetic, culinary, and nutritional qualities of vegetable soybeans should take into account the great differences in insect resistance found in the germplasm collection. The germplasm evaluated in this study indicates that, although some vegetable-type cultivars have levels of resistance to Mexican bean beetle defoliation similar to those of grain-type cultivars, many are susceptible. Because there exists a genetic potential for a shift toward susceptibility, soybean breeders who conduct selection trials under an insecticide umbrella could be masking a trend in that direction. The premium paid for specialty soybeans could be lost if increased pest control is required, and the excessive use of chemical pesticides could have a negative effect on consumers interested in the health benefits associated with soybean-based products.

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