Variation in *Allium* spp. Damage by Onion Maggot

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Abstract. Nearly 350 germplasm accessions representing 25 *Allium* species were evaluated for damage by onion maggot (OM) [*Delia antiqua* (Meigen)] in field experiments in 1989. In 1990, 188 additional accessions and breeding lines were evaluated, and 36 entries from the 1989 evaluation were re-evaluated. In both years, there were no significant differences in OM damage to seedlings among accessions within the species tested. However, differences among species were highly significant. *Allium cepa* L. (bulb onion) seedlings had consistently high OM damage. Species with significantly less seedling damage than *A. cepa* included: *A. altaicum* Pall., *A. angulosum* L., *A. galanthum* Kar. & Kir., *A. pskemense* B. Fedtsch., *A. scorodoprasum* L., *A. ampeloprasum* L. (leek), *A. fistulosum* L. (bunching onion), *A. schoenoprasum* L. (chive), and *A. tuberosum* Rottl. ex Spr. (garlic chive). Some species sustaining minimal damage as seedlings were nonetheless heavily damaged as mature plants by a later generation of OM. *Allium cepa* cultivars that were well-adapted to local conditions were heavily damaged as seedlings, but their bulbs were less damaged than those of poorly adapted *A. cepa* germplasm. *Allium ampeloprasum* seedlings and mature plants sustained low injury throughout both growing seasons.

The onion maggot (OM) is a major pest of onion and related crops in many temperate regions of the world. Severe infestations can destroy more than 50% of the seedlings in commercial fields when protection fails (Eckenrode and Nyrop, 1995). In North America, the OM is particularly severe in New York, Michigan, and Ontario, Canada, where conditions favor it and allium crops are grown in the same field or nearby fields year after year. The host range of OM is limited to alliums and it has been reported on various economically important crops, including bulb onion and shallot (*A. cepa*), bunching onion

(*A. fistulosum*), garlic (*A. sativum* L.), leek (*A. ampeloprasum*), and chive (*A. schoenoprasum*) (Ellis and Eckenrode, 1979).

Each spring, gravid OM females lay eggs on or just under the soil surface near host seedlings. Larvae feed on the seedling bases and roots, usually killing them. The first above-ground symptom of OM injury on young plants is wilting. The whole plant subsequently collapses and dies. The most visible damage is caused by first-generation larvae, which can destroy many young seedlings. Injury due to second- and third-generation larvae, although less visible above ground, is significant because damaged bulbs must be sorted out and discarded after harvest (Ellis and Eckenrode, 1979).

Where onions are grown year after year in cool-season climates favoring OM development, an in-furrow insecticide application is essential. However, the insect has developed resistance to insecticides, due in part to its narrow host range, which maximizes selection pressure for resistance to the few chemicals used for OM management (Ellis and Eckenrode, 1979). Thus, many compounds recommended in the past have become ineffective (Harris and Svec, 1976; Harris et al., 1982). There is increasing evidence that the OM has developed low but significant levels of resistance to O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate (chlorpyrifos), the current insecticide of choice for OM man-

agement in New York (Eckenrode and Nyrop, 1995; Eckenrode and Webb, 1994).

There is an urgent need to expand the range of control options and to integrate them with still-effective chemicals. Rotation to non-allium crops for 1 year reduces OM populations temporarily, but because adult OM flies can travel several kilometers (Martinson et al., 1989), relatively large areas must be rotated for maximum effectiveness. Removal of all bulbs from the field at harvest will minimize food for overwintering OM populations but does not prevent adult immigration from nearby sites the following spring. Additional control options might also help to avoid or delay development of resistance to insecticides in OM populations.

Plant resistance is an attractive but unexploited OM control strategy. Evaluations of *Allium* germplasm for OM resistance have been reported from various regions (Ellis and Eckenrode, 1979; Matthewman et al., 1953; McDonald et al., 1993a, 1993b; Perron et al., 1958; Scott and Franklin, 1972). Although some differences among *A. cepa* lines were reported in these evaluations, *A. cepa* germplasm showed little evidence of variation for resistance to OM in New York fields (Ellis et al., 1979; Munger and Plage, 1974, 1975). However, bunching onion seedlings sustained low OM damage in New York (Ellis et al., 1979).

The objectives of this research were to evaluate *Allium* spp. injury levels from first- and third-generation (brood) OM in field plantings and to identify potential sources of resistance for onion breeding. We report here our survey of all *Allium* germplasm available in 1989–90 in the USDA–ARS collections, as well as additional lines from the USDA–ARS and Univ. of Wisconsin onion breeding programs. Over 2 years, 535 *Allium* spp. accessions and breeding lines were evaluated, including 380 *A. cepa* accessions and breeding lines and 155 accessions of 24 other *Allium* species.

Materials and Methods

1989 evaluation. A total of 365 entries representing 25 *Allium* species were planted with a hand seeder in randomized complete blocks 20 to 21 Apr. in a commercial field near Potter, N.Y. (lat. 42°40'N, long. 77°0'W). Plots were 4.6 m long with two replications. Seeding rates were adjusted to ≈30 viable seeds/m. The center 1.5 m of each single-row plot containing the most even stand was marked for subsequent stand and OM damage counts. Eighteen commercial cultivars of *A. cepa* were used as treated controls and received an in-furrow insecticide application of chlorpyrifos (Lorsban 15G; Dow Elanco, Indianapolis, Ind.) at 1.4 g/4.6 m row. To minimize onion smut (*Urocystis cepulae* Frost), all plots were treated with zinc ion and manganese ethylene bisdithiocarbamate (mancozeb) (Dithane DF; Rohm and Haas, Philadelphia) at the recommended rate of 0.6 g/4.6 m row. Cultural and other pest management practices followed commercial recommendations.

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To determine initial plant populations before serious OM injury occurred in the plots, emerged seedlings were counted 2 to 5 June. Plots infested with first-brood OM were assessed twice weekly, 2 June to 10 July. Plants were considered damaged if they showed obvious wilting. Damaged plants were removed and examined for larvae to confirm OM attack. In both years, infestations by first-brood OM were uniformly heavy, allowing clear distinction between damaged and undamaged plants during the $\approx 20,000$ individual observations throughout the season. Second-brood OM injury was not evaluated. However, third-brood assessments were made 4 Oct. by removing up to 10 remaining plants per plot and examining their bases for naturally occurring larvae and feeding damage. Percent plants damaged was calculated from these assessments.

1990 evaluations. Selected entries from the 1989 evaluation were re-evaluated in 1990, with six replications and third-brood damage levels enhanced by providing OM eggs from a laboratory colony. A total of 36 entries representing four commonly cultivated species (*A. ampeloprasum*, *A. cepa*, *A. fistulosum*, and *A. schoenoprasum*) were planted 24 to 27 Apr. in a commercial field near Prattsburg, N.Y. (lat. 42°30'N, long. 77°15'W). Seeded rows were 1.5 m long and later trimmed to 1-m plots in randomized complete blocks. Insecticide-treated and untreated plots of two commercial cultivars (Spartan Banner 80 and Buccaneer) were included as controls. Chlorpyrifos was drenched into the seed furrow of treated controls at 0.15 ml/1.5 m row. Seedling emergence and first-brood OM damage were determined 30 May and twice weekly, 30 May to 5 July, respectively. Unless otherwise noted, plot establishment, evaluations, and management were as described for the 1989 evaluations.

To enhance uniform OM pressure on mature plants, ≈ 250 eggs were applied to the soil surface 10 to 14 Sept. next to five plants in each plot with sufficient surviving plants. Eggs were obtained from a laboratory colony established with larvae collected earlier in the year from nearby plantings and were flushed onto the soil surface with distilled water. Third-brood (percent plants damaged) evaluations were made 17 Oct.

In another 1990 experiment, 188 *A. cepa* accessions and breeding lines from the USDA-ARS and Univ. of Wisconsin breeding programs, in which selection has taken place under natural OM pressure, were compared with 12 insecticide-treated controls in four replications, using procedures described for the 1989 evaluation.

Analysis. Seedling losses (first-brood OM damage) counts from each evaluation date were summed and divided by initial stand counts to calculate percent seedling loss for each plot. Arcsin transformation of percent seedling loss and of percent mature plant damage (third-brood OM damage) data was required to satisfy the normal distribution requirement for analysis of variance (Sokal and Rohlf, 1981). Analyses of variance (ANOVA)

had species and blocks as main effects and transformed seedling loss and mature plant damage as dependent variables. Species means were compared to the mean of the untreated *A. cepa* accessions using Dunnett's comparison with a control. Transformations and analyses were performed with JMP Version 3 Statistical Software for the Macintosh (SAS Institute, Cary, N.C.).

Results and Discussion

1989 evaluations. Differences among species for both first-brood OM seedling loss and third-brood OM mature plant damage (Table 1) were highly significant (ANOVA, $P \leq 0.001$). Block effects were also highly significant and the coefficient of variation was 37%. The physical extent of the experiment and an early season flood that retarded or killed plants in one block are possible explanations for this large variation, which reduced our ability to detect statistically significant differences among accessions. Seedling loss in untreated *A. cepa* was high (74%). Although there were no significant differences in seedling loss among the *A. cepa* accessions, the range of seedlings lost (22% to 100%, detailed data not shown) suggests that low or moderate resistance may exist within these *A. cepa* accessions. The accessions within *Allium* Sect. *Cepa* and *A. ampeloprasum* showing the lowest levels of first-brood OM damage (Table 2) are of most interest for breeding purposes, but further evaluation is necessary to clarify the

true extent and utility of their response to OM. Significantly lower first-brood injury was measured in *A. altaicum*, *A. angulosum*, *A. galanthum*, *A. pskemense*, *A. scorodoprasum*, and in the cultivated species *A. ampeloprasum*, *A. fistulosum*, *A. schoenoprasum*, and *A. tuberosum*. Other species (*A. cernuum* Roth, *A. fuscoviolaceum* Fomin, *A. glaciale* Vved., *A. prostratum* Trevir, and *A. pseudoampeloprasum* Misch. ex Grossh.) sustained even less first-brood injury, but the few entries within these species precluded statistical significance. Numerous accessions of *A. ampeloprasum* (52), *A. cepa* (192), *A. fistulosum* (35), and *A. schoenoprasum* (17) were evaluated, but there was no significant effect of accession within any of these species, except for seedling loss within *A. ampeloprasum* (ANOVA, $P \leq 0.05$). Insecticide treatments reduced first-brood injury in this test (50% in treated plots vs. 74% in untreated plots), but not to commercially acceptable levels. Flooding in May followed by exceedingly dry soil conditions through July may have reduced effectiveness of the insecticide treatments.

Mature plant damage from third-brood OM feeding on untreated *A. cepa* was only 4%, significantly less than the injury levels of some other species (Table 1). Intact mature *A. cepa* bulbs frequently are less damaged by OM larvae than are immature plants (Eckenrode and Nyrop, 1986; Finch et al., 1986). Like immature *A. cepa*, many of the non-bulbing *Allium* species evaluated lacked

Table 1. Mean response of *Allium* spp. accessions evaluated in the field for onion maggot (OM) attack, Potter, N.Y., 1989. Response expressed as percent seedling loss (first-brood OM) and percent plants damaged (third-brood OM).

<i>Allium</i> species	No. accessions	Mean (%)	
		Seedling loss	Mature plants damaged
<i>albidum</i>	1	83	25
<i>altaicum</i>	7	42*	12
<i>ampeloprasum</i>	52	39***	9
<i>angulosum</i>	3	24**	37*
<i>cepa</i>	192	74	4
<i>cepa</i> (treated controls)	18	50***	ND ²
<i>cernuum</i>	1	24	100***
<i>dictyoprasum</i>	2	50	10
<i>fistulosum</i>	35	49***	2
<i>fuscoviolaceum</i>	1	6	50
<i>galanthum</i>	7	27***	7
<i>glaciale</i>	1	2	0
<i>ledebourianum</i>	2	51	48**
<i>lineare</i>	1	37	40
<i>obliquum</i>	1	33	40
<i>oreoprasum</i>	1	30	5
<i>prostratum</i>	1	0	10
<i>pseudoampeloprasum</i>	1	14	15
<i>pskemense</i>	1	4*	20
<i>pyrenacium</i>	1	60	60*
<i>ramosum</i>	4	44	9
<i>schoenoprasum</i>	17	47**	55***
<i>scorodoprasum</i>	3	32*	32
<i>senescens</i>	2	36	45**
<i>tuberosum</i>	4	5***	21
<i>vavilovii</i>	6	54	20

²ND = no data.

*, **, *** Seedling loss or mature plant damage significantly different from that of *A. cepa* accessions at $P \leq 0.05$, 0.01, or 0.001, respectively, according to Dunnett's comparison with a control.

protective dry outer scales. Likewise, under our conditions of daylength and temperature, some of the *A. cepa* accessions did not bulb, possibly altering their response to third-brood OM. *Allium angulosum*, *A. cernuum*, *A. ledebourianum* Roemer and Schultes, *A. pyrenacium*, *A. schoenoprasum*, and *A. senescens* L. all had significantly higher third-brood injury than *A. cepa*. No third-brood injury measurements were made for treated *A. cepa* since too few mature plants remained. The inconsistency between seedling loss and mature plant damage suggests that resistance based on seedling data alone may not provide season-long protection.

1990 evaluations. As in 1989, the species effect on seedling loss and mature plant damage was highly significant (ANOVA, $P \leq 0.001$). *Allium ampeloprasum*, *A. fistulosum*, *A. schoenoprasum*, and treated *A. cepa* again lost significantly fewer seedlings than untreated *A. cepa* (Table 3). Commercially acceptable levels of first-brood OM control were provided by the chlorpyrifos treatments (12% damage vs. 83% for the untreated plots). The *A. cepa* accessions sustained much higher mature plant damage than did the *A. cepa* accessions in 1989 (34% vs. 4%, respectively), probably because eggs from the laboratory colony were added in 1990 to increase infestation levels. In spite of the added eggs in 1990, control plots of two commercial *A. cepa* cultivars adapted to New York growing conditions sustained low third-brood injury levels (0% to 3%). These cultivars had already developed protective dry outer scales by the time eggs were applied. In fact, two other well-adapted cultivars (Norstar and Ruby) are suggested for New York (Cornell Univ. Press, 1995) for low third-brood OM injury. Among species evaluated in both years, only *A. ampeloprasum* had consistently low first- and third-brood injury, suggesting that this species has some resistance to first- and third-brood OM.

A total of 188 untreated *A. cepa* accessions and breeding lines were evaluated in the second 1990 experiment. Seedling losses for the untreated accessions in this planting averaged 83% compared to 21% in the 12 insecticide-treated controls. No third-brood damage data were collected from this planting. There were no significant differences in seedling loss among the *A. cepa* accessions evaluated in 1989 or in the second 1990 experiment, but the range of seedling loss (1989 range 22% to 100%, 1990 range 47% to 100%) suggests that low or moderate resistance may exist within these accessions. As in 1989, block effects for both 1990 experiments were highly significant, but CV values were lower, 20% and 19%, respectively. Nevertheless, more extensive testing is required to clarify the extent and utility of differences among accessions.

Our results are the first to demonstrate significant and consistent differences among a broad array of alliums for OM damage. This is the first step in understanding and exploiting genetic variation for host plant resistance to insect pests, as has been accomplished in a number of crop/pest interactions, including:

wheat (*Triticum aestivum* L.)/hessian fly (*Mayetiola destructor* Say) (Buntin et al., 1992); wheat/greenbug (*Schizaphis graminum* Rondani) (Porter et al., 1994); wheat/Russian wheat aphid (*Diuraphis noxia* Mordvilko) (Kindler et al., 1993); barley (*Hordeum vulgare* L.)/Russian wheat aphid (Webster et al., 1991); sorghum [*Sorghum bicolor* (L.) Moench]/greenbug (Andrews et al., 1993); maize/European cornborer (*Ostrinia nubilalis* Hübner) (Reid et al., 1991), and carrot (*Daucus carota* L.)/carrot rust fly (*Psila rosae* Fabricius) (Ellis et al., 1993). While strong resistance within *A. cepa* would be highly useful to onion breeders, we found only moderate levels of resistance in certain accessions and differences among accessions within a species were not statistically significant. Nevertheless, subsequent experiments have demonstrated that these accessions may have useable levels of resistance when combined with other management strategies (Walters and Eckenrode, 1996). The resistance in related species may be difficult to exploit, given sterility barriers limiting successful production of interspecific F₁s. Such hybrids are highly male and female sterile, and their meiosis is abnormal (McCollum, 1971, 1982; Saini and Davis, 1967; van Raamsdonk et al., 1992). However, more intensive use of conventional techniques, such as embryo rescue (Gonzalez and Ford-Lloyd, 1987), as well as emerging molecular technologies, may eventually permit introgression by avoiding barriers to sexual recombination among *Allium* spp. Protoplast regeneration methods for *A. ampeloprasum* have been reported (Schum et al., 1993) and might be applied to exploit first- and third-brood OM resistance in *A. ampeloprasum* through asexual hybridization. Related techniques could be applied to other alliums as well.

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Table 2. Accessions of *Allium* Section *Cepa* and *A. ampeloprasum* showing lowest percent seedling loss to first-brood onion maggot attack in field evaluations in Potter, N.Y., 1989. Number of accessions tested per species indicated in parentheses.

<i>Allium</i> accession	Mean seedling loss (%)
<i>altaicum</i> (7)	
PI 483406 ²	31
PI 280551	36
PI 280552	38
PI 369523	40
PI 280549	45
<i>cepa</i> (192)	
PI 262984	22
PI 261768	25
PI 262921	28
PI 275964	29
PI 264315	35
PI 264225	35
Dg11278	37
PI 249902	39
PI 264323	41
PI 432714	41
<i>fistulosum</i> (35)	
PI 462348	10
PI 280665	13
PI 461393	16
PI 462359	20
PI 462355	22
<i>galanthum</i> (7)	
C565	0
PI 280666	25
PI 280565	27
PI 280566	33
PI 280091	38
<i>pskemense</i> (1)	
PI 280577	4
<i>vavilovii</i> (6)	
PI 392509	27
PI 406677	33
C567	63
C566	67
PI 281727	68
<i>ampeloprasum</i> (52)	
PI 255582	2
PI 256050	5
PI 254535	5
PI 296381	9
PI 219900	13

²PI = plant introduction. PI accessions supplied by USDA-ARS germplasm collections, Geneva, N.Y., and Pullman, Wash. Other accessions supplied by W.H. Gabelman, Univ. of Wisconsin-Madison and M.J. Havey, USDA-ARS.

Table 3. *Allium* spp. accessions evaluated for onion maggot (OM) damage, Prattsburg, N.Y., 1990 with mean percent seedling loss (first-brood OM) and mean percent plants damaged (third-brood OM).

<i>Allium</i> species	Accessions evaluated (no.)	Mean (%)	
		Seedling loss	Mature plants damaged
<i>ampeloprasum</i>	4	35***	12*
<i>cepa</i> cvs.—treated ²	2	12***	3**
<i>cepa</i> cvs.—untreated ²	2	83 ^{NS}	0*
<i>cepa</i> —accessions	24	84	34
<i>fistulosum</i>	4	62***	60*
<i>schoenoprasum</i>	4	39***	37 ^{NS}

²Treated and untreated plots of *A. cepa* cvs. Spartan Banner 80 and Buccaneer were planted with and without in-furrow insecticide, respectively.

^{NS}, **, ***, **** Seedling loss or mature plant damage not significantly different, or significantly different at $P \leq 0.05$, 0.01, 0.001, respectively, according to Dunnett's comparison with a control (*A. cepa* accessions mean).

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