

Breeding for Diamondback Moth Resistance in *Brassica oleracea*

M. H. Dickson, C. J. Eckenrode, and J. Lin

New York State Agricultural Experiment Station, Geneva, NY 14456, USA

Abstract

PI234599, a glossy-leaved cauliflower from Australia was found to be highly resistant in the field to diamondback moth, *Plutella xylostella* L. We have been unable to separate this resistance from the glossy leaf character because the two traits are closely linked. The glossy character is inherited as a simple recessive. Broad sense heritability of resistance to damage by lepidopterous pests based on nonglossy plants from crosses involving PI234599 was 85% and narrow sense resistance was 35%, indicating progeny of a selection will be equal in resistance to the selected parent 25-50% of the time. In a study exclusively on *P. xylostella*, broad sense resistance based on numbers of larvae and pupae per plant was 75 and 88%, respectively. In a diallel study involving lines unrelated to PI234599 resistance was additive and dominant. In no case was resistance in a nonglossy selection as high as that in PI234599, but then selections were much more resistant than unselected lines.

Introduction

Insect resistance in cole crops is well documented (Brett and Sullivan 1974, Chalfant and Brett 1967, Creighton et al 1975, Dickson and Eckenrode 1975, Dunn and Kempton 1976, Pimental 1961, and Radcliffe and Chapman 1966). However, there has been very little breeding of cole crops for lepidopterous pest resistance, or specifically for diamondback moth (DBM) (*Plutella xylostella* L, Lepidoptera: Yponomeutidae) resistance, although damage produced by the DBM larvae is a worldwide phenomenon, especially in the tropics. Dickson and Eckenrode (1975) reported that Plant Introduction (PI) 234599, a dark green glossy-leaved cauliflower, was highly resistant to the cabbage looper (*Trichoplusia ni* [Hubner]), to imported cabbage worm (*Artogeia rapae* L), and to DBM, and that several other cabbage and cauliflower lines exhibited less feeding injury than standard cultivars. We also reported on screening cultivars and PI lines for resistance in the greenhouse, but this environment appeared to influence the level of resistance (Dickson and Eckenrode 1975, Kim 1979, Lin et al 1984).

These observations have resulted in two approaches to breeding for resistance to lepidopterous pests. The first is to use vertical resistance derived from PI234599, in which the resistance is closely linked or pleiotropic with the glossy-leaf character. This approach has resulted in the release of four glossy-leaved cabbage lines: NYIR 8329, 9602, 9605 (Dickson et al 1983) and NYIR 9909 cauliflower. A second approach using horizontal resistance (resistance due to multiple genes) at a lower level of resistance was reported by Dickson and Eckenrode (1980).

Resistance form PI234599

PI234599, a long-season cauliflower from Australia, was found to be resistant in the field to the lepidopterous complex. Data from screening tests are reported in this

symposium (Eckenrode et al 1985). Since a large population of DBM is unlikely to occur regularly in New York, natural populations were supplemented by placing additional pupae from our laboratory colonies in the field plots. Planting every third row with a susceptible cultivar also appeared to increase the degree of infestation. We attempted to suppress beneficial insects by application of carbaryl and unwanted members of the lepidopterous complex with application of permethrin.

Table 1 presents the results of an experiment to investigate the inheritance of resistance from PI234599. The broad sense heritability, 85%, indicates the percent of total variance caused by genetic influence (Mohammed and Kramer 1951) and the narrow sense heritability, 37%, predicts the effectiveness of selection on progeny performance (Warner 1952) for plants with normal bloom. However, most plants with glossy leaves are resistant and this glossy leaf character is inherited as a simple recessive character. Table 2 indicates that the genetics of resistance of DBM and other members of the complex are similar, although Radcliffe and Chapman (1966) reported that resistance to each pest may differ.

Table 1. Distribution of population from crosses of Snowball A and PI234599 in different damage score classes^a

Pedigree	Leaf type ^b	No. of plants in damage score ^c							x	s ²
		1	2	3	4	5	N			
Snowball A	N	—	—	3	21	19	43	4.4	0.382	
PI234599	G	46	3	—	—	—	49	1.1	0.059	
PI234599xSnow F ₂	N	1	5	16	12	20	54	3.8	1.20	
	G	7	4	6	—	—	17	1.9	0.81	
	G + N	8	9	22	12	20	71	3.4	1.73	
PI (PIxSnow) BC	N	—	3	10	12	9	34	3.6	0.90	
	G	24	5	8	—	—	37	1.5	0.70	
	G + N	24	8	18	12	9	71	4.9	2.04	
Snow (PIxSnow) BC	N	—	6	8	22	17	53	3.9	0.94	
NSH ^d G + N = 28%	BSH, G + N = 87%									
NSH, N = 47%	BSH, N = 82%									

^a Scored on 15 August in the field at Geneva, New York.

^b N = normal leaf with bloom, G = glossy leaf,

^c Damage score: 1 = 5% and 5 = 60% leaf surface,

^d NSH and BSH = narrow and broad sense heritability, respectively

The glossy leaf character has been associated with susceptibility to flea beetles (*Phyllotetra cruciferae* (Geoze) and *P. striolata* (F) (Superak 1976). Lines which are less glossy but which still carry the glossy gene and exhibit high levels of caterpillar resistance, could be selected with a corresponding reduced level of susceptibility to flea beetle. The caterpillar resistance associated with the gene for glossy leaves was not influenced by the modifying genes which influence the degree of glossiness of the leaves and corresponding susceptibility to flea beetles.

At the New York State Agricultural Experiment Station, Geneva, selected cabbage and cauliflower lines based on resistance from PI234599, showed a high level of field resistance to DBM and other lepidopterous pests (Table 3, see also Eckenrode et al, this volume). In all of these tests, the plants were at least 50 days old before lepidopterous pest pressure became serious. In Australia, Hamilton and Dickson (1978, unpublished data) observed that young plants were less resistant to DBM than older ones. Similar observations were noted in the Philippines by D. Rasco (unpublished). In both countries significant resistance was observed in older plants (over 50 days from seeding).

In 1982 three cabbage inbreds: NYIR9602, 9605, and 8329; derived from PI234599 as a resistance source (Figure 1) were released by the New York State Agricultural

Experiment Station (Dickson et al 1984). These have subsequently exhibited good insect resistance in England and Holland.

Table 2. Distribution of field resistance to DBM in two populations of *B. oleracea* resulting from crosses of resistant with susceptible parents

Pedigree	Leaf type ^a	No. of plant with no. of larvae and pupae										No.	Mean	s ²	
		0	1	2	3	4	5	6	7	8	9				10
G 9101 cauliflower ^b	G	22	3	—	—	—	—	—	—	—	—	—	25	0.19	0.07
G 7642 cauliflower	N	—	—	1	4	6	2	4	4	3	1	—	25	5.34	3.89
G 9101 × 7642-2 F ₁	N	—	1	2	3	1	1	—	2	2	2	2	16	5.43	9.14
G 9101 × 7642-2 F ₂	N	—	1	5	15	11	7	11	13	1	3	2	69	5.04	5.11
	G	15	—	—	—	—	—	—	—	—	—	—	15	0.02	0.01
	N+G	15	1	5	15	11	7	11	13	1	3	2	84	4.13	7.89
BSH ^c not using F ₁ = 0.75															
G 9602 cabbage ^b	G	19	6	—	—	—	—	—	—	—	—	—	25	0.20	0.06
G 326R cabbage	N	—	6	10	4	1	1	—	—	—	—	—	22	2.11	1.12
G 9602 × 326R F ₁	N	—	1	3	4	8	3	6	—	—	4	—	25	4.13	1.96
G 9602-1 × 326R F ₂	N	—	1	9	14	11	8	6	5	4	4	4	66	4.95	6.40
	G	17	—	—	—	—	—	—	—	—	—	—	17	0.40	0.01
	N+G	17	1	9	14	11	8	6	5	4	4	4	83	3.95	9.07
BSH ^c = 0.88															

^aG = Glossy (resistant); N = normal color (susceptible). ^bGlossy-leaved resistant parents, ^cBSH broad-sense heritability.

Table 3. Caterpillar counts and damage scores on cultivars and selected glossy resistant cauliflower in 1978 and cabbage lines in 1979

	Number of larvae per 4 plants			Damage score ^a
	<i>T. ni</i>	<i>P. rapae</i>	<i>P. xylostella</i>	
Snowball	21	18	39	4.5
PI234599	5	4	11	1.5
4160	3	8	2	1.0
4166	3	1	1	1.0
Round Up	5	15	4	4.5
5936	0.5	2.5	0.5	1.0

^aDamage score: 1 = 5% and 5 = 60% of leaf surface destroyed.

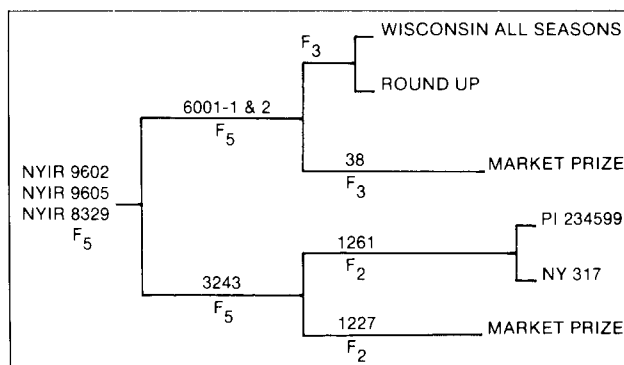


Figure 1. Pedigree of NYIR 9602, NYIR 9605, and NYIR 8329

Horizontal Resistance to Lepidopterous Pests

In glossy leaves the wax platelets on the cuticle lie horizontally rather than standing vertically, as they do in plants with blooms. This arrangement of wax platelets, which is not always considered desirable, is associated with resistance to lepidopterous pests. Hence an effort was made to breed for resistance in cabbage with normal leaf bloom. Several field trials at Geneva and Ithaca, New York, identified several lines less susceptible than most cultivars. A diallel (Hayman 1954) study of this type of tolerance involving five lines was undertaken. G364 was the most susceptible, and BM-15, 1228, 3220 and 3222 were selections which exhibited progressively reduced damage levels. Table 4 gives the results of this study in 1978 and 1979 and Figure 2 shows the regression of W_r (parent-offspring covariance) on V_r (Variance) for resistance to cabbage caterpillars for the five cabbage lines.

Table 4. Mean cabbage looper (CL), imported cabbage worm (ICW), and DBM larvae counts and damage ratings for a 5-parent diallel of cabbage

Pedigree	Mean no. larvae per 4 plants						Damage scores ^a		
	1978			1979			1978	1979	Mean
	CL	ICW	DBM	CL	ICW	DBM			
G364 (P1)	4.5	17.0	18.0	1.7	11.5	2.5	2.8	5.0	3.9
BM-15 (P2)	12.5	13.5	23.0	0.8	10.2	1.2	3.0	2.7	2.9
1228 (P3)	16.0	22.0	23.5	0.8	8.3	2.7	3.0	1.7	2.4
3220 (P4)	2.0	11.0	28.0	—	—	—	2.3	2.7	2.5
3222 (P5)	13.0	25.5	17.5	1.0	10.7	0.8	1.9	1.2	1.6
P1 × P2	20.5	36.0	22.5	1.5	12.5	2.3	3.2	3.5	3.3
P1 × P3	15.0	35.5	32.0	4.2	11.5	1.3	3.4	2.8	3.1
P1 × P4	14.5	25.5	22.0	1.2	17.0	1.3	2.7	2.7	2.2
P1 × P5	19.5	37.5	21.0	1.3	11.3	1.0	2.1	2.6	2.4
P2 × P3	10.0	22.5	14.0	1.0	6.5	0.5	2.5	2.3	2.4
P2 × P4	12.0	24.5	26.5	1.3	9.5	0.3	2.9	3.1	3.0
P2 × P5	9.0	21.0	22.5	1.3	9.5	0.3	2.8	1.7	2.2
P3 × P4	16.5	20.5	16.5	0.7	11.0	1.2	2.6	2.7	2.6
P3 × P5	8.5	13.5	27.0	0.8	8.5	0.3	2.6	2.0	2.3
P4 × P5	4.5	20.5	12.0	0.8	9.8	0.8	2.6	2.0	2.3
Round Up	23.5	45.0	26.0	1.7	29.0	4.3	3.8	4.2	4.0
LSD 5%	5.0	4.9	13.5	0.59	3.30	0.6	0.6	0.8	1.0
1%	6.8	6.7	18.5	0.78	4.37	0.8	0.8	1.1	1.3

^a Damage score 1 = 5% and 5 = 60% of leaf surface destroyed.

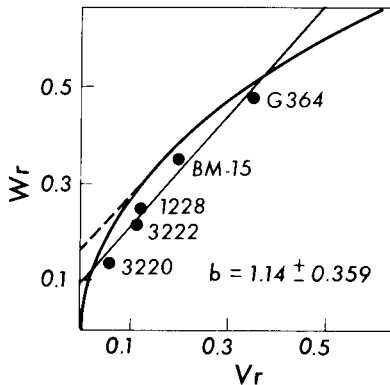


Figure 2.
Regression of W_r on V_r for cabbage caterpillar resistance in a diallel involving five cabbage lines

There was no genetic interaction, since the regression line is not significantly different from one, indicating simple additive dominance for resistance. The susceptible parent (G364) was clearly at the upper end of the regression line, while the most resistant parent (3222) was closest to the ordinate, indicating dominant genes for resistance.

Continued selection has not produced plants with normal leaf bloom with resistance comparable to PI234599, but selections exhibiting considerable reduction in damage were reported by Dickson and Eckenrode (1980) (Table 5). The number of DBM pupae and amount of damage were recorded on 80 lines in 1982 (Table 6). The glossy-leaved lines showed the best levels of resistance, selections with normal leaves were less resistant, but almost all were considerably better than unselected lines.

Table 5. Ratings for damage due to caterpillar^a feeding on seven cabbage and two cauliflower lines as influenced by plant maturity

Lines	Damage ratings ^b			
	Days from transplanting		Mean	Maturity effect (33-63)
	33	63		
Cabbage				
Storage Green	4.43	3.20	3.93	1.23*
Round Up	4.00	2.80	3.52	1.20*
King Cole	3.90	2.75	3.44	1.15*
BM15	3.40	1.60	2.68	1.80**
1228	3.77	1.50	2.86	2.27**
3270	2.77	1.90	2.42	0.87
3243 ^c	1.70	1.90	1.78	0.20
Cauliflower				
Snowball A	3.57	2.80	3.26	0.77
PI234599	1.07	1.00	1.04	0.07
Mean	3.18	2.16	2.77	1.02
LSD 5%	0.89	1.04	0.75	0.94
LSD 1%	1.08	1.50	1.01	1.47

^a Population consisted of *T. ni* and *A. rape*. ^b Rating: 1 = no damage to 5 = severely damaged (50% or more of foliage destroyed). ^c 3243 has resistance from PI234599

Table 6. Effects of selection for resistance to DBM and age of plant

Plant type	Date	No. of larvae per plant			
		Mean	Max.	Min.	st. dev.
Glossy ^a	7/23	0.25	2.35	0.0	0.36
Normal ^b	8/24	2.69	5.83	0.0	1.73
Glossy	7/23	0.02	0.25	0.0	0.01
Normal	8/24	2.63	6.25	0.0	2.30
Unselected ^c	7/23	4.12	9.00	0.0	7.26
Unselected	8/24	6.16	11.08	2.76	8.48
Damage rating ^d					
Glossy	7/23	2.14	3.00	1.00	0.53
Normal	8/24	2.02	3.00	1.00	0.42
Glossy	7/23	1.51	2.67	1.00	0.41
Normal	8/24	2.03	3.00	1.00	0.31
Unselected	7/23	2.55	3.00	1.33	0.31
Unselected	8/24	2.62	3.00	2.00	0.21

^a Populations = 41 lines, ^b population = 27 lines, ^c Population = 20 lines, ^d Scale 0 = no damage, 3 = severely damaged.

Crossing the best lines with normal leaves with the glossy-leaved lines produced F_1 s with normal leaves, with lower levels of resistance than in the parent with normal leaves. This was probably because minor genes for susceptibility in the glossy-leaved lines were masked, resulting in hybrids with lower resistance than in parents with normal leaves.

Conclusions

It appears that there are at least two approaches for selection for resistance to DBM. The first approach has produced cabbage and cauliflower lines with glossy leaves and which are highly resistant. Acceptable inbreds of both cabbage and cauliflower are available at the present time from the senior author. However, further breeding will be necessary to develop cultivars adapted to the many locations where DBM is a problem. This should be relatively simple, due to the very close linkage of the glossy leaf character and resistance.

The second approach would utilize recurrent selection to develop cultivars with normal waxy bloom which exhibit tolerance, but perhaps not with as strong a resistance to lepidopterous pests. However, wider diversity of parental material would increase the chances of improving the levels of resistance.

Literature Cited

- Brett, C. H. and M. J. Sullivan. 1974. The use of resistant varieties and other cultural practices for the control of insects on crucifers in North Carolina. North Carolina Agri. Exp. Sta. Bull. 449, 31 pp.
- Chalfant, R. B. and C. H. Brett. 1967. Interrelationship of cabbage variety, season, and insecticide on control of the cabbage looper and imported cabbage worm. J. Econ. Entomol. 60:687-689.
- Creighton, C. S., T. L. McFadden, and M. L. Robbins. 1975. Complementary influence of host plant resistance on microbial-chemical control of cabbage caterpillars. Hortscience 10:487-488.
- Dickson, M. H., and C. J. Eckenrode. 1975. Variation in *Brassica oleracea* resistance to cabbage looper and imported cabbage worm in the greenhouse and field. J. Econ. Entomol. 68:757-760.
- Dickson, M. H., and C. J. Eckenrode. 1980. Breeding for resistance in cabbage and cauliflower to cabbage looper, imported cabbage worm, and diamondback moth. J. Am. Soc. Hort. Sci. 105:782-785.
- Dickson, M. H., C. J. Eckenrode, and A. E. Blamble. 1984. NYIR 9602, NYIR 9605 and NYIR 8329 lepidopterous pest resistant cabbages. Hortscience. 19:311-312.
- Dunn, J. A. and D. P. K. Kempton. 1976. Varietal differences in the susceptibility of brussels sprouts to lepidopterous pests. Ann. Appl. Biol. 82:11-19.
- Eckenrode, C. J., M. H. Dickson, and J. Lin. 1985. Resistance in brassicas to diamondback moth and other lepidopterous pests. (This volume pp 129-136).
- Hayman, B. I. 1954. The theory and analysis of diallel crosses. Genetics 39:789-809.
- Jinks, J. L. 1954. Analysis of continuous variation in the diallel cross in *Nicotiana rustica* varieties. Genetics 39:767-788.
- Kim, J. H. 1979. *Brassica oleracea* L. resistance to cabbage caterpillars in New York State. M. S. Thesis, Cornell Univ., Ithaca, N.Y., 56 pp.
- Lin, J., C. J. Eckenrode, and M. H. Dickson. 1983. Variation in *Brassica oleracea* resistance to diamondback moth (*Lepidoptera plutellidae*). J. Econ. Entomol. 176:1423-1427.

- Lin, J., M. H. Dickson, and C. J. Eckenrode. 1984. Resistance of *Brassica* lines to the diamondback moth (*Lepidoptera yponomeutidae*) in the field, and inheritance of resistance. *J. Econ. Entomol.* 77:1293-1296.
- Mohammed, I. and H. H. Kramer. 1951. Segregation for yield, height and maturity following a soybean cross. *Agron. J.* 43:605-609.
- Pimental, D. 1961. An evaluation of insect resistance in broccoli, brussels sprouts, cabbage, collards, and kale. *J. Econ. Entomol.* 54:156-158.
- Radcliffe, E. B. and R. K. Chapman. 1966. Varietal resistance to insect attack in various cruciferous crops. *J. Econ. Entomol.* 59:120-125.
- Superak, T. H. 1976. Insect resistance in crucifer with emphasis on preference of *Pieris rapae* for cabbage varieties. Ph. D. Thesis Cornell University, Ithaca, N. Y., 134 pp.
- Warner, J. N. 1952. A method for estimating heritability. *Agron. J.* 44:427-430.