Am. J. Potato Res. (2013) 90:71–82
DOI 10.1007/s12230-012-9278-8

Screening for Resistance of Potato Lines to the Potato Tuberworm, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae)

Silvia I. Rondon · Charles R. Brown · Ruben Marchosky

Published online: 18 October 2012

Abstract The potato tuberworm, *Phthorimaea operculella* (Zeller) (PTW), is one of the most important limitations to potato, *Solanum tuberosum* L., productivity worldwide. Leaves, stems, petioles and more importantly, potato tubers, in the field and storage can be seriously affected. Due to the relatively recent arrival of the PTW in the United States Pacific Northwest, the local and regional lines have never been screened for tuber resistance to PTW. Thus, the objective of this study was to screen regional potato lines for potential PTW resistance by tubers under field and laboratory conditions. Experiments were conducted at the Hermiston Agricultural Research and Extension Center in Hermiston Oregon in 2006 and 2007. Accessions that had few number of mines per tuber were AC97521-1R/Y, Q174-2, Rubi, Yuguima, Paciencia, TM-3, KWPTM24 and CIP 780660; lines than had few larvae per tuber were A97287-6, PA00N10-5, AC97521-1R/Y, Q174-2, PA04LNC2-1, PA04LNC4-1, TM-3 and CIP 780660. Incorporating host plant resistance to tuber penetration by PTW larvae together with appropriate cultural practices including limitation of exposure time of tubers in the field and judicious use of chemicals may provide the best sustainable management option.

Resumen La polilla de la papa, *Phthorimaea operculella* (Zeller), es una de las plagas más importantes que limita la producción del cultivo de papa, *Solanum tuberosum* L., en el mundo. Hojas, tallos, peciolos, y especialmente los tubérculos son afectados. Debido a la relativa "nueva" llegada de esta plaga a la región del Pacífico Norte de los Estados Unidos, el material local y regional nunca fue evaluado para resistencia a la polilla de la papa. Así, el objetivo de este estudio fue evaluar el material regional en el campo y en el laboratorio. Los experimentos se condujeron en La Estación Experimental de Investigación Agrícola y de Extensión en Hermiston Oregon en el 2006 y 2007. Lineas que presentaron pocas minas por tubérculo fueron AC97521-1R/Y, Q174-2, Rubi, Yuguima, Paciencia, TM-3, KWPTM24 y CIP 780660; lineas que presentaron pocas larvas por tubérculo fueron A97287-6, PA00N10-5, AC97521-1R/Y, Q174-2, PA04LNC2-1, PA04LNC4-1, TM-3 y CIP 780660. La incorporación de resistencia, el uso de prácticas culturales tales como la limitación del tiempo de esposición de tubérculos a la presencia de la polilla de la papa, y el uso de químicos, proveen una buena alternative para controlar este devastador insecto.

Keywords Clones · Columbia basin · Germplasm · Insects · *Phthorimaea operculella* · Potato · Potato tubermoth · Resistance

S. I. Rondon (✉) · R. Marchosky
Hermiston Agricultural Research and Extension Center, Oregon State University,
2121 South First Street,
Hermiston, OR 97838, USA
e-mail: silvia.rondon@oregonstate.edu

C. R. Brown
USDA-ARS,
Prosser, WA, USA

Introduction

Phthorimaea operculella (Zeller) (Lepidoptera: Gelechiidae), a.k.a the potato tuberworm (PTW), is one of the most important constraints to potato, *Solanum tuberosum* L., productivity worldwide (Fenemore 1988; Trivedi and Rajagopal 1992). Leaves, stems, petioles and more importantly, potato tubers, can be seriously affected (Rondon et al. 2007; Rondon 2010). The greatest risk of getting tuber damage caused by the PTW occurs immediately before harvest while the crop sits in the field awaiting digging (Rondon et al. 2007; Rondon 2010). In general, the pest is relatively difficult to control and growers rely extensively on the use of insecticides (Foot 1974; Gubbaiah and Thontadarya 1975; Kroschel and Koch 1996) and a wide variety of cultural practices (Foot 1974, 1976a; Shelton and Wyman 1979; Clough et al. 2008, 2010). Incorporation of host plant resistance, including *Cry* proteins (Douches et al. 1998, 2002; Beuning et al. 2001; Estrada et al. 2007) may provide an additional management option (Rondon et al. 2009; Rondon 2010).

Few attempts have been made to identify potato varieties resistant to PTW (Foot 1976b; Raman and Palacios 1982; Musmeci et al. 1997; Rondon et al. 2009). So far, three types of host resistance for insect pests have been identified: 1) leptine glycoalkaloids (Sinden et al. 1986), 2) glandular trichomes (Plaisted et al. 1992), and 3) the introduction of *Bacillus thuringensis* (Bt) cry genes (Douches et al. 1998). In the early 80's, the International Potato Center tested 3,747 and 452 germplasm accessions of primitive cultivars and wild potato species, respectively, from which 22 primitive and 21 wild germplasm accessions were found to be resistant (Raman and Palacios 1982). Malakar and Tingey (1999) found limited foliage resistance of *Solanum berthaultii* Hawkes while Musmeci et al. (1997) found foliar resistance on wild potatoes and interspecific hybrids. Transferring genes for resistance to the PTW from wild potato species to cultivated potatoes through interspecific hybridization was demonstrated by Chavez et al. (1988). Gleave (1992) and Baltasar et al. (1997) demonstrated that some Cry proteins isolated from Bt have insecticide activity against PTW. Douches et al. (2002) described the production of a transgenic variety, SpuntaG2, resistant to PTW. Rondon et al. (2009) found that SpuntaG2 displayed very high resistance (zero tuber damage) in field and laboratory trials in eastern Oregon.

Due to the relatively recent arrival of the PTW in the Pacific Northwest (Rondon et al. 2007; Clough et al. 2010; DeBano et al. 2010), locally used cultivars and breeding lines have never been screened for tuber resistance to PTW. Thus, the objective of this study was to screen regional potato lines for potential PTW resistance by tubers under field and laboratory conditions.

Materials and Methods

Potato Lines

Experiments were conducted at the Hermiston Agricultural Research and Extension Center (HAREC) in Hermiston, Oregon. In 2006 and 2007, lines representing promising potato breeding material lines were evaluated. Both years, material came from the Tri-State state program. The Tri-State breeding program mission is to develop new potato varieties and it includes the cooperative effort of the USDA-ARS of Idaho and Washington, Oregon State University, University of Idaho and Washington State University, as well as potato commissions of the three states. The material tested included early material program (5–6 years in the Tri-State program), regional Tri State program (7–9 years in the Tri-State program), chip varieties, specialty germplasm and special selections from the USDA program in Aberdeen, ID. Sources and pedigrees of the lines are listed in Tables 1 and 2. Accessions presented on the tables do not follow any particular order.

Potato entries were planted at the HAREC to obtain tubers for testing in the field and laboratory. Plots were planted in the field and maintained using agronomic practices standard for the region using 86.4 cm beds, 22.9 cm plant spacing and 20.3 cm planting depth. In 2006, 118 germplasm were screened. Potatoes were planted on 4 April, vine killed occurred on 8 August and potatoes were harvested 11 September. In 2007, 27 lines were screened. Those 27 lines included two Russet varieties and SpuntaG2 previously tested. Potatoes were planted 25 April, vine killed 3 September and harvested on 10 September.

Potato Tuberworm Colony

In 2004, adults, pupae and larvae were collected from potato fields in eastern Oregon. Voucher specimens of PTW adults were deposited in the arthropod collection of Oregon State University (OSAC # 0127). The rearing procedure was previously described by Rondon et al. (2009). Periodically, wild PTW pupae and larvae from various locations were added to the culture. The colony consisted of potatoes infested with PTW that were kept under a photoperiod of 8:16 (L:D) h at~21 °C and 60 % RH. Infested potatoes were kept in sealed plastic containers (12×16.5×32 cm) (Pioneer Plastic, North Dixon, KY) containing 2-cm of silica sand in the base that served as pupation substrate. PTW pupae were sieved, collected and transferred into cylindrical food containers (14 cm diameter x 3.5 cm high). Each container used a piece of cheese cloth as lid to allow air flow. A sheet of filter paper was placed on top of the cheese cloth used as an oviposition substrate. Following emergence, adults were fed with 5 % sugar solution applied to a cotton wick placed on top of the lid; adults mated and oviposited through the cheese cloth and onto the filter paper. Adults were kept in the dark to increase oviposition (Broodryk 1971). Eggs were collected from filter paper and kept to either maintain the colony or used for further experiments.

Table 1 Lines (n=118) tested in field and laboratory potato tuberworm resistance studies. Hermiston, OR 2006

	Lines	Origin	Pedigree
1	RUSSET RANGER	Commercial	BUTTE X A6595-3
2	RUSSET BURBANK	Commercial	EARLY ROSE X UNKNOWN
3	CENTURY	PNW Tri-State[a]	A6789-7 x A6680-5
4	A95074-6	PNW Tri-State	AGRIA X SUMMIT RUSSET
5	A95109-1	PNW Tri-State	A89146-8 X RANGER RUSSET
6	A95409-1	PNW Tri-State	A89146-8 x RANGER RUSSET
7	A96104-2	PNW Tri-State	A88236-4 X A89512-3
8	AC96052-1RU	Colorado	A81386-1 x A9014-2
9	AO96141-3	PNW Tri-State	A89222-3 x COA90064-6
10	AO96160-3	PNW Tri-State	A89384-10 x A89512-3
11	Sage Russet	PNW Tri-State	A89384-10 X A91194-4
12	Owyhee Russet	PNW Tri-State	BANNOCK RUSSET x A89152-4
13	AOA95155-7	PNW Tri-State	BANNOCK RUSSET X A89163-3LS
14	AOTX95265-2ARU	Colorado	A89216-9 X A86102-6
15	AOTX95265-4RU	Colorado	A89216-9 X A86102-6
16	Mesa Russet	Colorado	RUSSET NUGGET X AC88165-3
17	CO95172-3RU	Colorado	A89384-10 and A89512-3
18	CO97137-1W	Colorado	NDO2904-7 X AC89047-1
19	MWTX2609-2RU	Texas	BURBANK X ONTARIOX4XHYBRID
20	MWTX2609-4RU	Texas	BURBANK X ONTARIOX4XHYBRID
21	TXA549-1RU	Texas	ND9687-3Ru X ND9852-1Ru
22	Palisade Russet	PNW Tri-State	AWN86514-2 X A86102-6
23	A97287-6	Idaho	A77715-6 X A86102-6
24	A99006-2TE	PNW Tri-State	A86070-7 X A92030-5
25	A9040-1TE	PNW Tri-State	BANNOCK RUSSET X A89163-3LS
26	Teton Russet	PNW Tri-State	BLAZER RUSSET X A95109-1
27	PA98NM2-3	PNW Tri-State	273-4 X SUMMIT RUSSET
28	PA98NM30-11	PNW Tri-State	PO94A10.3 X A9289-2
29	PA99N2-1	PNW Tri State	AO84275-3 X G66582-3
30	PA99N46-1	PNW Tri-State	PA9514-17 X RUSSET BULK
31	PA99N82-4	PNW Tri-State	PA95B4-149 X RUSSET BULK
32	PA00N10-5	PNW Tri-State	PA95A14-22 X RUSSET BULK A
33	ATLANTIC	Beltsville, USEA	WAUSEON x USEA B5141-6
34	CHIPETA	Colorado	WNC612-13 x WISCHIP
35	IVORY CRISP	PNW Tri-State	ND292-1 x A7726B-4
36	AC97097-14W	Colorado	BRODICK x A91746-8
37	ATTX95490-2W	Texas	RED LASODA X A89655-5DY
38	BO766-3T	Beltsville, USEA	B0243-18 X COASTAL CHIP
39	CO95051-7W	Colorado	AC88456-6W x BC0894-2W
40	CO96141-4W	Colorado	BC 894–2 x AC87340-2
41	CO97043-14W	Colorado	AC91817-5 x AC87340-2
42	CO97065-7W	Colorado	AC92513-3 x CHIPETA
43	DR NORLAND	North Dakota	REDKOTE x ND626
44	RED LASODA	Louisiana	TRIUMPH X KATAHDIN
45	AC97521-1R/Y	Colorado	SJP/T48YF X A91846-5R
46	CO97232-1R/Y	Colorado	CO94218-1 X VC0967-2
47	CO97232-2R/Y	Colorado	CO94218-1 X VC0967-2
48	CO97233-3R/Y	Colorado	CO94218-1 X VC0967-5
49	PA99P11-2	PNW Tri-State	GRANOLA X 9.1E+23

Table 1 (continued)

	Lines	Origin	Pedigree
50	CO97226-2R/R	Colorado	CO94183-1 X CO94214-1
51	PORO1PG20-12	PNW Tri-State	PA97B35-2 X PA97B29-3
52	PORO1PG22-1	PNW Tri-State	PA97B23-2 X RED BULK POLLEN
53	ALL BLUE	U.S.A.	N713-16 x N889-78-3
54	PORO1PG16-1	PNW Tri-State	NDOP5847-1 X RED BULK POLLEN
55	YUKON GOLD	Canada	NORGLEAM x W5279-4
56	A96510-4Y	PNW Tri-State	PA92A17-6 x A91194-4
57	VC1009-1W/Y	Colorado	AGRIA x MN12823
58	VC1123-2W/Y	Colorado	AGRIA X FV9307-3
59	A00ETB11-1	PNW Tri-State	A86102-6 x Etb 6-21-3
60	A00ETB12-2	PNW Tri-State	A92303-7 x Etb 6-21-3
61	A00ETB12-3	PNW Tri-State	A92303-7 x Etb 6-21-3
62	A00ETB18-1	PNW Tri-State	Etb 6-21-3 x LIU
63	A00ETB20-7	PNW Tri-State	Etb 6-21-5 x SUMMIT RUSSET
64	A00ETB22-20	PNW Tri-State	Etb 6-21-5 x GEMSTAR RUSSET
65	A00ETB24-3	PNW Tri-State	Etb 6-21-5 x A96764-19
66	A01687-15	PNW Tri-State	Etb 6-21-3 x GEMSTAR RUSSET
67	436-4	PNW Tri-State	US-W730 x *S. berthaultii* (PI 265857)
68	P2-4	PNW Tri-State	2-9-3B x KATHAHDIN
69	P2-5	PNW Tri-State	2-7-4A × KATAHDIN
70	ETB 5-31-2	PNW Tri-State	P2-3 x KATAHDIN
71	ETB 5-31-3	PNW Tri-State	P2-3 x KATAHDIN
72	ETB 6-21-3	PNW Tri-State	P2-3 x KATAHDIN
73	ETB 6-21-5	PNW Tri-State	P2-3 x KATAHDIN
74	ETB 6-21-12	PNW Tri-State	P2-3 x KATAHDIN
75	A00ETB12-4	PNW Tri-State	A92303-7 x ETB 6-21-3
76	A00ETB22-8	PNW Tri-State	ETB 6-21-5 x GEMSTAR RUSSET
77	A00ETB22-11	PNW Tri-State	ETB 6-21-5 x GEMSTAR RUSSET
78	A01687-22	PNW Tri-State	ETB 6-21-3 x GEMSTAR RUSSET
79	P2-2	PNW Tri-State	2-3-10A x KATAHDIN
80	V18-5	Not ID clone	?–possibly NY clone
81	NY123	Cornell University	Advanced hybrids with *S. berthaultii*
82	T88-4	Cornell University	Advanced hybrids with *S. berthaultii* (N142-72 X Pike)
83	Q174-2	Cornell University	Advanced hybrids with *S. berthaultii*
84	SPUNTA	Dutch Variety	Bt-cry1IaI
85	SPUNTA G2	Michigan	Spunta with Bt-cry1IaI
86	PALB0302-1	PNW Tri-State	A86102-6 x POR00LB6-1
87	PALB0303-1	PNW Tri-State	Blazer Russet x POR00LB6-1
88	PALB0303-2	PNW Tri-State	Blazer Russet x POR00LB6-1
89	PALB0304-1	PNW Tri-State	Highland Russet x POR00LB6-1
90	PALB03016-2	PNW Tri-State	POOLB5-31 x GemStar Russet
92	PALB03016-3	PNW Tri-State	POOLB5-31 x GemStar Russet
92	PALB3016-6	PNW Tri-State	POOLB5-31 x GemStar Russet
93	PALB03035-1	PNW Tri-State	POR00LB6-2 x GemStar Russet
94	PALB03035-7	PNW Tri-State	POR00LB6-2 x GemStar Russet
95	PA04LNC2-1	PNW Tri-State	97A-51 x PA97B3-2
96	PA04LNC3-1	PNW Tri-State	97A-64 x CORKBULK 420
97	PA04LNC4-1	PNW Tri-State	97A-68 x CORKBULK 420
98	PA04LNV4-2	PNW Tri-State	97A-68 x CORKBULK 420

Table 1 (continued)

	Lines	Origin	Pedigree
99	PA04LNC4-3Y	PNW Tri-State	97A-68 x CORKBULK 420
100	PA04LNC14-1	PNW Tri-State	POR00LB6-1 x PA99N2-1
101	PA04LNC17-4	PNW Tri-State	POR00LB6-2 x PA98NM15-1
102	PA04LNC18-1	PNW Tri-State	POR00LB6-2 x PA99N2-1
103	PA04LP6-1	PNW Tri-State	EGA9706-4 PA99P2-1
104	PA04LB1-1	PNW Tri-State	97A-51 x GemStar Russet
105	PA04LB2-1	PNW Tri-State	97A-68 x GemStar Russet
106	YURACC CCOMPIS	CIP[b]	*S. tuberosum* Group *Andigena*
107	SUYTU VILQUINA	CIP	*S. tuberosum* Group *Andigena*
108	POLLUNTA CHATA	CIP	*S. tuberosum* Group *Andigena*
109	RUBI	CIP	*S. tuberosum* Group *Andigena*
110	YUGUIMA	CIP	*S. tuberosum* Group *Andigena*
111	HUAGALINA	CIP	*S. tuberosum* Group *Andigena*
112	GAYNA	CIP	*S. tuberosum* Group *Andigena*
113	YANA MACUCO	CIP	*S. tuberosum* Group *Andigena*
114	PACIENCIA	CIP	*S. tuberosum* Group a*ndigena*
115	CHUNGUINA	CIP	*S. tuberosum* Group *Andigena*
116	RUSSET NORKOTAH	North Dakota	ND9526-4 x ND9687-5
117	UMATILLA	PNW Tri-State	BUTTE X A77268-4
118	SHEPODY	Canada	BAKE KING x F58050

[a] PNW Tri State: Pacific Northwest Tri State Variety Program

[b] CIP International Potato Center

Field Experiments

Both years, field material was harvested following standard procedures. Harvested tubers were kept at 10 °C for~3 weeks. This time served as pre-screening process to determine that the material was clean of PTW before the experiment. Tubers (2 per replication, 10 replications in a randomized complete block design) were placed in the field on the soil surface and pushed slightly into the soil and exposed to natural populations of PTW for 2 weeks and retrieved before frost. Tubers were placed in marked paper bags and stored at ~22±2 °C for 2 weeks before they were carefully sliced, using a commercial potato slice cutter (0.95 cm wide strips X 4.3 cm length), and graded. Number of mines per tuber and number of live larvae were counted per each tuber (Tables 3 and 4).

Laboratory Experiments

Laboratory experiment was conducted at 26±1 °C, 8:16 (L:D) h and 60 % RH. Individual tubers were placed in 18×14×95 cm containers (Pioneer Plastic, North Dixon, KY) with 50 eggs laid in paper filter placed randomly on the tubers. The experiment was a completely randomized block with 4 replications per germplasm accession. After allowing time for hatching and infestation (~2 weeks), tubers were carefully sliced as describe above and scored. Number of mines per tuber and number of live larvae were counted per each tuber (Tables 3 and 4).

Data Analysis

Resistance of potato lines was evaluated based on the number of live PTW larvae and PTW mines found in tubers. PROC MEANS were used to calculate mean ± SE number of mines and larvae per each potato accession per each year. A one-way analysis of variance using PROC GLM procedure (SAS/STAT, Version 9.2, Institute, 2008) was conducted to determine whether means were significantly different among lines. Means separation was carried out using Dunnett's test (Dunnett 1955). Mean differences were considered different at the 5 % significance level. Correlations were calculated to determine the relationship between mines and number of larvae.

Results

Field Experiments

2006

Mean (± SE) number of mines and larvae per accession evaluated in field trials in 2006 are presented in Table 3.

Table 2 Lines (n=27) tested in field and laboratory potato tuberworm resistance studies. Hermiston, OR 2007

	Germplasm	Origin	Pedigree
1	RUSSET RANGER	Commercial	Butte X A6595-3
2	RUSSET BURBANK	Commercial	Early Rose X Unknown
3	A96814-65LB	PNW Tri-State[a]	AWN86514-2 X A91194-3
4	A98345-1	PNW Tri-State	Ranger R x Premier
5	A99073-1	PNW Tri-State	A9201-6 X A9045-7
6	AO96305-3	PNW Tri-State	A91018-6 X A89152-4
7	A096365-2	PNW Tri-State	A91141-1 X Ranger
8	PA00N10-5	PNW Tri-State	PA95A14-22 X Russet Bulk A
9	PA00N14-2	PNW Tri-State	PA95A14-22 X (Bulk Rus + Gem)
10	PA98NM38-1	PNW Tri-State	PO94A19.6 X Summit Russet
11	PA98NM39-1	PNW Tri-State	PO94A19.6 X A9289-2
12	PA99N12-1	PNW Tri-State	PA95A11-14 x PA95A14-43
13	PA99N2-1	PNW Tri-State	AO84275-3 x G6582-3
14	SPUNTA G	Michigan	Bt-cry1IaI
15	CANASTA	CIP[b]	*S. tuberosum* Group *Andigena*
16	(2X)87HW13.8	?	Unknown
17	(2X)87HW12.16	?	Unknown
18	TM-2	?	Unknown
19	CIP702599	CIP	*S. tuberosum* Group *Andigena*
20	GARHUASH SUITO	CIP	*S. tuberosum* Group *Andigena*
21	PUCA TROMBOS	CIP	*S. tuberosum* Group *Andigena*
22	JANCKO PHINU	CIP	*S. tuberosum* Group *Andigena*
23	TM-3	?	Unknown
24	KWPTM24	CIP	*S. tuberosum* Group *Andigena*
25	CIP780660	CIP	Unknown
26	HH1-9	?	Unknown
27	SpuntaG2	Michigan	*Spunta with* Bt-cry1IaI

[a] PNW Tri State: Pacific Northwest Tri State Variety Program

[b] CIP International Potato Center

Significant variation was found among the 118 potato lines in the number of PTW mines per tuber (F=12.97; df=117, 1061; P<0.0001) and the number of larvae per tuber (F=3.76; df=117, 1064; P<0.0001). There were no mines into and no larvae within SpuntaG2 tubers. Thirty one and 17 % of the variation in the number of mines and number of larvae per tuber was accounted for by lines tested, respectively. Thirty one (31) germplasms exposed to natural infestation by PTW presented a significantly high number of larvae per tuber when compared to a control (SpuntaG2). Although no statistical different, accessions that had one or less than one larva per tuber were A97287-6, PA00N10-5, AC97521-1R/Y, Q174-2, PA04LNC2-1, and PA04LNC4-1. The line that showed the highest number of mines per tuber was ETB6-21-5 (7.3±0.8) and the one that showed the least (excluding SpuntaG2) was Q174-2 (1.5±0.3). The lines that showed the highest number of larvae per tuber were Owyhee Russet (2.9±0.8) and the one that showed the least (excluding SpuntaG2) was Q174-2 (0.4±0.2). The correlation between number of mines and number of larvae per tuber was not significant (r=0.4099).

2007

The mean (± SE) number of mines and larvae per line evaluated in field trials are presented in Table 4. We found significant variation among potato lines in the number of PTW mines per tuber (F=17.38; df=26; P<0.0001) and the number of larvae per tuber (F=2.68; df=26, 243; P<0.0001). In this experiment, 31 and 22 % of the variation in the number of mines per tuber and number of larvae per tuber, respectively, was accounted for by lines differences. A96814-65LB tubers were more frequently mined, and were infested with more PTW larvae (Table 4). Accessions that had low mines and larvae included TM-3 and CIP 780660. The source of both lines is unknown. The lines that showed the highest number of mines per tuber were Ranger (4.7±1.0) and A99073-1 (4.7±0.6) and the one that showed the least was CIP 780660 (1.1±0.3). The lines that showed the highest number of larvae per tuber were Ranger (2.9±1.0), Russet Burbank (2.9±0.9) and A99073-1 (2.9 ±0.6) and the ones that showed the least (excluding SpuntaG2) was CIP 780660 (0.8±0.2). The

Table 3 Mean (± SE) number of mines and larvae per accession evaluated in field and laboratory trials in 2006, Hermiston, OR

		Field				Laboratory			
		mines		larvae		mines		larvae	
Lines		Mean ± SE		Mean ± SE		Mean ± SE		Mean ± SE	
1	Ranger	4.5	0.5	1.9	0.2	16.25	1.97	2.25	0.75
2	Russet Burbank	3.0	0.6	1.5	0.4	18.00	3.03	3.00	1.08
3	Century	6.4	1.0	2.4	0.3	15.25	0.63	4.75	2.63
4	A95074-6	3.1	0.5	1.1	0.3	11.00	1.08	2.50	1.85
5	A95109-1	3.5	0.8	2.1	0.5	14.00	3.24	7.50	2.66
6	A95409-1	5.4	0.4	3.0	0.7	15.00	1.78	3.50	0.29
7	A96104-2	5.9	0.6	2.4	0.6	15.00	0.41	4.25	1.03
8	AC96052-1RU	2.6	0.3	0.8	0.3	12.00	0.71	2.25	1.93
9	AO96141-3	5.5	0.6	1.8	0.4	19.75	2.29	2.25	1.03
10	AO96160-3	4.9	0.5	1.5	0.5	17.00	2.12	5.50	1.19
11	Sage Russet	2.9	0.3	1.4	0.3	11.75	0.25	4.00	1.58
12	Owyhee Russet	4.4	0.4	2.9	0.8	15.25	2.66	4.75	1.70
13	AOA95155-7	3.9	0.6	1.8	0.4	12.25	0.48	2.25	0.75
14	AOTX95265-2ARU	2.9	0.5	1.5	0.3	16.75	2.56	3.25	1.97
15	AOTX95265-4RU	4.6	0.6	1.4	0.2	14.75	0.75	1.00	0.41
16	Mesa Russet	3.2	0.6	1.5	0.5	13.25	3.35	3.00	1.22
17	CO95172-3RU	4.7	1.1	2.1	0.6	14.75	3.71	5.00	1.22
18	CO97137-1W	5.7	0.8	2.9	0.5	16.00	2.35	12.00	2.52
19	MWTX2609-2RU	4.3	0.8	1.9	0.2	16.75	2.06	3.50	1.19
20	MWTX2609-4RU	3.2	0.3	1.7	0.4	15.75	2.17	5.00	2.27
21	TXA549-1RU	3.3	0.4	1.1	0.2	13.50	2.47	2.50	0.65
22	Palisade Russet	6.8	1.3	2.6	0.6	14.00	1.29	0.00	0.00
23	A97287-6	3.3	0.6	0.6	0.2	46.75	32.42	0.25	0.25
24	A99006-2TE	4.7	0.5	2.7	0.7	18.25	1.25	0.75	0.25
25	A99040-1TE	3.0	0.4	1.1	0.2	15.25	0.48	0.75	0.25
26	Teton Russet	4.0	0.7	2.6	0.5	17.00	0.71	4.50	1.04
27	PA98NM2-3	2.8	0.3	1.3	0.4	19.00	1.78	6.50	1.19
28	PA98NM30-11	4.7	0.6	2.1	0.5	15.00	0.00	6.50	0.65
29	PA992-1	3.7	0.5	1.1	0.2	13.75	0.48	0.75	0.48
30	PA99N46-1	4.3	0.5	2.2	0.4	13.50	0.50	6.25	1.11
31	PA99N82-4	4.6	0.4	2.4	0.6	15.50	1.94	1.50	0.65
32	PA00N10-5	4.6	0.3	0.9	0.2	19.75	0.75	0.75	0.48
33	ATLANTIC	3.9	0.8	1.5	0.3	8.00	2.68	1.50	1.19
34	CHIPETA	5.1	1.2	3.2	0.9	10.25	1.44	0.50	0.29
35	IVORY CRISP	3.8	0.9	2.1	0.5	9.50	1.04	5.50	0.65
36	AC97097-14W	2.4	0.4	1.5	0.3	4.50	0.65	3.25	1.31
37	ATTX95490-2W	4.3	0.4	2.1	0.5	7.75	1.11	4.75	1.89
38	BO766-3T	2.4	0.9	2.0	0.7	8.50	0.29	1.00	1.00
39	CO95051-7W	3.3	0.6	2.2	0.5	10.75	2.25	4.75	1.03
40	CO96141-4W	2.5	0.3	0.8	0.3	11.25	1.49	1.50	0.87
41	CO97043-14W	4.1	0.8	2.6	0.5	7.75	0.95	10.00	3.58
42	CO97065-7W	2.3	0.4	1.1	0.5	10.75	1.18	6.00	2.74
43	DR NORLAND	2.7	0.4	1.5	0.4	10.75	0.85	8.25	1.49
44	RED LASODA	4.3	0.6	1.7	0.4	9.50	1.19	7.00	1.47
45	AC97521-1R/Y	1.5	0.3	0.5	0.2	6.75	0.75	1.75	0.85

Table 3 (continued)

Lines		Field mines Mean ± SE		Field larvae Mean ± SE		Laboratory mines Mean ± SE		Laboratory larvae Mean ± SE	
46	CO97232-1R/Y	2.9	0.6	1.7	0.4	8.50	3.84	9.00	0.58
47	CO97232-2R/Y	4.3	0.6	1.4	0.3	8.00	1.35	2.25	0.75
48	CO97233-3R/Y	2.7	0.4	1.3	0.2	7.75	1.70	2.25	1.60
49	PA99P11-2	2.4	0.4	1.4	0.4	11.00	0.71	4.50	1.04
50	CO97226-2R/R	3.6	0.5	2.2	0.4	7.00	0.91	2.25	1.31
51	PORO1PG20-12	4.4	0.7	2.2	0.4	13.50	0.96	6.50	1.66
52	POR01PG22-1	4.5	0.5	2.2	0.4	12.25	2.39	2.75	1.89
53	ALL BLUE	3.2	0.5	2.2	0.5	12.00	1.87	2.25	1.11
54	POR01PG16-1	3.1	0.8	1.1	0.4	11.25	1.03	4.25	1.18
55	YUKON GOLD	3.3	0.5	1.5	0.4	7.25	2.14	3.25	0.48
56	A96510-4Y	4.1	0.5	1.1	0.4	11.75	1.89	0.50	0.29
57	VC1009-1W/Y	4.2	0.4	2.6	0.5	9.50	3.30	2.50	1.44
58	VC1123-2W/Y	2.9	0.5	1.4	0.3	8.75	2.17	3.25	1.31
59	A00ETB11-1	2.6	0.5	1.3	0.2	16.50	1.26	6.50	1.04
60	A00ETB12-2	3.4	0.7	1.6	0.4	14.00	2.35	7.75	1.93
61	A00ETB12-3	2.9	0.6	2.1	0.4	12.50	1.71	4.75	1.03
62	A00ETB18-1	4.7	0.5	1.7	0.3	10.25	1.31	2.75	0.48
63	A00ETB20-7	3.6	0.7	1.1	0.4	13.50	0.65	2.00	1.68
64	A00ETB22-20	4.5	0.4	1.5	0.3	17.25	1.60	3.00	1.47
65	A00ETB24-3	4.0	0.7	1.3	0.4	11.75	0.85	2.50	1.26
66	A01687-15	3.7	0.4	2.3	0.5	12.00	1.78	5.00	1.08
67	463-4	3.1	0.4	1.5	0.4	12.25	0.48	0.25	0.25
68	P2-4	4.0	0.7	1.2	0.3	13.75	1.25	3.25	1.18
69	P2-5	3.9	0.7	1.6	0.6	9.50	1.19	0.75	0.48
70	ETB5-31-2	5.3	0.8	1.9	0.7	12.75	0.63	4.25	1.93
71	ETB5-31-3	3.4	0.3	1.2	0.1	9.75	1.03	0.75	0.48
72	ETB6-21-3	4.2	0.8	1.3	0.2	9.75	0.48	4.75	0.95
73	ETB6-21-5	7.3	0.8	2.6	0.5	14.75	1.11	1.25	0.75
74	ETB6-21-12	2.4	0.5	2.2	0.4	9.75	1.44	7.25	2.02
75	A00ETB12-4	3.0	0.5	1.2	0.3	13.75	2.59	8.25	4.21
76	A00ETB22-8	3.0	0.5	0.9	0.4	14.75	1.49	1.50	0.29
77	A00ETB22-11	3.5	0.5	0.8	0.1	10.75	0.75	1.00	0.71
78	A01697-22	5.9	0.6	2.3	0.5	14.50	2.90	8.00	1.08
79	P2-2	2.2	0.3	1.1	0.4	9.25	1.11	0.25	0.25
80	V18-5	3.9	0.3	1.2	0.3	7.50	0.29	0.75	0.75
81	NY123	2.6	0.5	3.1	1.9	7.50	1.32	0.50	0.50
82	T88-4	2.5	0.5	1.3	0.3	7.00	0.82	0.25	0.25
83	Q174-2	1.5	0.3	0.4	0.2	7.50	0.87	0.25	0.25
84	Spunta	4.2	0.7	2.0	0.5	12.00	1.08	1.75	0.85
85	SpuntaG2	0.0	0.0	0.0	0.0	12.75	1.93	0.00	0.00
86	PALB0302-1	3.9	0.7	1.4	0.4	13.25	1.75	0.75	0.25
87	PALB0303-1	3.4	0.3	1.4	0.3	19.00	2.27	2.00	1.08
88	PALB0303-2	3.8	0.5	2.3	0.5	14.75	1.97	1.25	0.95
89	PALB0304-1	4.1	0.5	1.7	0.3	12.50	1.26	4.50	1.55
90	PALB03016-2	2.8	0.3	1.4	0.5	11.00	0.71	0.50	0.29

Table 3 (continued)

Lines		Field				Laboratory			
		mines		larvae		mines		larvae	
		Mean ± SE		Mean ± SE		Mean ± SE		Mean ± SE	
91	PALB03016-3	3.2	0.3	1.4	0.3	10.50	0.87	0.50	0.29
92	PALB3016-6	3.4	0.5	1.6	0.4	10.75	1.11	1.75	0.85
93	PALB03035-1	3.8	0.6	1.6	0.3	11.25	0.75	0.75	0.48
94	PALB03035-7	4.1	0.6	1.7	0.6	12.75	1.25	1.25	0.75
95	PA04LNC2-1	2.7	0.5	0.8	0.3	10.25	1.60	1.50	1.50
96	PA04LNC3-1	3.8	0.5	1.4	0.3	16.50	1.71	1.50	1.19
97	PA04LNC4-1	2.9	0.4	0.6	0.2	13.75	1.80	1.50	1.19
98	PA04LNC4-2	2.7	0.3	1.6	0.4	38.00	27.04	1.25	0.95
99	PA04LNC4-3Y	4.0	0.6	1.3	0.2	10.00	1.15	0.00	0.00
100	PA04LNC14-1	2.7	0.3	1.0	0.2	13.00	1.22	1.25	0.48
101	PA04LNC17-4	3.2	0.7	2.2	0.9	10.00	1.47	0.25	0.25
102	PA04LNC18-1	3.7	0.5	1.6	0.3	12.25	1.93	1.50	1.19
103	PA04LP6-1	4.6	0.6	2.8	0.5	16.25	1.38	7.25	2.50
104	PA04LB1-1	3.4	0.5	1.5	0.3	20.00	2.48	1.75	1.18
105	PA04LB2-1	5.0	0.6	2.4	0.4	12.00	1.22	2.75	1.11
106	Yuracc Ccompis	2.8	0.3	1.4	0.3	7.50	0.87	3.00	1.22
107	Suytu Vilquina	2.0	0.2	1.2	0.3	6.25	0.85	1.50	0.65
108	Pollunta Chata	2.2	0.4	1.2	0.3	16.50	1.55	8.75	2.14
109	Rubi	1.8	0.3	1.4	0.2	6.75	0.48	1.75	0.75
110	Yuguima	1.9	0.4	1.6	0.3	6.75	0.48	2.00	0.71
111	Huagalina	3.7	0.4	1.3	0.3	9.50	0.65	3.00	0.58
112	Gayna	2.0	0.2	1.0	0.2	7.00	1.00	2.00	0.00
113	Yana Macuco	2.0	0.3	1.1	0.3	13.50	4.52	2.75	0.75
114	Paciencia	1.6	0.3	1.1	0.2	6.50	0.65	1.00	0.41
115	Chunguina	2.1	0.2	1.4	0.3	12.00	0.91	2.25	0.63
116	Russet Norkotah	3.6	0.6	1.9	0.4	16.00	2.38	6.00	0.91
117	Umatilla	3.1	0.7	1.4	0.5	20.00	0.71	5.25	0.63
118	Shepody	3.7	0.7	0.8	0.3	13.00	0.58	3.75	0.63

Number of observations in the field (n=10) and laboratory (n=4)

correlation between number of mines and number of larvae per tuber was not significant (r=0.3004).

Laboratory Experiments

2006

The mean (± SE) number of mines and larvae per line evaluated in field trials are presented in Table 3. Significant variation was found among potato lines in the number of PTW mines per tuber (F=3.51; df=117; P<0.0001) and the number of larvae (F=3.83; df=117; P<0.0001) infesting potato tubers. In this experiment, 54 and 55 % of the variation in the number of mines per tuber and number of larvae per tuber, respectively, was accounted for by line differences (Table 3). The line that showed the highest number of mines per tuber was A97287-6 (46.75±32.42) and the one that showed the least was Paciencia (6.50±0.65). The line that showed the highest number of larvae per tuber was CO97137-1W (12.0±2.52) and the ones that showed the least (excluding SpuntaG2) were Palisade Russet (0.0±0.0) and PA04LNC4-3Y (0.0±0.0). The correlation between number of mines and number of larvae per tuber was not significant (r=0.4138).

2007

The mean (± SE) number of mines and larvae per line evaluated in field trials are presented in Table 4. We found significant variation among potato varieties in the number of PTW mines per tuber (F=7.51; df=26, 81; P<0.0001) and the number of larvae (F=7.64; df=26, 81; P<0.0001)

Table 4 Mean (± SE) number of mines and larvae per germplasm accession evaluated in field and laboratory trials in 2007, Hermiston, OR

Trt	Lines	Field				Laboratory			
		mines		larvae		mines		larvae	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	RANGER	4.7	1.0	2.9	1.0	4.5	0.5	1.5	0.3
2	R.BURBANK	4.1	0.9	2.9	0.9	5.3	0.6	3.8	0.9
3	A96814-65LB	4.1	0.5	2.7	0.5	1.8	0.3	1.3	0.3
4	A98345-1	2.7	0.4	2.0	0.5	4.5	1.0	3.5	1.0
5	A99073-1	4.7	0.6	2.9	0.6	4.3	0.5	4.3	0.5
6	AO96305-3	4.4	0.8	2.8	0.4	3.0	0.4	2.3	0.3
7	AO96365-2	3.5	0.8	2.3	0.5		0.9	4.0	0.6
8	PA00N10-5	4.4	0.6	3.0	0.5	5.3	0.8	3.8	0.5
9	PA00N14-2	3.6	0.8	2.7	0.7	5.8	0.5	4.8	0.9
10	PA98NM38-1	3.2	0.6	2.0	0.6	2.3	0.9	2.3	0.9
11	PA98NM39-1	4.6	0.6	2.6	0.7	7.3	0.9	7.0	0.9
12	PA99N12-1	2.8	0.7	1.8	0.6	4.3	0.8	3.5	0.6
13	PA99N2-1	3.5	0.7	1.9	0.5	6.5	0.3	5.3	0.3
14	Spunta G	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	Canasta	1.9	0.3	1.2	0.2	7.0	1.2	6.3	1.0
16	(2x)87HW13.8	3.5	0.6	2.1	0.3	9.0	1.1	8.8	0.9
17	(2X)87HW12.16	3.3	0.5	2.0	0.6	8.8	1.1	8.3	1.4
18	TM-2	2.3	0.5	1.3	0.3	5.0	0.9	4.8	0.9
19	CIP 702599	2.5	1.0	1.5	0.4	3.5	0.5	3.5	0.5
20	Garhuash Suito	4.1	0.6	2.6	0.6	6.0	0.9	5.5	0.6
21	Puca Trombos	2.6	0.5	1.7	0.4	5.0	0.7	5.0	0.7
22	Jancko Phinu	3.7	0.7	2.3	0.6	7.5	1.7	7.0	1.6
23	TM-3	1.5	0.7	0.8	0.4	8.0	0.6	7.8	0.5
24	KWPTM24	1.8	0.6	1.1	0.4	10.0	2.2	9.8	2.4
25	CIP 780660	1.1	0.3	0.8	0.2	3.8	1.0	3.8	1.0
26	HH 1-9	3.2	0.6	2.8	0.7	3.8	1.2	3.5	1.2
27	SpuntaG2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Number of observations in the field (n=10) and laboratory (n=4)

infesting potato tubers. In this experiment, 71 and 83 % of the variation in the number of mines per tuber and number of larvae per tuber, respectively, was accounted for by line differences. The line that showed the highest number of mines per tuber and highest number of larvae per tuber was KWPTM24 (10.0±2.2). The line that showed the least (excluding SpuntaG2) number of mines (1.8±0.3) and the least number of larvae per tuber was A96814-65LB (1.3±0.3). The correlation between number of mines and number of larvae per tuber was significant (r=0.4314).

Discussion

Under field and laboratory conditions, the PTW caused mining in all lines except SpuntaG2. Some lines had fairly low numbers of mines and larvae; in some cases significantly less than the standard commercial lines suggesting a promising characteristic. However it is important to note that in our experiment, field trials worked as a choice test where PTW females were offered a number of tubers for egg laying, therefore it is likely that in a commercial situation, breeding lines could potentially appear to be resistant. In this regard, the lab tests in this study are non-choice tests and are useful data. In the lab experiment, PTW young larvae were "forced" to feed and penetrate tubers. Following Chavez et al. (1988) protocol, germplasm were considered susceptible when at least one entry hole was found in any given tuber. Under this premise, several of the lines tested were promising. Several tested lines presented less mining that SpuntaG2 and few larvae per tuber. Raman and Palacios (1982) considered the number of entry holes on the tuber surface as a measured of resistance: lines with less than one entry hole per tuber were considered highly resistant; one to two holes were considered resistant, two to four susceptible and more than four holes highly susceptible. Taking this scale into consideration, all germplasm in the current study, except for the Bt transgenic line SpuntaG2, would be considered susceptible to PTW larvae infestation on tubers. A combination of PTW partially resistant germplasms and appropriate management practices could allow to obtain the "zero" tolerance required by the potato industry. Under this premise, it is unwise to come up with a resistance rate based on the information presented since more lines needed to be screened. Rondon et al. (2009) suggested earlier that PTW resistant by the transgenic clone SpuntaG2 could be introgressed into germplasm of interest to the Tri-State Program via conventional crosses or by genetic transformation of Tri-State germplasm using the Bt gene. Unfortunately, financial support to undertake this task is limited. Also, we still need to take into account that the general public is still debating the cost/benefit of using transgenic technology. Several countries now accept the production and consumption of GMO potatoes (Grafius and Douches 2008) but we still face some drawbacks.

Commercial varieties such as Russet Ranger and Burbank hold up well against natural (field) and artificial (laboratory) infestations. Interestingly enough, in our laboratory studies we infested tubers with 50 viable PTW eggs but the tubers had relatively few larvae per tuber suggesting a strong competition among PTW larvae for the same resource (Tables 3 and 4). Broodryk (1971) studied the effect of larval densities in potato tubers. They indicated that higher densities caused crowding and malnutrition. Rondon et al. (2009) indicated that based on empirical observations, crowding had an effect on larvae size and weight which unfortunately was not evaluated mainly due to the large number of lines tested. However, Raman and Palacios (1982) correlated tuber weight and number of larvae. The authors found that 5 to 10 g tubers supported 2 larvae; 15 to 20 g tubers and 30 to 50 g tubers supported 6 larvae; 60 to 80 g tubers supported 8 larvae; > 100 g tubers supported 10 larvae.

Our data suggest that lines that contain indigenous roots may show some promising traits. Future research should focus not only on tuber resistance but also on other resistance mechanisms at the foliar level (e.g., glandular trichomes). Thus, incorporation of host plant resistance to tuber penetration by PTW larvae together with appropriate cultural practices including limitation of exposure time of tubers in the field and judicious use of chemicals may provide the best sustainable management option.

Acknowledgments We thank the Pacific Northwest Tri-State Potato Program, Salomon Yilma and Drs. David Douches, Walter DeJong, Dan Hane, Isabel Vales and Rich Novy for providing plant material. The authors also thank Chiho Kimoto, Mahmut Dogramaci, and Laurie Leroux for collecting and organizing the data. We gratefully acknowledge the Oregon Potato Commission and Western IPM center for financial support.

References

Baltasar, E., J. Ferre, and F.J. Silvia. 1997. Occurrence of a common binding site in *Mamestra brassicae*, *Phthorimaea operculella*, and *Spodoptera exigua* for the insecticidal crystal proteins CryIA from *Bacillus thuringensis*. *Insect Biochemistry and Molecular Biology* 27: 651–656.

Beuning, L.L., D.S. Mitra, N.P. Markwick, and A.P. Gleave. 2001. Minor modification to the Cry1Ac9 nucleotide sequence are sufficient to generate transgenic plants resistant to *Phthorimaea operculella*. *Annals of Applied Biology* 138: 281–292.

Broodryk, S.W. 1971. Ecological investigations of the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). *Phytophylactica* 3: 73–84.

Chavez, R., P.E. Schmiediche, M.T. Jackson, and K.V. Raman. 1988. The breeding potential of wild species resistant to the potato tuber moth, *Phthorimaea operculella* (Zeller). *Euphytica* 39: 123–132.

Clough, G.H., S.I. Rondon, S.J. DeBano, N. David, and P.B. Hamm. 2008. Use of cultural and chemical practices to reduce tuber damage from the potato tuberworm in the Columbia Basin. *HortScience* 43: 1159–1160.

Clough, G.H., S.I. Rondon, S.J. DeBano, N. David, and P.B. Hamm. 2010. Cultural practices to control the potato tuberworm. *Journal of Economic Entomology* 103(4): 1306–1311.

DeBano, S.J., P.B. Hamm, A. Jensen, S.I. Rondon, and P.J. Landolt. 2010. Spatial and temporal dynamics of potato tuberworm (Lepidoptera: Gelechiidae) in the Columbia Basin of the Pacific Northwest. *Journal of Economic Entomology* 39(1): 1–14.

Douches, D.S., A.L. Westedt, K. Zarka, and B. Schoroeter. 1998. Potato transformation to combine natural and engineered resistance for controlling tuber moth. *HortScience* 33: 1053–1056.

Douches, D.S., W. Li, K. Zarka, J. Coombs, W. Pett, E. Grafius, and T. El-Nasr. 2002. Development of Bt-cry5 insect resistant potato lines Spunta-G2 and Spunta G3. *HortScience* 37: 1103–1107.

Dunnett, C.W. 1955. A multiple comparison procedure for comparing several treatments with a control. *Journal of the American Statistical Association* 50:1096–1121.

Estrada, M.A., K. Zarka, S. Cooper, J. Coombs, and D.S. Douches. 2007. Potato tuberworm (Lepidoptera: Gelechiidae) resistance in potato lines with the *Bacillus thuringensis* cry1Ac gene and natural resistance. *HortScience* 42(5): 1306–1311.

Fenemore, P.G. 1988. Host-plant location and selection by adult potato moth: *Phthorimaea operculella* (Lepidoptera: Gelechiidae): a review. *Journal of Insect Physiology* 34: 175–177.

Foot, M.A. 1974. Field assessment of several insecticides against the potato tubermoth (*Phthorimaea operculella* Zell. Lepidoptera, Gelechiidae) at Pukekohe. *New Zealand Journal of Experimental Agriculture* 2: 191–197.

Foot, M.A. 1976a. Cultural practices in relation to infestation of potato crops by the potato tuber moth. II. Effect of seed depth, remounding, pre-harvest defoliation, and delayed harvest. *New Zealand Journal of Experimental Agriculture* 4: 121–124.

Foot, M.A. 1976b. Susceptibility of twenty potato germplasms to the potato tuber moth at Pukekohe a preliminary assessment. *New Zealand Journal of Experimental Agriculture* 4: 239–242.

Gleave, A.P. 1992. A versatile binary vector system with a T-DNA organizational structure conductive to efficient integration of cloned DNA into the plant genome. *Plant Molecular Biology* 20: 1203–1207.

Grafius, E.J., and D.S. Douches. 2008. The present and future role of insect-resistant genetically modified potato cultivars in IPM. In *Integration of Insect-Resistant Genetically Modified Crops within IPM programs*, ed. J. Romeis, A.M. Shelton, G.G. Kennedy, 195–221. Dordrecht: Springer Science Business Media B.V.

Gubbaiah, M., and T.S. Thontadarya. 1975. Chemical control of the tuber worm, *Gnorimoschema operculella* Zeller in Karnataka. *Mysore Journal of Agricultural Sciences* 9: 415–417.

Kroschel, J., and W. Koch. 1996. Studies on the use of chemicals, botanicals, and *Bacillus thuringiensis* in the management of the potato tuber moth in potato stores. *Crop Protection* 15: 197–203.

Malakar, R., and V.M. Tingey. 1999. Resistance of *Solanum berthaultii* foliage to potato tuberworm (Lepidoptera: Gelechiidae). *Journal of Economic Entomology* 92: 493–497.

Musmeci, S.R., R. Ciccoli, V. Di Gioia, A. Sonnino, and S. Arnone. 1997. Leaf effect of wild species of *Solanum* and interspecific hybrids on growth and behavior of the potato tuber moth, *Phthorimaea operculella* Zeller. *Potato Research* 40: 417–430.

Plaisted, R.L., W.M. Tingey, and J.C. Steffens. 1992. The germplasm release of NYL 235–4, a clone with resistance to the Colorado potato beetle. *American Potato Journal* 60: 843–847.

Raman, K.V., and M. Palacios. 1982. Screening potato for resistance to potato tuberworm. *Journal of Economic Entomology* 75: 47–49.

Rondon, S.I. 2010. The potato tuberworm: a literature review of its biology, ecology, and control. *American Journal of Potato Research* 87: 149–166.

Rondon, S.I., S.J. DeBano, G.H. Clough, P.B. Hamm, A. Jensen, A. Schreiber, J.M. Alvarez, M. Thornton, J. Barbour, and M. Dogramaci. 2007. *Biology and management of the potato tuberworm in the Pacific Northwest*. PNW 594, 8 pp.

Rondon, S.I., D. Hane, C.R. Brown, M.I. Vales, and M. Dǒgramaci. 2009. Resistance of potato germplasm to the potato tuberworm (Lepidoptera: Gelechiidae). *Journal of Economic Entomology* 102(4): 1649–1653.

Sinden, S.L., L.L. Sanford, W.W. Cantelo, and K.L. Deahl. 1986. Leptine glycoalkaloids and resistance to the Colorado potato beetle (Coleoptera; Chrysomelidae) in *Solanum chacoense*. *Environmental Entomology* 15: 1057–1062.

SAS Institute. 2008. *Stat view reference*, 2nd ed. Cary: SAS Institute.

Shelton, A.M., and J.A. Wyman. 1979. Potato tuberworm damage to potatoes grown under different irrigation and cultural practices. *Journal of Economic Entomology* 72: 261–264.

Trivedi, T.P., and D. Rajagopal. 1992. Distribution, biology, ecology and management of potato tuber moth, Phthorimaea operculella (Zeller) (Lepidoptera: Gelechiidae): a review. *Tropical Pest Management* 38: 279–285.