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Evaluation of Onion Germplasm for Resistance to Iris Yellow Spot (*Iris Yellow Spot Virus*) and Onion Thrips, *Thrips tabaci*

C. O. Boateng[1]*, H. F. Schwartz[1]*, M. J. Havey[2], and K. Otto[1]

Abstract. Onion (*Allium cepa* L.) is the most economically important monocot besides grasses. The crop suffers severe damage from onion thrips, *Thrips tabaci* Lindeman, a cosmopolitan and polyphagous insect pest. In addition to causing direct feeding damage, onion thrips is the principal vector of the economically important *Iris yellow spot virus* (*Tospovirus* sp., family Bunyaviridae). Any attempt to manage this pathosystem will require a multifaceted approach based on integrated pest management. Host plant resistance is an important foundation to the success of such approaches. A multi-state, multi-disciplinary research project was established to identify, validate, and deliver resistance to this pathosystem for use by the onion industry. As part of the project, diverse onion plant introduction (PI) accessions from the USDA germplasm collection, advanced breeding lines, and commercial cultivars were evaluated from 2009 through 2011 in fields in Colorado. Sixteen, 15, and 10 better performing onion genotypes were selected in 2009, 2010, and 2011, respectively. Of these, PI 264320 (Grano), PI 546140 (San Joaquin), and PI 546192 (Yellow Sweet Spanish) were selected in both 2009 and 2010, and PI 258956 (Calderana 1028) and PI 546188 (Yellow Sweet Spanish Winegar) were selected in all 3 years. These genotypes should be useful to improve commercial cultivars to reduce losses by the two pests.

Introduction

Edible alliums include some of the most ancient crops cultivated by humans. The wild relatives from which the cultivated crops evolved grow in mountainous regions of central Asia. Only a few species of alliums are commercially cultivated as crops, and many of the edible species are still collected for food. Onion (*Allium cepa* L.) has been cultivated for more than 5,000 years and does not exist as a wild species (Brewster 1994). A wide range of cultivars (and landraces) has been

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developed over the centuries to fit the diverse climates and food preferences of the world. Cultivars have been developed for varying adaptations (e.g., to photoperiod and temperature), bulb size, carbohydrate composition, sweetness, storability, and processing quality (McCallum et al. 2006).

Onion thrips, *Thrips tabaci* Lindeman, is a cosmopolitan and polyphagous insect that routinely infests and damages onion crops (Lewis 1997). The thrips remove contents of mesophyll cells in onion leaves. This removal results in silvery leaf spots that turn into white blotches as leaves grow. The blotches develop into silvery patches and the leaves curl (Cranshaw 2008, Diaz-Montano et al. 2011). Larval and adult onion thrips feed on flower pedicels and buds and reduce seed yield in onions grown for seed production (Elmore 1949). Extensive feeding results in retardation of plant growth, and during the onset of bulb formation can cause as much as 60% yield loss because of reduced bulb size and weight (Parrella and Lewis 1997, Rueda et al. 2007, Waiganjo et al. 2008, Dai et al. 2009, Diaz-Montano et al. 2010).

In addition to direct feeding, onion thrips is the principal vector of the economically important *Iris yellow spot virus* (*Tospovirus* sp., family Bunyaviridae) in the USA (Pappu et al. 2009). On onion flowering scapes, symptoms of iris yellow spot caused by *Iris yellow spot virus* appear as chlorotic or necrotic, straw-colored to white, dry, and elongate or spindle-shaped lesions, with some lesions having an island of green tissue that develops in the center of the necrotic tissue. As more lesions develop and increase in size, they coalesce, often girdling the scape (Gent et al. 2006). Leaf symptoms are expressed as straw-colored, lenticular-shaped lesions with green centers or alternating rings of green and straw-colored tissues (Gent and Schwartz 2008, Pappu et al. 2008). Economic losses occur at all stages of infection, however, infections at early stages of crop growth often cause the most loss in yield and quality of produce (Pappu et al. 2008). Significant losses occur because of smaller bulb size, resulting in significant reductions in the percentage of colossal- and jumbo-grade bulbs of susceptible cultivars. Total yield losses of 1-10% or more are frequently reported in the USA, with the loss varying in relation to host tolerance, time of infection, and other factors (Schwartz et al. 2002, Gent et al. 2004, 2006, Gent and Schwartz 2008, Shock et al. 2008). Estimated yield losses in individual fields ranged from insignificant to 60% (Mohan and Wilson 1989) and became 100% (Pozzer et al. 1999). In green onions, symptomatic leaves are unsalable. Infected scapes often lodge, leading to umbel rot and loss, resulting in significant losses in seed onion production (Crowe and Pappu 2005, du Toit et al. 2007, Gent et al. 2007).

Iris yellow spot virus and its onion thrips vector have become major production and economic concerns for the US onion industry. The virus was ranked as an important research priority in the Western Regional Pest Management Strategic Plan developed during a meeting of regional stakeholders in Boise, ID, in 2004 and reaffirmed as a top priority with the revised plan in 2013 (IPMCENTERS 2013). In a web-based survey throughout North America in 2006, onion growers, processors, and researchers identified *Iris yellow spot virus* (and its disease iris yellow spot) and onion thrips as important production constraints for fresh and processed onions in the USA (Havey Lab 2006). The Pacific Northwest has been particularly affected by iris yellow spot and experienced outbreaks in bulb and seed onion crops (Pappu et al. 2009). The disease is considered the greatest threat to sustainable production by onion growers in the region.

Management of iris yellow spot is complicated by the need to manage the vector as well as the virus. For this reason, control needs to be based on sound epidemiological principles and deployed within an integrated disease management framework (Jones 2004, 2006). Although induction of systemic-acquired resistance in onion plants by the exogenous application of Actigard (acibenzolar-*S*-methyl, Syngenta Crop Protection, NC) resulted in 34% reduction in incidence of iris yellow spot in Colorado (Gent et al. 2004), no chemical or biological control is available for the virus. Currently, onion thrips are managed almost exclusively by frequent applications of insecticides, primarily organophosphates, carbamates, and pyrethroids. However, effective control with foliar insecticides is challenging because complete spray coverage is difficult to accomplish because thrips eggs are protected by leaf tissues, prepupae and pupae are in the soil or, as with larvae and some adults, are in the inner spaces between leaves (Shelton et al. 2003, 2006, Cranshaw 2008). Adult thrips are mobile and may rapidly reinfest crops from surrounding vegetation or nearby harvested onion, alfalfa (*Medicago sativa* L.), or other crops (Cranshaw 2008, Diaz-Montano et al. 2011). Besides environmental and worker-safety concerns, chemical control is further complicated by development of resistance by thrips to insecticides in several parts of the world (Al-Dosari 1995, Martin et al. 2003, Shelton et al. 2003, 2006, MacIntyre-Allen et al. 2005, Herron et al. 2008, Morishita 2008). These difficulties warrant the development of alternate control for onion thrips. Attempts to significantly reduce the economic impact of iris yellow spot and onion thrips will require a multifaceted approach that integrates plant resistance, judicious use of chemical tools, cultural practices, and other strategies (Gent et al. 2006, Schumann and D'Arcy 2006, Pappu et al. 2009).

Plant resistance is an important foundation in integrated disease management strategies (Panda and Khush 1995, Kennedy 2008). Onion cultivars with reduced damage by onion thrips have been identified (Jones et al. 1935, Brar et al. 1993, Diaz-Montano et al. 2010, 2011). Unlike other tospovirus diseases such as tomato spotted wilt in which resistance is known (Hutton and Peak 1949, 1953, Finlay 1952, 1953), genetic resistance to iris yellow spot has not been identified, and no onion cultivar with resistance has yet been developed (Diaz-Montano et al. 2010). In evaluation of onion germplasm for reaction to iris yellow spot in the state of Washington, all 46 cultivars tested were susceptible, with infection rates of 58 to 97% (du Toit and Pelter 2005). On a scale of 0 (no symptoms) to 5 (100% foliage diseased), all evaluated cultivars were susceptible in Oregon, with a range of 0.9-1.9, 0.7-2.0, and 1.6-4.1, respectively, in 2004, 2005, and 2006 (Shock et al. 2008). In a similar experiment in New York, the authors concluded there is potential for developing resistance to onion thrips, but identifying resistance to iris yellow spot in onion may be difficult (Diaz-Montano et al. 2010). Researchers such as du Toit et al. (2004), Multani et al. (2009), and Mohseni-Moghadam et al. (2011) similarly evaluated for resistance to disease, with varying results. As a result, we developed a collaborative project with the main goal of identifying, validating, and delivering germplasm with resistance or tolerance to thrips and/or iris yellow spot for use by the onion industry. The objectives of this study were to 1) identify sources of resistance to iris yellow spot and/or onion thrips by evaluating onion genotypes and 2) investigate the effects of pesticides on the response of select onion genotypes to iris yellow spot and onion thrips. The combination of resistance to thrips and iris yellow spot will provide a formidable foundation for integrated management of this pathosystem.

Materials and Methods

Onion genotypes were evaluated for response to iris yellow spot and/or onion thrips during a 3-year period from 2009 through 2011 at the Colorado State University Agricultural Research, Extension and Education Center near Fort Collins in northern Colorado. Landraces, advanced breeding lines, and commercial cultivars were obtained from sources including the USDA-ARS Plant Introduction Station (Geneva, NY), seed companies, and onion breeders. There were 80 plant introductions (PIs), one advanced breeding line, and four commercial cultivars in 2009; 58, one, and three plant introductions, advanced breeding line, and commercial cultivars, respectively, in 2010; and 69, five, and seven plant introductions, advanced breeding lines, and commercial cultivars, respectively, in 2011. The plant introduction genotypes showed variation for amounts of epicuticular waxes. Plants from seed were grown to the 4-6 leaf stage in a greenhouse before transplanted in a field with a long history of the presence of onion thrips and infection by iris yellow spot.

In 2009, raw seeds were sown in jiffy-transplant pellets (Stuewe and Sons Inc., Tangent, OR) at a rate of three seeds per pellet on 9 March. After germination and emergence, seedlings were thinned to one plant per pellet. In 2010 and 2011, raw seeds were sown on 12 January and 1 January, respectively, in a soil-less potting mix (Fafard's Professional Custom Mix Formula, Conrad Fafard Inc., Agawam, MA) in nursery trays. Greenhouse conditions were 25-30^{o}C day and 20-25^{o}C night temperatures, 60-80% relative humidity, and a photoperiod of 14:10 light:dark hours with the aid of supplemental lighting.

The field used in 2009 was previously planted to common beans (*Phaseolus vulgaris* L.). In 2010, iris yellow spot-infected onion plants (bulbs and remnant foliage) with associated onion thrips (from the 2009 season) were planted around the periphery and on spreader rows within the experimental field. In 2011, overwintered infested onion bulbs and iris yellow spot-infected volunteer onion plants from the 2010 growing season were thoroughly incorporated into the soil during field preparation. Plots were single-line, 3-m beds with 0.9-m alleys between plots in a randomized complete block design with three replications in 2009 and 2010, and four replications in 2011. Seedlings were transplanted on 3 May 2009 (55 days after sowing), 14 April 2010 (92 days after sowing), and 13 April 2011 (102 days after sowing). Fields were furrow irrigated when needed to prevent moisture stress, and weeds were controlled. No fungicide or insecticide was applied.

In 2011, four genotypes selected in 2009 and again in 2010 were used to determine the effects of pesticides on the pathosystem. The twice-selected plant introductions were PI 258956, PI 264320, PI 546140, and PI 546188; commercial cultivars 'Colorado 6', 'Talon', and 'Salsa Red' were used as checks. Plants from seed were grown to the 4-6 leaf stage in a greenhouse and at 54 days after sowing were transplanted to the field. The pesticide treatments were untreated check, insecticide, and insecticide+Actigard. The insecticide treatment involved rotation of Carzol (formetanate hydrochloride, Gowan Co. LLC, Yuma, AZ), Radiant (spinetoram, Dow AgroSciences LLC, Indianapolis, NC), and Movento (spirotetramat, Bayer CropScience, Research Triangle Park, NC) insecticides at product application rates of 2.75, 2.75, and 1.20 g per liter, respectively. For the insecticide+Actigard treatment, 0.12 g per liter of Actigard (acibenzolar-S-methly, Syngenta Crop Protection, Greensboro, NC) product was added to each insecticide. Pesticides were applied on a weekly basis from 85 to 120 days after planting by

using a CO_2-pressurized backpack sprayer with a handheld spray boom with one flat-fan nozzle per bed. The experimental location, field preparation, transplanting, and cultural practices for the experiment were the same as described for the evaluation experiments. The experiment was in a randomized split-plot design with four replications. Pesticide treatments were the main-plot factors, and the seven genotypes were the subplot factors.

Plant characteristics were measured for each genotype. A SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd., Japan) was used to measure leaf color between the top and mid-section of fresh, fully expanded, mature leaves. To determine the number of leaves per plant, all leaves on a plant were counted with the exception of those exhibiting more than 60% leaf senescence. Plants were continually monitored for bulbing, cropping/topping (when foliage collapses or falls over at the neck region), and maturity growth stages. Plants were considered mature when more than 50% of the foliage had senesced after cropping or when 60% or more of plants had more than 50% of foliage senesced in genotypes that did not crop. Plants were pulled by hand, and a pair of shears was used to cut the tops and roots from the bulbs. Bulb size and weight and the percentage of split/bunched (bulbs with multiple centers/branching) bulbs or plants were determined. Seasonal abundance of onion thrips was estimated by counting adults and larvae on the plant. Counting was stopped when plant neck and leaves began to open and abundance of onion thrips decreased significantly. Onion thrips were counted at 71, 86, and 99 days after planting in 2009; 63 and 83 days after planting in 2010; and 89, 96, and 112 days after planting in 2011. Incidence of iris yellow spot was determined by the percentage of symptomatic plants per genotype. This was done at 71, 86, 99, and 113 days after planting in 2009; 84, 97, and 112 days after planting in 2010; and 107, 120, and 134 days after planting in 2011. Severity of iris yellow spot disease was assessed based on a scale of 1-4 (Schwartz and du Toit 2005) on 40 arbitrarily selected infected plants per genotype. It was not assessed in 2009, assessed at 117 days after planting in 2010, and at 107, 120, and 134 days after planting in 2011. For the pesticide experiments, abundance of onion thrips was assessed at 82, 89, 105, and 119 days after planting; both incidence and severity of iris yellow spot at 100, 107, 114, and 121 days after planting; and one additional severity assessment at 128 days after planting.

Leaf tissues were periodically sampled for *Iris yellow spot virus* detected in a laboratory. This was done only to confirm the presence of the virus in the field and not to compare virus titer between genotypes. Not all genotypes were tested, and sampling date and size were discretionarily determined by the first author. With symptomatic leaves, samples were taken from healthy tissues surrounding the necrotic regions, whereas leaf base tissues close to the bulb were sampled in non-symptomatic leaves (Kritzman et al. 2001). Double antibody sandwich enzyme-linked immunosorbent assay (DAS ELISA) using the Agdia kit (Agdia Inc., IN) and following the protocol of the manufacturer was used on 0.5-g leaf samples after samples had been frozen in liquid nitrogen and ground by mortar and pestle to a powder (Gent et al. 2004). The ELx 800 Universal Micro-plate Reader (Bio-Tek Instruments Inc., Winooski, VT) was used to read absorbance values at 405 nm. Tissues were considered positive for *Iris yellow spot virus* if their absorbance values were equal to or greater than three times the values of healthy negative checks.

Density of onion thrips throughout the growing season was expressed as a cumulative thrips-day value (Schwartz et al. 2010) and calculated as:

$$\sum_{i=1}^{n} \left[\frac{x_{i+1}+x_i}{2}\right][t_{i+1} - t_i]$$

where x_i is the mean number of thrips per plant at time t_i, and n is the total number of observations.

Iris yellow spot virus pathogenesis was expressed as relative area under the disease progress curve for incidence (rAUDPC-in) and severity (rAUDPC-sv) of iris yellow spot by dividing the area under the disease progress curve (AUDPC) by the total area of the graph (Madden et al. 2007). AUDPC was calculated as:

$$\sum_{i=1}^{n} \left[\frac{x_{i+1}+x_i}{2}\right][t_{i+1} - t_i]$$

where x_i is incidence or severity of iris yellow spot at time t_i, and n is the total number of observations.

Genotype response to iris yellow spot (both rAUDPC-in and rAUDPC-sv) was modeled as *Y = leaves/plant + leaf color + days to bulbing + days maturity + S/B + thrips-day.* Cumulative thrips-day was modeled as *Y = leaves/plant + leaf color + days to bulbing + days maturity + S/B.* Predictors of bulb yield was modeled as *Y = leaves/plant + leaf color + days to bulbing + days maturity + S/B + thrips-day + rAUDPC-in + rAUDPC-sv.* No severity term was included in the 2009 model, and in 2010, average severity rating was used in the model instead of rAUDPC-sv because only one late-season rating was taken. Using these models, the REG procedure (SAS Institute Inc., Cary, NC) was used for multiple linear regressions with the Mallows' C_p (CP) model selection method. The Adjusted R^2 method (ADJRSQ) was used to confirm models selected by CP. Pearson's correlation coefficients were obtained using the CORR procedure in SAS. For genotype evaluation, the GLM procedure in SAS was used for the analysis of genotype means in which significant differences were determined using adjusted Tukey's studentized range test at a 0.05 probability level. For the pesticide experiment, the MIXED procedure in SAS was used for data analysis. Significant differences between pesticide and genotype means were determined using adjusted Tukey's studentized range test at a 0.05 probability level.

Results

Seasonal Dynamics of Iris Yellow Spot Incidence and Severity. Incidence of iris yellow spot was scored four times in 2009. Of the 80 plant introductions, nine, 21, 29, and 37 expressed symptoms of infection at 71, 85, 99, and 113 days after planting, respectively. There was no infection in the advanced breeding line OLYS05N5 (subsequently released as Advantage by Crookham Co., Caldwell, ID). Of the commercial cultivars, Salsa Red (Nunhems, Parma, ID) was infected throughout the season, with Colorado 6 (D. V. Burrell Seed Co., Rocky Ford, CO) and Cometa (Nunhems) each having 3% late-season infections at 113 days after planting. Relative area under the disease progress curve (rAUDPC) for virus incidence (rAUDPC-in) ranged from 0.05 to 0.3 among the plant introductions, and 0.1 to 0.3 among the commercial cultivars. Mean rAUDPC-in was 0.0 in OLYS05N5, 0.07 in the plant introductions, and 0.1 in the commercial cultivars (Table 1). No severity rating was assessed because of low incidence of virus.

Both disease incidence and infection severity were used to assess genotype response to *Iris yellow spot virus* in 2010 and 2011. In 2010, incidence increased with time and was greatest on the last evaluation day (112 days after planting). Seasonal mean incidence was the same for both plant introductions and commercial cultivars at ≈27%; however, rAUDPC-in was 0.189 in plant introductions and 0.133 in commercial cultivars. OLYS05N5 had a seasonal average infection of 17.6% with a corresponding rAUDPC-in of 0.1 (Table 1). Severity of disease was

Table 1. Onion Genotypes Selected for Response to Iris Yellow Spot (*Iris yellow spot virus*) and Onion Thrips (*Thrips tabaci* L.) at Fort Collins, CO, from 2009 to 2011

		Iris yellow spot (mean ± SE)				Onion thrips (mean ± SE)		Bulb (mean ± SE)	
Year	Genotype	Incidence (%)	Severity	rAUDPC-in	rAUDPC-sv	Per plant	Thrips-day (thrips/plant/day)	Size (mm)	Weight (g)
2009	172701[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	5.2 ± 2.6	0.6 ± 0.2	33.8 ± 10.1	N/A
	172702[x]	4.4 ± 4.5	N/A	0.2 ± 0.1	N/A	12.2 ± 0.6	1.4 ± 0.1	50.5 ± 8.6	N/A
	172703[x]	1.8 ± 2.5	N/A	0.1 ± 0.1	N/A	11.4 ± 0.8	1.3 ± 0.1	46.9 ± 5.6	N/A
	179627[x]	1.4 ± 2.0	N/A	0.1 ± 0.1	N/A	9.3 ± 0.1	1.0 ± 0.0	39.1 ± 3.7	N/A
	258956[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	15.1 ± 4.5	1.6 ± 0.4	97.1 ± 1.6	N/A
	264320[x]	1.1 ± 1.6	N/A	0.1 ± 0.1	N/A	13.5 ± 2.4	1.5 ± 0.2	79.4 ± 6.6	N/A
	288270[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	8.9 ± 3.3	1.0 ± 0.4	48.7 ± 7.6	N/A
	288909[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	8.6 ± 0.7	1.0 ± 0.1	76.3 ± 4.9	N/A
	289689[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	2.6 ± 0.4	0.3 ± 0.1	54.3 ± 4.5	N/A
	343049[x]	2.3 ± 3.2	N/A	0.2 ± 0.3	N/A	10.3 ± 1.3	1.1 ± 0.1	67.0 ± 9.0	N/A
	546140[x]	1.7 ± 2.3	N/A	0.1 ± 0.1	N/A	7.7 ± 0.6	0.9 ± 0.1	63.8 ± 2.1	N/A
	546188[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	10.0 ± 1.2	1.1 ± 0.1	105.1 ± 5.8	N/A
	546192[x]	3.2 ± 4.5	N/A	0.2 ± 0.2	N/A	12.6 ± 0.3	1.4 ± 0.1	103.0 ± 11.0	N/A
	639911[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	17.7 ± 4.5	1.9 ± 0.4	54.6 ± 3.5	N/A
	239633-1[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	5.7 ± 0.0	0.6 ± 0.0	44.4 ± 0.0	N/A
	239633-2[x]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	12.5 ± 5.0	1.3 ± 0.6	42.9 ± 0.0	N/A
	Mean[x]	1.5 ± 1.7	N/A	0.066 ± 0.069	N/A	12.8 ± 2.8	1.4 ± 0.3	55.5 ± 5.0	N/A
	OLYS05N5[y]	0.0 ± 0.0	N/A	0.0 ± 0.0	N/A	11.1 ± 2.3	1.2 ± 0.3	88.0 ± 15.4	N/A
	Colorado 6[z]	0.8 ± 1.1	N/A	0.1 ± 0.1	N/A	15.3 ± 1.1	1.7 ± 0.1	101.1 ± 0.8	N/A
	Mean[z]	2.6 ± 1.6	N/A	0.1 ± 0.091	N/A	13.6 ± 2.8	1.5 ± 0.2	90.7 ± 6.0	N/A
	Tukey's (0.05)[†]	12.9	-	0.502	-	19.2	2.1	29.6	-
2010	248753[x]	7.9 ± 0. 0	1.0 ± 0.0	0.200 ± 0.000	N/A	0.7 ± 0.2	0.1 ± 0.0	28.0 ± 2.3	13.6 ± 4.2
	248754[x]	11.4 ± 1.6	2.0 ± 1.4	0.100 ± 0.000	N/A	9.7 ± 2.2	1.0 ± 0.2	40.7 ± 5.6	40.2 ± 4.4
	258956[x]	40.9 ± 2.9	3.0 ± 0.0	0.100 ± 0.000	N/A	31.0 ± 1.4	3.1 ± 0.1	100.8 ± 2.4	390.6 ± 2.6
	264320[x]	42.7 ± 10.3	4.0 ± 0.0	0.150 ± 0.071	N/A	54.6 ± 6.9	5.5 ± 0.7	113.6 ± 3.6	394.8 ± 12.6
	271039[x]	23.0 ± 19.4	1.5 ± 0.7	0.200 ± 0.141	N/A	9.1 ± 0.3	0.9 ± 0.0	43.3 ± 6.2	41.0 ± 14.0
	274780[x]	14.7 ± 2.9	2.0 ± 0.0	0.200 ± 0.141	N/A	10.9 ± 0.6	1.1 ± 0.1	43.0 ± 2.2	38.9 ± 2.2
	288073[x]	37.0 ± 14.6	2.0 ± 0.0	0.200 ± 0.000	N/A	38.7 ± 24.6	3.9 ± 2.5	44.5 ± 0.6	19.1 ± 4.5
	288272[x]	11.5 ± 3.7	1.0 ± 0.0	0.200 ± 0.000	N/A	3.4 ± 0.2	0.3 ± 0.0	31.4 ± 0.8	18.2 ± 2.2
	546096[x]	66.1 ± 6.2	2.0 ± 0.0	0.250 ± 0.071	N/A	77.8 ± 4.9	7.8 ± 0.5	59.8 ± 0.7	118.1 ± 5.1
	546100[x]	20.3 ± 5.0	3.0 ± 0.0	0.150 ± 0.071	N/A	41.0 ± 7.6	4.1 ± 0.8	111.3 ± 2.6	510.0 ± 2.2
	546101[x]	27.2 ± 13.0	3.0 ± 0.0	0.200 ± 0.000	N/A	53.6 ± 4.0	5.4 ± 0.4	91.1 ± 1.3	322.1 ± 22

	546106[x]	25.7 ± 10.8	2.0 ± 0.0	0.200 ± 0.000	N/A	57.4 ± 5.1	5.7 ± 0.5	65.0 ± 0.1	138.7 ± 0.8
	546140[x]	32.1 ± 20.1	2.0 ± 0.0	0.200 ± 0.000	N/A	34.6 ± 1.1	3.5 ± 0.1	70.2 ± 3.8	173.3 ± 26.2
	546188[x]	21.6 ± 9.9	3.5 ± 0.7	0.150 ± 0.071	N/A	36.5 ± 9.4	3.7 ± 0.9	106.4 ± 11	491.2 ± 3.2
	546192[x]	18.5 ± 6.6	3.0 ± 1.4	0.150 ± 0.071	N/A	41.5 ± 0.0	4.2 ± 0.0	106.2 ± 1.1	765.8 ± 301.9
	Mean[x]	27.1 ± 8.1	2.5 ± 0.3	0.189 ± 0.037	N/A	38.6 ± 5.9	3.9 ± 0.6	59.4 ± 3.4	127.8 ± 16.3
	OLYSO5N5[y]	17.6 ± 7.4	3.5 ± 0.7	0.100 ± 0.000	N/A	50.8 ± 10.0	5.1 ± 1.0	100.9 ± 1.5	526.6 ± 10.8
	Colorado 6[z]	17.7 ± 3.3	3.5 ± 0.7	0.100 ± 0.000	N/A	31.3 ± 4.4	3.1 ± 0.4	111.2 ± 0.3	683.8 ± 86.7
	Mean[z]	26.7 ± 5.9	3.5 ± 0.2	0.133 ± 0.047	N/A	59.3 ± 10.7	5.9 ± 1.0	101.6 ± 5.7	471.6 ± 56.4
	Tukey's (0.05)[†]	42.4	2.2	0.263	-	37.8	3.8	19.8	188.6
2011	NMSU10620[x]	78.0 ± 6.9	2.2 ± 0.3	0.163 ± 0.015	0.144 ± 0.01	15.4 ± 7.6	2.0 ± 1.0	65.0 ± 6.2	108.4 ± 31.8
	NMSU10621[x]	87.8 ± 8.5	2.4 ± 0.5	0.184 ± 0.012	0.141 ± 0.008	15.6 ± 2.1	2.0 ± 0.3	63.7 ± 12.4	85.4 ± 43.8
	NMSU10634[x]	90.8 ± 1.5	2.4 ± 0.2	0.188 ± 0.002	0.123 ± 0.015	18.2 ± 4.9	2.4 ± 0.6	77.8 ± 3.2	222.4 ± 28.7
	NMSU10648[x]	86.7 ± 0.0	2.3 ± 0.0	0.182 ± 0.000	0.115 ± 0.000	20.4 ± 6.9	2.7 ± 0.9	78.7 ± 3.3	220.1 ± 31.5
	NMSU10656[x]	82.8 ± 17.3	2.7 ± 0.3	0.171 ± 0.035	0.137 ± 0.016	15.7 ± 10.5	2.0 ± 1.4	70.4 ± 8.6	178.4 ± 60.8
	NMSU10753[x]	81.8 ± 4.6	2.7 ± 0.2	0.175 ± 0.007	0.163 ± 0.024	9.8 ± 0.5	1.3 ± 0.1	62.3 ± 5.1	74.4 ± 15.6
	NMSU10769[x]	80.8 ± 8.2	2.7 ± 0.0	0.167 ± 0.021	0.133 ± 0.009	14.7 ± 2.1	1.9 ± 0.3	74.3 ± 3.5	251.9 ± 45.1
	258956[x]	79.7 ± 7.2	2.6 ± 0.2	0.172 ± 0.010	0.132 ± 0.015	15.7 ± 5.4	2.1 ± 0.7	77.9 ± 7.4	234.6 ± 52.5
	546188[x]	86.7 ± 6.3	2.7 ± 0.2	0.179 ± 0.013	0.146 ± 0.007	21.1 ± 6.0	2.8 ± 0.8	81.5 ± 2.8	285.5 ± 30.9
	B5336C[x]	88.8 ± 15.8	2.3 ± 0.0	0.185 ± 0.023	0.115 ± 0.000	12.1 ± 1.1	1.6 ± 0.1	90.3 ± 0.0	311.5 ± 0.0
	Mean[x]	79.9 ± 7.9	2.2 ± 0.3	0.168 ± 0.017	0.136 ± 0.017	11.2 ± 4.5	1.5 ± 0.6	55.5 ± 7.3	106.3 ± 27.6
	OLYS05N5[y]	80.0 ± 9.0	2.5 ± 0.2	0.169 ± 0.021	0.127 ± 0.015	15.0 ± 8.5	2.0 ± 1.1	90.8 ± 7.2	365.0 ± 37.1
	Mean[y]	88.6 ± 7.3	2.8 ± 0.2	0.184 ± 0.012	0.142 ± 0.011	20.9 ± 7.6	2.7 ± 1.0	90.7 ± 5.4	347.7 ± 41.3
	Colorado 6[z]	82.8 ± 5.6	2.7 ± 0.3	0.175 ± 0.009	0.130 ± 0.016	19.7 ± 11.3	2.6 ± 1.5	94.5 ± 2.5	395.2 ± 31.8
	Mean[z]	86.2 ± 5.0	2.7 ± 0.3	0.181 ± 0.008	0.135 ± 0.014	21.9 ± 7.1	2.9 ± 0.9	80.6 ± 5.7	268.9 ± 37.0
	Tukey's (0.05)[†]	30.3	1.3	0.063	0.067	19.5	2.5	28.8	121.2

Incidence of iris yellow spot was assessed at 71, 86, 99, and 113 days after planting in 2009; 84, 97, and 112 days after planting in 2010; and 107, 120, and 134 days after planting in 2011. There was no disease severity assessment in 2009; it was assessed at 117 days after planting in 2010; and at 107, 120, and 134 days after planting in 2011. Onion thrips were counted at 71, 86, and 99 days after planting in 2009; 63 and 83 days after planting in 2010; and 89, 96, and 112 days after planting in 2011.

[†]Tukey's values were obtained from analysis involving all the genotypes used in that year and not just the selected genotypes.

[x]USDA plant introductions (PI). PIs NMSU10634, NMSU10648 and NMSU10656 are selections from PI 258956 from the 2009 and 2010 evaluations; PI NMSU10753 is a selection from PI 288909 from the 2009 evaluations; PIs NMSU1620 and NMSU10621 are selections from PI 343049 from the 2009 evaluations; PI NMSU10769 is a selection from Mesquite.

[y]Advanced breeding line with which to compare PI genotypes.

[z]Commercial cultivar with which to compare PI genotypes.

rAUDPC-in = relative area under the disease progress curve for incidence of iris yellow spot disease.

rAUDPC-sv = relative area under the disease progress curve for severity of iris yellow spot disease.

N/A = parameter not measured.

Mean[x] = mean of all the PIs used that year. Mean[y] = mean of all the advanced breeding lines used that year. Mean[z] = mean of all the commercial cultivars used that year.

not expressed in terms of rAUDPC in 2010 because only one late-season rating was done at 117 days after planting. Severity was greatest at 4 in PI168962, PI 168966, and PI R64320, and least at 0.5 in PI 124525 and PI 248753. Severity was in the increasing order of Salsa Red, Colorado 6, and Vantage among the commercial cultivars, with values of 3, 3.5, and 4.0, respectively. Mean severity score was 2.5 in the plant introductions and 3.5 in OLYS05N5 and the commercial cultivars.

Incidence of disease was great from the beginning of the 2011 growing season, with an overall average incidence of 58.3% on the first day of evaluation (107 days after planting). There was more than 96% incidence in all genotypes by 120 days after planting, and by 134 days after planting, every plant in the field was infected. Incidence ranged from a rAUDPC-in of 0.201 in NMSU10632 to 0.136 in NMSU10597 among the plant introductions. Incidence was greatest in NUN76060N and least in OLYS05N5, with rAUDPC-in of 0.19 and 0.169, respectively, among the advanced breeding lines. Among the commercial cultivars, infection was greatest in T-433 (American Takii, Salinas, CA) and least in Rumba (Nunhems), with rAUDPC-in of 0.188 and 0.173, respectively. Seasonal incidence ranged from a rAUDPC-in of 0.168 in plant introductions, 0.181 in commercial cultivars, to 0.184 in advanced breeding lines, with mean incidence of 79.9, 86.2, and 88.6% in that order (Table 1). Severity of infection increased with time such that 4 was reached in OLYS05N5 and all commercial cultivars, and >3 in most plant introductions by 134 days after planting. Infection was most severe in NMSU10696 and least in NMSU10718, with rAUDPC-sv of 0.201 and 0.1, respectively, among the plant introductions. The rAUDPC-sv ranged from 0.127 in OLYS05N5 to 0.149 in NUN76060N (Nunhems) and OLYS03-207 (Crookham Co.) among the advanced breeding lines. Of the commercial cultivars, disease severity was least in Rumba with a rAUDPC-sv of 0.124, and most in T-433 with a 0.149 rAUDPC-sv. Mean severity was greatest at 2.8 in the advanced breeding lines, 2.7 in the commercial cultivars, and least at 2.2 in the plant introductions, with corresponding rAUDPC-sv of 0.142, 0.135, and 0.136, respectively.

For the pesticide experiments, all genotypes had 100% incidence of iris yellow spot by 121 days after planting. There was a significant rAUDPC-in effect among the genotypes, with PI 546188 having the highest of 0.156 and PI 546140 the lowest of 0.089. There was no significant pesticide effect on rAUDPC-in (P = 0.1115) and no significant genotype-by-pesticide interaction (P = 0.7269) (Table 2). Disease severity was >3 by 128 days after planting and significantly different among the genotypes and pesticide treatments, with p-values of <0.0001 for both average severity and rAUDPC-sv in genotypes, and 0.0016 and 0.0065, respectively, for average severity and rAUDPC-sv in the pesticide treatments. There were no significant genotype-by-pesticide interactions (P > 0.05) for both average severity and rAUDPC-sv.

Seasonal Dynamics of Onion Thrips Populations. Average abundance of thrips decreased with time on all genotypes in 2009. Thrips per plant per day were 1.5, 1.4, and 1.2 for commercial cultivars, plant introductions, and OLYS05N5, respectively (Table 1). Among the selected plant introductions in 2010, thrips were most abundant on PI 546096, with a seasonal average of 78 per plant and 7.8 per plant per day. PI 248753 had the lowest seasonal average of 0.7 thrips per plant and 0.1 per plant per day. Colorado 6 had ≈31 thrips per plant on all evaluation dates, with 3.1 per plant per day. OLYS05N5 had a seasonal average of 50 thrips per plant and corresponding 5.1 per plant per day. In 2011, thrips were generally

Table 2. Effects of Pesticides on the Responses of Onion Genotypes to Iris Yellow Spot (*Iris yellow spot virus*) and Onion Thrips (*Thrips tabaci* L.) in Fort Collins, CO, in 2011

		Iris yellow spot (mean ± SE)				Onion thrips (mean ± SE)		Bulb (mean ± SE)	
Genotype	Treatment	Incidence (%)	Severity	rAUDPC-in	rAUDPC-sv	Per plant	Thrips-day (thrips/plant/day)	Size (mm)	Weight (g)
258956	Check	84.5 ± 4.2x	2.7 ± 0.1x	0.152 ± 0.01x	0.149 ± 0.01x	10.3 ± 1.2x	1.3 ± 0.2xy	81.0 ± 2.0x	250.5 ± 12.9x
	Inst	81.9 ± 4.2x	3.3 ± 0.1y	0.145 ± 0.01x	0.189 ± 0.01y	9.2 ± 1.2x	1.0 ± 0.2x	76.3 ± 2.1x	214.3 ± 13.7y
	Inst+Act	85.1 ± 4.2x	2.8 ± 0.1x	0.154 ± 0.01x	0.154 ± 0.01x	11.5 ± 1.2x	1.4 ± 0.2y	81.1 ± 2.1x	249.7 ± 13.7x
	Mean	83.8 ± 4.2a	2.9 ± 0.1a	0.15 ± 0.01a	0.164 ± 0.00a	10.4 ± 1.2a	1.2 ± 0.2a	79.5 ± 2.1a	238.1 ± 13.4a
264320	Check	83.7 ± 4.2x	2.8 ± 0.1x	0.151 ± 0.01x	0.156 ± 0.01x	12.6 ± 1.2x	1.4 ± 0.2x	81.7 ± 2.0x	241.3 ± 12.7x
	Inst	88.7 ± 4.2x	3.1 ± 0.1x	0.157 ± 0.01x	0.174 ± 0.01x	9.9 ± 1.2x	1.1 ± 0.2x	82.7 ± 2.0x	249.1 ± 12.5x
	Inst+Act	86.2 ± 4.2x	2.9 ± 0.1x	0.153 ± 0.01x	0.159 ± 0.01x	12.7 ± 1.2x	1.4 ± 0.2x	86.9 ± 2.1x	288.4 ± 13.0y
	Mean	86.2 ± 4.2ab	2.9 ± 0.1ab	0.154 ± 0.01a	0.163 ± 0.0ab	11.7 ± 1.2b	1.3 ± 0.2a	83.7 ± 2.0b	259.6 ± 12.7b
546140	Check	75.1 ± 4.2x	2.0 ± 0.1x	0.08 ± 0.01x	0.087 ± 0.01x	4.9 ± 1.2x	1.0 ± 0.2x	43.8 ± 1.8x	37.2 ± 10.8x
	Inst	75.3 ± 4.2x	2.2 ± 0.1x	0.082 ± 0.01x	0.096 ± 0.01x	3.4 ± 1.2x	0.5 ± 0.2y	42.9 ± 1.9x	41.0 ± 11.6x
	Inst+Act	82.6 ± 4.2x	1.9 ± 0.1x	0.106 ± 0.01y	0.109 ± 0.01x	2.7 ± 1.2x	0.4 ± 0.2y	47.8 ± 2.1x	51.2 ± 13.0x
	Mean	77.7 ± 4.2ac	2.0 ± 0.1c	0.089 ± 0.01b	0.097 ± 0.00c	3.6 ± 1.2c	0.7 ± 0.2b	44.8 ± 1.9c	43.1 ± 11.8c
546188	Check	87.8 ± 4.2x	2.9 ± 0.1x	0.157 ± 0.01x	0.159 ± 0.01x	11.1 ± 1.2x	1.2 ± 0.2x	82.2 ± 2.0x	284.7 ± 12.9x
	Inst	89.4 ± 4.2x	3.0 ± 0.1x	0.159 ± 0.01x	0.168 ± 0.01x	11.1 ± 1.2x	1.2 ± 0.2x	83.3 ± 2.0x	295.9 ± 12.8x
	Inst+Act	84.8 ± 4.2x	3.1 ± 0.1x	0.153 ± 0.01x	0.171 ± 0.01x	11.5 ± 1.2x	1.2 ± 0.2x	81.4 ± 2.2x	287.5 ± 14.0x
	Mean	87.3 ± 4.2ad	3.0 ± 0.1abd	0.156 ± 0.01a	0.166 ± 0.0abd	11.2 ± 1.2ab	1.2 ± 0.2a	82.3 ± 2bd	289.4 ± 13.2d
Colorado 6	Check	77.9 ± 4.2x	2.6 ± 0.1x	0.137 ± 0.01x	0.138 ± 0.01x	8.9 ± 1.5x	1.1 ± 0.2x	83.1 ± 3.3x	293.3 ± 22.2x
	Inst	82.0 ± 4.2x	2.9 ± 0.1x	0.146 ± 0.01x	0.174 ± 0.01y	7.9 ± 1.5x	0.9 ± 0.2x	86.5 ± 2.9x	323.3 ± 19.3x
	Inst+Act	84.9 ± 4.2x	2.8 ± 0.1x	0.151 ± 0.01x	0.156 ± 0.01xy	11.3 ± 1.6x	1.2 ± 0.2x	84.6 ± 2.8x	296.0 ± 18.3x
	Mean	81.6 ± 4.2a	2.8 ± 0.1abe	0.145 ± 0.01a	0.156 ± 0.0abde	9.4 ± 1.5a	1.1 ± 0.2a	84.7 ± 3bde	304.2 ± 19de
Salsa Red	Check	79.9 ± 4.2x	2.7 ± 0.1x	0.142 ± 0.01x	0.175 ± 0.01x	17.2 ± 1.2x	1.9 ± 0.2x	63.9 ± 2.2x	132.1 ± 14.0x
	Inst	82.4 ± 4.2x	2.8 ± 0.1x	0.151 ± 0.01x	0.157 ± 0.01x	14.8 ± 1.2x	1.6 ± 0.2x	68.8 ± 2.1x	152.9 ± 13.6x
	Inst+Act	89.4 ± 4.2x	2.9 ± 0.1x	0.161 ± 0.01x	0.161 ± 0.01x	17.9 ± 1.2x	1.9 ± 0.2x	69.1 ± 2.1x	160.3 ± 13.3x
	Mean	83.9 ± 4.2a	2.8 ± 0.1abde	0.151 ± 0.01a	0.164 ± 0.0abde	16.6 ± 1.2d	1.9 ± 0.2c	67.3 ± 2.1f	148.4 ± 13.7f
Talon	Check	83.9 ± 4.2x	2.8 ± 0.1x	0.15 ± 0.01x	0.157 ± 0.01x	14.6 ± 1.2x	1.6 ± 0.2x	59.8 ± 1.9x	112.4 ± 12.1x

	Inst	85.2 ± 4.2x	3.1 ± 0.1x	0.152 ± 0.01x	0.174 ± 0.01x	12.9 ± 1.2x	1.4 ± 0.2x	55.0 ± 2.2x	95.5 ± 13.8x
	Inst+Act	84.1 ± 4.2x	3.1 ± 0.1x	0.152 ± 0.01x	0.174 ± 0.01x	12.5 ± 1.1x	1.4 ± 0.2x	60.5 ± 2.1x	121.2 ± 13.2x
	Mean	84.4 ± 4.2ae	3.0 ± 0.1abdf	0.151 ± 0.01a	0.169 ± 0.0abde	13.4 ± 1.1e	1.5 ± 0.2d	58.5 ± 2.1g	109.7 ± 13.0g
	Grand mean	83.6 ± 4.2	2.8 ± 0.1	0.142 ± 0.01	0.154 ± 0.00	10.9 ± 1.3	1.3 ± 0.2	71.5 ± 2.2	198.9 ± 14.0
Main-Plot Factors									
	Check	81.8 ± 1.8r	2.6 ± 0.1r	0.138 ± 0.00r	0.146 ± 0.00r	11.4 ± 0.9r	1.4 ± 0.1r	70.8 ± 1.4r	193.1 ± 7.9r
	Inst	83.6 ± 1.8r	2.9 ± 0.1s	0.142 ± 0.00rs	0.162 ± 0.00s	9.9 ± 0.9r	1.1 ± 0.1r	70.8 ± 1.4r	196.0 ± 7.8r
	Inst+Act	85.3 ± 1.8r	2.8 ± 0.1s	0.147 ± 0.00s	0.155 ± 0.00s	11.5 ± 0.9r	1.3 ± 0.1r	73.1 ± 1.4r	207.7 ± 7.8r

Both incidence and severity of iris yellow spot were assessed at 100, 107, 114, and 121 days after planting; with one additional severity assessment at 128 days after planting. Onion thrips abundance was assessed at 82, 89, 105, and 119 days after planting.
Genotypes with the same letters in a column are not significantly different at α = 0.05.
Treatments with the same letters within a genotype are not significantly different at α = 0.05.
Main plot factors with the same letters in a column are not significantly different at α = 0.05.
Inst = insecticide treatment. Inst+Act = insecticide+Actigard treatment.
rAUDPC-in = relative area under the disease progress curve for iris yellow spot disease incidence.
rAUDPC-sv = relative area under the disease progress curve for iris yellow spot disease severity.

most abundant on most genotypes at 96 days after planting and least on the last evaluation day (112 days after planting). Among the selected plant introductions, PI 546188 was most infested with 2.8 thrips per plant per day and NMSU10753 the least with 1.3 thrips per plant per day. Least infestation among the advanced breeding lines was 2.0 thrips per plant per day on OLYS05N5. Among the commercial cultivars, thrips were most abundant on Vantage and Rumba with 3.4 and 2.0 per plant per day, respectively. Although differences were not significant, commercial cultivars, followed by advanced breeding lines, and plant introductions were most infested by thrips in 2010 and 2011.

For the pesticide experiments, thrips were most abundant at 89 days after planting and decreased to least at 119 days after planting, the last estimation day. Abundance of thrips throughout the season differed significantly among the genotypes ($P < 0.001$). The greatest seasonal average was 16.6 thrips per plant of Salsa Red and the least was 3.6 thrips per plant on PI 546140, with 1.9 and 0.7 thrips per plant per day, respectively (Table 2). Pesticide treatments had no significant impact on thrips ($P > 0.05$); neither were there significant genotype-by-pesticide interactions ($P = 0.1295$).

Onion Bulb Yield. Bulb size (diameter) was the only parameter used in 2009. Both bulb size and weight were measured in 2010 and 2011. In 2009, bulbs of PI 546188 were largest (105.1 mm) among the plant introductions. Colorado 6 had the largest bulbs (101.1 mm) among the commercial cultivars, and the size of OLYS05N5 was only 88.0 mm per bulb. Bulb size averaged 55.5 mm in the plant introductions and 90.7 mm in the commercial cultivars (Table 1). In 2010, bulb size ranged from 28.0 mm in PI 248753 to 113.6 mm in PI 264320, 111.2 mm in Colorado 6, and 100.9 mm in OLYS05N5. Mean bulb weight was 526.6 g in OLYS05N5, 471.6 g in the commercial cultivars, and 127.8 g in the plant introductions. In 2011, advanced breeding lines had the largest mean bulb size of 90.7 mm with corresponding greatest mean bulb weight of 347.7 g, followed by commercial cultivars with bulb size of 80.6 mm and weight of 268.9 g, and then plant introductions with bulb size of 55.5 mm and weight of 106.3 g.

In the pesticide experiments, the genotypes were significantly different in bulb size ($P < 0.0001$) and weight ($P < 0.0001$), with Colorado 6 having the largest bulbs at 84.7 mm and greatest weight of 304.2 g. Among the plant introductions, PI 264320 had the largest at 83.7 mm and PI 546188 the greatest weight of 289.4 g per bulb. The least yield was produced by PI 546140 with a size of 44.8 mm and weight of 43.1 g per bulb (Table 2). Pesticide treatments had no significant effect on bulb size ($P = 0.4418$) or weight ($P = 0.4116$). There were no significant genotype-by-pesticide interactions ($P > 0.05$) for yield, except for PI 258956 and PI 264320 in which there were significant interactions for bulb weight. In these interactions, insecticide+Actigard produced the heaviest bulbs.

Selection of Onion Genotypes for Resistance to Iris Yellow Spot and/or Onion Thrips. Only the plant introductions were selected. Genotypes were selected for exhibiting response to *Iris yellow spot virus* and/or onion thrips better than the commercial standard Colorado 6 or OLYS05N5, or better than the average response of the commercial cultivars, while still providing acceptable bulb yield and agronomic characteristics. Acceptable agronomic characteristics included among other things, adaptability to Colorado weather/growing conditions. Therefore, genotypes that did not produce bulbs and showed indeterminate habits (prolific leaf production with no crop maturation) were rejected. The selection criteria were modified to reflect the pest/pathogen situation that prevailed in a given year. In

2009, selection was based on bulb size and numbers of thrips because of low incidence of virus. In 2010, selection was based on either having low disease incidence and severity, and low thrips abundance (e.g., PI 248753) or for yielding well even in the presence of high pest/pathogen pressure (e.g., PI 264320) (Table 1). Because of 100% incidence in all genotypes in 2011, selection was based on disease severity, thrips abundance, and a minimum bulb size of 62 mm. Sixteen of 80, 15 of 58, and 10 of 69 genotypes were selected in 2009, 2010, and 2011, respectively.

PI 264320 (Grano), PI 546140 (San Joaquin), and PI 546192 (Yellow Sweet Spanish L) were selected in 2009 and in 2010, while PI 258956 (Calderana 1028) and PI 546188 (Yellow Sweet Spanish Winegar) were selected in all 3 years of the study (Table 1). In 2009, there was no virus in PI 258956 or PI 546188 while rAUDPC-in in PI 264320 and PI 546140 was the same as in the commercial cultivars. PI 546192 had a higher (but not significant) rAUDPC-in of 0.2, yet its bulbs were slightly larger than those of Colorado 6 that had a rAUDPC-in of 0.1. Bulbs of PI 258956 and PI 546192 were larger but more infested than OLY05N5 with thrips. Fewer thrips were on the five plant introductions than Colorado 6. In 2010, all five plant introductions had rAUDPC-in equal to or greater (but not significant) than OLY05N5 and Colorado 6. Yet, all except PI 546140 produced bulbs equal to those of the commercial cultivars. In 2011, PI 258956 had less incidence of iris yellow spot and thrips pressure than Colorado 6, while PI 546188 yielded more than the mean of the commercial cultivars despite sustaining almost the same virus and thrips pressure. The agronomic characteristics of the five plant introductions are shown in Table 3. PI 546140 had the fewest leaves per plant and matured earliest in all 3 years. Leaves per plant and days to bulbing and maturity were almost the same for the other four plant introductions in each year. Leaf color in each plant introduction except PI 258956 that had lighter colored leaves in 2010 was fairly consistent in all 3 years. All plant introductions, except PI 546140, had some split/bunch habit in 2009; however, due in part, to selection of single-centered bulbs from the segregating population for advancement, this habit was lacking or substantially reduced in 2010 and 2011.

Model Selection for Bulb Yield, Response to Iris Yellow Spot, and Abundance of Onion Thrips. Several agronomic characteristics were measured as determinants of yield or response to iris yellow spot and/or onion thrips. Variables influential in the genotype evaluation study and the pesticide experiment are presented in Tables 4 and 5, respectively. In 2009, none of the measured parameters significantly impacted disease incidence although days to bulbing, relative maturity, and percentage of split/bunched were selected by the model. In 2010, days to bulbing and maturity, and thrips-day were determinants of disease incidence; leaves per plant, leaf color, days to maturity, and thrips-day were incidence determinants in 2011. Days to maturity and thrips-day were significant determinants of disease severity in 2010 and 2011; and leaves per plant and split/bunch were additional determinants in 2010 and 2011, respectively. Leaves per plant and days to bulbing and maturity were positively related with infestation by thrips, while split/bunch negatively impacted thrips abundance in all 3 years. Leaf color significantly impacted thrips-day in 2010. For all 3 years, bulb size increased with increasing leaves per plant and days to maturity but decreased with increasing days to bulbing and split/bunch. Leaf color was significantly positively related to bulb size in 2009 (Marlows' C_p) and 2010 (Pearson's correlation coefficient) but had

Table 3. Agronomic Characteristics of Onion Genotypes Selected for Response to Iris Yellow Spot (*Iris yellow spot virus*) and Onion Thrips (*Thrips tabaci* L.) in Fort Collins, CO, from 2009 to 2011

Year	Genotype	Leaves/plant (mean ± SE)	Leaf color (CCI) (mean ± SE)	Bulbing (DAP) (mean ± SE)	Maturity (DAP) (mean ± SE)	Split/bunch (%) (mean ± SE)
2009	258956[x]	10.2 ± 0.1	62.2 ± 0.0	86.0 ± 0.0	143.0 ± 0.0	6.1 ± 0.0
	264320[x]	10.6 ± 0.0	62.6 ± 0.0	87.9 ± 2.7	143.0 ± 0.0	20.9 ± 0.0
	546140[x]	8.3 ± 0.3	61.5 ± 6.9	88.4 ± 0.7	122.0 ± 0.0	0.0 ± 0.0
	546188[x]	10.5 ± 0.4	59.8 ± 0.0	86.5 ± 0.8	144.0 ± 0.0	15.8 ± 0.0
	546192[x]	10.2 ± 1.3	65.3 ± 0.0	89.4 ± 3.1	144.0 ± 0.0	17.4 ± 0.0
	Mean[x]	8.7 ± 0.6	64.3 ± 0.5	*96.3 ± 3.6*	*137.4 ± 0*	*33.2 ± 0.*0
	OLYS05N5[y]	8.3 ± 1.2	70.9 ± 0.7	96.3 ± 4.2	137.0 ± 0.0	0.0 ± 0.0
	Colorado 6[z]	9.9 ± 0.6	68.4 ± 0.6	93.2 ± 3.3	143.0 ± 0.0	0.0 ± 0.0
	Mean[z]	9.9 ± 0.7	65.7 ± 0.3	*91.4 ± 3.8*	*138.0 ± 0.*0	*07 ± 0.*0
	Tukey (0.05)[†]	3.4	6.6	61.3	0	0
2010	258956[x]	10.9 ± 2.7	53.9 ± 1.0	84.0 ± 0.0	142.0 ± 0.0	0.0 ± 0.0
	264320[x]	9.1 ± 0.5	57.9 ± 1.2	85.4 ± 1.0	142.0 ± 0.0	5.0 ± 7.1
	546140[x]	6.7 ± 0.6	65.8 ± 1.4	84.0 ± 0.0	119.1 ± 1.2	0.0 ± 0.0
	546188[x]	8.8 ± 0.5	60.6 ± 0.8	84.4 ± 0.5	142.0 ± 0.0	0.0 ± 0.0
	546192[x]	9.6 ± 0.2	63.5 ± 2.5	84.0 ± 0.0	142.0 ± 0.0	0.0 ± 0.0
	Mean[x]	*7.6 ± 0.5*	*57.8 ± 1.5*	*85.5 ± 0.8*	*129.3 ± 2.4*	*26.1 ± 6.6*
	OLYO5N5[y]	9.5 ± 0.2	58.8 ± 1.7	85.1 ± 1.5	142.0 ± 0.0	0.0 ± 0.0
	Colorado 6[z]	10.1 ± 0.1	57.2 ± 2.9	85.4 ± 2.0	142.0 ± 0.0	0.0 ± 0.0
	Mean[z]	*9.8 ± 0.2*	*57.7 ± 1.1*	*85.0 ± 1.3*	*139.2 ± 0.5*	*0.0 ± 0.0*
	Tukey's (0.05)[†]	3	8.2	6	14.3	45.8
2011	258956[x]	8.5 ± 1.5	60.7 ± 3.1	185.3 ± 2.2	226.7 ± 8.1	0.0 ± 0.0
	264320[x]	9.9 ± 0.7	63.2 ± 1.9	186.0 ± 3.7	229.0 ± 0.0	0.3 ± 0.2
	546140[x]	6.6 ± 0.9	N/A	176.5 ± 1.1	203.5 ± 4.3	0.0 ± 0.0
	546188[x]	9.5 ± 1.3	61.7 ± 3.0	193.0 ± 7.8	234.3 ± 3.5	0.0 ± 0.0
	546192[x]	9.5 ± 1.8	65.6 ± 3.7	194.1 ± 5.5	238.8 ± 6.7	0.2 ± 0.2
	Mean[x]	*6.7 ± 1.0*	*63.8 ± 3.6*	*188.1 ± 7.4*	*224.0 ± 6.7*	*0.2 ± 0.1*

OLYS05N5[y]	8.4 ± 1.5	64.5 ± 2.4	199.1 ± 9.4	238.5 ± 16.7	0.0 ± 0.0
Mean[y]	*9.7 ± 1.1*	*67.3 ± 2.0*	*193.6 ± 4.6*	*238.7 ± 7.4*	*0.0 ± 0.0*
Colorado 6[z]	10.1 ± 3.7	69.3 ± 5.6	196.2 ± 9.0	246.5 ± 4.0	0.0 ± 0.0
Mean[z]	*8.7 ± 1.1*	66.2 ± 2.6	*193.1 ± 5.4*	*238.0 ± 3.6*	*0.1 ± 0.1*
Tukey's (0.05)[†]	3.9	9.2 ± 2.7	60	42.5	0.6

[†]Tukey's values were obtained from analysis involving all the genotypes used in that year and not just the selected genotypes.
[x]USDA plant introductions (PI).
[y]Advanced breeding line with which to compare PI genotypes.
[z]Commercial cultivar with which to compare PI genotypes.
Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter.
N/A = not measured because leaves were too thick to fit in the chlorophyll meter.
Mean[x] = mean of all the PIs used that year. Mean[y] = mean of all the advanced breeding lines used that year. Mean[z] = mean of all the commercial cultivars used that year.

an insignificant negative relationship in 2011. Bulb weight increased with increasing leaves per plant, leaf color, and relative maturity, but decreased with split/bunch, thrips-day, and rAUDPC-in in 2010, which it increased with leaves per plant and days to maturity but decreased with split/bunch in 2011 (Table 4). Because the pesticide treatments were not significant, this factor was excluded from the correlation and regression analyses. Infestation by thrips determined incidence but not severity of iris yellow spot. Severity, rather than incidence, of *Iris yellow spot virus* was the best predictor of bulb yield. Thrips abundance negatively affected bulb weight but not size (Table 5).

Table 4. Predictors of Onion Genotype Responses to Iris Yellow Spot (*Iris yellow spot virus*) and Onion Thrips (*Thrips tabaci* L.) as Determined by Marlows' C_p Method and Pearson's Correlation Coefficients

Response	Year	Variable	Parameter estimate	*P*	Correlation coefficients	*P*
rAUDPC-in	2009	Intercept	-0.12	0.6886	-	-
		S/B	0.00	0.0880	-0.132	0.2293
		Bulbing	0.00	0.2330	-0.131	0.2306
		Maturity	0.00	0.1892	0.046	0.6753
	2010	Intercept	0.00	0.9853	-	-
		Bulbing	0.01	0.0010	0.317	0.0120
		Maturity	0.00	<0.0001	-0.469	0.0001
		Thrips-day	0.01	0.0018	0.099	0.4449
	2011	Intercept	0.09	0.0001	-	-
		Leaves/plant	0.01	<0.0001	0.658	<0.0001
		Leaf color	0.00	0.1764	0.262	0.0337
		Maturity*	-	-	0.292	0.0082
		Thrips-day*	-	-	0.664	<0.0001
Severity	2010	Intercept	3.35	0.2851	-	-
		Leaves/plant	0.29	0.0001	0.707	<0.0001
		Thrips-day	0.05	0.2970	0.352	0.0050
		Maturity*	-	-	0.624	<0.0001
		Thrips-day*	-	-	0.352	0.0050
rAUDPC-sv	2011	Intercept	0.20	<0.0001	-	-
		Maturity	0.00	0.0199	-0.107	0.3425
		Thrips-day	0.01	<0.0001	0.229	0.0402
		S/B*	-	-	-0.251	0.0236
Thrips-day	2009	Intercept	-10.28	<0.0001	-	-
		Leaves/plant	0.24	<0.0001	0.382	0.0003
		S/B	-0.01	<0.0001	-0.059	0.5892
		Bulbing	0.03	0.0001	0.215	0.0482
		Maturity	0.05	<0.0001	0.373	0.0004
	2010	Intercept	-25.99	0.0003	-	-
		Leaves/plant	0.99	<0.0001	0.687	<0.0001
		S/B	-0.02	0.0068	-0.243	0.0570
		Bulbing	0.24	0.0036	0.183	0.1543
		rAUDPC-in	11.44	0.0040	0.099	0.4449
		Leaf color*	-	-	0.315	0.0127

		Maturity*	-	-	0.475	<0.0001
		Severity*	-	-	0.352	0.0050
	2011	Intercept	-5.28	0.0014	-	-
		Leaves/plant	0.40	<0.0001	0.894	<0.0001
		S/B	-0.53	0.0264	-0.043	0.7035
		Maturity	0.01	0.0706	0.551	<0.0001
		rAUDPC-sv	10.92	0.0381	0.229	0.0402
		rAUDPC-in*	-	-	0.664	<0.0001
Bulb size	2009	Intercept	-196.49	<0.0001	-	-
		Leaves/plant	5.28	<0.0001	0.350	0.0010
		Leaf color	1.43	0.0002	0.129	0.2445
		S/B	-0.50	<0.0001	-0.428	<0.0001
		Bulbing	-0.60	0.0049	-0.327	0.0022
		Maturity	1.39	<0.0001	0.092	0.4014
	2010	Intercept	-27.88	0.6886	-	-
		Leaves/plant	6.55	0.0006	0.763	<0.0001
		Leaf color	0.80	0.1191	0.369	0.0031
		S/B	-0.38	<0.0001	-0.469	0.0001
		Bulbing	-1.09	0.1495	-0.243	0.0570
		Maturity	0.70	0.0035	0.678	<0.0001
		Thrips-day	-1.23	0.2274	-0.495	<0.0001
		rAUDPC-in*	-	-	-0.383	0.0021
	2011	Intercept	-85.21	0.0556	-	-
		Leaves/plant	5.51	<0.0001	0.816	<0.0001
		Leaf color	-0.47	0.1838	-0.016	0.9020
		S/B	-24.09	<0.0001	-0.102	0.3642
		Bulbing	-0.12	0.3111	0.142	0.2036
		Maturity	0.72	<0.0001	0.659	<0.0001
Bulb weight	2010	Intercept	-1219.89	0.0006	-	-
		Leaves/plant	60.17	<0.0001	0.626	<0.0001
		Leaf color	7.29	0.1017	0.361	0.0039
		S/B	-3.49	<0.0001	-0.514	<0.0001
		Maturity	5.26	0.0050	0.598	<0.0001
		Thrips-day	-29.10	0.0006	-0.330	0.0088
		rAUDPC-in*	-	-	-0.421	0.0007
	2011	Intercept	-1109.58	<0.0001	-	-
		Leaves/plant	32.93	<0.0001	0.757	<0.0001
		S/B	-190.72	<0.0001	-0.202	0.0691
		Maturity	4.57	<0.0001	0.595	<0.0001

rAUDPC-in = relative area under the disease progress curve for iris yellow spot disease incidence.
rAUDPC-sv = relative area under the disease progress curve for iris yellow spot disease severity.
*Variables not selected by Marlows' C_p but shown by Pearson's correlation coefficient as significant predictors.
S/B = percentage of split/bunched.

Table 5. Effects of Pesticides on the Predictors of Onion Genotype Response to Iris Yellow Spot (*Iris yellow spot virus*) and Onion Thrips (*Thrips tabaci* L.) as Determined by Marlows' C_p Method and Pearson's Correlation Coefficients

Response	Variable	Parameter estimate	*P*	Correlation coefficients	*P*
rAUDPC-in	Intercept	0.65	<0.0001	-	-
	Bulbing	4.53	0.0017	0.61	0.0033
	Thrips-day	0.11	<0.0001	0.96	<0.0001
	Maturity*	-	-	0.48	0.0276
rAUDPC-sv	Intercept	63.27	<0.0001	-	-
	Bulbing	160.66	<0.0001	0.81	<0.0001
	Leaves/plant*	-	-	0.70	0.0004
	Maturity*	-	-	0.64	0.0016
	Thrips-day*	-	-	0.51	0.0169
Thrips-day	Intercept	-5.08	0.0005	-	-
	Leaves/plant	0.23	0.3232	0.50	0.0202
	Bulbing	55.77	0.0006	0.76	<0.0001
	rAUDPC-in	8.04	<0.0001	0.96	<0.0001
	Maturity*	-	-	0.63	0.0020
	rAUDPC-sv*	-	-	0.51	0.0169
Bulb size	Intercept	0.03	0.4988	-	-
	Leaves/plant	-0.01	0.0356	0.60	0.0037
	Bulbing	0.67	0.0034	0.88	<0.0001
	Maturity	0.05	<0.0001	0.94	<0.0001
	rAUDPC-sv	0.00	0.2579	-0.62	0.0025
Bulb weight	Intercept	191.81	<0.0001	-	-
	Bulbing	450.04	<0.0001	0.57	0.0069
	rAUDPC-sv	-1.78	0.0001	-0.11	0.6489
	Thrips-day	-0.34	0.3155	-0.45	0.0388
	Maturity*	-	-	0.53	0.0137

rAUDPC-in = relative area under the disease progress curve for Iris yellow spot disease incidence.
rAUDPC-sv = relative area under the disease progress curve for Iris yellow spot disease severity.
*Variables not selected by Marlows' C_p but shown by Pearson's correlation coefficient as significant predictors.

Discussion

In the *Iris yellow spot virus*-onion and thrips-onion pathosystem, management approaches would benefit from onion cultivars with resistance to the virus and/or vector. There is little to no evidence of resistance in onion cultivars currently available for commercial production (du Toit and Pelter 2005, Shock et al. 2008, Diaz-Montano et al. 2010). This necessitates the search for this vital component for the economic management of this pathosystem. The results of this study indicated that onion genotypes existed that showed reduced damage and yield losses. Thirty-four genotypes were identified that exhibited better performance

under natural pressure from *Iris yellow spot virus* and onion thrips. Of these, PI 258956 (Calderana 1028), PI 264320 (Grano), PI 546140 (San Joaquin), PI 546192 (Yellow Sweet Spanish), and PI 546188 (Yellow Sweet Spanish Winegar) provided consistent performance (Table 1). With the exception of PI 546140 that has fewer leaves and exhibits early maturity, the other four plant introductions have agronomic characteristics similar to Colorado 6 and OLY05N5 if not for their tendency to split/bunch (Table 3). They also have the potential for yield (and bulb size) comparable to Colorado 6 (e.g., PI 546192 in 2009 and PI 264320 in 2010 (Table 1)). These genotypes should be useful to improve the performance of commercial cultivars to reduce losses by the two pests.

Although the mode of action by the genotypes was not determined, clues can be garnered from the model selection procedure and Pearson's correlation coefficients to determine the variables that predict performance. The model selection method did not identify iris yellow spot as a significant predictor of bulb yield in this study (Table 4). This was expected in 2009 because infection was low. Although infection was high in 2011, unfavorable environmental conditions might have masked the adverse effects of the virus. Between 3 and 20 days after planting, night temperatures were colder than -2.2^{o}C six times, resulting in severe damage or death of many plants. Maturity of plants that survived the frost was delayed 80 to >100 days across all genotypes as compared to 2009 and 2010 (sample examples shown in Table 3). This extended presence in the field also predisposed the plants to other pathogens, particularly bacterial leaf blight caused by *Xanthomonas axonopodis* pv. *allii* (Dowson) (Boateng et al. 2011). In 2010, pressure by iris yellow spot was great and most genotypes showed significant differential effects. The Pearson's correlation coefficients indicated that 38-42% of yield loss in 2010 could have been caused by infection by iris yellow spot, and damage by thrips might have caused 33-44% yield loss (Table 4).

Both incidence/severity of disease and infestation by thrips increased with increasing leaf number and days to bulbing and maturity (Table 4). Thus, plants with fewer leaves and earlier maturity without compromising yield might attract fewer thrips and suffer less feeding (Loges et al. 2004) and iris yellow spot damage. Such a phenotype was expressed by PI 546140 in the pesticide experiment (Table 2). Leaves of this genotype were fewer, thicker, shorter, and circular, and plants had a more open canopy. It matured at a time when bulbing had just started in the other genotypes. These characteristics have been reported to create antixenotic phenotypes that deter onion thrips (Jones et al. 1935, Coudriet et al. 1979, Loges et al. 2004). Such characteristics resulted in less infection by virus and infestation by thrips; however, bulb yield was much less. A relationship between lighter leaf color and fewer thrips has long been hypothesized (e.g., Jones et al. 1935). Unfortunately, the significance of such a relationship was not consistent in this study because only in 2010 did leaf color impact abundance of thrips (Table 4). This could be caused, in part, by the fact that the genotypes were selected within the same leaf color group. Leaf color, however, significantly influenced incidence of iris yellow spot and bulb yield. It should be noted that in 2010 and 2011, thrips abundance increased with increasing iris yellow spot disease. This was observed in both evaluation study and the pesticide experiments (Table 5).

The pesticide treatments did not control thrips and iris yellow spot (Table 2). Actigard is used to activate plant natural defense mechanisms. Because it has no curative activity, it must be applied before infection (Syngenta 2012) to induce systemic-acquired resistance. Thus, its failure to curtail infection by iris yellow spot

in this study could be caused by an untimely application on plants already infected. Insecticidal management of onion thrips is the single most widely used control strategy in most onion-production systems. With the right choice of insecticides, it is currently reliable to significantly reduce thrips abundance and prevent economic injuries (Hammon 2004, Cranshaw 2006, Diaz-Montano et al. 2011). The three insecticides used in this experiment were for rotational purposes and not for direct comparison between the insecticides. Unlike Actigard which has no direct activity against pathogens, the other insecticides are directly lethal to onion thrips (Dow AgroSciences 2012, Gowan 2012) and should have provided significant control. Timing of application and mode of application and application rate were chosen to ensure efficient plant coverage and control. Although thrips in onion leaf crevices are not easily reached by insecticides (Cranshaw 2008), Movento provides two-way systemicity (both upward and downward systemic movement) in plants and targets pests wherever they live and feed on the plant (Bayer 2012). In an insecticide study in Colorado, conventional insecticides (Lannate alternated with Warrior) had 17-26% more thrips abundance than in untreated checks. Reduced-risk/microbial insecticides (e.g., spinosad alternated with azadirachtin) significantly reduced thrips abundance (Schwartz et al. 2009). Conventional insecticides might be losing their efficacy in controlling thrips in Colorado.

Selection of a genotype resistant to iris yellow spot was subjective and depended on the virus pressure at the evaluation site. Onion researchers should develop a clear definition of resistance and a standardized protocol for assessment of reaction to iris yellow spot. Such a protocol could be based on incidence and severity of disease expressed in relative area under the disease progress curve (rAUDPC), which in this study provided a better expression than only incidence percentage and severity score of the response of the genotype to iris yellow spot. In 2010 for example, PI 248753 had only 7.9% average incidence but a rAUDPC higher than PI 258956 that had 40.9% incidence (Table 1). A rAUDPC-based standardized protocol might lend itself to year-to-year as well as between-location and state comparisons of genotype response in the search for resistance to iris yellow spot.

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References Cited

Al-dosari, S. A. 1995. Development of an IPM system for onion thrips (*Thrips tabac*i Lindemann) as a pest of bulb onions. Ph.D. dissertation. Colorado State University, Fort Collins.

Bayer Crop Science. 2012. Movento Insecticide. http://www.bayercropscience.us/products/insecticides/movento/

Boateng, C. O., H. F. Schwartz, and K. Otto. 2011. Response of onion germplasms to frost and *Xanthomonas* leaf blight caused by *Xanthomonas axonopodis* pv. a*llii* (Dowson) in Colorado. Allium and Umbelliferae Improvement Newsl. 21: 6-10.

Brar, K. S., A. S. Sidhu, and M. L. Chadha. 1993. Screening onion varieties for resistance to *Thrips tabac*i Lind. and *Helicoverpa armigera* (Hubner). J. Insect Sci. 6: 123-124.

Brewster, J. L. 1994. Onions and Other Vegetable Alliums. CAB International, Oxon, UK.

Coudriet, D. L., A. N. Kishaba, J. D. McCreight, and W. G. Bohn. 1979. Varietal resistance in onions to thrips (Thysanoptera: Thripidae). J. Econ. Entomol. 72: 614-615.

Cranshaw, W. S. 2006. Colorado Insecticide Trials for Control of Thrips on Onions, 1995-2006. Colorado State Univ. Agric. Exp. Stn. Rep. TB06-01.

Cranshaw, W. S. 2008. Thrips, pp. 89-91. *In* H. F. Schwartz and S. K. Mohan [eds.], Compendium of Onion and Garlic Diseases and Pests, 2nd ed. APS Press, Minneapolis, MN.

Crowe, F. J., and H. R. Pappu. 2005. Outbreak of *Iris yellow spot virus* in onion seed crops in central Oregon. Plant Dis. 89: 105.

Dai, Y., M. Shao, D. Hannaway, L. Wang, J. Liang, L. Hu, and H. Lu. 2009. Effects of *Thrips tabaci* on anatomical features, photosynthetic characteristics and chlorophyll fluorescence of *Hypericum sampsonii* leaves. Crop Protection 28: 327-332.

Diaz-Montano, J., M. Fuchs, B. A. Nault, and A M. Shelton. 2010. Evaluation of onion cultivars for resistance to onion thrips (Thysanoptera: Thripidae) and *Iris yellow spot virus*. J. Econ. Entomol. 103: 925-937.

Diaz-Montano, J., M. Fuchs, B. A. Nault, J. Fail, and A. M. Shelton. 2011. Onion thrips (Thysanoptera: Thripidae): a global pest of increasing concern in onion. J. Econ. Entomol. 104: 1-13.

Dow AgroSciences. 2012. Radiant SC Insecticide. http://www.dowagro.com/usag/prod/033.htm

du Toit, L. J., and G. Q. Pelter. 2005. Susceptibility of storage onion cultivars to *Iris yellow spot virus* in the Columbia Basin of Washington. Biological & Cultural Tests 20: V006.

du Toit, L. J., G. Q. Pelter, and H. R. Pappu. 2004. IYSV challenges to the onion seed industry in Washington, pp. 103, 213-217. *In* Proc. National Allium Res. Conf., Grand Junction, CO.

du Toit, L. J., J. T. Burger, A. McLeod, M. Engelbrecht, and A. Viljoen. 2007. *Iris yellow spot virus* in onion seed crops in South Africa. Plant Dis. 91: 1203.

Elmore, J. C. 1949. Thrips injury to onions grown for seed. J. Econ. Entomol. 42: 756-760.

Finlay, K. W. 1952. Inheritance of spotted wilt resistance in the tomato. I. Identification of strains of the virus by the resistance or susceptibility of tomato species. Aust. J. Sci. Res. 5: 303-314.

Finlay, K. W. 1953. Inheritance of spotted wilt resistance in the tomato. II. Five genes controlling spotted wilt resistance in four tomato types. Aust. J. Sci. Res. 6: 153-163.

Gent, D. H., and H. F. Schwartz. 2008. Iris yellow spot, pp. 80-83. *In* H. F. Schwartz and S. K. Mohan [eds.], Compendium of Onion and Garlic Diseases and Pests, 2nd ed. APS Press, Minneapolis, MN.

Gent, D. H., H. F. Schwartz, and R. Khosla. 2004. Distribution and incidence of *Iris yellow spot virus* and its relation to onion plant population and yield. Plant Dis. 88: 446-452.
Gent, D. H., L. J. du Toit, S. F. Fichtner, S. K. Mohan, H. R. Pappu, and H. F. Schwartz. 2006. *Iris yellow spot virus*: an emerging threat to onion bulb and seed production. Plant Dis. 90: 1468-1480.
Gent, D. H., R. R. Martin, and C. M. Ocamb. 2007. First report of *Iris yellow spot virus* on onion and leek in western Oregon. Plant Dis. 91: 468.
Gowan Company. 2012. Carzol SP Insecticide. http://www.gowanco.com/ProductInfo.aspx?pid=45&Carzol SP/
Hammon, R. 2004. Managing thrips in western Colorado onions, pp. 107. *In* Proc. 2004 Natl. Allium Res. Conf., Grand Junction, CO.
Havey Lab. 2006. http://haveylab.hort.wisc.edu/cap/AlliumCAP%20Final%20Report.pdf.
Herron, G. A., T. M. James, and J. H. Mo. 2008. Australian populations of onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), are resistant to some insecticides used for their control. Aust. J. Entomol. 47: 361-364.
Hutton, E. M., and A. R. Peak. 1949. Spotted wilt resistance in the tomato. J. Aust. Inst. Agric. Sci. 15: 32-36.
Hutton, E. M., and A. R. Peak. 1953. Spotted-wilt development in resistant and susceptible *Lycopersicon* species. Aust. J. Agric. Res. 4: 160-167.
IPMCENTERS. 2013. Pest Management Strategic Plan for Dry Bulb Storage Onions in the United States. http://www.ipmcenters.org/pmsp/pdf/USonionPMSP.pdf with Contact Agency: Western IPM Center, http://www.wripmc.org.
Jones, R. A. C. 2004. Patterns of spread of *Tomato spotted wilt virus* in field crops of lettuce and pepper: spatial dynamics and validation of control measures. Ann. Appl. Biol. 145: 231-245.
Jones, R. A. C. 2006. Control of plant virus diseases. Adv. Virus Res. 67: 205-244.
Jones, H. A., S. F. Bailey, and S. L. Emsweller. 1935. Field studies of *Thrips tabaci* Lind. with special reference to resistance in onions. J. Econ. Entomol. 28: 678-680.
Kennedy, G. G. 2008. Integration of insect-resistant genetically modified crops within IPM programs, pp. 11-26. *In* J. Romeis, A. M. Shelton, and G. G. Kennedy [eds.], Integration of Insect-resistant Genetically Modified Crops within IPM Programs. Springer, Dordrecht, Netherlands.
Kritzman, A., M. Lampel, B. Raccah, and A. Gera. 2001. Distribution and transmission of *Iris yellow spot virus*. Plant Dis. 85: 838-842.
Lewis, T. 1997. Pest thrips in perspective, pp. 1-13. *In* T. Lewis [ed.], Thrips as Crop Pests. CAB International, New York, NY.
Loges, V., M. A. Lemos, L. V. Resende, D. Menezes, J. A. Candeia, and V. F. Santos. 2004. Resisteˆncia de cultivares e hõ´bridos de cebola a tripes. Hortic. Bras. 22: 222-225.
MacIntyre-Allen, J. K., C. D. Scott-Dupree, J. H. Tolman, and C. R. Harris. 2005. Resistance of *Thrips tabaci* to pyrethroid and organophosphorus insecticides in Ontario, Canada. Pest Manag. Sci. 61: 809-815.
Madden, L. V., G. Hughes, and F. van den Bosch. 2007. The Study of Plant Disease Epidemics. American Phytopathological Society, St. Paul, MN.

Martin, N. A., P. J. Workman, and R. C. Butler. 2003. Insecticide resistance in onion thrips (*Thrips tabaci*) (Thysanoptera: Thripidae). N. Z. J. Crop Hortic. 31: 99-106.

McCallum, J., A. Clarke, M. Pither-Joyce, M. Shaw, R. Butler, D. Brash, J. Scheffer, I. Sims, S. van Heusden, M. Shigyo, and M. J. Havey. 2006. Genetic mapping of a major gene affecting onion bulb fructan content. Theor. Appl. Genet. 112: 958-967.

Mohan, S. K., and D. O. Wilson Jr. 1989. Scape blight of onion, pp. 103-104. *In* Proc. Nat. Onion Res. Conf., Boise, ID.

Mohseni-Moghadam, M., C. S. Cramer, R. L. K. Steiner, and R. Creamer. 2011. Evaluating winter-sown onion entries for *Iris yellow spot virus* susceptibility. HortSci. 46: 1224-1229.

Morishita, M. 2008. Pyrethroid-resistant onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), infesting persimmon fruit. Appl. Entomol. Zool. 43: 25-31.

Multani, P. S., C. S. Cramer, R. L. Steiner, and R. Creamer. 2009. Screening winter-sown onion entries for *Iris yellow spot virus* tolerance. HortSci. 44: 627-632.

Panda, N., and G. S. Khush. 1995. Host Plant Resistance to Insects. CAB International, Wallingford, UK.

Pappu, H. R., I. M. Rosales, and K. L. Druffel. 2008. Serological and molecular assays for rapid and sensitive detection of *Iris yellow spot virus* infection of bulb and seed onion crops. Plant Dis. 92: 588-594.

Pappu, H. R., R. A. C. Jones, and R. K. Jain. 2009. Global status of tospovirus epidemics in diverse cropping systems: successes gained and challenges ahead. Virus Res. 141: 219-236.

Parrella, M. P., and T. Lewis. 1997. Integrated pest management in field crops, pp. 595-614. *In* T. Lewis [ed.], Thrips as Crop Pests. CAB Wallingford, Oxon, UK.

Pozzer, L., I. C. Bezerra, R. Kormelink, M. Prins, D. Peters, R. O. Resende, and A. C. de Avila. 1999. Characterization of a tospovirus isolate of *Iris yellow spot virus* associated with a disease in onion fields in Brazil. Plant Dis. 83: 345-350.

Rueda, A., F. R. Badenes-Perez, and A. M. Shelton. 2007. Developing economic thresholds for onion thrips in Honduras. Crop Prot. 26: 1099-1107.

SAS v. 9.3., SAS Institute Inc., Cary, NC.

Schumann, G. L., and C. J. D'Arcy. 2006. How can we prevent or manage plant disease epidemics?, pp. 255–291. *In* G. L. Schumann and C. J. D' Arcy [eds.], Essential Plant Pathology, APS Press, Minneapolis, MN.

Schwartz, H. F., and L. du Toit. 2005. Onion IYSV Disease Severity Rating Guidelines. http://www.alliumnet.com/images/IYSV%20Disease%20Rating%20Guidelines%202.pdf

Schwartz, H. F., W. M. Brown Jr., T. Blunt, and D. H. Gent. 2002. *Iris yellow spot virus* on onion in Colorado. Plant Dis. 86: 560.

Schwartz, H. F., D. H. Gent, S. M. Fichtner, R. Hammon, W. S. Cranshaw, L. Mahaffey, M. Camper, K. Otto, and M. McMillan. 2009. Straw mulch and reduced-risk pesticide impacts on thrips and *Iris yellow spot virus* on western-grown onions. Southwest. Entomol. 34: 13-29.

Schwartz, H. F., D. H. Gent, S. M. Fichtner, R. Khosla, R. Reich, M. A. Camper, L. A. Mahaffey, and W. S. Cranshaw. 2010. Spatial and temporal distribution of *Iris yellow spot virus* and thrips in Colorado onion fields. APS Plant Management Network doi:10:1094/PHP-2010-0820-01-RS.

Shelton, A. M., B. A. Nault, J. Plate, and J. Z. Zhao. 2003. Regional and temporal variation in susceptibility to λ-cyhalothrin in onion thrips, *Thrips tabaci* (Thysanoptera:Thripidae) in onion fields in New York. J. Econ. Entomol. 96: 1843-1848.

Shelton, A. M., J. Z. Zhao, B. A. Nault, J. Plate, F. R. Musser, and E. Larentzaki. 2006. Patterns of insecticide resistance in onion thrips (Thysanoptera: Thripidae) in onion fields in New York. J. Econ. Entomol. 99: 1798-1804.

Shock, C. C., E. Feibert, L. Jensen, S. K. Mohan, and L. D. Saunders. 2008. Onion variety response to *Iris yellow spot virus*. Hort Tech. 18: 539-544.

Syngenta. 2012. Actigard 50WG. http://www.syngentacropprotection.com/prodrender/index.aspx?nav=MOA&ProdID=644&ProdNM=Actigard 50WG

Waiganjo, M. M., J. M. Mueke, and L. M. Gitonga. 2008. Susceptible onion growth stages for selective and economic protection from onion thrips infestation, pp. 193- 200. *In* R. K. Prange and S. D. Bishop [eds.], Proc. Symp.: Sustainability Through Integrated and Organic Horticulture. Int. Symp. Soc. for Hort. Sci. (ISHS), 13-19 August 2006, Seoul, Korea. Pub. Acta Hort. 767.