Screening Onion Plant Introduction Accessions for Tolerance to Onion Thrips and Iris Yellow Spot

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Abstract. Iris yellow spot is an economically important disease of onion that reduces bulb size and yield and is difficult to control. The disease is spread by *Thrips tabaci* (onion thrips) and disease symptoms are exacerbated by hot, dry climatic conditions that also favor rapid thrips multiplication and make control programs less effective. Currently, no onion cultivar is resistant to the disease and/or thrips. Certain onion foliar characteristics have shown nonpreferential feeding activity by thrips and may be the first step in developing Iris yellow spot (IYS)-tolerant onion cultivars. Seventy-five onion PI accessions from the U.S. germplasm collection were evaluated for leaf color, waxiness (bloom), and axil pattern; thrips number per plant; and IYS disease severity under conditions that favored thrips and disease buildup. Plants of PI 289689 were less attractive to thrips and had a lower number of thrips per plant than plants of most other accessions. These plants were rated as having light green to green-colored foliage and a relatively low amount of epicuticular leaf wax. Plants of PIs 239633 and 546192 generally exhibited less severe IYS disease symptoms than those of other accessions. Individual plants, that exhibited less leaf area exhibiting IYS disease symptoms, were selected at bulb maturity from 22 different accessions with PI 546140 producing the largest number of selected bulbs. Physiological plant development, environmental conditions, and tolerance to plant stress may influence the degree of disease symptom expression. Further work that examines the role of plant maturity and host plant tolerance to stress with respect to disease expression is needed.

In the United States, IYS disease, caused by *Iris yellow spot virus* (IYSV) (family *Bunyaviridae*, genus *Tospovirus*), was first observed in bulb onion crops in the Treasure Valley of Idaho and Oregon (Hall et al., 1993) and later in Colorado (Schwartz et al., 2002). Since then, IYS has been confirmed in most other onion producing states in the United States, including Arizona, California, Florida, Georgia, Michigan, New Mexico, New York, Nevada, Oregon, Texas, and Washington (Bag et al., 2009; Creamer et al., 2004; Crowe and Pappu, 2005; du Toit et al., 2004a; Gent et al., 2006; Hoepting et al., 2007; Miller et al., 2006; Mullis et al., 2004; Pappu et al., 2009; Pappu and Matheron, 2008; Poole et al., 2007). An IYS epidemic

in Colorado during 2003 was estimated to have cost growers \$2.5 to \$5.0 million in farm receipts alone (Schwartz and Gent, unpublished data). The virus is spread by onion thrips (*Thrips tabaci* L.). If the rate of spread and damage from IYS and onion thrips continues to be unchecked in the western United States, projected economic impacts could reach \$60 million (10% loss) to \$90 million (15% loss in farm gate value) per year in addition to environmental and economic costs incurred from an increase in numbers of pesticide sprays despite their limited efficacy (\$7.5 to \$12.5 million for three to five additional sprays on 48,500 ha per year) (Schwartz, unpublished data).

IYS is characterized by irregular or diamond-shaped straw-colored lesions that develop on leaves and seedstalks (du Toit et al., 2004a; Gent et al., 2004; Schwartz et al., 2002). If IYS symptoms become severe, bulb size is reduced and the yield of larger bulb classes is reduced (du Toit et al., 2004b; Gent et al., 2004). Control of IYS requires an integrated approach including control of the vector, cultural practices, and genetic resistance/tolerance. IYSV is transmitted principally by onion thrips (Kritzman et al., 2001; Nagata et al., 1999) that acquire the virus during their larval stage and transmit the virus

for their entire life. IYSV can also be transmitted by tobacco thrips (*Frankliniella fusca*) (Srinivasan et al., 2012). The primary means of controlling onion thrips is with insecticides. A promising and sustainable means for long-term thrips and IYS control is the development of cultivars that have an increased tolerance or resistance to the virus, thrips damage, and/or reduced thrips feeding injury.

Several evaluations of onion cultivar suitability as thrips hosts have been reported (Coudriet et al., 1979; Jones et al., 1934; Saxena, 1977). These studies documented differences in thrips populations colonizing on different cultivars, but the differences in thrips numbers on different cultivars have generally been more modest. Al-dosari (1995) expanded the idea of thrips resistance in onion by considering cultivar response to injury along with cultivar suitability to thrips as a factor in resistance to thrips. These studies developed the idea that tolerance to thrips feeding, rather than host plant resistance to insect infestation, can be a very important resistance mechanism involved in reducing damage to onion crops. A wide range in tolerance to thrips feeding injury was demonstrated independent of thrips populations on plants and these were expanded into the idea of varietal-based action thresholds that have been promoted in Midwest onion production (Davis et al., 1995). The idea behind this is that some cultivars suffer high yield loss from thrips infestation; others sustain little, if any, yield loss at similar thrips infestation levels (Mahaffey, 2006). These types of studies suggest that some cultivars (e.g., ‘Aspen’) are more susceptible to the effects of thrips feeding than are other cultivars (e.g., ‘Yula’) and that tolerance to injury is an important thrips resistance mechanism (Mahaffey, 2006).

In addition, cultivar differences for thrips damage are often associated with amounts of epicuticular waxes on leaves (Coudriet et al., 1979; Damon et al., 2014; Jones et al., 1934). Normal waxy onions possess copious amounts of epicuticular waxes (Damon et al., 2014) that build up on leaf surfaces and allow thrips to adhere to the plant and incite damage. Glossy foliage accumulates only sparse amounts of epicuticular waxes, appears lighter green in color, slows the growth of thrips populations, and experiences less damage from thrips feeding (Alimousavi et al., 2007; Damon et al., 2014; Jones et al., 1934; Molenaar, 1984; Mote and Sonone, 1977; Pawar et al., 1975). Some heirloom cultivars of onion (such as ‘Colorado #6’ and many ‘Sweet Spanish’ cultivars) are “semi-glossy” (Damon et al., 2014), meaning that the plants accumulate an intermediate amount of epicuticular waxes relative to glossy and waxy plants. As suggested by some studies, thrips also prefer blue-colored foliage to light green and green-colored foliage (Czencz, 1987; Kirk, 1984; Lu, 1990; cited in Gent et al., 2006). Plants with a higher amount of epicuticular leaf wax tend to have blue-colored foliage. Diaz-Montano et al. (2012) observed that two cultivars, Yankee and Nebula, had

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significantly higher numbers of thrips larvae as compared with other cultivars. Both of these cultivars possessed blue-colored foliage. Plant architecture has been suggested to influence a cultivar's susceptibility/resistance to thrips. Onion thrips typically reside in the tight junction (axil) of the basal portion of the visible leaves. Jones et al. (1934) suggested that the tight leaf axil of 'White Persian' might be a possible mechanism of thrips resistance in that cultivar.

Although numerous evaluations have been conducted, no onion cultivar or breeding line has been found to be highly resistant to IYS (Boateng et al., 2014; du Toit et al., 2004b; Gent et al., 2004, 2006; Mohseni-Moghadam et al., 2011; Multani et al., 2009; Schwartz et al., 2005; Shock et al., 2008). Creamer et al. (2004) reported differences in the IYS incidence of three onion cultivars grown in a growth chamber. du Toit et al. (2004b) rated 46 onion cultivars for IYS severity and observed significant differences for IYS susceptibility. IYS incidence ranged from 58% to 97% among different cultivars. Schwartz et al. (2005) reported significant differences for IYS incidence among onion cultivars when IYS incidence ranged from 16% to 100% in 2003 and 13% to 61% in 2004. Shock et al. (2008) found that 'Joaquin', 'Charismatic', and 'Affirmed' expressed some of the lowest IYS ratings over a 2-year period. Multani et al. (2009) observed that among 18 winter-sown entries, NMSU 03-52-1, NMSU 04-41, NMSU 04-44-1, and 'NuMex Jose Fernandez' exhibited the fewest IYS symptoms. NMSU 05-33-1 exhibited a delayed symptom expression when compared with 12 other entries (Mohseni-Moghadam et al., 2011). In another study, 'Cometa' and NMSU 05-35-1 exhibited a delay in symptom expression and lower IYSV levels relative to 20 other entries (Cramer et al., 2012). The objective of this research was to evaluate onion PI accessions in the current collection for foliage color, visible amount of epicuticular leaf wax, number of thrips per plant, and IYS disease severity and incidence and to select individual plants with reduced disease symptom expression in the hopes of developing disease-resistant populations.

Materials and Methods

Using the Genetic Resources Information Network (USDA, ARS, National Genetic Resources Program, 2014a), the U.S. germplasm collection was searched for onion (*Allium cepa* L. and *A. cepa* var. *cepa*) PI accessions. Accessions were selected from the collection based on their availability and their descriptor score of 1, 2, or 3 for leaf bloom that indicated a lesser amount of epicuticular leaf wax (Tables 1 and 2) (USDA, ARS, National Genetic Resources Program, 2014b). In addition, accessions that originated from central Asia (Afghanistan, Iran, Uzbekistan) were selected because this area is thought to be the center of origin for progenitor species of *Allium cepa* (Havey, 1997) and if any mechanism of host plant

tolerance to thrips were to have developed, it may be expected to be present in this material (USDA, ARS, National Genetic Resources Program, 2014c). Two accessions that were collected from the Republic of Georgia and 11 accessions collected from the United States were included in the evaluation because they were being grown for seed regeneration. Eighty-four unique PI accessions were tested over 3 years. Most accessions were not tested in all 3 years. At least 2 years of evaluation was attempted for each accession; however, some accessions only received a single year of evaluation.

Seeds of accessions were sown into black plastic trays that contained Metro Mix 510 (Sun Gro, Bellevue, WA) on 18 Feb. 2009, 6 Jan. 2010, and 8 Jan. 2011. The resulting seedlings were grown in a greenhouse at the Fabian Garcia Science Center in Las Cruces, NM. Once plants reached the four to five leaf stage, they were transplanted on 30 Apr. 2009, 5 Apr. 2010, and 17 Mar. 2011 to the evaluation field at the Leyendecker Plant Science Research Center in Las Cruces, NM. Based on the number of plants produced by each accession, accessions were placed in one of two studies in each year. Those accessions that produced more than 120 plants were placed in Group 1 where the plot length was 3 m, whereas those accessions that produced fewer than 120 plants but more than 30 plants were placed in Group 2 where the plot length was 1.5 m. Some accessions may not have produced enough plants to be evaluated in that particular year. Plots consisted of a single-planted, raised bed with two equally spaced planted rows in which plants were spaced 7.5 cm apart within the row. A 60-cm alley was placed between plots on the same bed and beds were 1 m apart (center to center). Accessions were arranged in a randomized complete block design with three replications.

The evaluation field was designed such that IYSV and thrips would be brought to the field and both would be spread throughout the field to ensure that plants in all plots were challenged with thrips and IYSV at the same time. Bulbs, that were saved and stored at ambient conditions from the previous year's IYSV evaluation, were placed in Jan. 2009, Oct. 2009, and 2010 on the first and last bed and at the front and back borders of the study. These bulbs presumably hosted adult viruliferous thrips among the dry outer scale layers and these thrips reinfected bulbs with IYSV once bulbs began sprouting. The presence of IYSV in representative bulbs was confirmed using enzyme-linked immunosorbent assay (ELISA) and reverse transcription-polymerase chain reaction (RT-PCR) (Mohseni-Moghadam et al., 2011). On beds just inside the first and last bed and on every third bed thereafter, a fall-sown, IYS-susceptible cultivar was transplanted in Feb. 2009 or direct sown in Oct. 2009 and 2010 as a means to facilitate the spread of thrips and IYSV throughout the field. This planting left pairs of beds that were used for the PI accession evaluation. The field was designed such that onion thrips would

acquire IYSV from the infected bulbs, live on these bulbs until scape formation that occurred in May, then move to the IYS-susceptible plants on every third bed, and once these plants matured in June, then move to the test plants. Onion plants were grown using standard cultural practices for growing onions in southern New Mexico except that chemical sprays were not applied for reducing onion thrips levels (Walker et al., 2009).

At 12, 16, and 20 weeks in 2009 and 2010 and 9, 12, and 15 weeks in 2011 post-planting or transplanting, 10 plants were arbitrarily selected from each plot and the numbers of thrips (adults and larvae) were counted on each plant. At 16 weeks in 2009 and 2010 and 9 weeks in 2011, plants in a plot were evaluated for leaf color on scale of 1 to 4, where 1 = light green foliage, 2 = dark green, 3 = blue green, and 4 = blue. At the same time, plants in a plot were evaluated for the visible amount of epicuticular wax on the leaf on a scale of 1 to 4, where 1 = glossy (no wax present), 2 = semiglossy (an intermediate amount of wax) (Damon et al., 2014), 3 = light wax, and 4 = waxy. At 16 weeks in 2009 and 2010 only, plants in the plot were evaluated for leaf axil pattern on a scale of 1 to 4, where 1 = very open and 4 = tight. This trait was measured because it was thought that an open leaf axil pattern would be less attractive to thrips because it would provide them less protection from predators than a tight leaf axil pattern. In addition, Jones et al. (1934) suggested that a tight leaf axil might be involved in thrips resistance. At 16 and 20 weeks in 2009 and 2010 and 18 and 20 weeks in 2011, 10 plants were arbitrarily selected from each plot and were rated for IYS disease severity on a scale of 0 to 4, where 0 = no symptoms, 1 = one to two small lesions per leaf, 2 = more than two medium-sized lesions per leaf, 3 = lesions coalescing on more than 25% of the leaf, and 4 = more than 50% leaf death.

When more than 80% of the plants had matured, visible through the lodging of the plant tops, all bulbs from the plot were harvested. From within a plot, plants that exhibited fewer IYS foliar symptoms on maturing foliage were selected and kept separate from other bulbs harvested from the plot. Leaves and roots from the harvested bulbs were removed and bulbs were stored. Bulbs, selected for reduced symptom expression, were saved for seed production to occur in the next year. Any progress made for reduced symptom expression would be determined in later studies.

Plots that possessed five plants or less were not used in any statistical analysis. If an entry only had one replication of data, the entry was not included in any analysis for that year. Plot means were calculated for thrips number per plant and IYS severity rating at each observation date using the 'Proc Means' statement in SAS (SAS 9.2; SAS Institute Inc., Cary, NC). Entry means for leaf color, waxiness, axil pattern rating, thrips number per plant, and IYS severity rating were calculated. Some entries were tested in only 1 year. Entries were grouped based on the

Table 1. Leaf color, waxiness, axil openness ratings, number of onion thrips per plant, and Iris yellow spot (IYS) severity rating for entries in Group 1 measured several times throughout the 2009, 2010, and 2011 growing seasons at the Leyendecker Plant Science Research Center, Las Cruces, NM.

Entry ^z	Leaf color rating ^y	Leaf waxiness rating ^x	Leaf axil openness rating ^w	Onion thrips (number/plant) ^v	IYS virus disease severity rating ^u		
	Time after transplanting (weeks)						
	16	16	16	12	16	16	20
2009							
G 32590	3.0	4.0	4.0	25.3	11.4	1.6	2.9
G 32787	3.0	4.0	4.0	12.9	15.3	1.1	2.0
<i>PI 164361</i>	2.3	4.0	3.3	11.3	12.9	1.1	2.1
<i>PI 164807</i>	2.0	3.0	3.7	8.2	5.9	1.3	—
<i>PI 165498</i>	2.3	3.3	3.7	13.9	9.2	1.5	3.2
<i>PI 171475</i>	3.0	4.0	3.3	11.3	18.7	1.4	3.0
<i>PI 171477</i>	4.0	4.0	4.0	6.9	17.8	1.5	2.1
<i>PI 172702</i>	3.0	4.0	3.7	9.1	21.4	1.4	2.0
<i>PI 172703</i>	3.0	4.0	3.0	9.0	14.6	1.4	2.1
<i>PI 172704</i>	4.0	4.0	3.3	13.0	9.5	1.7	3.3
<i>PI 174018</i>	3.0	4.0	4.0	4.9	15.0	1.5	2.1
<i>PI 174024</i>	3.0	4.0	3.7	11.4	14.3	1.2	1.9
<i>PI 177242</i>	3.3	4.0	4.0	13.5	19.4	1.6	2.9
<i>PI 179164</i>	3.0	4.0	3.3	6.9	22.3	1.4	2.6
<i>PI 182138</i>	3.0	4.0	3.7	17.6	22.5	1.5	1.9
<i>PI 183660</i>	2.7	4.0	3.7	14.1	14.6	1.2	1.9
<i>PI 233186</i>	3.0	4.0	3.0	9.3	17.9	1.3	2.3
PI 239633	2.0	1.0	3.0	3.4	9.0	1.0	1.3
<i>PI 248754</i>	2.0	3.0	3.3	7.5	6.1	1.5	2.6
<i>PI 249899</i>	2.7	4.0	3.7	13.3	22.8	1.2	1.9
<i>PI 251325</i>	4.0	4.0	4.0	14.3	18.0	1.5	3.1
<i>PI 255557</i>	2.7	4.0	3.0	19.3	27.1	1.1	1.7
PI 256049	3.0	4.0	3.7	12.3	22.7	1.3	2.3
<i>PI 258956</i>	2.0	2.0	3.7	13.7	11.4	1.0	1.7
<i>PI 264320</i>	2.0	3.0	4.0	5.8	18.7	1.2	1.2
<i>PI 264321</i>	2.3	3.7	3.7	8.6	15.9	1.1	2.1
<i>PI 264648</i>	3.3	4.0	3.7	8.8	21.1	1.2	1.6
<i>PI 269306</i>	3.3	4.0	3.7	16.7	26.6	1.4	2.0
<i>PI 271039</i>	1.7	3.0	3.0	9.0	6.9	1.9	—
<i>PI 274780</i>	2.0	3.0	3.0	10.2	2.6	1.7	—
<i>PI 288270</i>	3.3	4.0	3.3	9.4	11.1	1.1	1.9
<i>PI 288272</i>	2.0	3.3	3.3	6.0	1.1	1.5	—
<i>PI 289689</i>	2.0	1.3	3.0	3.2	2.8	1.2	2.3
<i>PI 293756</i>	2.7	4.0	3.7	15.0	23.2	1.3	1.9
<i>PI 318886</i>	3.0	4.0	3.3	21.8	24.9	1.3	3.0
<i>PI 321385</i>	1.7	3.0	3.7	11.3	23.7	1.1	1.3
<i>PI 343049</i>	3.7	4.0	3.7	10.8	17.5	1.1	2.1
<i>PI 344392</i>	3.7	4.0	4.0	15.1	20.6	1.5	2.9
<i>PI 433330</i>	3.3	4.0	4.0	20.8	26.5	1.4	1.9
<i>PI 546101</i>	2.0	3.0	3.3	3.5	21.6	1.2	1.4
<i>PI 546106</i>	3.0	4.0	3.7	8.9	35.7	1.3	1.8
<i>PI 546115</i>	1.7	3.0	3.7	7.7	21.9	1.2	1.3
<i>PI 546140</i>	2.0	3.0	3.7	9.6	10.1	1.3	—
<i>PI 546188</i>	1.7	2.3	4.0	3.9	14.3	1.0	1.1
<i>PI 546192</i>	2.0	2.0	3.3	5.7	17.6	1.1	1.2
PI 639912	3.0	4.0	4.0	11.9	33.7	1.2	2.3
PI 639915	3.0	4.0	4.0	11.5	30.2	1.4	2.2
PI 639916	2.7	4.0	3.7	19.2	21.2	1.2	2.2
LSD (5%)	0.7***	0.2***	NS	NS	15.1*	NS	0.6***
2010							
<i>PI 165498</i>	2.0	2.0	3.5	3.2	1.6	4.0	—
<i>PI 168962</i>	2.7	2.7	3.7	11.4	0.7	4.0	—
<i>PI 168966</i>	2.7	3.3	3.7	8.9	3.1	4.0	—
<i>PI 171475</i>	2.5	3.0	4.0	17.7	1.9	4.0	—
<i>PI 171477</i>	2.0	2.5	4.0	7.2	0.4	3.8	—
<i>PI 172701</i>	2.0	2.7	3.7	11.2	4.8	3.8	4.0
<i>PI 172702</i>	2.7	2.7	3.7	8.5	2.3	3.9	—
PI 200874	2.3	2.7	3.7	11.0	0.9	4.0	—
<i>PI 233186</i>	3.3	2.7	3.7	15.1	2.0	4.0	—
<i>PI 249899</i>	2.0	3.0	3.3	25.6	6.5	3.0	3.6
<i>PI 255557</i>	3.3	3.3	3.7	14.9	2.6	3.8	—
<i>PI 258956</i>	1.7	2.0	4.0	12.9	4.4	3.7	—
<i>PI 264320</i>	2.0	2.3	3.7	17.8	4.8	3.5	3.9
<i>PI 264648</i>	4.0	4.0	4.0	20.6	3.3	3.2	3.8
<i>PI 288073</i>	4.0	4.0	3.7	14.7	5.0	3.1	3.4
<i>PI 288270</i>	2.7	3.0	3.7	11.8	3.1	4.0	—
<i>PI 288903</i>	4.0	4.0	3.7	25.0	4.8	3.2	3.5

(Continued on next page)

Table 1. (Continued) Leaf color, waxiness, axil openness ratings, number of onion thrips per plant, and Iris yellow spot (IYS) severity rating for entries in Group 1 measured several times throughout the 2009, 2010, and 2011 growing seasons at the Leyendecker Plant Science Research Center, Las Cruces, NM.

Entry ^z	Leaf color rating ^y	Leaf waxiness rating ^x	Leaf axil openness rating ^w	Onion thrips (number/plant) ^v		IYS virus disease severity rating ^u	
	Time after transplanting (weeks)						
	16	16	16	12	16	16	20
PI 293756	3.7	3.7	3.7	24.2	5.8	3.5	3.9
PI 546096	3.3	3.3	3.7	29.0	4.1	3.9	—
PI 546100	2.0	3.0	4.0	22.4	4.3	3.7	—
PI 546101	2.3	3.0	3.7	21.3	7.2	3.5	3.9
PI 546106	3.0	3.3	4.0	26.6	3.7	3.9	—
PI 639911	2.7	3.3	4.0	24.3	6.9	3.5	3.5
PI 639912	3.0	3.0	3.3	27.0	4.8	3.4	3.9
PI 639915	3.0	3.0	3.7	30.7	6.3	3.8	—
PI 639916	3.3	3.7	3.7	30.2	9.2	3.7	3.8
LSD (5%)	0.7***	0.6***	NS	6.4***	4.1*	0.5***	NS
2011							
G 32590	4.0	3.7	—	15.9	15.7	1.1	2.2
G 32787	3.0	3.0	—	17.1	10.3	1.0	1.5
PI 174024	3.3	3.0	—	22.4	22.5	1.0	1.7
PI 177242	3.3	3.3	—	30.3	16.5	1.0	2.0
PI 182138	3.7	3.3	—	22.6	37.4	1.1	1.7
PI 183660	2.7	2.7	—	13.9	7.8	1.0	1.6
PI 256049	2.7	3.0	—	18.0	18.4	1.0	1.6
PI 264321	2.7	3.0	—	18.6	12.6	1.1	1.8
PI 288902	3.3	3.0	—	14.1	11.3	1.2	1.6
PI 344392	3.0	3.0	—	19.3	32.7	1.0	1.9
PI 391509	3.0	3.0	—	9.5	14.4	1.1	1.4
PI 433332	3.7	3.7	—	21.1	18.6	1.1	1.6
PI 546106	3.0	3.0	—	23.5	23.5	1.0	1.2
PI 546115	1.7	2.3	—	16.9	42.5	1.0	1.5
PI 546162	2.7	3.0	—	16.2	18.0	1.2	1.4
PI 546174	4.0	3.3	—	20.5	33.5	1.0	1.6
PI 546192	1.3	2.0	—	21.3	9.9	1.0	1.1
PI 546201	2.0	2.0	—	20.9	19.9	1.0	1.3
LSD (5%)	0.8***	0.6***	—	11.8**	21.1**	NS	0.5***

^zEntries were tested in three blocks with one replication per block. Plots were 3 m in length and consisted of two equally spaced rows sown per plot. Entries in italics were selected for evaluation because they were rated as having less wax on their leaves. The entries in bold were selected for evaluation because they were collected in Afghanistan (PI 200874, 256049), Iran (PI 239633, 391509), or Uzbekistan (PI 639111, 639912, 639915, 639916). Those entries in bold and italics were collected in Georgia. The remaining entries were selected because they were known to possess green to light green foliage color. In 2010, plants of PIs 124525, 164807, 172704, 179627, 248753, 248754, 251325, 271039, 274780, 288272, 288908, 288909, 289690, and 546140 matured before 16 weeks and data were not collected at 16 and 20 weeks for these accessions.

^yPlots were rated for plant leaf color on a scale of 1 to 4, where 1 = light green, 2 = dark green, 3 = blue green, and 4 = blue. In 2011, plots were rated at 9 weeks post-transplanting.

^xPlots were rated for plant leaf waxiness on a scale of 1 to 4, where 1 = glossy, 2 = semi-glossy, 3 = light wax, and 4 = waxy. In 2011, plots were rated at 9 weeks post-transplanting.

^wPlots were rated for plant leaf axil pattern on a scale of 1 to 4, where 1 = very open, 2 = open, 3 = slightly closed, and 4 = tight.

^vThe number of thrips (larvae and adults) per plant were counted from 10 plants in the center of each plot. In 2011, thrips were counted at 9 and 12 weeks post-transplanting.

^uTen plants per plot were rated individually for IYS virus severity on a scale of 0 to 4, where 0 = no symptoms, 1 = one to two small lesions per leaf, 2 = more than two medium-sized lesions per leaf, 3 = lesions coalescing on more than 25% of the leaf, and 4 = more than 50% leaf death. In 2011, plants were rated at 12 and 15 weeks post-transplanting.

NS, *, **, ***Nonsignificant at $P > 0.05$, significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

LSD = least significant difference.

plot length used in the evaluation. Entry differences were determined using the 'Proc GLM' statement in SAS and Fisher's least significant difference mean separation test was performed when more than two entries were present in an analysis.

Results and Discussion

Leaf color varied depending on the year. Of those entries with blue foliage, plants of PI 171477 were rated 4.0 in 2009 and 2.0 in 2010; plants of PI 264648 were rated 3.3 in 2009 and 4.0 in 2010; plants of G 32590 were rated 3.0 in 2009 and 4.0 in 2011 (Table 1); plants of PI 256048 were rated 3.3 in 2009 and 4.0 in 2011 (Table 2). The amount of epicuticular leaf wax has been associated with leaf color. Those plants with more epi-

cuticular wax tend to produce foliage with bluish color. In our results, those entries rated as having bluish foliage also were rated as having waxy foliage (Tables 1 and 2). When the color rating of these entries varied from year to year (mentioned earlier), the amount of epicuticular wax remained high. The only exception was PI 171477. When plants were rated in 2010 as being green in color (2.0) rather than blue in color (4.0) in 2009, they were rated as having a lower amount of wax (2.5) in 2010 than in 2009 (4.0) (Table 1). Aside from this exception, changes in the amount of epicuticular leaf wax were not responsible for changes in leaf color. Numerous entries exhibited light to dark green foliage (Tables 1 and 2). The ratings for those entries with light to dark green foliage were mostly consistent over years; however, there

were a few exceptions. For those entries with a leaf color rating of 2.0 or less, the leaf wax rating was not always low and varied depending on the entry and year. In addition, methods to objectively measure leaf color might eliminate some year-to-year variation. In the future, removal of the epicuticular leaf wax (by lightly rubbing the surface to be measured) before rating may aid in the process and prevent confounding effects resulting from the amount of leaf wax.

A large number of entries (≈ 50) was rated as having waxy foliage and they were rated as such mostly in 2009 rather than in other years (Tables 1 and 2). Numerous entries exhibited yearly differences for amount of leaf wax. A large number of entries were selected from the U.S. germplasm collection because they were evaluated and reported previously as

Table 2. Leaf color, waxiness, axil openness ratings, number of onion thrips per plant, and Iris yellow spot (IYS) severity rating for entries in Group 2 measured several times throughout the 2009, 2010, 2011 growing seasons at the Leyendecker Plant Science Research Center, Las Cruces, NM.

	Leaf color rating ^y	Leaf waxiness rating ^x	Leaf axil openness rating ^w	Onion thrips (number/plant) ^v	IYS disease severity rating ^u		
	Time after transplanting (weeks)						
Entry ^z	16	16	16	12	16	16	20
2009							
PI 124525	3.0	4.0	3.0	3.5	5.6	1.6	—
PI 142790	4.0	4.0	2.3	2.7	20.2	1.2	1.2
PI 168962	2.7	4.0	3.0	5.4	22.1	1.3	3.2
PI 168966	3.0	4.0	3.0	6.9	15.3	1.3	3.5
PI 172701	2.3	4.0	3.0	6.7	17.6	1.2	2.2
PI 179627	3.0	4.0	3.0	4.3	16.7	1.7	—
PI 200874	3.0	4.0	3.0	5.2	19.1	1.2	1.1
PI 248753	2.0	3.0	2.7	2.2	2.1	1.6	—
PI 256048	3.3	4.0	3.0	3.7	23.2	1.1	2.6
PI 264631	3.0	4.0	2.7	9.5	21.4	1.2	1.9
PI 273211	3.0	4.0	3.0	3.6	23.9	1.2	2.6
PI 288073	4.0	4.0	3.0	5.4	22.2	1.0	1.5
PI 288902	2.5	4.0	2.5	5.9	16.9	1.2	2.3
PI 288903	4.0	4.0	3.0	3.7	23.7	1.1	1.7
PI 288908	3.0	4.0	3.0	7.9	26.9	1.2	3.1
PI 288909	3.0	4.0	3.0	7.3	17.8	1.1	2.8
PI 289690	3.0	4.0	3.0	3.6	18.0	1.2	3.1
PI 342943	3.0	4.0	3.0	8.7	22.4	1.3	2.9
PI 391509	3.0	3.7	2.3	2.0	14.6	1.0	1.9
PI 430371	2.7	3.7	3.0	3.2	2.2	1.5	—
PI 433332	4.0	4.0	2.7	3.2	20.0	1.0	1.9
PI 546096	3.0	4.0	3.0	2.5	31.3	1.1	2.8
PI 546100	2.0	3.0	3.0	3.2	28.6	0.9	1.3
PI 546162	3.0	4.0	3.0	12.1	27.8	1.2	2.2
PI 546174	3.0	4.0	3.0	5.4	33.3	1.0	2.6
PI 639911	2.7	4.0	3.0	5.4	21.3	1.2	2.3
PI 639913	3.0	4.0	3.0	9.5	24.4	1.2	2.6
LSD (5%)	0.4***	0.3***	NS	NS	13.7**	0.3***	0.5***
2010							
PI 174024	3.0	3.0	3.0	25.2	0.3	4.0	—
PI 288902	3.5	3.5	3.0	17.2	2.4	3.5	—
PI 391509	2.3	2.7	2.0	19.0	2.6	3.0	—
PI 546115	2.3	2.7	3.7	26.4	1.3	4.0	—
PI 546162	2.0	2.5	3.5	39.4	—	3.9	—
PI 639913	2.5	3.0	4.0	28.0	0.9	4.0	—
LSD (5%)	NS	NS	0.7*	NS	NS	0.4**	
2011							
PI 164361	2.7	2.7	—	15.9	13.9	1.1	1.7
PI 179627	3.3	3.3	—	26.8	3.0	1.8	—
PI 256048	4.0	3.7	—	50.8	27.6	1.1	1.9
PI 289689	1.0	1.5	—	7.0	4.8	1.2	2.5
PI 343049	3.3	3.0	—	42.7	15.4	1.1	2.3
PI 433330	2.7	2.7	—	34.3	29.8	1.2	1.8
LSD (5%)	0.9***	1.0***	—	23.6**	13.1**	0.3***	0.8*

^zEntries were tested in three blocks with one replication per block. Plots were 1.5 m in length and consisted of two equally spaced rows sown per plot. Entries in italics were selected for evaluation because they were rated as having less wax on their leaves. The entries in bold were selected for evaluation because they were collected in Afghanistan (PI 200874, 256048), Iran (PI 142790, 391509), or Uzbekistan (PI 639111, 639913). The remaining entries were selected because they were known to possess green to light green foliage color. In 2010, plants of PIs 289689 and 344392 matured before 16 weeks and data were not collected at 16 and 20 weeks for these accessions.

^yPlots were rated for plant leaf color on a scale of 1 to 4, where 1 = light green, 2 = dark green, 3 = blue green, and 4 = blue. In 2011, plots were rated at 9 weeks post-transplanting.

^xPlots were rated for plant leaf waxiness on a scale of 1 to 4, where 1 = glossy, 2 = semi-glossy, 3 = light wax, and 4 = waxy. In 2011, plots were rated at 9 weeks post-transplanting.

^wPlots were rated for plant leaf axil pattern on a scale of 1 to 4, where 1 = very open, 2 = open, 3 = slightly closed, and 4 = tight.

^vThe number of thrips (larvae and adults) per plant were counted from 10 plants in the center of each plot. In 2011, thrips were counted at 9 and 12 weeks post-transplanting.

^uTen plants per plot were rated individually for IYS virus severity on a scale of 0 to 4, where 0 = no symptoms, 1 = one to two small lesions per leaf, 2 = more than two medium-sized lesions per leaf, 3 = lesions coalescing on more than 25% of the leaf, and 4 = more than 50% leaf death. In 2011, plants were rated at 12 and 15 weeks post-transplanting.

NS, *, **, ***Nonsignificant at $P > 0.05$, significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

LSD = least significant difference.

having a low amount of leaf wax or less leaf bloom. Of those entries, 60% were rated as having waxy leaves although they were supposed to have a minimal amount of wax on their leaves. Only two entries, PIs 239633 and 289689, were rated as having a low amount of leaf wax (Tables 1 and 2).

For most entries, the leaf axil pattern was slightly closed to tight (Tables 1 and 2). The one exception to this observation was PI 391509 that was rated to have an open leaf axil pattern in 2010 (Table 2). In 2009, the pattern of this entry was not different from the pattern of other entries. Although

plants of this entry possessed a more open leaf axil pattern, they hosted a comparable number of thrips per plant as those plants with a more closed leaf pattern. This trait was not measured in 2011 because little variation in the trait between entries was observed.

The pattern of thrips number per plant over time changed for each year. In 2009, the mean number of thrips per plant increased from 12 to 16 weeks post-transplanting for a majority of entries from Group 1 and Group 2 (Tables 1 and 2). In 2010, the mean number of thrips per plant decreased from 12 to 16 weeks for all entries in both groups (Tables 1 and 2). This result would indicate that the thrips number increased earlier in the year than in 2009.

In 2009, there was no difference in the number of thrips per plant at 12 weeks after transplanting between entries from Group 1 or Group 2 (Tables 1 and 2). In 2010, plants of PI 165498 exhibited fewer thrips per plant at 12 weeks than plants of most other entries within Group 1 (Table 1). Plants of this accession did possess dark green, semi-glossy foliage that might have reduced the number of thrips. However, plants of other entries (PIs 258956, 264648) in this group also exhibited similar foliage characteristics but possessed a greater number of thrips per plant. In 2009, plants of PI 165498 exhibited a similar number of thrips per plant at 12 weeks as plants of other entries evaluated as part of Group 1 (Table 1).

In 2011, plants of PI 391509 possessed fewer thrips per plant at 12 weeks than plants of five other entries within Group 1 (Table 1). This accession was also evaluated during 2009 and 2010 as part of Group 2 but plants exhibited a similar number of thrips per plant as plants of other entries evaluated at the time (Table 2). In 2010, plants of this accession exhibited a more open leaf axil pattern than plants of other accessions; however, this plant architecture did not translate into a reduced number of thrips per plant (Table 2). The degree of leaf axil openness was not measured in 2011 as a result of the lack of variation in this trait among entries and the lack of correlation with reduced thrips number per plant.

Among the limited number of entries from Group 2 evaluated in 2011, plants of PI 289689 exhibited fewer thrips per plant at 12 weeks than plants of three other entries (Table 2). In 2009, plants of this entry also exhibited a low number of thrips per plant at 12 weeks but that number was not different from other plants evaluated as part of Group 1 (Table 1). In both years, plants of PI 289689 were rated as having light green to green-colored foliage and a low amount of epicuticular leaf wax (Tables 1 and 2). These two foliage characteristics may have made plants of PI 289689 less attractive to onion thrips early in the season, particularly when in close proximity, there were more attractive plants of other entries that possessed bluish and waxy foliage. Although only tested in 2009, plants of PI 239633 also exhibited green foliage with a low amount of foliage wax and a low number of thrips; however, this number was not different from plants of other entries evaluated at 12 weeks in Group 1 (Table 1). In the management of thrips on onions, a delay in the buildup of thrips would be advantageous for onion production. Control methods, most likely chemical means,

could be delayed perhaps eliminating one chemical spray application, thus reducing input costs and delaying the development of insecticidal resistance in the thrips population. This feeding nonpreference by onion thrips on plants of PI 289689 may disappear if plants of this accession were the only plants available for the thrips.

In 2009, a majority of entries within Group 1 exhibited an increase in the number of thrips per plant from 12 to 16 weeks after transplanting (Table 1). Of those 10 entries that exhibited a decrease in the number of thrips per plant, PIs 274780, 288272, and 289689 exhibited fewer thrips per plant at 16 weeks than 13 other entries within Group 1 (Table 1). Of those three entries, only PI 289689 was evaluated for a second year. In 2011, plants of PI 289689 possessed a low number of thrips per plant at 16 weeks when compared with plants of other entries evaluated within Group 2 (Table 2). Plants of PI 289689 also possessed a low number of thrips per plant at 12 weeks when tested in 2009 and 2011 (Tables 1 and 2). The feeding nonpreference exhibited by thrips for plants of this accession continued up to 16 weeks when thrips had choice of plants from other accessions to feed on. Unlike plants of PI 289689 that possessed light green to green-colored foliage and a low amount of leaf wax, plants of PIs 274780 and 288272 possessed dark green-colored foliage (2.0) and a moderate amount of leaf wax (3.0 to 3.3) (Table 1). As a result, it is unlikely that foliage characteristics were the cause for the decrease in thrips number per plant. For both accessions, ratings for IYS disease severity were not taken at 20 weeks (Table 1) because plants of those accessions had matured and were harvested between 16 and 20 weeks. Perhaps at 16 weeks, plants of these accessions had already begun the senescence process in preparation for dormancy and thrips found these plants less desirable as a result. As a potential food source for onion thrips, actively growing plants might be more desirable to them than plants beginning to senesce.

Among those entries tested within Group 2 during 2009, plants of PIs 248753 and 430371 had fewer thrips per plant at 16 weeks than 23 other entries (Table 2). Both of these accessions exhibited a low number of thrips per plant at 12 weeks (Table 2). However, both entries were evaluated only in 2009. In 2010, plants of PI 248753 matured before 16 weeks and data were not collected for thrips number at 16 weeks. Plants of both entries exhibited dark green to bluish green foliage (2.0 to 2.7) and moderate to high levels of leaf wax (3.0 to 3.7) (Table 2). With these foliage characteristics, it is unlikely that thrips found plants of these accessions undesirable as a result of their foliage. Plants of both accessions matured and were harvested between 16 and 20 weeks before the IYS disease severity rating at 20 weeks. As mentioned earlier with PIs 274780 and 288272, plants of these accessions may have begun the senescence process at $\approx$ 16 weeks and as a result, thrips found these plants less desir-

able for feeding. Plants of PI 124525 also matured and were harvested between 16 and 20 weeks before the IYS rating at 20 weeks (Table 2). This accession also exhibited a low thrips number per plant at 16 weeks that was not different from PIs 248753 and 430371 (Table 2). However, this entry was also evaluated only in 2009. In 2010, plants of PI 124525 matured before 16 weeks and data were not collected for thrips number at 16 weeks.

In 2010, the number of thrips per plant decreased from 12 to 16 weeks for all entries within both groups (Tables 1 and 2). The number of thrips per plant at 16 weeks was low (less than 10) for most entries within Group 1; however, plants of PIs 168962, 171477, and 200874 exhibited a lower number of thrips than plants of seven other entries within Group 1 (Table 1). Plants of these accessions and several others matured and were harvested between 16 and 20 weeks before the IYS severity rating at 20 weeks (Table 1). These three accessions within Group 1 were also evaluated in 2009. In that year, plants of these accessions exhibited a comparable number of thrips per plant as plants of other accessions within the group (Table 1). In 2009, plants of these three accessions were not harvested before 20 weeks when an IYS rating was recorded (Table 1). Plants of accessions were transplanted 3 weeks earlier in 2010 than in 2009. With this additional time of plant development in the field during 2010, plants reached a larger size and were more attractive to thrips earlier in the season than during 2009. This earlier thrips feeding in 2010 was evident by a greater number of thrips per plant at 12 weeks than in 2009. Maximum daily temperatures in Las Cruces during May and June were greater in 2010 than in 2009 (New Mexico Climate Center, 2014). These higher temperatures would have hastened growth and maturity of onion accessions in 2010 as compared with 2009. In 2010, plants of 16 accessions matured before 16 weeks and data for leaf characteristics, thrips number, and IYS severity rating were not collected for these accessions.

In 2011, plants of PIs 183660 and 546192 possessed fewer thrips per plant at 16 weeks than plants of four other accessions within group 1 (Table 1). In 2009, plants of those accessions were comparable to plants of other accessions in terms of thrips number per plant (Table 1). Among a limited number of accessions within Group 2 evaluated in 2011, plants of PIs 179627 and 289689 possessed fewer thrips per plant at 16 weeks than plants of two other accessions (Table 2). In 2009, plants of PI 179627 exhibited a comparable number of thrips per plant as plants of other entries tested within Group 2 (Table 2). The performance of PI 289689 with respect to thrips number per plant has been discussed earlier.

In each year, disease severity increased from 16 to 20 weeks in each group (Tables 1 and 2). IYS at 16 weeks was more severe in 2010 than in 2009 or 2011. As mentioned

earlier, the number of thrips per plant at 12 weeks was greater in 2010 than in the other 2 years. In addition, the maximum daily temperatures in Las Cruces during May and June were greater in 2010 than in 2009 (New Mexico Climate Center, 2014). These two factors could have caused greater plant stress and, subsequently, more severe symptoms earlier in the cropping season in 2010 than in the other 2 years.

During 2009, accessions of Group 1 did not differ in their IYS severity when they were rated at 16 weeks (Table 1). Among entries of Group 2, plants of PI 546100 exhibited less severe disease symptoms at 16 weeks than plants of 19 other accessions (Table 2). Plants of this accession were not different from plants of eight other accessions in terms of disease severity (Table 2). When plants of this accession were evaluated during 2010, they exhibited a similar disease severity as plants of all other accessions of Group 1 (Table 1). During 2010, plants of PI 249899 exhibited less severe IYS symptoms at 16 weeks than plants of 21 other entries tested as part of Group 1 (Table 1). When tested in 2009, plants of this accession were not different from plants of other entries of Group 1 with respect to IYS severity (Table 1). Among the limited number of accessions evaluated in 2010 as part of Group 2, plants of PI 391509 exhibited less severe disease symptoms at 16 weeks than plants of other accessions (Table 2). When plants of this accession were evaluated in 2009, they exhibited less severe disease symptoms than plants of six other accessions (Table 2). During 2011, accessions of Group 1 did not differ in their IYS disease severity at 16 weeks (Table 1). Among those accessions of Group 2, plants of PI 179627 exhibited more disease symptoms at 16 weeks than plants of other accessions (Table 2). This greater level of disease severity could have resulted from plants being more susceptible because they were closer to maturity. Plants of this accession matured before 20 weeks and an IYS disease rating could not be taken (Table 2). Plants of other accessions had not matured by this time (Table 2). During 2009, plants of this accession also exhibited a higher disease severity at 16 weeks than plants of other accessions (Table 2). In addition, plants of this accession matured before 20 weeks and a second disease rating could not be taken (Table 2).

Of those accessions that had not matured yet in 2009, plants of PIs 239633, 264320, 321385, 546115, 546188, and 546192 exhibited less severe disease symptoms at 20 weeks than plants of most other accessions within Group 1 (Table 1). When evaluated in 2011, plants of PI 546192 also exhibited less severe disease symptoms at 20 weeks than plants of other accessions within Group 1 (Table 1). Plants of PI 546115 exhibited a similar severity of disease symptoms at 20 weeks as plants of other accessions of Group 2 in 2010 (Table 2) and of Group 1 in 2011 (Table 1). During 2010, plants of PI 264320 exhibited a similar disease severity at 20

weeks as plants of other accessions within Group 1 (Table 1). Plants of PIs 546188 and 546192 exhibited light to dark green, semi-glossy foliage (Table 1). Plants of both accessions exhibited a low number of thrips at 12 weeks and a reduced number of thrips at 16 weeks as compared with plants of other accessions within Group 1 (Table 1). Although these characteristics could have contributed to lower disease severity, plants of other accessions (G 32590, G 32787, and PIs 164361, 165498, 171475, 171477, 172702, 172703, 172704) within Group 1 also exhibited a lower or comparable number of thrips per plant at 12 and 16 weeks but a higher disease severity at 20 weeks than plants of PIs 546188 and PI 546192 (Table 1). Another mechanism besides thrips feeding tolerance or thrips feeding nonpreference must be causing a reduction in disease severity as compared with other accessions. Plants of PI 239633 exhibited dark green, glossy foliage and a reduced number of thrips at 12 and 16 weeks when compared with plants of other accessions within Group 1 (Table 1).

Among those accessions within Group 2 evaluated in 2009, plants of PIs 142790, 200874, and 546100 exhibited less severe disease symptoms at 20 weeks than plants of 18 other accessions that had not yet matured (Table 2). PIs 200874 and 546100 were evaluated in 2010 as part of Group 1 and plants of both accessions matured before a severity rating could be taken at 20 weeks (Table 1). At 16 weeks, plants of both accessions exhibited a similar disease severity as plants of other accessions (Table 1). Plants of PI 142790 exhibited bluish, waxy foliage and comparable number of thrips per plant at 12 and 16 weeks as plants of other accessions within Group 2 evaluated during 2009 (Table 2). During 2010, disease severity was high for most entries with no difference in severity among accessions within Group 1 and a large number of accession within both groups that matured before a rating could be taken at 20 weeks (Tables 1 and 2).

During 2009 and 2011, individual plants that exhibited few IYS disease symptoms were selected from 22 different accessions (Table 3). These selected bulbs were either self-pollinated (2009) or cross-pollinated as a small mass of bulbs (2011) so that progress for reduced disease severity could be made and evaluated in subsequent generations. No plants were selected in 2010 as a result of the high levels of disease observed that year. In absolute number and as a percentage, PI 546140 produced the most selected plants [54 (27%)] of the accessions evaluated in either year (Table 3). In terms of IYS disease severity, all plants of this accession were rated in 2009 as having a similar amount of disease at 16 weeks as plants of other accessions (Table 1). Unfortunately, plants of this accession matured before 16 weeks so that selections were not made in 2010 (Table 1). PIs 239633 and 258956 also produced a large number of selected plants in 2009 (Table 3). At 20 weeks, plants of PI 239633 in general tended to exhibit fewer disease

Table 3. Number of bulbs harvested and number of bulbs selected for Iris yellow spot resistance from onion accessions grown at 2009 and 2011.

Accession	Bulb number			
	Harvested		Selected	
	2009	2011	2009	2011
Group 1				
PI 172702	213		3	
PI 172703	173		11	
PI 174024		85		2
PI 177242		98		1
PI 183660		133		5
PI 239633	252		24	
PI 258956	205		37	
PI 264320	206		10	
PI 288270	90		6	
PI 289689	155		6	
PI 343049	194		12	
PI 546115		106		1
PI 546140	200		54	
PI 546174		55		1
PI 546188	37		2	
PI 546201		82		2
Group 2				
PI 172701	100		1	
PI 179627	113		2	
PI 288909	107		12	
PI 289689		15		2
PI 343049		104		2
PI 639911	51		1	

symptoms in 2009 than plants of most other accessions (Table 1).

Although the maturity and/or harvest date were not measured in this study, the relative maturity date among accessions can be inferred based on those accessions and years in which data for IYS disease severity were not collected at 16 and/or 20 weeks after transplanting. Data were not collected for those accessions because plants of those accessions had already been harvested. Although plants of some accessions had matured by these dates, plants of other accessions had not so data were collected for disease severity at 20 weeks. Most of these accessions are assumed to be genetically distinct from one another. With those inherent genetic differences, accessions may differ in their daylength bulbing sensitivity, i.e., the daylength required to initiate the bulbing process. With these differences in bulbing initiation, accessions also differ in their bulb maturity or when they initiate senescence and become dormant. At a certain point in time, plants of different accessions would be at different physiological growth stages. Plants that are closer to maturity and have initiated plant senescence may be more susceptible to plant stress and express more disease symptoms than plants that are 4 weeks from maturity. Some of the differences that we observed in disease expression may be a result of differences in physiological growth stages. These inherent physiological differences among accessions make comparisons among a diverse set of germplasm difficult to interpret. If maturity differences among accessions are known before an evaluation is conducted, similar maturing accessions could be evaluated together as a group and this evaluation may be more informative.

With IYS, disease expression is a function of IYSV being present in the field, thrips being present in the field to spread the virus, and suitable environmental conditions present for a certain length of time. These suitable environmental conditions are usually an abiotic stress such as heat, light intensity, drought, or a combination that results in further plant stress in addition to the plant stress caused by the thrips feeding activity and virus itself. Asymptomatic plants, that have thrips and IYSV, have been observed particularly when the environmental conditions do not cause further plant stress (personal observation). A plant's inherent tolerance to plant stress may influence its expression of disease symptoms. In addition, a plant's susceptibility to plant stress may differ depending on its physiological growth stage with plants that are actively growing being more tolerant to plant stress and less likely to express disease symptoms than plants that are close to maturity and begun the senescence process. Some of the differences that we observed in disease expression may be a result of differences in susceptibility to plant stress and/or physiological growth stages.

Each year, ELISA and RT-PCR tests showed that IYSV was present in plants from the evaluation field. Although random plants were sampled and tested for the presence of IYSV, we did not sample plants from each plot, accession, and rating date. Plants from different accessions could have differed in their virus titer that could influence disease expression. Previous work observed a strong, positive correlation between virus titer and disease expression when the same individual plants were rated and sampled (Mohseni-Moghadam et al., 2011).

Bulb yield was measured for all accessions in each year. Because damage from thrips and IYS tends to reduce bulb size, bulb diameter was measured and bulbs were sorted based on diameter. Bulb yield of each accession was not reported because there were inherent genetic differences between accessions in terms of bulb shape and size that caused differences in graded bulb yield among accessions. Some plants of accessions produced bulbs but did not mature within the time period, whereas plants of other accessions did not bulb or mature at all. In addition, because companion plots, in which thrips feeding and disease development were prevented, were not established, the effect of both pests on bulb yield could not be measured for each accession. Most of the accessions evaluated in this study would not be commercially acceptable in the U.S. onion market as a result of their undesirable bulb shape, small bulb size, bulb shape and size variability, low percentage of single-centered bulbs, bulb scale color variation, and bulb maturity variation. However, PI 546096 ('Southport Red Globe'), PI 546100 ('Sweet Spanish Utah Strain'), PI 546101 ('Sweet Spanish Los Animas Strain'), PI 546106 ('White Sweet Spanish California'), PI

546115 ('White Sweet Spanish Jumbo'), PI 546140 ('San Joaquin'), PI 546162 ('Southport Yellow Globe'), PI 546174 ('Yellow Ebenezer'), PI 546188 ('Yellow Sweet Spanish Winegar'), PI 546192 ('Yellow Sweet Spanish L'), and PI 546201 ('Yellow Sweet Spanish Utah') have been used in the past as commercial cultivars.

In conclusion, of those accessions evaluated in New Mexico, plants of PI 289689 were less attractive to thrips and possessed a lower number of thrips per plant than plants of most other accessions. Plant leaf color and amount of epicuticular leaf wax influence thrips feeding among a diverse group of foliage types; however, these foliage traits are not the sole determining factor for degree of thrips feeding. Plants of PIs 239633 and 546192 generally exhibited less severe IYS disease symptoms than plants of other accessions. PI 546140 produced a large number of individual plants that exhibited few disease symptoms at maturity and these plants were selected to generate a subsequent generation with reduced symptom expression. PIs 546140 and 546192 were also selected as germplasm that was most resistant to IYS and thrips under field conditions in Colorado (Boateng et al., 2014). Physiological plant development, environmental conditions, and tolerance to plant stress may influence the degree of disease symptom expression. Further work that examines the role of plant maturity and host plant tolerance to stress with respect to disease expression is needed in more onion production regions.

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