DISSERTATION

PHYSIOLOGICAL RESPONSES OF ONION GERMPLASMS TO *IRIS YELLOW SPOT VIRUS* AND ONION THRIPS (*THRIPS TABACI*)

Submitted by

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ABSTRACT

PHYSIOLOGICAL RESPONSES OF ONION GERMPLASMS TO IRIS YELLOW SPOT VIRUS AND ONION THRIPS (*THRIPS TABACI*)

Onion (*Allium cepa* L.) is the most economically important monocot outside of the grasses. Onion thrips (*Thrips tabaci*), a cosmopolitan and polyphagous insect, infests and damages onion crops grown between sea level and 2,000 m. In recent years, onion thrips has emerged as the principal vector of the economically important *Iris yellow spot virus* (IYSV, family *Bunyaviridae*). Any attempt to significantly reduce the economic impact of this pest/pathogen will require a multifaceted approach designed in an IPM framework. Host plant resistance is an important foundation to the success of such approaches, and in an effort to find sources of resistance to IYSV and onion thrips, 137, 104 and 84 onion germplasms, respectively, were evaluated in 2009, 2010 and 2011 in northern Colorado, near Fort Collins. Sixteen, 18 and 11 germplasms, respectively, were selected in 2009, 2010 and 2012 for exhibiting acceptable level of tolerance/resistance to the two pests. Of these, PIs 264320, 546140, and 546192 were selected in both 2009 and 2010, and PIs 258956 and 546188 were selected in all three years of the evaluation. Selected germplasms were included as candidates for the onion translational genomics component of this national endeavor.

Greenhouse experiments were carried out to study the effects of five treatments; Healthy Control (HC), Spray (S), Thrips Only (T), IYSV Only (V) and Thrips + IYSV (TV), on the growth, physiology and productivity of Colorado 6, Talon and Salsa Red onion cultivars. Seasonal mean net photosynthesis (*A*) and late season light response curves were higher in Colorado 6 than in Talon. Late season curves were significantly lower in TV, V and T than in HC and S in all

cultivars. Seasonal mean growth rate was significantly higher in Colorado 6 than in Talon. Among the treatments, seasonal mean growth rate was in the decreasing order of HC, V, TV and T in 2009; and S, HC, V, T and TV in 2011. In one of three years, yield was significantly higher in Colorado 6 than in Salsa Red and Talon. Biomass partitioning pattern revealed that Talon had the highest harvest index among the cultivars. TV had the lowest bulb yield among the treatments in all three years of the study, and caused 14-60% yield loss in Colorado 6, 14-46% loss in Talon, and 17-48% loss in Salsa Red.

Seasonal dynamics of IYSV titer in leaves of Colorado 6 and Talon indicated that virus titer for TV and V were consistently higher in Talon than in Colorado 6. Titer was in the increasing order of middle, top and base leaf sections. In naturally infected pre-bulb plants, virus titer increased from Leaf 1 (outer leaf) to Leaf 4 (inner leaf) after which it declined in subsequent younger leaves. Virus was not detected in dead leaves, bulb scales, basal plates or roots. In post-bulb plants, virus titer distribution was considerably non-uniform, with no apparent trend within or between leaves.

Sources of resistance to IYSV and onion thrips exist in the onion gene pool. The search for these vital sources should continue so that the sustainability of the U.S. onion industry may be achieved through the use of efficient, reliable and environmentally safe integrated disease management strategies.

DEDICATIONS

This is dedicated to my lovely wife, Mrs. Francisca A. Bamfo, my family, especially my dear parents, and to my yet to be born children.

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CHAPTER I

LITERATURE REVIEW

INTRODUCTION

ONION

Origin and Taxonomy

Edible alliums include some of man's most ancient cultivated crops. The wild relatives from which the cultivated crops evolved grow in the mountainous regions of central Asia, including Turkey, Iran, Afghanistan, Pakistan, Tajikstan, China, Mongolia and Siberia. 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 5000 years and *A. cepa* does not exist as a wild species. They form large single bulbs and are mostly grown from seed (which also include sets and transplants) (Brewster, 1994).

Onion belongs to the plant class Monocotyledons; order Asparagales; family Alliaceae; tribe Alliae and genus Allium (Brewster, 1994). Cultivated onion is an outcrossing, herbaceous, biennial, diploid (2n = 2x = 16) plant and has over 16.4 Gbp of DNA per haploid genome (Arumuganathan and Earle, 1991). This genome size is one of the largest among all cultivated species; similar to hexaploid wheat (*Triticum aestivum*), and 6-, 16-, 36- and 107 times bigger than maize (*Zea mays*), tomato (*Lycopersicon esculentum*), rice (*Oryza sativa*) and *Arabidopsis thaliana*, respectively (King et al., 1998; Jakše et al., 2006; Jakše et al., 2008; McCallum et al., 2001; McCallum et al., 2006). Although onion is biennial, it is normally grown as an annual for bulb production and is only carried forward into a second year for seed production. The enormous genome size, coupled with the biennial generation time and severe inbreeding depression, have hampered molecular and genomic studies in onion; and this has delayed development of molecular and genomic resources for this economically and phylogenetically important plant (Jakše et al., 2008; King et al., 1998; Suzuki et al., 2001)

Production and Economic Importance

Bulb onions are produced from the subarctic regions of northern Finland to the humid tropics, although they are best adapted to production in subtropical and temperate areas. There is a wide range of cultivars (and landraces) which have been 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, sweetness, storability, processing quality and bulb carbohydrate composition (McCallum et al., 2006). In the USA, autumn-sown, early, sweet cultivars are produced in the southernmost states; late winter-sown, large, mild and sweet cultivars in the west mountain states; and long-day, hard, pungent and long-keeping cultivars in the north and northeastern states (Brewster, 1994).

Cultivated types of *Allium cepa* fall into two broad horticultural groups: the Common Onion Group and the Aggregatum Group. The former group form large single bulbs, is mostly grown from seeds and constitutes the vast bulk of the economically important cultivars. The latter group has clusters of small bulbs and is usually vegetatively propagated (Brewster, 1994).

Onion is the most economically significant member of the Asparagales (Jakše et al., 2006). It is the 17th most valuable food commodity in the world and the 18th in the USA. It is the second most valuable vegetable in the world, following tomato; and the third most valuable vegetable in the USA, following tomato and lettuce. In 2010, 3.7 million and 60,570 hectares were cultivated, respectively, to onion globally and in the USA. In 2009, gross production value of $19.6 billion and $915 million were, respectively, generated globally and in the USA, with a global net production value of $15.4 billion. China is the world's leading producer of onion, followed by India and then USA, generating $4.4 billion, $2.9 billion and $714 million, respectively, in 2009 (FAO, 2011).

Onion is used as a spice and food in most parts of the world (Do et al., 2004); however, it has been valued for millennia also for medicinal properties (Griffiths et al., 2002). The onion bulb contains low molecular weight fructans and oligofructose, and constitutes the second major dietary source of naturally occurring fructans and oligofructose, contributing 25% of the average American intake (Moshfegh et al., 1999). These polysaccharides confer prebiotic properties and have been correlated with lower rates of colorectal cancers, decreased levels of serum cholesterol, phospholipids and triglycerides, and decreased insulin levels (Ritsema and Smeekens, 2003; Roberfroid and Delzenne, 1998; Wun, 1996).

ONION THRIPS

Origin and Taxonomy

Onion thrips, *Thrips tabaci L*, was first described in 1888 by the Russian entomologist Karl Eduard Lindeman and is believed to be a native of eastern Mediterranean, the center of origin of its most important host plant, onion (*Allium cepa*). It is a cosmopolitan pest with a large host range, infesting plant hosts in Europe, North and South America, Africa, Asia and Australia

(Lewis, 1997; Mound, 1997). They belong to the insect order Thysanoptera; suborder Terebrantia; family Thripidae and subfamily Thripinae (Mound and Walker, 1982).

Morphology and Biology

Adult onion thrips vary in color and size depending on environmental temperature during their development. Summer temperatures (high temperature) usually result in fast growing, small and pale yellow insects; while winter temperatures (low temperature) give rise to slow growing, large and dark brown thrips. Adult body color is determined by pupal stage temperatures, while body size is determined by larval stage temperatures. Sexual dimorphism is evident in which male thrips are usually smaller and paler than females at the same temperature range, with females having a body length of 1.0 – 1.3 mm and ≈0.7 mm for males (Murai and Toda, 2001; Triplehorn and Johnson, 2005). The life cycle (Fig. I.5) consists of an egg, first and second larval instars, prepupal, pupal and adult stages. The ≈0.26 mm, kidney-shaped eggs are diagonally inserted at approximately 60^{o} superficially in lower or upper leaf surfaces (Nakahara, 1991).

Although sexual reproduction has been reported in eastern Mediterranean and Iran (Lewis, 1973; Mound, 1973), thelytokous parthenogenesis, in which unfertilized eggs develop into females, is the most common reproduction mode in most temperate regions of the world. They can also reproduce by arrhenotokous parthenogenesis in which unfertilized eggs develop into males and fertilized eggs develop into females (Kendall and Capinera, 1990). Deuterotokous parthenogenesis, in which unfertilized eggs develop into either males or females, is very uncommon and has only recently been reported for the first time to occur in some onion thrips populations in New York (Nault et al., 2006). Sexual reproduction results in a sex ratio of 1:1

(Lewis, 1973; Mound, 1973), whereas in parthenogenetic populations all individuals were females (MacIntyre-Allen et al., 2005a) or mostly females (Nault et al., 2006).

Thrips tabaci development from egg to adult takes between 11 and 30 days depending on prevailing temperatures; and they live for 11 – 60 days, also depending on environmental temperatures (Diaz-Montano et al., 2011). Adults have wings but are weak fliers, and are dispersed widely on winds. They may overwinter in all life stages, but typically dormant adult stages predominate during the winter (Cranshaw, 2008; Sites and Chambers, 1990).

Economic Importance of *Thrips tabaci*

Onion thrips infestation results in both direct and indirect damage depending on the production system. They feed on onion by removing mesophyll cell contents which results in small silvery leaf spots that turn into white blotches as leaves expand. These blotches develop into silvery patches and the leaves curl (Cranshaw, 2008; Diaz-Montano et al., 2011). In green onion production, such blotches, patches and leaf curls render the crop unmarketable. Larva and adult onion thrips feed on flower pedicels and buds, and reduce seed yield in onions grown for seed production (Elmore, 1949). The loss of mesophyll cell contents reduces the photosynthetic ability of plants and also interferes with the translocation of nutrients to bulbs (Molenaar, 1984). Extensive feeding results in plant growth retardation and if this occurs during the onset of bulb formation, results in reduced bulb weight and size up to 60% yield loss (Waiganjo et al., 2008; Reuda et al., 2007).

Although researchers at Georgia have recently confirmed that tobacco thrips (*Frankliniella fusca*) could transmit *Iris yellow spot virus* (IYSV) (Srinivasan et al., 2012), *Thrips tabaci* is currently the principal confirmed vector of the virus. IYSV is an economically important tospovirus that can cause up to 100% crop loss (Gent and Schwartz, 2008; Pozzer et al., 1999).

Management of *Thrips tabaci*

Like most crop pests, several management strategies need to be devised and integrated to achieve efficient control of onion thrips. Foliar insecticides are the most commonly used control method, however, complete control is difficult to achieve because complete spray coverage is difficult to accomplish as eggs are protected under leaf tissues, prepupae and pupae are in the soil or, as with larvae and some adults, are in the inner spaces between leaves where insecticides don't reach (Cranshaw, 2008; Shelton et al., 2003; Shelton et al., 2006). Also, adult thrips are highly mobile and may rapidly re-infest crops from surrounding vegetation or nearby harvested onion, alfalfa or other crop fields (Cranshaw, 2008; Diaz-Montano et al., 2011). Chemical control is further complicated by the development of resistance to some insecticides in some thrips populations in several parts of the world (Herron et al., 2008; MacIntyre-Allen et al., 2005b; Martin et al., 2003; Morishita, 2008; Shelton et al., 2003; Shelton et al., 2006). Different states and countries have different economic injury and action threshold levels for onion thrips control. Cranshaw (2008) and Diaz-Montano et al. (2011) have reviewed practices for the management of onion thrips.

IRIS YELLOW SPOT VIRUS

Taxonomy of Iris yellow spot virus

The name tospovirus is derived from *Tomato spotted wilt virus* (TSWV), the type species and the first member of the group to be described. Based on the genome structure, organization and molecular relationships of their nucleocapsid protein (N) genes, tospoviruses belong to the family Bunyaviridae. It’s the only member of the family that infects plants; while others are known pathogens of human and other vertebrate animals. The family contains over 350 virus species divided into five genera of which the others are Hantavirus, Nairovirus, Orthobunyavirus and Phlebovirus (Hogenhout et al., 2008).

Of the 19 distinct tospoviruses described globally to date (Table I.1 and Fig. I.1), eight have been accepted by the International Committee for the Taxonomy of Viruses (ICTV) as confirmed species while the rest are considered tentative species (Fauquet et al., 2005). Descriptors for the considerable degree of biological diversity displayed by tospoviruses include symptom variants, pathogenicity/virulence variants, differences in thrips specificity and transmission, and ability to break host resistance (Ciuffo et al., 2008; Dong et al., 2008; Hassani-Mehraban et al., 2005; Mandal et al., 2006; Persley et al., 2006; Qiu et al., 1998; Ullman et al., 1997; Whitfield et al., 2005). Using the N gene sequence, the genetic diversity within and among tospoviruses has been described for different geographic regions (e.g., Sivprasad and Gubba, 2008) (Table I.1 and Fig. I.1). Unique tospovirus species share less than 90% amino acid identity of the N protein (Fauquet et al., 2005).

Molecular Biology of *Iris yellow spot virus*

TSWV is the type member of the tospoviruses and has received the most attention in terms of research. As such, description of the morphology, genome structure and organization of IYSV (and the other members of the Bunyaviridae family) is as described for TSWV (Hogenhout et al., 2008). The virus particle (Fig. I.2) is 80 – 110 nm in diameter. The virus is a tripartite, single stranded RNA (ssRNA) referred to as large (L, 8.9 kb), medium (M, 4.8 kb) and small (S, 2.9 kb). The L RNA codes for the 331.5 kDa RNA-dependent-RNA-polymerase (RdRp) and is in negative sense. The M and S RNAs code for the precursor of two glycoproteins (GN and GC) and the N protein, respectively, and are ambisense. The two glycoproteins are translated as a polyprotein from a single open reading frame which is then cleaved to produce the individual glycoproteins that are required for virus transmission by thrips.

The M and S RNAs also code non-structural proteins NSm and NSs, respectively, which have been respectively shown to function as movement proteins and silencing suppressors (Bag et al., 2010; Kormelink et al., 1992; Pappu et al., 2008; Tsompana and Moyer, 2008). The three RNAs form pseudocircular structures that result from complementary base pairing at their ends and are tightly associated with the 29 kDa N protein to form ribonucleoproteins (RNPs). These RNPs are encased within a lipid envelop consisting of the two virus-coded glycoproteins (GN and GC) and a host-derived membrane. The glycoproteins are embedded in the host-derived membrane and project from the surface (Hogenhout et al., 2008; Pappu et al, 2009). The complete genome sequences of the S, M and L RNAs of IYSV are respectively reported by Cortês et al. (1998), Bag et al. (2009b) and Bag et al. (2009a), with Gene Bank accession numbers AF001387, FJ361359 and FJ623474, respectively.

Symptomatology of *Iris yellow spot virus* infection in onion (*Allium cepa*)

The majority of tospoviruses cause systemic infections in most of the crop plants they infect. Infections at early stages of plant growth cause the greatest damage, often resulting in severe stunting of the entire plant which may lead to death. Others, such as IYSV, move systemically less readily and tend to remain localized (Smith et al., 2006).

Symptoms of IYSV infection (Fig. I.3) appear as chlorotic or necrotic, straw-colored to white, dry, elongate or spindle-shaped lesions along the scape, with lesions frequently more numerous at mid- to lower portions of the scape. Some lesions have 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 completely girdling the scape and affecting seed set (Fig. I.3 A-C) (Gent et al., 2006). Straw-colored, lenticular-shaped lesions appear on leaves, with lesions having green centers or alternating rings of green and straw-colored tissues (Gent et al., 2006; Pappu et al., 2008) affecting foliage vigor and bulb enlargement.

First Reports of *Iris yellow spot virus* in Global Agricultural

The first report of *Iris yellow spot virus* was in the Netherlands in 1992 on an iris (*Iris hollandica*) grown for cut flowers (Derks and Lemmers, 1996). However, it was first identified in Brazil in 1981 (de Ávila et al., 1981). Since then, the virus has spread to many different hosts worldwide, been reported on amaryllis (*Hippeastrum hybridum*) in 1996 in Israel (Gera et al., 1998a,b), lisianthus (*Eustoma grandiflorum*) in 1999 in Israel and/or the Netherlands (Kritzman et al., 2000), in leek (*Allium porrum*) in 1998 and 1999, respectively, in the Netherlands (Anon,

2007) and Slovenia (Mavrič and Ravnikar, 2000), and in onions (*Allium cepa*) in Israel in 1996 (Gera et al., 1998a).

Globally, outbreaks of the virus have been reported in Asia (India, Iran, Israel and Japan), Europe (France, Italy, the Netherlands, Poland, Slovenia, Spain and United Kingdom), North America (several states of the United States of America, (Fig. I.4), (Pappu et al., 2007)), Central America (Guatemala), South America (Brazil, Chile and Peru), Africa (South Africa, Reunion Island) and Oceania (Australia) (FERA, 2007). In recent years, IYSV has been confirmed in some other countries including New Zealand (Ward et al., 2008), Uruguay (Colnago et al., 2010), Germany (Leinhos et al., 2007), Serbia (Bulajic et al., 2008), Austria (Plenk and Grausgruber-Gröger, 2011), Greece (Chatzivassiliou et al., 2009), Mauritius (Lobin et al., 2010), Tunisia (Moussa et al., 2005), Egypt (Elnagar et al., 2005), Sri Lanka (Widana-Gamage et al., 2010), Canada (Hoepting et al., 2008), Hawaii (Sether et al., 2010) and in more states in the U.S. (Pappu et al., 2009).

Host Range of *Iris yellow spot virus*

Due to the frequent incidence of the virus in the plant genus *Allium*, the host range of the virus is usually cited as natural-allium hosts (Table I.2), natural non-allium hosts (Table I.3) and non-natural/experimental hosts (Table I.4). In recent years more natural hosts (weeds) have been reported for different geographic regions e.g., Evans et al. (2009a,b), Hsu et al. (2011) and Smith et al. (2011).

Onion thrips (*Thrips tabaci*) transmission of *Iris yellow spot virus*

Several species of thrips transmit tospoviruses in a circulative propagative manner. More than 5000 species of thrips have been described, of which only 10 are known to vector tospoviruses, suggesting marked co-evolution for transmission specificity (Mound, 2001). IYSV is currently known to be transmitted exclusively by onion thrips; however, limited transmission by tobacco thrips (*Frankliniella fusca*) has been confirmed in Georgia (Srinivasan et al., 2012). For successful transmission to occur, virus acquisition must occur during the first or second larval stages (Fig. I.5). The virus then multiplies in the larvae, survive through the later developmental stages, and the emerging adult thrips are viruliferous and infective. Adult thrips that feed on infected plants and acquire the virus are unable to transmit even if they are allowed lengthy feeding periods (Hogenhout et al., 2008; Moritz et al., 2004; Whitfield et al., 2005).

The passage of tospoviruses through the alimentary canal to the salivary glands in their thrips vectors have been described (Fig. I.6). Upon ingestion, virions travel through the lumen of the foregut into the midgut, where they move across the microvilli of the midgut into the columnar epithelial cells of the midgut. Following replication in the epithelial cells, virions exit, and traverse the basement membrane and the alternating series of longitudinal and circular muscle cells that encircle the midgut epithelium. Tospoviruses entering the salivary gland must traverse the basal membrane of the primary salivary glands. The lumen of each primary salivary gland lobe is lined with microvilli and these represent the last membrane the virus must cross for transmission to occur. Once inside the salivary gland lumen, virions can move with saliva into a canal that leads to an efferent salivary canal, a common salivary reservoir, and then a duct that ultimately allows virus-laden saliva to exit the combined salivary-food canal in the maxillary stylets (Assis Filho et al., 2002; Hogenhout et al., 2008; Nagata et al., 1999; Nagata et al., 2002;

Ullman et al., 1992a,b; Ullman et al., 1993). During this passage, tospoviruses replicate within different tissue systems of the vector, including the midgut epithelial cells, muscles surrounding the alimentary canal, the primary salivary glands and parts of the Golgi complex (Hogenhout et al., 2008; Ullman et al., 1993; Ullman et al., 1995).

The two glycoproteins that decorate the virion surface probably are the first viral components that interact with molecules in the thrips midgut. Studies by Bandla et al. (1998) and Whitfield et al. (2004) support the hypothesis that GN and GC are involved in virus entry and interact with receptor molecules in thrips. A direct interaction between GN and thrips midgut was demonstrated *in vivo* by Whitfield et al. (2004). Isolates of TSWV that had mutations and deletions in the glycoprotein open reading frame were rendered non-transmissible by *Franklinella occidentalis* even though the infectivity of the virus was not compromised (Nagata et al., 2000; Naidu et al., 2008; Sin et al., 2005). Although these studies support the role of GN in virus attachment, the role of GC is not currently understood. Recent evidence indicates that GC protein may mediate fusion of virion and cell membranes during entry into vector cells (Cortês et al., 2002; Whitfield et al., 2005). The identity of the virus receptors in thrips continues to elude scientists studying tospovirus-thrips interactions (Hogenhout et al., 2008).

Economic Importance of *Iris yellow spot virus*

Edible allium crops and some of the cut flower and potted ornamental species including alstroemeria, chrysanthemum, iris and lisianthus are the most economically important crops identified as hosts of IYSV (FERA, 2007). Infections at early stages of crop growth often result in a substantial decrease in plant stand leading to considerable yield losses, but infections at later stages still cause significant losses in yield and quality of produce (Culbreath et al., 2003; Pappu et al., 2008). Infections result in loss in quantity and/or quality of produce depending on the host species (Table I.5). In all its incidences, onion crops have been particularly affected. In bulb onion, significant losses occur in the form of reduced bulb size, and significant reductions in the percentage of colossal and jumbo grade bulbs in susceptible cultivars have been reported. This is a result of affected plants poorly storing assimilates and not developing fully. However, no symptoms are found associated with bulbs. Total yield loss of 1-10% or more are frequently reported in Colorado, USA (Gent et al., 2004; Gent et al., 2006; Schwartz et al., 2002) with the reductions in bulb yield and grade varying in relation to host resistance, infection timing and other factors (Gent and Schwartz, 2008). Quality losses may occur in green onions which are harvested young for their fresh, green and succulent leaves. In such a production system, symptomatic plants will be rendered unsalable, leading to losses in marketable yield. In seed onion production systems, infected scapes often lodge (Fig. I.3C) leading to umbel rot and loss, which in turn leads to significant seed loss (Crowe and Pappu, 2005; du Toit et al., 2007; Gent et al., 2006; Gent et al., 2007; Pozzer et al., 1999). In its ornamental hosts, losses in aesthetic (quality) and quantity are frequently common (Table I.5).

After its introduction and subsequent spread, IYSV and its vector have become major production and economic concerns to the onion industry in the USA. The virus was ranked as a high research priority in the Western Regional Pest Management Strategic Plan developed during a regional stakeholders' meeting held in Boise, Idaho, in 2004 (IPMCENTERS, 2004). In a web-based survey held throughout North America in 2006, onion growers, processors and researchers identified this pathogen as an important production constraint for fresh and processed onions in the USA (Havey Lab, 2006). The Pacific Northwest is particularly hit by the virus and is experiencing increased outbreaks in bulb and seed onion crops, and the virus is considered the biggest threat to sustainable production by onion growers in this region (Pappu et al., 2009).

Management of *Iris yellow spot virus*

The management of IYSV infection is not different from any other vector-borne virus disease in principle. This is because control of the virus is further complicated by the need to manage the vector as well. For this reason, control needs to be based on sound epidemiological principles and deployed within an integrated disease management (IDM) framework that includes phytosanitation, cultural, host plant resistance, chemical, physical and biological measures as appropriate. Such strategies should be optimized to address both internal and external initial virus inoculum sources, early or late phases of virus spread, and should target vulnerable stages in the virus-vector-crop pathosystem. An effective IDM plan should include strategies that are both selective and non-selective in their action (Jones, 2004; Jones, 2006) and seek to avoid, eradicate and/or exclude the pest/pathogen while protecting the plant (Schumann and D'Arcy, 2006).

Phytosanitary measures currently available to growers include elimination of volunteer plants within fields, removal of cull piles of discarded onions, and removal of weeds in and around onion fields. Cultural practices that avoid plant stress such as deficient or excessive irrigation and nutrient fertilization, soil compaction, saline or alkaline soils, and herbicide injury are encouraged. Adoption of optimal plant density to avoid thin, patchy stands and to promote uniform plant stands augment IDM strategies (Gent et al., 2006; Pappu et al., 2009). Fields of seed onions (which are biennials) should be separated from fields of bulb onions (which are annuals) to eliminate the 'green bridge' effect for both IYSV and its vector (Pappu et al., 2009). The use of high quality transplants and sets free from onion thrips and IYSV should be practiced and all onion propagules should be obtained from certified sources. Manipulation of planting dates, in addition to 3-years or more rotations between onion crops with non-host crops, should be adopted (Schwartz and Gent, 2007).

Even though host resistance is an important foundation in all IDM strategies (Kennedy, 2008; Panda and Khush, 1995), completely resistant onion germplasms have been difficult to come by for this pathosystem. In a study to evaluate the response of onion cultivars to IYSV, all 46 cultivars tested were susceptible to the virus, with infection rates of 58 to 97% (du Toit and Pelter, 2005). However, in another study carried out recently, some cultivars exhibiting less susceptibility to the virus were identified (Diaz-Montano et al., 2010), and these should be planted where possible.

There is currently no chemical or biological control for the virus. However, induction of systemic acquired resistance (SAR) in onion plants by the exogenous application of acibenzolar-*S*-methyl (Actigard, Syngenta Crop Protection, NC, USA) resulted in a 34% reduction in IYSV incidence in Colorado (Gent et al., 2004). This may be practiced in those production systems in which onion cultivars with some level of field resistance are cultivated.

IYSV is not mechanically transmitted in nature (Hogenhout et al., 2008; Whitfield et al., 2005). Thus, appropriate control and management of the onion thrips vector might provide some level of control of the disease (Schwartz et al., 2009). Both conventional (such as pyrethroids, organophosphates and carbamates) and reduced-risk (such as spinosad and azadirachtin) insecticides have been intensively adopted in various control programs to suppress onion thrips populations and thus, reduce the incidence and/or severity of IYSV (Cranshaw, 2006; Hammon, 2004; Jensen and Shock, 2004; MacIntyre-Allen et al., 2005b; Shelton et al., 2003). Using straw mulch in combination with reduced-risk (spinosad alternated with azadirachtin) insecticide provided 36% reduction in thrips-days compared to nontreated checks in Colorado (Schwartz et al., 2009). Overhead irrigation can provide some onion thrips suppression, and so does all practices that promote predation of onion thrips and prevent contact between onion thrips and plants. However, it must be emphasized that onion thrips control alone is not sufficient to economically control IYSV (Cranshaw, 2006; Schwartz and Gent, 2007).

EFFECTS OF VIRUS INFECTION ON PLANTS

In a susceptible host, plant viruses often induce a number of common physiological alterations: decrease in photosynthesis, increase in respiration, accumulation of nitrogen compounds, and expanded oxidase activity. Combined, these, and presumably other physiological effects, underlie the display of virus-induced disease symptoms (Culver and Padmanabhan, 2007). Virus effects on host physiology and symptom development is not well understood owing in part to the intracellular replication sites of these pathogens and the lack of specific virus-derived metabolic products such as the toxins and hormones associated with fungal and bacterial diseases (Culver and Padmanabhan, 2007). The mechanisms responsible for these physiological and molecular alterations remain largely unknown, in part owing to the physiological variability associated with virus infections. Specifically, virus effects may occur locally within the infection foci or systemically in the regions distal from the site of infection. Virus effects on the host also vary spatially and temporally within the area of infection (Wang and Maule, 1995).

MECHANISMS OF VIRUS PATHOGENESIS

The mechanisms underlying the physiological and molecular alterations of virus infections are largely unknown. However, competition and interactive mechanisms are the two general models proposed.

1. **Competition Disease Model**

This model suggests that viruses replicate within the host to such an extent as to usurp a substantial amount of plant's metabolic resources, thus adversely affecting its growth and development. Many viruses, to a significant degree, commandeer host transcriptional and translational machinery. Whereas viral proteins and genomes make up about 1% of the fresh weight of a *Tomato mosaic virus* (TMV)-infected tobacco leaf, TMV translation may account for more than half the total protein production in infected cells (Matthews, 1991; Siegel et al., 1978). As viral gene expressions increase, that of the host decline, presumably representing a method of increasing the availability of host resources for virus synthesis (Maule et al., 2000; Tecsi et al., 1996; Wang and Maule, 1995).

Virus RNAs are known to contain unique structures, such as internal ribosome entry sites or translation enhancer sequences that provide a competitive advantage over host mRNAs for access to the cell's metabolic machinery (Thivierge et al., 2005).

Although competition may play a role in virus pathogenesis, there are many virus pathosystems where variabilities in symptom severity do not correlate with the level of virus accumulation, suggesting that this model may not be sufficiently sustained, and therefore, may not be a major contributor to the disruption of host physiology (Agrios, 2005; Culver and Padmanabhan, 2007). Some of the factors that conflict with this model include:

a. The nature of virus infection cycle is transient, where virus replication rapidly increases and then subsides, often within a matter of hours. This suggests that virus sequestration of host cellular resources may also be transient (Maule et al., 2000; Wang and Maule, 1995).
b. There is a restoration of host gene transcription and translation once virus replication abates (Maule et al., 2000; Wang and Maule, 1995).
c. Symptom differences between two strains of TMV were not attributable to resource competition but rather to specific virus properties (Balachandran et al., 1995).
d. Rowland et al. (2005) observed that tolerance to TSWV in peanut is associated with near-normal photosynthetic levels in symptomless tissues even in the presence of the virus.

2. Interactive Disease Model

This is a more complex model in which specific interactions between virus and host components disrupt host physiology to cause disease. This represents a selective model that significantly can explain the variations in disease severity observed when comparing similar viruses on the same host or the same virus in different hosts. Consequential and inconsequential virus-host interactions have been described although the latter has not been particularly well studied (Culver and Padmanabhan, 2007).

Consequential interactions directly contribute to the development and establishment of a systemic infection, whereas an inconsequential interaction does not contribute to the success of the infection but nevertheless disrupts host physiology. Virus-host interactions cover a wide range of virus and host components, including protein and nucleic acid, and represent the complexity of processes through which plant viruses induce symptoms and cause disease under certain environmental or tissue/cell conditions (Culver and Padmanabhan, 2007).

Auxin is a major plant hormone that controls a diverse array of developmental and cellular responses (Teale et al., 2006). In the TMV-arabidopsis pathosystem, TMV replicase proteins are identified to interact with a subset of host's Aux/IAA proteins which leads to a cytoplasmic, instead of a nuclear, localization of the Aux/IAA protein, disrupting their normal functions and presumably leading to many of the physiological and developmental abnormalities that occur during infection (Golem and Culver, 2003; Padmanabhan et al., 2005; Padmanabhan et al., 2006). In rice, an interaction between the P2 protein of *Rice dwarf virus* (RDV) and rice *ent*-kaurene oxidase (a key component in the synthesis of gibberellins) was established. There appears to be a direct correlation between the level of gibberellic acid synthesis in infected plants, the interaction of RDV P2 with *ent*-kaurene oxidase, and the appearance of disease symptoms, including stunting (Tomaru et al., 1997; Zhu et al., 2005). Increases in the production of ethylene typically occur during virus infection and are associated with the development of chlorosis, necrosis and senescence symptoms (Jameson and Clarke, 2002; Ohtsubo et al., 1999; van Loon et al., 2006). A link between the expression of the P6 protein of *Cauliflower mosaic virus* (CaMV) and the disruption of the ethylene response pathway has been suggested (Cecchini et a., 1997; Geri et al., 1999; Love et al., 2005).

In terms of host interactions leading to disease, suppressors of RNAi have been shown to play a direct role in disrupting host physiology and development. These viral-derived RNAi suppressors disrupt the microRNA-guided cleavage of host mRNAs leading to the accumulation of host mRNAs that would normally be degraded. The severity of the symptoms caused by the disruption of RNAi pathways is determined by several factors, including the strength of the suppressor function, the step in the silencing pathway being targeted by the suppressor, and the ability of the virus and/or its suppressor to reach meristematic tissues where microRNA regulation is likely to have the greatest effect on host development (Chapman et al., 2004; Chellappan et al., 2005; Jones-Rhoades et al., 2006; Zhang et al., 2006,). Studies by Wang et al. (2004) suggest that targeted degradation of host mRNA sequences that have sequence similarities with virus RNA sequences represents a potential mechanism for altering gene expression and host physiology (Wang et al., 2004).

The alteration of the permeability and the size exclusion limits of the plasmodesmata by virus encoded movement proteins directly affect the transport of carbohydrates, small RNAs and proteins. This alters the allocation of cellular resources as well as cell-to-cell communication signals, representing a potentially effective means of disrupting host physiology (Biemelt and Sonnewald, 2006; Guo and Ding, 2002; Kim et al., 2001; Lough and Lucas 2006; Scholthof, 2005).

Sites of active virus infections have been known to function as photosynthetic sinks, expanding the availability of resources at the site of virus replication and movement. The expression of viral movement proteins leads to accumulation of carbohydrates and starch in infected leaves; however, the mechanisms through which this reallocation occurs are virus specific and likely the result of interactions between specific virus and host components (Culver and Padmanabhan, 2007; Herbers et al., 2000; Shalitin and Wolf, 2000; Tecsi et al., 1996).

Some viruses, specifically those in the family Geminiviridae, replicate utilizing host-encoded DNA polymerase and need to be introduced into actively dividing meristematic or endoreduplicating tissues where DNA replication machinery is abundant. If introduced into any other cell, geminiviruses are known to reprogram infected cells to re-enter the DNA replication/S phase of cell division, leading to the production of host DNA replication machinery and providing a more appropriate environment for virus replication (Hanley-Bowdoin et al., 2004; Kong et al., 2000; Rojas et al., 2005; Xie et al., 1995).

Some other viruses, including Begomoviruses, are known to clearly encode the ability to utilize or disrupt specific protein modification processes including post-translational phosphorylation, acetylation, myristoylation, ubiquitionation and glycosylation, thus potentially affecting normal host protein processing (Culver and Padmanabhan, 2007; Kouzarides, 2000; Lee et al., 2005; Qin et al., 1998; Shapka et al., 2005; Waigmann et al., 2000).

The key determinants modulating virus effects on host physiology and disease development appear to be derived from the interaction of virus and host components, and not from general metabolic perturbations caused by the overproduction of viral components and competition for host resources. The interactions affecting host physiology target a broad array of host processes including hormone regulation, cell cycle control, host transport, protein modification and several others, providing the basis for a causal chain leading from infection to the display of symptoms. These interactions function to disrupt host physiology as a way to promote virus replication and spread, whereas others affect host functions indirectly. However, it must be emphasized that, not all interactions, even those that are essential for infection, have effects on host physiology (Culver and Padmanabhan, 2007).

Table I.1. Geographic distribution of known tospoviruses in different continents.

Africa	Asia	Australasia	Europe	North America	South America[a]
GRSV	CaCV	CaCV	CSNV	INSV	CSNV
INSV	CSNV	INSV	INSV	IYSV	GRSV
IYSV	CCSV	IYSV	IYSV	MSMV	INSV
TSWV	GBNV[b]	TSWV	PoRSV	TSWV	IYSV
	INSV		TSWV		PCFV
	IYSV				TCSV
	MYSV				TSWV
	PBNV[b]				ZLCV
	PSMV				
	PYSV				
	TSWV				
	TYRV[b]				
	TZSV				
	WBNV				
	WSMoV				

Virus acronyms: CaCV, *Capsicum chlorosis virus*; CCSV, *Calla lily chlorotic spot virus*; CSNV, *Chrysanthemum stem necrosis virus*; GRSV, *Groundnut ring spot virus*; GBNV, *Groundnut bud necrosis virus*; INSV, *Impatiens necrotic spot virus*; IYSV, *Iris yellow spot virus*; MSMV, *Melon severe mosaic virus*; MYSV, *Melon yellow spot virus*; PCFV, *Peanut chlorotic fanspot virus*; PoRSV, *Polygonum ringspot virus*; PSMV, *Physalis silver mottle virus*; PYSV, *Peanut yellow spot virus*; TCSV, *Tomato chlorotic spot virus*; TSWV, *Tomato spotted wilt virus*; TYFRV, *Tomato yellow fruit ring virus*; TZSV, *Tomato zonate spot virus*; WBNV, *Watermelon bud necrosis virus*; WSMV, *Watermelon silver mottle virus*; ZLCV, *Zucchini lethal chlorosis virus*. Two potentially new, yet to be characterized tospoviruses from Australia, one from an orchid and the other from *Bossiaea eriocarpa* are not included in the above list. [a]Includes Central America and the Caribbean. [b]TFYRV, *Tomato fruit yellow ring virus*, is considered as an isolate of *Tomato yellow ring virus* (TYRV). GBNV is also referred to as PBNV, *Peanut bud necrosis virus*; Adopted and modified from Pappu et al. (2009).

Table I.2. Allium species reported as natural hosts of *Iris Yellow Spot Virus*.

Host		**Location**[a]	**Year of First Published Report**
Allium altaicum	Wild onion	Washington	2006 (Pappu et al., 2006)
		New Mexico	2010 (Cramer et al., 2011)
A. cepa	Onion	Idaho	1993 (Hall et al., 1993)
		Brazil	1994 (Pozzer et al., 1999)
		Israel	1998 (Gera et al., 1998a)
		Japan	1999 (Kumar & Rawal, 1999)
		Slovenia	2000 (Mavric & Ravnikar, 2000)
		Colorado	2002 (Schwartz et al., 2002)
		Arizona	2003 (Moyer & Mohan, 1993)
		California	2003 (Moyer & Mohan, 1993)
		Utah	2003 (Abad et al., 2003)
		Italy	2003 (Cosmi et al., 2003)
		Australia	2003 (Coutts et al, 2003)
		New Mexico	2004 (Creamer et al., 2004)
		Washington	2004 (du Toit et al., 2004)
		Georgia	2004 (Mullis et al., 2004)
		Tunisia	2005 (Moussa et al., 2005)
		Spain	2005 (Cordoba-Sellés et al., 2005)
		Oregon	2005 (Crowe & Pappu, 2005)
		Chile	2005 (Rosales et al., 2005)
		India	2006 (Ravi et al., 2006)
		Rèunion Island	2006 (Robène-Soustrade et al., 2006)
		Peru	2006 (Mullis et al., 2006)
		Texas	2006 (Miller et al., 2006)
		Guatemala	2006 (Nischwitz et al., 2006)
		New York	2006 (Hoepting et al., 2007)
		France	2007 (Huchette et al., 2008)
		Canada	2007 (Hoepting et al., 2008)
		Serbia	2007 (Bulajic et al., 2008)
		South Africa	2007 (du Toit et al., 2007)
		Arizona	2008 (Pappu & Matheron, 2008)
		Nevada	2008 (Bag et al., 2009c)
		Greece	2008 (Chatzivassiliou et al., 2009)
		Mauritius	2010 (Lobin et al., 2010)
		Uruguay	2010 (Colnago et al. 2010)
		Hawaii	2010 (Sether et al., 2010)
		Austria	2011 (Plenk et al., 2011)
A. ampeloprasum	Egyptian leek	Egypt	2011 (Hafez et al., 2011)
A. cepa var. *ascalonicum*	Shallot	Rèunion Island	2005 (Robène-Soustrade et al., 2006)
A. galanthum	Snowdrop Onion	New Mexico	2010 (Cramer et al., 2011)
A. porrum	Leek	Australia	2003 (Coutts et al., 2003)
		Rèunion Island	2005 (Robène-Soustrade et al., 2006)
		Colorado	2006 (Schwartz et al., 2007)
		Oregon	2006 (Gent et al., 2007)
		Greece	2008 (Chatzivassiliou et al., 2009)
A. pskemense	Wild onion	Washington	2006 (Pappu et al., 2006)
A. roylei	Wild onion	New Mexico	2010 (Cramer et al., 2011)
A. sativum	Garlic	Rèunion Island	2005 (Robène-Soustrade et al., 2006)
		Oregon	2008 (Bag et al., 2009c)
		India	2010 (Gawande et al., 2010)
		Egypt	2011 (Hafez et al., 2011)
A. schoenoprasum	Chive	New Mexico	2010 (Cramer et al., 2011)
A. tuberosum	Chinese Chive	New Mexico	2010 (Cramer et al., 2011)
A. vavilovii	Wild onion	Washington	2006 (Pappu et al., 2006)
		New Mexico	2010 (Cramer et al., 2011)

[a]The following states are located in the United States: Arizona, California, Colorado, Georgia, Hawaii, Idaho, Nevada, New Mexico, New York, Oregon, Texas, Utah, and Washington. (Alliumnet, 2011).

Table I.3. *Species other than Allium reported as natural host of Iris yellow spot virus.*

Host		Location[a]	Year of First Published Report
Alstroemeria sp.	Alstroemeria	Japan	2001 (Okuda & Hanada, 2001)
Amaranthus retroflexus	Pigweed	Idaho, Wash.	2007 (Sampangi et al., 2007)
Atriplex micrantha	Twoscale Saltbush	Utah	2009 (Evans et al., 2009a)
Bessera elegans	Bessera	Japan	2005 (Jones, 2005)
Chenopodium album	Lambsquarters	Idaho, Wash.	2007 (Sampangi et al., 2007)
Clivia minata	Clivia	Japan	2005 (Jones, 2005)
Cycas sp.	Cycad	Iran	2005 (Ghotbi et al., 2005)
Eustoma grandiflorum	Lisianthus	Japan	2003 (Doi et al., 2003)
Eustomarussellianum	Lisianthus	Israel	2000 (Kritzman et al., 2000)
Hippeastrum hybridum	Amaryllis	Israel	1998 (Gera et al., 1998a)
Iris hollandica	Iris	The Netherlands	1996 (Derks & Lemmers, 1996)
Kochia scoparia	Kochia	Idaho, Wash.	2007 (Sampangi et al., 2007)
Lactuca serriola	Prickly Lettuce	Idaho, Wash.	2007 (Sampangi et al., 2007)
Pelargonium hortorum	Geranium	Iran	2005 (Ghotbi et al., 2005)
Petunia hybrida	Petunia	Iran	2005 (Ghotbi et al., 2005)
Portulaca sp.	Purslane	Italy	2003 (Cosmi et al., 2003)
Rosa sp.	Rose	Iran	2005 (Ghotbi et al., 2005)
Scindapsus sp.	Pothos	Iran	2005 (Ghotbi et al., 2005)
Setaria viridis	Green Foxtail	Utah	2008 (Evans et al., 2009b)
Sonchus asper	Spiny Sowthistle	Georgia	2003 (Nischwitz et al., 2007)
Tribulus terrestris	Puncturevine	Idaho, Wash.	2007 (Sampangi et al., 2007)
Vigna unguiculata	Cowpea	Iran	2005 (Ghotbi et al., 2005)

[a]Idaho, Utah and Georgia are states located in the United States of America. (Alliumnet, 2011).

Table I.4. Experimental hosts of *Iris yellow spot virus* (FERA, 2007).

Host	Symptom	References
Chenopodium amaranticolor (Tree spinach)	Local necrotic lesions	Doi et al., 2003; Gera et al., 2002; Pozzer et al., 1999
Chenopodium murale (Nettleleaf goosefoot)	Local necrotic lesions	Mavrič & Ravnikar, 2000
Chenopodium quinoa (Quinoa)	Local necrotic lesions	Doi et al., 2003; Gera et al., 2002
Datura stramonium (Thorn apple)	Occasional local necrotic lesions	Gera et al., 2002; Pozzer et al., 1999
Emilia sonchifolia (Cupid's shaving brush)	Occasional local necrotic lesions	Gera et al., 2002
Gomphrena globosa (Globe amaranth)	Local necrotic lesions	Doi et al., 2003; Gera et al., 2002
Impatiens sultani (Busy lizzie)	Necrotic spots on leaves	Doi et al., 2003
Lactuca sativa (Lettuce)	Necrotic spots on leaves and leaf mosaic symptoms	Doi et al., 2003
Nicotiana benthamiana	Chlorotic spots or vein lesions on inoculated leaves followed by systemic leaf deformation, leaf mosaic symptoms also observed	Doi et al., 2003; Gera et al. 2002; Ghotbi et al., 2005; Pozzer et al., 1999
Nicotiana glutinosa	Leaf mosaic symptoms	Doi et al., 2003
Nicotiana rustica	Lesions on the veins of inoculated leaves followed by systemic leaf deformation	Doi et al., 2003; Pozzer et al., 1999
Petunia x *hybrida* (Petunia)	Occasional local necrotic lesions	Doi et al., 2003; Ghotbi et al., 2005; Gera et al., 2002
Spinacia oleracea (Spinach)	Necrotic spots and leaf mosaic symptoms	Doi et al., 2003
Vica faba (Broad bean)	Occasional local necrotic lesions	Doi et al., 2003
Vigna unguiculata (Cowpea)	Systemic mild necrotic lesions and necrotic leaf spots	Ghotbi et al., 2005

Table I.5. Economic impacts (where given) associated with outbreaks of *Iris yellow spot virus.*

Location and date	**Crop**	**Impact**	**Reference**
Australia, 2002	Onion	Widespread symptoms sometimes causing complete crop abandonment	Coutts et al., 2003
Brazil, 1994	Onion	Disease incidence often reached levels of 100%, resulting in a total loss of bulb and seed production	Pozzer et al., 1999
Chile, 2004	Onion	50% of the crop showed symptoms in fields that were sampled	Rosales et al., 2005
Colorado, 2001-2003	Onion	5% incidence, general reduction in bulb size. Survey work 2 years later found 73%incidence. Conservative estimates of 5-10%losses	Schwartz et al.,2002; Gent et al., 2004; Gent et al., 2006
Idaho and Oregon, 1989	Onion	Up to 90% loss of seed yield in some instances	Mohan & Moyer, 2004
India, 1999	Onion	'Potential to cause complete crop loss'	Kumar & Rawal, 1999
Israel, 1998	Onion	Disease incidences of up to 60% resulting in heavy losses in onion bulb production	Kritzman et a1., 2001
New Mexico, 2002-2003	Onion	ELISA showed 24 to 59% infection with a 0.5 to 30% incidence of diseases symptoms	Creamer et al., 2004
Oregon, 2002	Onion	Up to 100% incidence of symptoms at one site, leading to 95% lodging and near total crop failure. Less severe at other sites	Crowe & Pappu, 2005
Rèunion Island, 2005	Onion	Survey of 10 onion fields found 75% of leaves with symptoms and 27% of bulbs ELISA positive. Present in 15% of 45 day old seedlings at one nursery	Robène-Soustrade et . . . al., 2006
Slovenia, 1999	Onion	Over 90% level of disease incidence in one field but no obvious effect on yield	Mavrič &Ravnikar, 2000
Spain, 2003	Onion	Severely infected plants eventually died, 'potentially devastating'	Córdoba-Sellés et al., 2005
Texas, 2006	Onion	Disease incidence approached 100% in some fields with associated yield loss and quality problems	Miller et al., 2006
Washington, 2003	Onion	Symptomatic plants observed in five seed crops at incidences ranging from <1% to approximately 20%	du Toit et al., 2004
Netherlands, 1992 onwards.	Onion, leek, Alstroemeria	"With exception of the first infection in Iris, there was only limited or even very little damage by the virus, so its economic impact is low."	Verhoeven, Pers. Comm
.Netherlands, 1992	Iris	50-90% incidence of infected plants	Mavrič &Ravnikar, 2000
Australia, 2002	Leek	10% of infected leeks had pale bands along mid-rib	Coutts et al., 2003
Colorado, 2006	Leek	Incidence of plants with foliar lesions on multiple leaves (25-30%) and stunting of 5% of infected plants in both leek cultivars affected suggests that IYSV could seriously reduce leek stem development and marketability	Schwartz et al., 2007
South Africa, 2006	Onion	At the time symptoms were observed, approximately 5% of the scapes had lodged as a result of extensive lesions.	du Toit et al., 2007
Oregon, 2006	Onion and leek	Disease incidence was 20% in one onion seed crop with 1% of plants lodged. Negligible losses and a disease incidence of 5% in an onion bulb crop and leek seed crop.	Gent et al., 2007.

Source: FERA, 2007

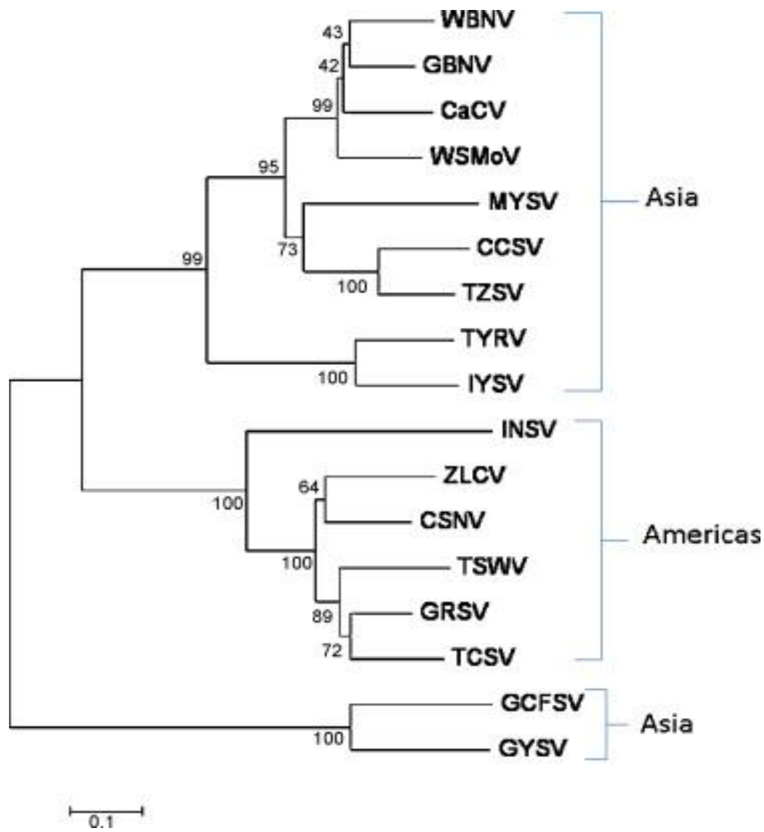

Figure I.1. Phylogeny based on nucleocapsid protein amino acid sequences of tospoviruses (Dong et al., 2008). Polygonum ringspot virus and *Melon severe mosaic virus* are not included. The known tospoviruses fall into two major groups (Asia and the Americas) based on their prevalence and distribution. Virus acronyms are explained in Table I.1; Adopted from Pappu et al. (2009).

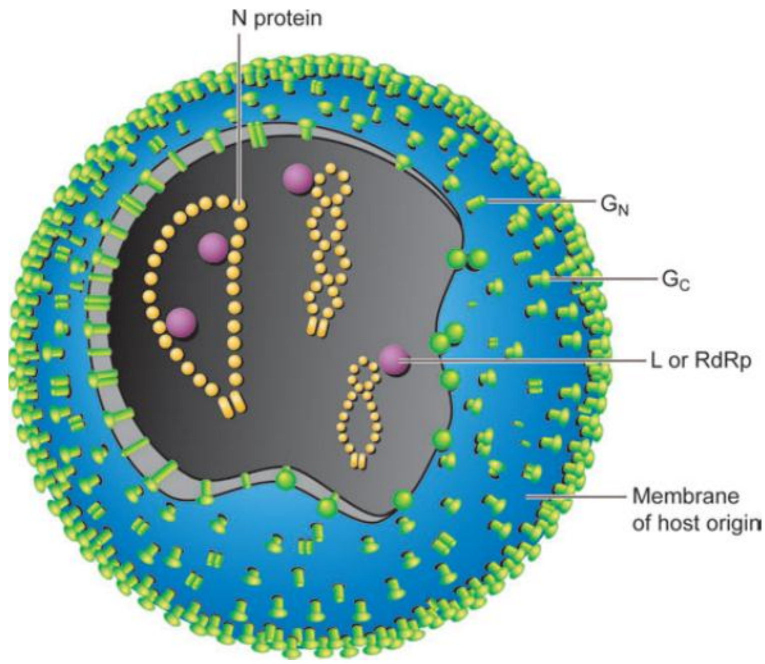

Figure I.2. Diagram of TSWV virion. A double-layered membrane of host origin (blue) is shown with the viral-encoded proteins GN and GC (green) projecting from the surface in monomeric and dimeric configurations. The genomic RNA is presented as noncovalently closed circles in the form of a ribonucleoprotein (RNP) complex created by its association with many copies of N protein (yellow). A few copies of the virion-associated RNA-dependent RNA polymerase (RdRp or L) are shown (purple) in association with the RNPs; Adopted from Hogenhout et al. (2008).

Figure I.3. Symptoms caused by *Iris yellow spot virus* in onion crops. A-C: onion scapes at different stages of IYSV infection. The extensive necrosis eventually results in scape lodging (C). D: IYSV symptoms on onion leaves. Individual lesions expand and coalesce, leading to drying of the affected part. E: onion plants severely infected by IYSV.

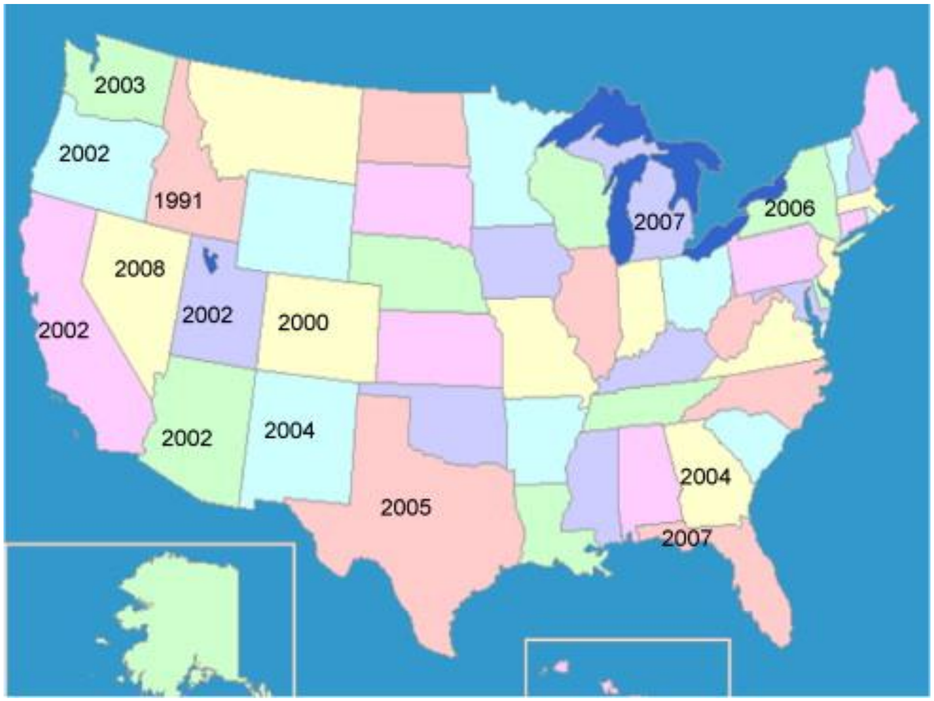

Figure I.4. Year of first report and spread of *Iris yellow spot virus* in several states in the USA; Adopted from Pappu et al. (2009).

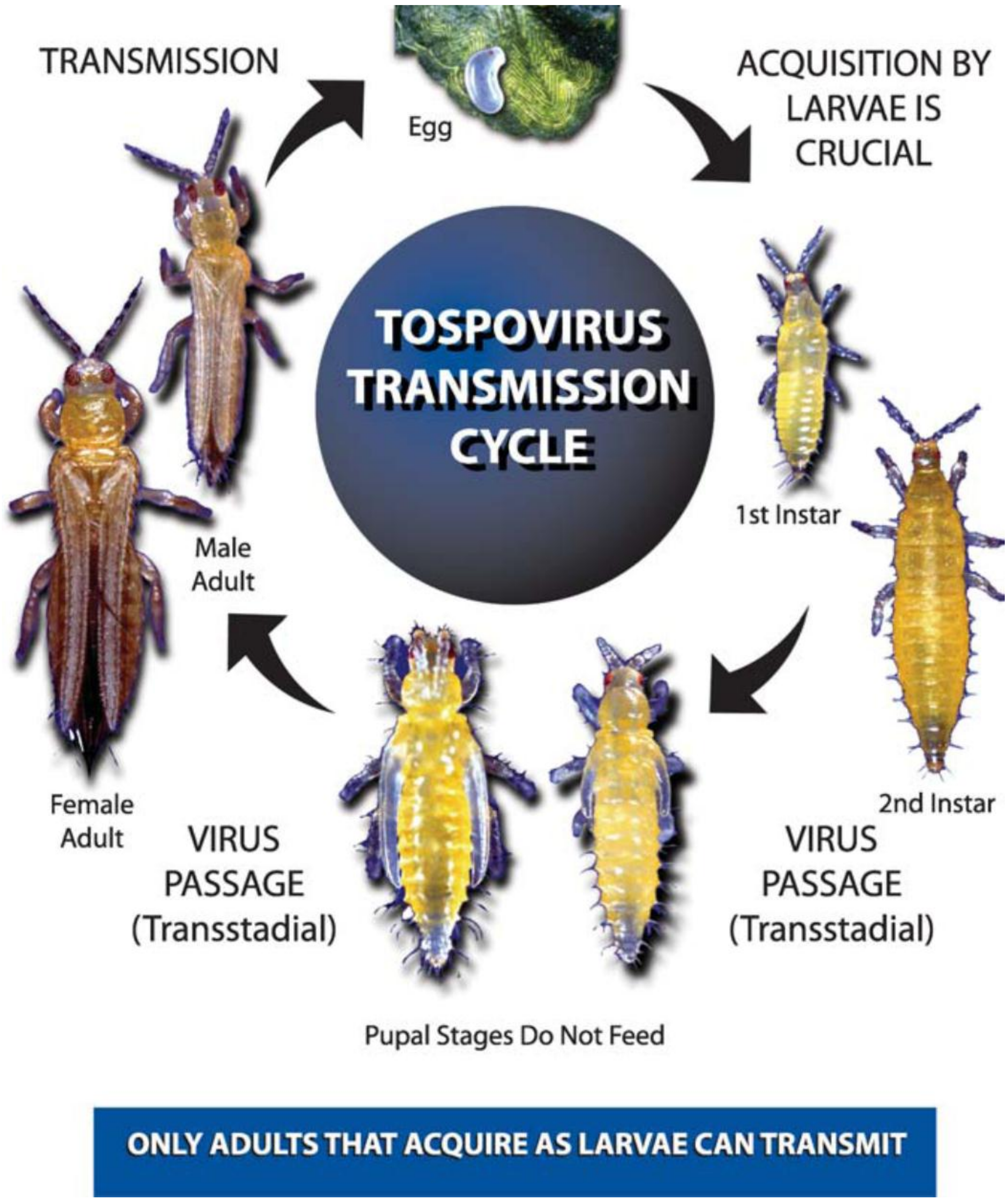

Figure I.5. Graphic representation of the thrips life cycle and the tospovirus transmission cycle. Thrips eggs are oviposited into plant tissue and within a few days the first instar larvae emerge. Virus acquisition occurs solely during the larval stages after which the virus is passed transstadially to the adult. The pupal stages are nonfeeding and do not move, although they do maintain virus infection. Adults emerge and have a tendency to disperse widely. Only adult thrips (male and female) that acquired the virus during their larval stages can transmit tospoviruses; Adopted from Whitfield et al. (2005).

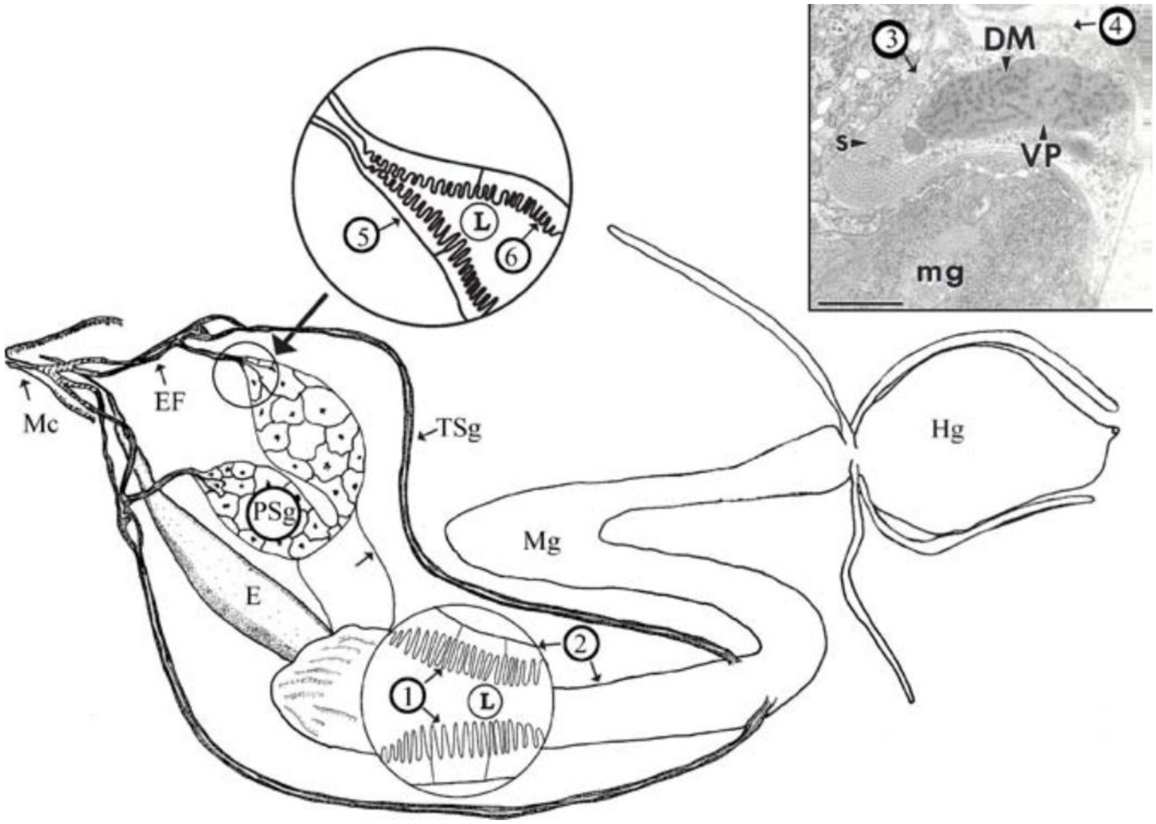

Figure I.6. Schematic representation of thrips internal organs and their putative role in virus passage to the salivary glands. It illustrates the membrane barriers the virus must pass before successful inoculation of a plant can occur. Tospoviruses enter the midgut lumen and move across the apical membrane of the brush border [1]. Tospoviruses replicate in the midgut and by an unknown mechanism cross the basement membrane [2] into the visceral muscle cells where replication continues as indicated by the presence of viroplasm [inset, 3]. The viruses must then exit these cells across their basal membrane [inset, 4] and enter the salivary gland [5]. Virions exit the salivary gland across the apical membrane [6] and flow with the salivary secretions into the plant during thrips feeding. Hg, hindgut; Mc, mouthcone; Mg, midgut; E, esophagus; EF, efferent salivary duct; L, lumen; PSg, primary salivary gland; s, cross sections of muscle; TSg, tubular salivary gland; VP, viroplasm; DM, dense mass; Adopted from Whitfield et al. (2005).

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CHAPTER II

EVALUATION OF ONION GERMPLASM FOR RESISTANCE TO *IRIS YELLOW SPOT VIRUS* AND/OR ONION THRIPS (*THRIPS TABACI*)

INTRODUCTION

Onion (*Allium cepa* L.) is the most economically important monocot outside of the grasses. It is the third most valuable vegetable crop in the USA (following only lettuce and tomato), and the second most valuable vegetable in the world (following only tomato) (FAO, 2011). Various species of thrips damage onion throughout the U.S. but are particularly important in the more arid western production areas. Onion thrips (*Thrips tabaci*), a cosmopolitan and polyphagous insect, infests and damages onion crops grown between sea level and 2,000 m (Lewis, 1997). Its feeding can reduce onion bulb weight and cause up to 60% yield loss (Dai et al., 2009; Diaz-Montano et al., 2010; Parrella and Lewis, 1997; Waiganjo et al., 2008). Currently thrips are managed almost exclusively with frequent insecticide applications, primarily organophosphate, carbamates and pyrethroids. Besides their adverse effects on non-target organisms (e.g., fish and birds), concerns with worker safety due to their high acute toxicity, and the application complications mentioned in chapter 1, these chemicals have become ineffective in most regions due to widespread development of resistant thrips populations (Al-Dosari, 1995; MacIntyle-Allen et al., 2005; Shelton et al., 2003, 2006). This implies that the ability of U.S. onion growers to control thrips with the use of insecticides in the future is unsustainable. Alternative methods for managing thrips must be developed to allow future profitable production of this crop.

Onion thrips has emerged as a proficient and the principal vector of the economically important *Iris yellow spot virus* (IYSV, family *Bunyaviridae*), one of only three tospoviruses found in the USA (Pappu et al., 2009). Virus reduces bulb size (Gent et al., 2006) and estimated yield losses in individual fields ranged from insignificant to 60% (Mohan and Wilson, 1989) and up to 100% crop loss (Pozzer et al., 1999). No viricide is currently available for controlling the virus even though some control has been obtained with systemic acquired resistance by the exogenous application of acibenzolar-S-methyl (Actigard, Syngenta Crop Protection, NC, USA) (Gent et al., 2004). Thus, any attempt to significantly reduce the economic impact of the pest/pathogen will require a multifaceted approach that integrates host plant resistance, judicious use of chemical tools, cultural practices and other strategies that eradicate and exclude the pathogens while protecting the plants (Gent et al., 2006; Pappu et al., 2009; Schumann and D'Arcy, 2006). Even though host plant resistance is an important foundation in all integrated disease management strategies (Kennedy, 2008; Panda and Khush, 1995), completely resistant onion germplasms have been difficult to come by for this pathosystem.

In an onion germplasm evaluation for resistance/tolerance to IYSV, all 46 onion cultivars tested were susceptible to the virus, with infection rates of 58 to 97% (du Toit and Pelter, 2005). In a recent evaluation study, some cultivars with less susceptibility were identified (Diaz-Montano et al., 2010; Shock et al., 2008). These studies indicate that resistance/tolerance to the pest/pathogen exit in the onion gene pool. Colorado State University, New Mexico State University, University of Wisconsin and Washington State University, together with The J. Craig Venter Institute, are parties in a multi-state, multi-discipline research effort (of which the research reported here is a part) with the main goal of sustaining U.S. onion production by the identification, validation and delivery of resistance to these pests/pathogens for use by the onion industry. The objective of this study was to find sources of resistance to IYSV and onion thrips by evaluating a large collection of onion germplasms. Combining IYSV resistance with thrips tolerance may be a sustainable management strategy to reduce (or even eliminate) conventional insecticide use with subsequent reduced risks to human health and the environment, and minimize the evolution of resistance to insecticides in thrips.

MATERIALS AND METHODS

Onion germplasms were evaluated for their response to IYSV and/or onion thrips over a 3-year period from 2009 to 2011 in northern Colorado, near Fort Collins. The evaluation site has a history of both IYSV infection and onion thrips infestations on onion. Some germplasms were raised as transplants in a greenhouse before they were planted in the field whereas others were directly seeded. Transplant production was carried out in the greenhouse facility at Colorado State University, Colorado, USA.

TRANSPLANTED ENTRIES

Production of Transplants

Raw seeds of onion germplasms were obtained from several sources, including USDA-ARS/ Plant Introduction Station (Geneva, NY, USA), seed companies, onion breeders and other co-operators such as Dr. Chris Cramer at New Mexico State University. Germplasms consisted of landraces, advanced breeding lines and commercial cultivars (Appendix II.D).

In 2009, raw seeds were sown in jiffy transplant pellets (Stuewe and Sons, Inc, Oregon, USA) (Fig. II.1A) at a rate of 3 seeds/pellet on 9 March. After germination and emergence, seedlings were thinned to 1 plant/pellet (Fig. II.1B). In 2010 and 2011, raw seeds were sown in nursery trays (Fig. II.2A) using a soil-less potting mix (Fafard's Professional Custom Mix Formula, Conrad Fafard Inc. USA) on 12 January in 2010 and on 1 January in 2011. There were 85, 62 and 82 entries, respectively, in 2009, 2010 and 2011 (Appendix II.D). Seedlings were irrigated as needed. In 2009, seedlings were raised until 24 April (46 days after sowing ((DAS)) after which they were hardened for transplanting. Hardening was not carried out in 2010 and 2011; however, seedlings were regularly cut back to a height of approximately 15-18 cm above soil level (Fig. II.2B). Cutting back thickened seedling necks, making them more portable and durable during transplanting.

Greenhouse environmental conditions were held at a day time temperature of 25-30^{o}C, a night time temperature of 20-25^{o}C, 60-70% relative humidity, and a photoperiod of 14 hours light and 10 hours darkness with the aid of supplemental lighting.

Hardening of Transplants

In 2009, seedlings were transferred to an outdoor covered storage site at the Agricultural Research, Development and Education Center (ARDEC) in northern Colorado, near Fort Collins, USA, on 24 April (46 DAS). Seedlings were not irrigated two days prior to the transfer and were maintained on that residual moisture throughout the nine-days hardening period until they were transplanted on 3 May (55 DAS). In addition to priming the seedlings to better withstand the harsh field conditions, the drying process also made transplanting easier and less messy.

Field Preparation, Layout and Experimental Design

A 0.16 hectare field at ARDEC (approximately 40°36'41.03" N, 104°59'40.17" W, elevation: 1550 m.) was used for the field evaluations. The field is a sandy-loam, with 2.2-2.6% organic matter content and was previously planted to common beans (*Phaseolus vulgaris* L.). The field was deep ripped, disked, roller harrowed, leveled and made into beds using a GPS-mounted John Deere 7820 (IVT) tractor (Deere & Company, USA) with attachments for the respective operations (Fig. II.3A-E). Deep ripping was carried out twice in two directions using the John Deere 915 V-Ripper, disking with the John Deere 640 Disk, roller harrowing with the John Deere 970 Roller Harrow, leveling with the Eversman 2400 Land Plane. After leveling, a dry blend of N: P: K fertilizer was applied at a rate of 72:18:0 kg/acre, respectively. The fertilizer was roller-harrowed for better incorporation into the soil. The field was formed into beds using a Roto-bedder. Beds were 0.8 m (0.4 m on the flat, with 0.2 m sides) ridges with 0.25 m furrows between them (Fig. II.3F).

In 2010, IYSV-infected and onion thrips-infested onion plants and bulbs harvested and stored from the previous year's growing season were planted around the periphery and on spreader rows within the experimental field. In 2011, onion bulbs and volunteer onion plants heavily infected with these pest/pathogen from the 2010 growing season were incorporated thoroughly throughout the field during field preparation and served as a source of primary inoculum for the season.

Plots were single-line, 3 m beds with 0.9 m alleys between plots (Fig. II.4) and were laid out in a randomized complete block design (RCBD) with two replications in 2009 and 2010; and with four replications in 2011.

Field Transplanting

Seedlings were transplanted on 3 May (55 DAS), 14 April (92 DAS) and 13 April (102 DAS) in 2009, 2010 and 2011, respectively, using a 2-row MT 1000 transplanter (Mechanical Transplanter Co., USA) mounted on a John Deere 4710 tractor (Fig. II.5A). Transplanting was carried out to a depth of approximately 5 cm and a within row spacing of approximately 8 cm (Fig. II.5B). There were between 30-60 plants/entry/plot depending on transplant availability. Transplants were manually fed into the transplanter and the transplanter was followed by a transplanting crew who filled in missed spots and also ensured the proper placement and coverage of the transplants.

Crop Maintenance and Cultural Practices

Fields were furrow irrigated (Fig. II.6A) when needed to prevent moisture stress. To prevent undue competition, weed control was rigorously undertaken by both physical/mechanical (hoeing and hand rogueing) (Fig. II.6B and II.6C) and chemical (Fig. II.6D, Table II.1) means. Herbicide application was both mechanized and manual depending on the level and distribution of infestation. A portable CO_2-pressurized backpack sprayer was used for the manual herbicide applications.

Onion Leaf Count

The first leaf count was carried out on 13 July (71 days after planting (DAP)) in 2009, on 17 June (64 DAP) in 2010 and on 13 July (91 DAP) in 2011; and continued on a biweekly basis until 10 August (99 DAP), 28 July (106 DAP) and 17 August (126 DAP) in 2009, 2010 and 2011, respectively. Overall, there were 3 counts in 2009, 4 counts in 2010, and 3 counts in 2011. All leaves on a plant were counted with the exception of those exhibiting more than 60% leaf senescence. Fifty plants/entry were counted in 2009, whereas 40 plants/entry were counted in 2010 and 2011.

Onion Thrips Count

Seasonal abundance of onion thrips was estimated (Fig. II.7) three times in 2009 and 2011, whereas there were 2 estimates in 2010. Field estimates were taken on 13 July (71 DAP), 28 July (86 DAP) and 10 August (99 DAP) in 2009; on 16 June (63 DAP) and 6 July (83 DAP) in 2010; and on 11 July (89 DAP), 18 July (96 DAP) and 3 August (112 DAP) in 2011. Both adults and larvae were included in the total counts. In 2009, onion thrips on 25 arbitrarily selected plants/entry/replication were counted, whereas counting was undertaken on 20 and 10 plants/entry/replication in 2010 and 2011, respectively. In all three years of the study, counting was stopped when plant neck and leaves began to open and onion thrips abundance decreased significantly.

Onion Leaf Color

Leaf color of 20 plants/entry was measured on 10 August (99 DAP) in the field in 2009. However, in both 2010 and 2011, leaf color was measured twice; once in the greenhouse before plants were transplanted, and once in the field after transplanting. Measurements were taken on 20 plants/entry on 1 April (79 DAS) in 2010 and on 21 March in 2011 (61 DAS) in the greenhouse. In the field, leaf color was determined on 10 plants/entry/replication on 7 July (84 DAP) and 17 August (126 DAP) in 2010 and 2011, respectively.

Measurements were taken between the top and mid-section of fresh, fully expanded, matured leaves using the SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan) (Fig. II.8). Leaf color was also visually categorized by five independent onion researchers into green (G), green blue (GB, more green than blue), blue green (BG, more blue than green) and Blue (B) (Fig. II.9).

Evaluation of IYSV Incidence and Severity

IYSV incidence was determined by taking the percentage of symptomatic plants/entry. In 2009, leaf tissues from symptomatic plants and two arbitrarily chosen plants from either side of the symptomatic plant within a row were sampled for laboratory verification of virus infection using double antibody sandwich – enzyme-linked immune-sorbent assay (DAS-ELISA) (Gent et al., 2004). This was done because virus pressure was very low up until the very last part of the 2009 growing season. In 2010 and 2011, however, virus incidence was solely confirmed symptomatically as incidence level was high enough right from the beginning of the season.

There were 4 incidence evaluations in 2009, beginning on 13 July (71 DAP) and continuing on a biweekly basis until 24 August (113 DAP). Three evaluations each were carried out in 2010 and 2011, beginning on 7 July (84 DAP) through to 4 August (112 DAP) in 2010, and from 29 July (107 DAP) to 25 August (134 DAP) in 2011, on a biweekly basis.

Severity of IYSV infection was assessed based on a rating scale of 1 – 4 (Table II.2) on 40 arbitrarily selected plants per entry. Severity was defined as the number and size of lesions per symptomatic leaf (Fig. II.10) (Schwartz and du Toit, 2005). There was one evaluation in 2010 on 9 August (117 DAP), whereas there were 3 evaluations in 2011 on 29 July (107 DAP), 11 August (120 DAP) and 25 August (134 DAP). There was no severity evaluation in 2009 due to low disease incidence.

Serological Detection of *Iris yellow spot virus* Using DAS ELISA

Leaf tissues were routinely sampled for serological detection of IYSV in the laboratory. Double antibody sandwich enzyme-linked immunosorbent assay (DAS ELISA) using the Agdia kit (Agdia Inc. IN, USA.) and following manufacturer's protocol, was carried out on 0.5 g leaf samples after samples had been frozen in liquid nitrogen and ground to a fine powder with a mortar and pestle (Gent et al., 2004). The ELx 800 Universal Micro-plate Reader (Bio-Tek Instruments Inc. VT, USA.) was used to read absorbance values at 405 nm. Tissues were considered **positive** for IYSV if their absorbance values were equal to or higher than 2X the values of healthy negative controls, or **highly positive** if their absorbance values were equal to or higher than 3X the values of healthy negative controls.

Growth and Development Monitoring

Plants were continually monitored for bulbing, cropping/topping and maturity growth stages (Fig. II.11). Initiation of bulbing (Fig. II.11A) was marked by the growth stage where the diameter of the bulb was twice that of the neck region (Brewster, 1994). Cropping is the stage at which the top of the plant falls over at the neck region (Fig. II.11B). Plants were considered matured when more than 50% of the foliage had senesced after cropping (Fig. II.11C), or when 60% or more of plants had more than 50% of their foliage senesced in entries that did not crop (Fig. II.11D).

Harvesting

Harvesting was done by hand pulling of plants and cutting the tops and roots off the bulbs using a pair of shears.

During the 2009 harvesting, bulb size, color and the percentage of bunched/split (S_B) bulbs were determined. In addition to these parameters, bulb weight was measured during the 2010 and 2011 harvesting. A digital electronic vernier caliper (Swiss Precision Instruments Inc. CA, USA) was used for determining bulb size (Fig. II.12A), whereas an Ohaus Precision flat pan weighing scale (Ohaus Corporation. NJ, USA.) was used for weighing each bulb (Fig. II.12B).

DIRECTLY SEEDED ENTRIES

In 2009 and 2010, some commercial cultivars and advanced breeding lines were directly seeded in the field. Seeding was carried out on 23 April and 14 April in 2009 and 2010, respectively. In all, there were 52 and 42 entries, respectively, in 2009 and 2010 (Appendix II.D).

Field location, preparation and layout were the same as described for transplanted entries; however, there were double-lined beds in seeded entries instead of single-lined beds in the transplants. Five spreader rows separated the seeded field from the transplanted field. For raw seeds, direct seeding was carried out using a manually driven JP-3 3-row Hand Seeder (Mechanical Transplanter Co, USA) whereas for pelleted seeds, the above mentioned seeder was attached to a John Deere 7820 (IVT) tractor (Deere & Company, USA) (Fig. II.13). Plots were laid out in a randomized complete block design with two replications. Crop management practices and data collections were the same as described in their respective sections under transplanted entries.

In 2009, there were two IYSV incidence evaluations, the first on 1 October (161 DAS) and the second on 15 October (175 DAS). Twenty plants per entry were arbitrarily selected for leaf color measurements on 19 August (118 DAS). There were three leaf number counts on 22 July (90 DAS), 5 August (104 DAS) and 19 August (118 DAS). There were three biweekly onion thrips counts, the first on 22 July (90 DAS) and the last on 19 August (118 DAS). Twenty plants per entry were evaluated for both leaf and onion thrips counts. Plots were harvested on 15 October (175 DAS).

Three IYSV incidence evaluations were carried out in 2010 on 20 July (97 DAS), 4 August (112 DAS) and 14 August (122 DAS). Two IYSV severity ratings were carried out on 9 August (117

DAS) and 28 August (136 DAS). Leaf color, measured on 20 plants per entry, was taken on 11 August (119 DAS). Four leaf number counts were carried out on a biweekly basis, starting on 29 June (76 DAS), with the last counting on 10 August (118 DAS). Onion thrips counts were carried out on 23 June (70 DAS), 2 July (79 DAS) and 5 August (113 DAS). All entries were harvested on 11 October (180 DAS).

Statistical Analysis

The General Linear Model (GLM) procedures in SAS (SAS v 9.3, SAS Institute Inc., NC, USA) was used for statistical analysis of data. Significant differences between cultivar means were determined using adjusted Tukey's studentized range test at a 0.05 probability level.

Onion thrips density throughout the growing season was expressed as a cumulative thrips-day value (Schwartz et al., 2010) and was calculated as:

$$\sum_{i=1}^{n} [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

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

IYSV incidence and severity were expressed as relative area under the disease progress curve, rAUDPC-in and rAUDPC-sv, respectively, by dividing area under the disease progress curve (AUDPC) by the total area of the graph (Madden et al., 2007). AUDPC was calculated as:

$$\sum_{i=1}^{n} [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

where x_i is incidence or severity of IYSV at time t_i and n is the total number of observations.

The evaluation study was modeled as depicted in Fig. II.14. In this model, final yield (bulb weight and size) of each germplasm is predicted by IYSV incidence and severity, thrips population, inherent germplasm characteristics, and how these parameters interrelate to affect each other. Leaf number and color, thrips population, S_B and time to bulbing and maturity were used as predictors of IYSV incidence and severity. Leaf number and color, and days to bulbing and maturity, and IYSV incidence and severity, were used as predictors of thrips population. Using this model, the REG procedure in SAS was used to carry out a multiple linear regression 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.

All tabular presentations were modeled in Microsoft Excel (Microsoft Office v 2010. Microsoft Corporation, USA).

RESULTS

Seasonal Leaf Growth and Development

The results of leaf growth and development are presented in Appendix II.A.1 - Appendix II.A.5.

In 2009, number of leaves/plant of transplanted entries increased with time from a mean of 7, 6 and 9 leaves/plant in PIs, OLYSO5N5 (the only transplanted advanced breeding line (ABL) in the entire study) and commercial cultivars, respectively, at 71 days after planting (DAP) to ≈11 leaves/plant at 99 DAP in all genotype categories. All plants had a general increase in leaf number over the study period except PI 430371 that had 5 leaves/plant at 71 DAP but had only 4 leaves/plant by 99 DAP. In seeded entries, both commercial cultivars and ABLs exhibited a similar leaf growth and development trend in which there were means of ≈ 5, 7 and 10 leaves/plant at 90, 104 and 118 days after sowing (DAS), respectively, in both groups.

Between transplanting and direct seeding, the former resulted in more leaves/plant than the latter, with a seasonal average of ≈10 and 8 leaves/plant in transplanted commercial cultivars and OLYSO5N5, respectively, and ≈8 and ≈7 leaves/plant in seeded commercial cultivars and OLYSO5N5, respectively.

In 2010, PI 258956 had the highest seasonal average of ≈11 leaves/plant and PI 288272 the least of 3 leaves/plant among transplanted entries. Seasonal mean was ≈8 leaves/plant for the PIs. Commercial cultivars and OLYSO5N5 had a seasonal average of ≈10 leaves/plant each. In seeded entries, seasonal mean leaf number ranged between 7 and 8 leaves/plant for ABLs and 7 and 9 leaves/plant for commercial cultivars. Colorado 6 and Salsa Red each had a seasonal mean of 2 leaves/plant more when transplanted than when direct-seeded.

Unlike 2009 and 2010 in which leaf number generally increased with time up to the last counting day in almost all entries, leaf number in 2011 exhibited several trends in transplanted PI entries. Whilst some entries, such as 602, B5336C and GCA-SYN, had a general increase with time, others, such as 622, 700, and 546140, had a decrease with time, whilst still other, such as 579 and 615, maintained the same number of leaves throughout the season. Nineteen PIs, including 597, 172703 and E203, had a seasonal average of less than 5 leaves/plant. Unlike in PIs, however, leaf number increased with time in both seeded ABLs and commercial cultivars, with OLYSO3-207 having the highest seasonal average of 10 leaves/plant and OLYSO5N5 the lowest of 8 leaves/plant among the ABLs, and Colorado 6 and Salsa Red having the highest and lowest leaf numbers of 10 and 7 leaves/plant, respectively, among the commercial cultivars.

Seasonal Dynamics of *Iris yellow spot virus* (IYSV) Incidence and Severity

Incidence and severity of IYSV infection are shown in Appendix II.A.6 - Appendix II.A.10.

Incidence if IYSV was determined twice and four times in seeded and transplanted entries, respectively, in 2009. Of 80 transplanted PIs, 9, 21, 29 and 37 expressed symptoms of IYSV infection at 71, 85, 99 and 113 DAP, respectively, with seasonal average infection ranging from 0.5 % in 639912 to 10.2 % in 174024. There was no infection in OLYSO5N5. Of the commercial cultivars, only Salsa Red was infected throughout the season, with infection ranging from 6 % at 71 DAP to 12 % at 113 DAP. Colorado 6 and Cometa each had 3 % late season infections at 113 DAP whereas there was no infection in Mt. Blanc. Infection was generally higher in commercial cultivars than in PIs. Relative area under the disease progress curve (rAUDPC) for virus incidence (rAUDPC-in) ranged from 0.05 (in e.g., PI 288272) to 0.3 in 179164 and 182138 among the PIs, and was 0.05, 0.05 and 0.3 in Colorado 6, Cometa and Salsa Red, respectively, among the commercial cultivars. Unlike in transplanted entries that had low virus incidence, infection in seeded entries was high, ranging from a seasonal lowest of 25 % in T-433 to a highest of 75 % in each of Joaquin and Milestone of the commercial cultivars. rAUDPC-in was highest at 0.08 in Colorado 6 and lowest at 0.04 in T-433 among the commercial cultivars. ABLs had a seasonal average infection of 47.3 %, with rAUDPC-in ranging from 0.046 in OLYS03-209 to 0.124 in NUN76060N.

Transplanted Colorado 6, Cometa and Salsa Red had a seasonal average virus infection of 0.7, 0.7 and 9 %, respectively, whereas when direct-seeded, infection was 70, 42.5 and 52.5 %, respectively, with rAUDPC-in of 0.08, 0.05 and 0.065 when seeded; and 0.05, 0.05 and 0.3, respectively, when transplanted. Direct-seeded OLYSO5N5 had 47.5 % incidence with rAUDPC-in of 0.076, whereas there was no infection in transplanted OLYSO5N5. In seeded entries, virus incidence was higher in ABLs than in commercial cultivars, with an rAUDPC-in of 0.067 and 0.062, respectively. In transplanted entries, virus incidence was in the increasing order of OLYSO5N5 (ABL), PIs and commercial cultivars with rAUDPC-in of 0.0, 0.006 and 0.1, respectively.

Both virus incidence and infection severity were used to express genotype response to IYSV in 2010 and 2011. In 2010, incidence in transplanted entries increased with time so that incidence was highest on the last evaluation day (112 DAP). Seasonal mean incidence was the same for both PIs and commercial cultivars at ≈27 %, however, rAUDPC-in was 0.189 in PIs and 0.133 in commercial cultivars, indicating higher incidence in PIs than in commercial cultivars. Although 546096 and 248753 had the highest and lowest seasonal mean infections, respectively, among the PIs, 288908 had the highest rAUDPC-in of 0.35, with 165498 been one of the several PIs with the lowest rAUDPC-in of 0.1. Vantage and Colorado 6 had the highest and lowest seasonal mean infections, respectively, among the commercial cultivars; however, rAUDPC-in was the same for Vantage and Salsa Red at 0.15, with Colorado 6 having an rAUDPC-in of 0.1. Infection severity was not expressed in terms of rAUDPC in 2010 because only one severity rating was carried out in transplanted entries. Infection severity was highest at 4 in 168962, 168966 and R64320, and lowest at 0.5 in 124525 and 248753 of the PIs. 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, respectively. OLYSO5N5 had a seasonal average infection of 17.6 % (0.1 rAUDPC-in) and a severity rating of 3.5.

The same trend of increasing incidence with time observed in transplanted entries was observed in direct-seeded entries, with a mean of 92.6, 91.6 and 89.6 % incidence in PIs, ABLs and commercial cultivars, respectively, on 122 DAS (last evaluation day), a drastic increase from the previous 22.0, 19.9 and 17.8 % infections, respectively, on 112 DAS. Level of infection was in the increasing order of 903-1, 905-1 and 904-1 in the PIs, with rAUDPC-in of 0.066, 0.067 and 0.074, respectively. Relative area under the disease progress curve of infection severity (rAUDPC-sv) was 0.135, 0.128 and 0.122 in 903-1, 904-1 and 905-1, respectively. NUN70090N had the highest seasonal mean incidence of 43.9 % and SBO-5420 the lowest of 33.4 % among the ABLs however; rAUDPC-in was highest at 0.08 in R5978 and lowest at 0.052 in SBO-5508. EX14593 had the highest rAUDPC-sv of 0.14 and 16535 the lowest of 0.107. Genesis and Mesquite of the commercial cultivars had the highest and lowest seasonal mean incidence of 48.3 and 32.4 %, respectively. However, rAUDPC-in ranged from a lowest 0.05 in Colorado 6, to a highest of 0.089 in Genesis. Infection severity was highest in Mesquite and Tequila at rAUDPC-sv of 0.14 each, and lowest in both Colorado 6 and Advantage with rAUDPC-sv of 0.116.

Virus incidence (rAUDPC-in) and severity (rAUDPC-sv) were higher in transplanted than in direct-seeded Colorado 6 and Salsa Red.

Virus incidence was high right from the beginning of the 2011 growing season; with an overall average incidence of 58.3 % on the first day of evaluation (107 DAP). There was more than 96 % incidence in all entries by 120 DAP and by 134 DAP, every single plant in the field was infected. Incidence ranged from an rAUDPC-in of 0.201 in 632 to 0.136 in 597 among the PIs. Incidence was highest in NUN76060N with an rAUDPC-in of 0.19, and lowest in OLYSO5N5 with rAUDPC-in of 0.169 among the ABLs. With the commercial cultivars, infection was highest in T-433 and lowest in Rumba, with an rAUDPC-in of 0.188 and 0.173, respectively. Severity of infection increased with time such that 4 was reached in all ABLs and commercial cultivars, and more than 3 in most PIs by 134 DAP. Infection severity was highest in 696 and lowest in 718, with rAUDPC-sv of 0.201 and 0.1, respectively, among the PIs. rAUDPC-sv ranged from 0.127 in OLYSO5N5 to 0.149 in both NUN76060N and OLYSO3-207 among the ABLs. Of the commercial cultivars, just as was observed for incidence, severity was lowest in Rumba with an rAUDPC-sv of 0.124, and highest in T-433 with 0.149 rAUDPC-sv.

In general, both IYSV incidence (rAUDPC-in) and severity (rAUDPC-sv) were highest in ABLs than in PIs and commercial cultivars. Between PIs and commercial cultivars, incidence was higher in commercial cultivars than in PIs, whereas severity was higher in PIs than in commercial cultivars.

Seasonal Dynamics of Onion Thrips Population

Both thrips number/plant and thrips-day were used to express seasonal dynamics of onion thrips as shown in Appendix II.A.11 - Appendix II.A.15.

In general, average thrips population in transplanted entries decreased with time among all genotype categories in 2009. Although most PIs, such as 172703, 288270 and 546100, had a steady/gradual decline in thrips population during the season, others, such as 171475, 288073 and 343049, had a rather drastic decline. In PIs in which thrips numbers increased over time, such as 249899, 264631 and 433330, the numbers were highest on the last evaluation day (99 DAP). PI 172702 maintained relatively the same number of thrips of ≈12 thrips/plant on all evaluation dates. PIs 264648 and 430371 had the highest and lowest thrips-day values of ≈4 and 0.2 thrips/plant/day, respectively. Among the commercial cultivars, Salsa Red had the highest thrips-day value of 1.9 thrips/plant/day and Mt. Blanc the lowest of 0.7 thrips/plant/day. Between genotype groups, thrips-day was in the decreasing order of commercial cultivars, PIs and OLYSO5N5, with values of 1.5, 1.4 and 1.2 thrips/plant/day, respectively. In direct-seeded entries, thrips population in both commercial cultivars and ABLs increased from the first evaluation day up to 104 DAS and then declined. Of the commercial cultivars, Denali had the lowest thrips population throughout the study period with a corresponding lowest thrips-day of 0.3 thrips/plant/day, whereas Milestone had the highest thrips-day of 1.7 thrips/plant/day. EX 16529 had the highest average thrips population with a corresponding highest thrips-day, whereas OLYXO6-25 had the lowest thrips population and the lowest thrips-day, among the ABLs.

Thrips population (thrips-day) was about twice higher in transplanted than in seeded Colorado 6 and Salsa Red, and 3X higher in transplanted than in direct-seeded Cometa. Thrips-day was 0.7 and 1.2 thrips/plant/day in seeded and transplanted OLYSO5N5, respectively. Thrips population was generally highest in commercial cultivars, followed by ABLs and then PIs.

Two and three thrips population estimates were carried out in transplanted and direct-seeded entries, respectively, in 2010. With transplanted entries, PI 433330 had the highest thrips population, with a seasonal average of 91 thrips/plant and a thrips-day of 9 thrips/plant/day. PI 248753 had the lowest seasonal average of 0.7 thrips/plant and a thrips-day of 0.1 thrips/plant/day. Thrips population on Colorado 6 remained fairly the same at ≈31 thrips/plant between 63 and 83 DAP, whereas there was a 76 % and 30 % increase in Salsa Red and Vantage, respectively, between the same time period. Thrips-day value was in the increasing order of 3.1, 7.1 and 7.5 thrips/plant/day, respectively, for Colorado 6, Salsa Red and Vantage. OLYSO5N5 had 39 and 63 thrips/plant on 63 and 83 DAP, respectively, with thrips-day of 5.1 thrips/plant/day. Seeded entries had a rather low thrips population on the first estimation day (70 DAS), however, there was a 10-fold increase by the last evaluation day (113 DAS) in all genotype groups. 903-1, 18495 and Salsa Red had the highest thrips population of 2.5, 2.5 and 3.5 thrips/plant/day in PIs, ABLs and commercial cultivars, respectively, whereas 905-1, SN-626 and Tequila had the lowest population of 1.9, 0.9 and 1.6 thrips/plant/day in PIs, ABLs and commercial cultivars, respectively.

Thrips population was higher in transplanted than in direct-seeded Colorado 6 and Salsa Red, with values of 3.1 and 1.8 thrips/plant/day for transplanted and seeded Colorado 6, respectively; and 7.1 and 3.5 thrips/plant/day, respectively, for transplanted and seeded Salsa Red. Thrips population was generally in the increasing order of PIs, ABLs and commercial cultivars in transplanted entries. In seeded entries however, commercial cultivars and PIs had the same thrips population of 2.2 thrips/plant/day whereas ABLs had the lowest population of 1.7 thrips/plant/day.

In 2011, thrips population was generally highest for most entries at 96 DAP and lowest on the last evaluation day (112 DAP). Among the PIs, 632 had the highest infestation of 4.6 thrips/plant/day and 615 the lowest at 0.1 thrips/plant/day. NUN7606ON had the highest population among the ABLs, with OLYSO5N5 having the lowest infestation of 3.2 and 2.0 thrips/plant/day, respectively. Among the commercial cultivars, Vantage and Rumba had the highest and lowest populations of 3.4 and 2.0 thrips/plant/day, respectively.

Thrips population was highest in commercial cultivars, followed by ABLs and then PIs.

Onion Leaf Color

Onion leaf color was quantitatively measured with the Minolta SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan). The higher the SPAD reading, the bluer the leaf and the higher the chlorophyll content. Leaf color data are presented in Appendix II.A.1 - Appendix II.A.6.

In 2009, values ranged from 52.8 chlorophyll content index (CCI) in 546162 to 76.1 CCI in 239633-1 among the PIs. OLYSO5N5 had a leaf color of 70.9 CCI whilst Colorado 6 had the highest of 68.4 CCI and Mt. Blanc the lowest of 63.1 CCI among the commercial cultivars. In direct-seeded entries, Ranchero had the highest of 71.4 CCI and Marquette the lowest of 60.2 CCI among the commercial cultivars. Values ranged from 67.5 CCI in OLYX06-25 to 73.2 CCI in EX 16529 among the ABLs.

In general, there wasn't much difference in leaf color between transplanted and seeded entries as, for example, values were 68.4, 67.9 and 63.5 CCI in transplanted Colorado 6, Cometa and Salsa Red, respectively, whereas values were 69.1, 67.1 and 62.4 CCI, respectively when they were direct-seeded. Values were 70.9 and 68.9 CCI in transplanted and direct-seeded OLYSO5N5, respectively.

In transplanted germplasms in 2010, except for five genotypes; 172701, 248754, 255557, 546140 and Salsa Red which had about 5 CCI or more difference between their greenhouse (early leaf color) and field (late leaf color) values, there wasn't much difference between the two measurements in all other genotypes. In seeded entries, Cometa had the highest of 66.2 CCI and

Mesquite the lowest of 59.7 CCI among the commercial cultivars. SBO-5288 and SBO-5419 had the lowest and the highest of 59.7 and 65.3 CCI, respectively, among the ABLs.

Seeded Colorado 6 and Salsa Red had slightly higher values than when they were transplanted.

Most genotypes had different leaf color values between 2009 and 2010.

In 2011, leaf color was both quantitatively and categorically assessed in the greenhouse. However, the two methods failed to establish a direct correlation. Some genotypes visually categorized as green (G) had higher SPAD values than others categorized as blue (B) (e.g., PIs 577 and 597). Also, greenhouse values were significantly lower than field values in almost all genotypes, unlike was observed in 2010. For these reasons, field leaf color, and not greenhouse leaf color, was used in all data analysis.

Split/Bunching (S_B) growth habit

Transplanted Mt. Blanc had ≈3.0 % S_B plants in 2009, whereas Mesquite and Salsa Red had 10 % and 20 % S_B types, respectively, in 2011. There was no S_B in all ABLs or other commercial cultivars in all three years of the study. S_B ranged between 2.5 % to 100 % among transplanted PIs in 2009. Of the 80 PIs, 25 (31 %) had 50 -100 % S_B plants and 48 (60 %) had 1 – 49.9 % S_B plants. S_B ranged from 5 – 86 % in 2010 and 10 – 100 % in 2011 among PIs. More than 13 % of PIs had between 50 – 86 % S_B types and more than 69 % had between 5 and 49.9 % S_B in 2010. Eighteen and 13 % of all PIs had between 50 – 100% and 10 – 49.9 % S_B plants, respectively, in 2011. S_B data is shown in Appendix II.A.16 - Appendix II.A.20).

Days to Bulbing

Appendix II.A.16 - Appendix II.A.20 have the bulbing information for all genotypes.

With transplanted entries in 2009, PI lines took an average of 96 DAP to reach bulbing, with PI 239633-1 and G3290 having the longest durations of 113 DAP each, and PI 248754 the shortest duration of 72 DAP. OLYSO5N5 bulbed at 96 DAP. The average duration to bulbing was 91 DAP in commercial cultivars, with duration been in the decreasing order of Cometa, Colorado 6, Mt. Blanc and Salsa Red, with values 95, 93, 86 and 86 DAP, respectively. Both commercial cultivars and ABLs reached bulbing at an average of 119 DAS when direct-seeded.

In 2010, all transplanted entries (PIs, OLYSO5N5 and commercial cultivars) reached bulbing at an average of 85 DAP, with a range of 84 DAP (in e.g., PI 165498) to 96 DAP in PI 288073. All seeded entries bulbed at an average of 86 DAS, with NUN70060N taking the longest duration of 91 DAS among the ABLs and Salsa Red taking the longest duration of 90 DAS among the commercial cultivars. When transplanted, both Colorado 6 and Salsa Red bulbed at 85 DAP whereas as direct-seeded, they bulbed at 86 and 90 DAS, respectively.

In 2011, PIs reached bulbing at an average of 188 DAP whereas ABLs and commercial cultivars took ≈193 DAP to bulb. In each genotype category, 592, OLYSO5N5 and Salsa Red took the longest duration to bulb at 291, 199 and 200 DAP, respectively, whereas 696, OLYX06-25 and Rumba were the first to bulb at 176, 190, and 187 DAP, respectively.

Days to Maturity

Maturity information is given in Appendix II.A.16 - Appendix II.A.20.

In 2009, all transplanted entries reached maturity at ≈138 DAP. Among the PIs, time to maturity ranged from 122 DAP in 546140 to 144 DAP in 174024. Colorado 6 was last to mature among the commercial cultivars at 143 DAP, with Salsa Red and Mt. Blanc maturing earliest at the same time at 136 DAP. All direct-seeded entries were harvested at 175 DAS.

In 2010, 124525 was first to mature at 114 DAP and 258956 was one of the several entries at were last to mature at 142 DAP among the transplanted PIs. Vantage matured first and Colorado last at 136 and 142 DAP, respectively, among the transplanted commercial cultivars, whereas transplanted OLYSO5N5 matured at 142 DAP. All seeded entries were harvested at 180 DAS.

In 2011, 224, 239 and 238 DAP were the mean maturity dates for PIs, ABLs and commercial cultivars, respectively, of transplanted entries.

Onion Bulb Yield

Bulb size (diameter) was used as the only yield parameter in 2009, however, bulb size and weight were used to determine yield in 2010 and 2011. Yield information is presented in Appendix II.A.16 - Appendix II.A.20.

In 2009, transplanted 546188 had the largest bulb size of 105 mm/bulb and 288903 the smallest of 2.5 mm/bulb among the PIs. Colorado 6 had the largest bulb size among the commercial cultivars, followed by Cometa, Mt. Blanc and then Salsa Red with 101.1, 98.4, 86.3 and 76.9 mm/bulb, respectively. OLYSO5N5 had a bulb size of 88 mm/bulb. The average size for all PIs was 55.5 mm/bulb, and 90.7 mm/bulb for the commercial cultivars. In direct-seeded entries, Oro Blanco had the largest bulb size of 102.9 mm/bulb and Ruby Ring the smallest of 60.4 mm/bulb among commercial cultivars, whereas bulb size ranged from 70.2 mm/bulb in OLRHO8-9 to 86.4 mm/bulb in EX16529 among the ABLs. Average bulb size was slightly higher in commercial cultivars than in ABLs. Transplanting resulted in larger bulb sizes in Colorado 6, Cometa, Salsa Red and OLYSO5N5 than in their direct-seeded counterparts.

Among transplanted entries in 2010, bulb size ranged from 28.0 mm/bulb in 248753 to 113.6 mm/bulb in 264320 among the PIs; 111.2 mm/bulb in Colorado 6 to 92.3 mm/bulb in Salsa Red among the commercial cultivars; and 100.9 mm/bulb in OLYSO5N5. Bulb weight ranged from 765.8 g/bulb for 546192 to 13.6 g for 248753 among the PIs; 683.8 g/bulb for Colorado 6 to 278.6 g/bulb for Salsa Red among the commercial cultivars; and 526.6 g/bulb for OLYSO5N5. With direct seeding, Tequila had the largest bulb size of 97.2 mm/bulb and Salsa Red the smallest of 57.9 mm/bulb among the commercial cultivars. Bulbs of White Cloud weighed the most at 918.6 g/bulb, more than twice as much as the second highest, Tequila, at 455.8 g/bulb, and bulbs of Salsa Red weighed the least at 96.6 g/bulb. Bulbs of NUN70090N were the largest (90.6 mm/bulb) and the heaviest (398.6 g/bulb), whereas bulbs of R-5978 were the smallest (59.6 mm/bulb) and lightest (113.1 g/bulb) among the ABLs. Bulbs of transplanted Colorado 6 and Salsa Red were larger and heavier than when they were direct-seeded.

In 2011, ABLs had the largest mean bulb size of 90.7 mm/bulb with a corresponding highest mean bulb weight of 347.7 g/bulb, followed by commercial cultivars with mean bulb size of 80.6 mm/bulb and mean bulb weight of 268.9 g/bulb, and then PIs with mean bulb size of 55.5 mm/bulb and mean bulb weight of 106.3 g/bulb. The highest yielding genotypes by weight were Cometa, OLYSO5N5 and 658 for commercial cultivar, ABL and PI genotype categories, respectively, and the least yielding were Salsa Red, NUN7606ON and 582, respectively, for the same genotype categories. By size, the highest yielding were Cometa, NUN7606ON and 568 for commercial cultivar, ABL and PI genotype categories, respectively, and the least yielding were Salsa Red, OLYSO3-207 and 582, respectively, for commercial cultivars, ABLs and PIs.

Selection of Onion Genotypes for Resistance/Tolerance to *Iris yellow spot virus* (IYSV) and/or Onion Thrips (*Thrips Tabaci*)

The various parameters that were measured in this study are summarized and presented in Appendix II.B for all selected genotypes.

Sixteen out of the 85 genotypes evaluated in 2009 were selected (Table II.3) for exhibiting acceptable responses to IYSV and onion thrips whiles giving acceptable bulb yield Appendix II.B). Due to the very low incidence of IYSV in 2009, bulb size and thrips population were the main criteria used for genotype selection. All selected genotypes (except PI 639911) had thrips population less than the commercial cultivars. PI 182138 and OLYSO5N5 were included as PI and ABL checks, respectively, and Colorado 6, Cometa and Salsa Red were included as commercial cultivar checks for comparison of genotype response to the pest/pathogen.

In 2010, 15 of the 62 evaluated entries were selected (Table II.4) for either having low virus incidence, severity and thrips population (e.g., PI 248753) or for producing high yield even in the presence of high pest/pathogen pressure (e.g., 264320).

Due to the 100 % virus incidence in all evaluated genotypes in 2011, selection was based on infection severity, thrips population and a minimum bulb size of 62 mm/bulb. Using bulb size as the baseline selection criterion, PI genotypes were selected (Table II.5) for having virus severity and/or thrips population lower than in the commercial cultivars.

Five PIs; 258956, 264320, 546140, 546188 and 546192 were selected in two of the three years of the evaluation whilst two PIs; 258956 and 546188, were selected in all three years of the study.

Model Selection for Onion Bulb Yield, *Iris yellow spot virus* Response and Onion Thrips Population

Figure II.14 represents the research model for this study. The various parameters of the model and the way they interact to affect each other are shown by Pearson's correlation coefficients given in Appendix II.C. The variables that were influential determinants of yield (bulb size and weight), IYSV incidence and severity, and onion thrips population are presented in Table II.6 and are discussed below.

Onion Bulb Yield

Among the transplanted entries in all three years, bulb size increased with increasing leaf number/plant and days to maturity and decreased with increasing days to bulbing and percent split/bunch. Leaf color had an inconclusive effect on bulb size as the relationship was positive in 2009 and 2010, but negative in 2011. IYSV incidence had a negative relationship with bulb size in 2009 but was not an important determinant in 2010 and 2011. Thrips infestation had an effect on bulb size only in 2010 in which bulb size decreased with increasing thrips-day. Similar to bulb size, bulb weight increased with increasing leaf number/plant and days to maturity, and with leaf color (in 2010 only), and decreased with increasing thrips population (in 2010 only) and S_B %.

Among the direct-seeded entries, bulb size and weight also increased with increasing leaf number/plant and decreased with increasing thrips population and IYSV incidence in 2010. In 2009, however, a non-significant relationship between bulb size and thrips-day and IYSV incidence was observed.

Incidence and Severity of *Iris yellow spot virus* (IYSV)

In 2009, days to bulbing was an influential determinant of IYSV incidence in both transplanted and direct-seeded entries, however, days to maturity and S_B % were additional determinant in transplanted entries. Thrips-day determined virus incidence in both transplanted and direct-seeded entries in 2010 and as in 2009, days to bulbing and maturity were additional determinants in transplanted entries. In 2011, leaf color and leaf number/plant were positive determinants of virus incidence in which incidence increased with increasing leaf color and leaf number/plant.

Onion thrips population was an influential determinant of virus infection severity in both 2010 and 2011 in transplanted entries. Leaf number/plant and days to bulbing, and days to maturity were additional severity determinants in the transplants in 2010 and 2011, respectively. Leaf number/plant and virus incidence determined infection severity in direct-seeded entries in 2010.

Onion Thrips (*Thrips tabaci*) Population

Population of onion thrips depended on leaf number/plant and days to bulbing in both transplanted and direct-seeded entries in 2009, however, days to maturity and S_B % were additional determinants in transplanted entries. In 2010, onion thrips population depended on leaf number/plant and virus incidence in both transplanted and direct-seeded entries. Population also depended on days to bulbing and S_B % in transplanted entries whereas leaf color was an additional determinant in direct-seeded entries in which thrips-day increased with increasing leaf color. Just as in 2010, leaf number/plant and S_B % determined thrips population in 2011; however, virus severity and days to maturity were additional determinants in 2011 instead of days to bulbing and virus incidence observed in 2010.

DISCUSSION

Plant pests and pathogens are a significant hindrance to agricultural production and food security. Most production systems require a significant investment in pest/pathogen management in order to realize production potential. The use of pathogen-free plant propagules and an educated choice of location and timing of crop production are encouraged as the first line of disease management strategy. However, in situations where the above mentioned are not possible, onsite disease management becomes mandatory. In the IYSV-onion thrips-onion pathosystem, such onsite management involves the control of the onion thrips vector and the choice of an onion cultivar(s) with resistance/tolerance to the virus and/or the vector. The very limited (or complete absence) of such resistance in the onion cultivars currently available for commercial production (Diaz-Montano et al., 2010; du Toit and Pelter, 2005; Shock et al., 2008) necessitates the continuous search for this vital tool in the economic management of this pathosystem. It was one such effort to deliver host plant resistance (HPR) for use by the onion industry that this evaluation study was undertaken.

The results of the study indicate that incorporation of HRP into the current commercial germplasms is possible as some promising genotypes were identified. The identification of the exact mode of resistance was beyond the scope of this study, however, clues can be garnered from the results of the model selection procedure and the Pearson's correlation coefficients to determine the variables that predict (to some extent) a particular parameter of interest. For example, in transplanted entries in 2010 (Appendix II.C.3), thrips-day increased with increasing leaf color ($r = 0.3147$, p-value = 0.0127) and with increasing leaf number ($r = 0.6865$, p-value = <0.0001). Thus, plants with fewer leaves and green or green-blue foliage (Fig. II.9) may attract fewer thrips and hence suffer less feeding damage (Loges et al., 2004). The relationship between onion leaf color and thrips population has long been hypothesized (e.g., Jones et al., 1935). Unfortunately, however, the significance of such a relationship was not firmly established in this study.

Even though the model selection method did not identify IYSV as a significant predictor of onion bulb yield (Table II.6), the correlation coefficients (Appendix II.C) revealed its economic ramifications. In 2010, bulb size and weight in both transplanted and direct-seeded entries were significantly negatively impacted by IYSV (Appendix II.C.3 and Appendix II.C.4). It should be remembered that virus pressure was high in 2010 so the observed impact was commensurably expected. The 2010 evaluation is the best representation of this important research as virus pressure was high enough (unlike the lower pressure in 2009) and there was no adverse environmental conditions (the cold spell in 2011 discussed below, Appendix II.E) to predispose plants to other pathogens (Xanthomonas leaf blight infection caused by *Xanthomonas axonopodis pv. allii* was unusually high in 2011, Appendix II.E). It was also in 2010 that the economic effect of onion thrips and IYSV on onion production was appropriately expressed (Appendix II.C.3 and Appendix II.C.4). The search for resistance to onion thrips and IYSV should therefore be relentlessly pursued in order to prevent such economic adversities from this pest/pathogen.

Attention is drawn to the bulbing and maturity dates over the study period in transplanted entries. In 2009, 2010 and 2011, plants reached bulbing at an overall average of 94.6, 85.2 and 191 DAP, respectively. Maturity dates were 137.5, 136.8 and 233.6 DAP, respectively in 2009, 2010 and 2011. The ≈ 100 days difference between the 2011 dates and the other years is due to frost damage (Fig. II.15, Appendix II.E) that nearly obliterated the 2011 study. Even though the plants recovered from the shock (as indicated by their normal leaf growth and development compared to previous years'), the extended period on the field and their late growth in to the season may be the reason they had the highest virus incidence (rAUDPC-in of 0.178 compared to the second highest of 0.141 in 2010 transplants) and the highest infection severity (rAUDPC-sv of 0.138 compared to 0.125 in 2010 seeded entries) (Appendix II.A.6 - Appendix II.A.10). This may also be the reason they had the smallest bulb of 75.6 mm/bulb compared to 78.1 and 87.3 mm/bulb in 2009 and 2010, respectively (Appendix II.A.16 - Appendix II.A.20).

In seeded entries in 2010, there was a drastic increase (≈ 70 %) in IYSV infection between 112 DAS and 122 DAS (Appendix II.A.9). This increase could be due to the drastic increase in thrips population from an overall mean of 3.2 thrips/plant at 70 DAS to 42.9 thrips/plant at 113 DAS (Appendix II.A.14). The increased thrips activity did not result in an observed increased infection on the 112 DAS incidence evaluation due to the latent period that precedes symptom expression after inoculation (Whitfield et al., 2005).

Onion thrips are highly migratory such that populations in one field are usually attributed to immigration from nearby harvested crops or nearby vegetation (Cranshaw, 2008; Hsu et al., 2010). This scenario should have resulted in higher thrips population in seeded entries due to their migration from older, open-necked plants of transplanted fields. This phenomenon, however, was not observed in this study as thrips population was always higher in transplanted fields than in seeded fields. If the two fields were not only a few meters apart, then the above observation would have been typical as thrips population is known to be higher in transplanted onions than in direct-seeded onions (e.g., Hsu et al., 2010). The migratory pattern of onion thrips in and around the vicinity of the research field needs to be investigated.

The use of different genotypes in different years, the lack of consistent IYSV and onion thrips pressure, and the very different weather conditions that prevailed in the course of the study make it difficult to make exact comparison between genotypes across years. Nonetheless, this circumstance presented a plethora of disease situation such that the 5 genotypes selected in both 2009 and 2010 and the 2 selected in all three years of the evaluation can be guaranteed as reliable candidates for the fulfillment/realization of the objectives of this study. The five genotypes that were selected in 2009 and 2010 were also selected in a similar germplasms evaluation study in New Mexico as promising candidates (Dr. Chris Cramer, personal communication). The evaluation study at New Mexico State University is also part of this multi-state, multi-disciplinary effort to identify, validate and deliver resistance to IYSV and/or for use by the onion industry. In this study, selected genotypes were sent to Dr. Chris Cramer of New Mexico State

University and Dr. Michael Havey of University of Wisconsin for further evaluations and so as candidates for the onion translational genomics that the research reported here is a part of.

It should be mentioned; however, that selection of a genotype as resistant to IYSV is currently very subjective and depends on the prevailing virus pressure at the evaluation site. The onion industry and onion researchers should come out with a clear definition of resistance and a standardized protocol for assessment. Such a protocol should be based on disease incidence and severity expressed in relative area under the disease progress curve (rAUDPC). rAUDPC was observed to be a better expression of genotype response to IYSV than just percent incidence and severity rating commonly used by the industry in germplasms evaluations for resistance (e.g., Diaz-Montano et al., 2010; du Toit and Pelter, 2005; Shock et al., 2008). Although percent virus incidence was higher in seeded entries (e.g., 70 % seasonal average in Colorado 6, Appendix II.A.7) than in transplanted entries (e.g., 0.8 % seasonal average in Colorado 6, Appendix II.A.6) in 2009, rAUDPC was higher in transplanted Colorado 6 (at 0.8) than in seeded Colorado 6 (at 0.1). This was also observed in 2010 in which rAUDPC-in were 0.189 and 0.133 in transplanted PIs and commercial cultivars, respectively, even though they both had a seasonal mean incidence of 27 % (Appendix II.A.8 and Appendix II.A.9). Thus, an rAUDPC-based standard protocol will lend itself to year-to-year as well as between location and state comparisons of genotypes responses to IYSV. OLYSON5N is a near isogenic line (NIL) of the commercial cultivar Advantage and has recently been listed as a commercial cultivar by the name Advantage (Dr. Howard Schwartz, personal communication). However, because OLYSO5N5 was transplanted but Advantage was direct-seeded in the same year (2010) the two were evaluated, an exact comparison between their response to IYSV and onion thrips cannot be effectively made as, in both 2009 and 2010, virus pressure and thrips population were higher in transplanted than in direct-seeded fields. A standardized protocol will permit such a comparison.

Table II.1. List of herbicides used for weed control during a three year onion germplasm evaluation for resistance to IYSV and onion thrips in northern Colorado, near Fort Collins.

Product	Active Ingredient	Chemical Company
Goaltender	oxyfluorfen	Dow AgroSciences LLC
Starane	fluroxypyr1-methylheptyl ester	Dow AgroSciences LLC
Stinger	clopyralid	Dow AgroSciences LLC
Prowl H_2O	pendimethalin	BASF Crop Protection
Outlook	dimethenamid-P	BASF Crop Protection
Nortron SC	ethofumesate	Bayer Crop Science
Targa	quizalofop	Gowan Company LLC
Dual II Magnum	S-metolachlor	Syngenta Crop Protection LLC

Table II.2. Rating scale for *Iris yellow spot virus* severity evaluation on onions.

Rating Scale	**Description**
1	1-2 small lesions per leaf (Fig. 9A).
2	3 – 10 medium lesions per leaf (Fig. 9B).
3	11 – 25 medium to large lesions per leaf (Fig. 9C).
4	>25 medium to large lesions per leaf (Fig. 9D)

Adopted from (Schwartz and du Toit, 2005).

Table II.3. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2009.

Genotype	**Leaf-avg** (mean ± SE)[a]	**Leaf color** (mean ± SE)[b]	**rAUDPC-in** (mean ± SE)[c]	**Thrips-day** (mean ± SE)[e]	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)
172701[x]	7.4 ± 1.1	60.1 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	95.1 ± 7.4	130.0 ± 0.0	33.8 ± 10.1
172702[x]	8.0 ± 1.0	68.75 ± 0.1	0.2 ± 0.1	1.4 ± 0.1	98.2 ± 1.3	137.0 ± 0.0	50.5 ± 8.6
172703[x]	9.0 ± 0.8	62.75 ± 3.6	0.1 ± 0.1	1.3 ± 0.1	98.0 ± 8.0	136.0 ± 0.0	46.9 ± 5.6
179627[x]	10.4 ± 0.1	65.35 ± 1.1	0.1 ± 0.1	1.0 ± 0.0	91.8 ± 4.4	13.07 ± 0.0	39.1 ± 3.7
258956[x]	10.2 ± 0.1	62.2 ± 0.0	0.0 ± 0.0	1.6 ± 0.4	86.0 ± 0.0	143.0 ± 0.0	97.1 ± 1.6
264320[x]	10.6 ± 0.0	62.6 ± 0.0	0.1 ± 0.1	1.5 ± 0.2	87.9 ± 2.7	143.0 ± 0.0	79.4 ± 6.6
288270[x]	7.3 ± 1.3	68.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4	103.9 ± 4.7	143.0 ± 0.0	48.7 ± 7.6
288909[x]	9.3 ± 0.1	62.6 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	89.9 ± 0.1	130.0 ± 0.0	76.3 ± 4.9
289689[x]	6.7 ± 0.5	72.1 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	87.3 ± 0.7	122.0 ± 0.0	54.3 ± 4.5
343049[x]	9.1 ± 0.7	60.5 ± 0.0	0.2 ± 0.3	1.1 ± 0.1	88.1 ± 3.0	122.0 ± 0.0	67.0 ± 9.0
546140[x]	8.3 ± 0.3	61.5 ± 6.9	0.1 ± 0.1	0.9 ± 0.1	88.4 ± 0.7	122.0 ± 0.0	63.8 ± 2.1
546188[x]	10.5 ± 0.4	59.8 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	86.5 ± 0.8	144.0 ± 0.0	105.1 ± 5.8
546192[x]	10.2 ± 1.3	65.3 ± 0.0	0.2 ± 0.2	1.4 ± 0.1	89.4 ± 3.1	144.0 ± 0.0	103.0 ± 11.0
639911[x]	6.8 ± 0.4	70.7 ± 0.0	0.0 ± 0.0	1.9 ± 0.4	109.5 ± 0.0	143.0 ± 0.0	54.6 ± 3.5
239633-1[x]	5.3 ± 0.0	76.1 ± 0.0	0.0 ± 0.0	0.6 ± 0.0	113.0 ± 0.0	137.0 ± 0.0	44.4 ± 0.0
239633-2[x]	11.2 ± 0.8	64.75 ± 0.9	0.0 ± 0.0	1.3 ± 0.6	106.1 ± 3.1	143.0 ± 0.0	42.9 ± 0.0
182138[w]	8.6 ± 1.5	62.65 ± 3.0	0.3 ± 0.0	2.1 ± 0.4	107.8 ± 3.4	137.0 ± 0.0	39.5 ± 1.9
OLYS05N5[y]	8.3 ± 1.2	70.9 ± 0.7	0.0 ± 0.0	1.2 ± 0.3	96.3 ± 4.2	137.0 ± 0.0	88.0 ± 15.4
Colorado 6[z]	9.9 ± 0.6	68.4 ± 0.6	0.1 ± 0.1	1.7 ± 0.1	93.2 ± 3.3	143.0 ± 0.0	101.1 ± 0.8
Cometa[z]	10.0 ± 0.6	67.85 ± 0.5	0.1 ± 0.1	1.7 ± 0.7	95.0 ± 7.8	137.0 ± 0.0	98.4 ± 13.4
Salsa Red[z]	10.1 ± 0.4	63.5 ± 0.0	0.3 ± 0.1	1.9 ± 0.2	88.6 ± 2.9	136.0 ± 0.0	76.9 ± 3.7

Tukey (0.05)	3.4	6.6	0.502	2.1	61.3	0.0	29.6

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Relative area under the disease progress curve for IYSV incidence.

[e]Number of thrips/plant/day.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Table II.4. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2010.

Genotype	**Leaf-avg** (mean ± SE)[a]	**Leaf color** (mean ± SE)[b]	**rAUDPC-in** (mean ± SE)[c]	**Severity** (mean ± SE)[d]	**Thrips-day** (mean ± SE)[e]	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)
248753[x]	3.5 ± 0.0	54.3 ± 2.4	0.20 ± 0.000	1.0 ± 0.0	0.1 ± 0.0	84.0 ± 0.0	123.5 ± 2.2	28.0 ± 2.3
248754[x]	5.0 ± 0.6	51.8 ± 5.8	0.10 ± 0.000	2.0 ± 1.4	1.0 ± 0.2	84.0 ± 0.0	125.8 ± 1.1	40.7 ± 5.6
258956[xv]	10.9 ± 2.7	53.9 ± 1.0	0.10 ± 0.000	3.0 ± 0.0	3.1 ± 0.1	84.0 ± 0.0	142.0 ± 0.0	100.8 ± 2.4
264320[xv]	9.1 ± 0.5	57.9 ± 1.2	0.15 ± 0.071	4.0 ± 0.0	5.5 ± 0.7	85.4 ± 1.0	142.0 ± 0.0	113.6 ± 3.6
271039[x]	5.3 ± 0.6	57.5 ± 4.4	0.20 ± 0.141	1.5 ± 0.7	0.9 ± 0.0	85.4 ± 2.0	120.8 ± 0.8	43.3 ± 6.2
274780[x]	5.4 ± 1.1	53.6 ± 0.3	0.20 ± 0.141	2.0 ± 0.0	1.1 ± 0.1	84.0 ± 0.0	118.1 ± 3.7	43.0 ± 2.2
288073[x]	6.2 ± 0.1	57.7 ± 2.0	0.20 ± 0.000	2.0 ± 0.0	3.9 ± 2.5	95.6 ± 4.5	142.0 ± 0.0	44.5 ± 0.6
288272[x]	3.3 ± 0.6	57.3 ± 1.9	0.20 ± 0.000	1.0 ± 0.0	0.3 ± 0.0	86.3 ± 0.7	117.6 ± 4.4	31.4 ± 0.8
546096[x]	8.4 ± 0.3	58.1 ± 1.5	0.25 ± 0.071	2.0 ± 0.0	7.8 ± 0.5	85.1 ± 0.5	125.1 ± 1.9	59.8 ± 0.7
546100[x]	9.2 ± 0.4	60.2 ± 0.5	0.15 ± 0.071	3.0 ± 0.0	4.1 ± 0.8	84.0 ± 0.0	142.0 ± 0.0	111.3 ± 2.6
546101[x]	9.8 ± 0.1	60.6 ± 2.3	0.20 ± 0.000	3.0 ± 0.0	5.4 ± 0.4	84.0 ± 0.0	138.7 ± 1.6	91.1 ± 1.3
546106[x]	8.5 ± 0.2	60.8 ± 3.2	0.20 ± 0.000	2.0 ± 0.0	5.7 ± 0.5	84.0 ± 0.0	123.9 ± 0.0	65.0 ± 0.1
546140[xv]	6.7 ± 0.6	65.8 ± 1.4	0.20 ± 0.000	2.0 ± 0.0	3.5 ± 0.1	84.0 ± 0.0	119.1 ± 1.2	70.2 ± 3.8
546188[xv]	8.8 ± 0.5	60.6 ± 0.8	0.15 ± 0.071	3.5 ± 0.7	3.7 ± 0.9	84.4 ± 0.5	142.0 ± 0.0	106.4 ± 11
546192[xv]	9.6 ± 0.2	63.5 ± 2.5	0.15 ± 0.071	3.0 ± 1.4	4.2 ± 0.0	84.0 ± 0.0	142.0 ± 0.0	106.2 ± 1.1
182138[w]	8.0 ± 0.2	56.8 ± 2.5	0.20 ± 0.000	3.5 ± 0.7	4.8 ± 1.1	87.2 ± 4.5	134.3 ± 4.7	52.4 ± 3.7
OLYO5N5[y]	9.5 ± 0.2	58.8 ± 1.7	0.10 ± 0.000	3.5 ± 0.7	5.1 ± 1.0	85.1 ± 1.5	142.0 ± 0.0	100.9 ± 1.5
Colorado 6[z]	10.1 ± 0.1	57.2 ± 2.9	0.10 ± 0.000	3.5 ± 0.7	3.1 ± 0.4	85.4 ± 2.0	142.0 ± 0.0	111.2 ± 0.3
Salsa Red[z]	9.2 ± 0.4	55.6 ± 0.1	0.15 ± 0.071	3.0 ± 0.0	7.1 ± 2.6	85.1 ± 1.5	139.7 ± 0.9	92.3 ± 11.7
Vantage[z]	10.2 ± 0.2	60.2 ± 0.4	0.15 ± 0.071	4.0 ± 0.0	7.5 ± 0.1	84.4 ± 0.5	135.9 ± 0.6	101.2 ± 5.1
Tukey's (0.05)	3.0	8.2	0.263	2.2	3.8	6.0	14.3	19.8

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Relative area under the disease progress curve for IYSV incidence.

[d]Severity rated at 117 DAP and was based on a rating scale of 1 – 4 (Schwartz and du Toit, 2005).

[e]Number of thrips/plant/day.

[v]Genotype was also selected in 2009 as resistant/tolerant to *Iris yellow sport virus* and/or onion thrips (*Thrips tabaci*).

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Table II.5. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2011.

Genotype	**Leaf-avg** (mean ± SE)[a]	**Leaf color** (mean ± SE)[b]	**rAUDPC-in** (mean ± SE)[c]	**rAUDPC-sv** (mean ± SE)[d]	**Thrips-day** (mean ± SE)[e]	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)
620[x]	5.8 ± 0.6	65.2	0.163 ± 0.015	0.144 ± 0.010	2.0 ± 1.0	186.2 ± 2.3	219.7 ± 0.8	65.0 ± 6.2
621[x]	8.0 ± 0.5	64.7	0.184 ± 0.012	0.141 ± 0.008	2.0 ± 0.3	187.7 ± 4.3	231.0 ± 2.8	63.7 ± 12.4
634[x]	8.6 ± 0.8	59.2	0.188 ± 0.002	0. 123 ± 0.015	2.4 ± 0.6	190.9 ± 0.1	236.0 ± 0.0	77.8 ± 3.2
648[x]	8.9 ± 0.4	63	0.182 ± 0.000	0.115 ± 0.000	2.7 ± 0.9	190.4 ± 5.9	236.0 ± 0.0	78.7 ± 3.3
656[x]	8.5 ± 2.2	62.2	0.171 ± 0.035	0.137 ± 0.016	2.0 ± 1.4	189.2 ± 10.2	225.4 ± 4.1	70.4 ± 8.6
753[x]	6.3 ± 0.4	50.9	0.175 ± 0.007	0.163 ± 0.024	1.3 ± 0.1	182.5 ± 1.9	218.3 ± 4.0	62.3 ± 5.1
769[x]	7.2 ± 1.0	65.7	0.167 ± 0.021	0.133 ± 0.009	1.9 ± 0.3	192.7 ± 7.6	236.0 ± 0.0	74.3 ± 3.5
258956[xq]	8.5 ± 1.5	60.7	0.172 ± 0.010	0.132 ± 0.015	2.1 ± 0.7	185.3 ± 2.2	226.7 ± 8.1	77.9 ± 7.4
546188[xq]	9.5 ± 1.3	61.7	0.179 ± 0.013	0.146 ± 0.007	2.8 ± 0.8	193.0 ± 7.8	234.3 ± 3.5	81.5 ± 2.8
B5336C[x]	9.1 ± 1.2	64.4	0.185 ± 0.023	0.115 ± 0.000	1.6 ± 0.1	194.5 ± 0.0	243.0 ± 0.0	90.3 ± 0.0
696[w]	4.1 ± 0.8	N/A	0.163 ± 0.000	0.201 ± 0.000	0.3 ± 0.3	174.6 ± 2.8	199.5 ± 1.8	30.6 ± 4.9
OLYS05N5[y]	8.4 ± 1.5	64.5	0.169 ± 0.021	0.127 ± 0.015	2.0 ± 1.1	199.1 ± 9.4	238.5 ± 16.7	90.8 ± 7.2
Colorado 6[z]	10.1 ± 3.7	69.3	0.175 ± 0.009	0.130 ± 0.016	2.6 ± 1.5	196.2 ± 9.0	246.5 ± 4.0	94.5 ± 2.5
Cometa[z]	9.6 ± 0.4	71.9	0.182 ± 0.005	0.136 ± 0.012	3.1 ± 0.2	193.2 ± 5.2	243.0 ± 0.0	99.0 ± 2.9
Salsa Red[z]	7.4 ± 1.6	64.1	0.181 ± 0.006	0.133 ± 0.017	3.2 ± 1.6	200.7 ± 7.2	240.5 ± 11.0	60.5 ± 11.6
Tukey's (0.05)	3.9		0.063	0.067	2.5	60.0	42.5	28.8

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Relative area under the disease progress curve for IYSV incidence.

[d]Relative area under the disease progress curve for IYSV severity.

[e]Number of thrips/plant/day.

[q]Genotype was selected in all three years of the study as resistant/tolerant to *Iris yellow sport virus* and/or onion thrips (*Thrips tabaci*).

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

N/A indicates genotype matured before measurement was taken.

Table II.6. Predictors of onion bulb yield, Iris yellow spot virus (IYSV) incidence and severity, and onion thrips (Thrips tabaci) population during an onion germplasm evaluation study for resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collin.

Year		Transplanted Entries[a]			Direct-Seeded Entries[b]		
2009	**Response**	**Variable**	**Parameter Estimate**	**P-value**	**Variable**	**Parameter Estimate**	**P-value**
	Bulb size	Intercept	-196.4893	< 0.0001	Intercept	212.9124	<.0001
		Leaf_avg	5.2769	< 0.0001	Bulbing	-1.1991	<.0001
		rAUDPC-in	-22.8842	0.1432	rAUDPC-in	106.6190	0.1336
		Bulbing	-0.6041	0.0049	Thrips_day	3.5141	0.3168
		Maturity	1.3887	< 0.0001			
		S_B	-0.5047	< 0.0001			
		Leaf color	1.4313	0.0002			
	rAUDPC-in	Intercept	-0.1161	0.6886	Intercept	-0.0372	0.4132
		Bulbing	-0.0016	0.233	Bulbing	0.0008	0.0308
		Maturity	0.0027	0.1892			
		S_B	-0.0008	0.088			
	Thrips-day	Intercept	-10.2792	<.0001	Intercept	-4.8116	0.0001
		Leaf_avg	0.2429	<.0001	Bulbing	0.0247	0.0008
		Bulbing	0.0332	0.0001	Leaf_avg	0.3503	<.0001
		Maturity	0.0487	<.0001			
		S_B	-0.0111	<.0001			
2010	**Response**	**Variable**	**Parameter Estimate**	**P-value**	**Variable**	**Parameter Estimate**	**P-value**
	Bulb size	Intercept	-27.8815	0.6886	Intercept	24.4684	0.2606
		Thrips-day	-1.2330	0.2274	Thrips-day	-4.7145	0.0541
		Leaf_avg	6.5492	0.0006	Leaf_avg	11.4335	<.0001
		Bulbing	-1.0891	0.1495	rAUDPC-in	-339.7195	0.0295
		Maturity	0.6964	0.0035			
		S_B	-0.3776	<.0001			

	Leaf color	0.8025	0.1191			
Bulb weight	Intercept	-1219.8897	0.0006	Intercept	-25.0777	0.9483
	Thrips-day	-29.1020	0.0006	Thrips-day	-54.9578	0.2044
	Leaf_avg	60.1708	<.0001	Leaf_avg	85.5140	0.0416
	Maturity	5.2565	0.005	rAUDPC-in	-3560.9249	0.1944
	S_B	-3.4949	<.0001			
	Leaf color	7.2894	0.1017			
rAUDPC-in	Intercept	-0.0035	0.9853	Intercept	0.0531	<.0001
	Thrips-day	0.0080	0.0018	Thrips-day	0.0065	0.0055
	Bulbing	0.0073	0.001			
	Maturity	-0.0036	<.0001			
rAUDPC-sv	Intercept	3.3474	0.2851	Intercept	0.1512	<.0001
	Thrips-day	-0.0477	0.297	Leaf_avg	-0.0049	0.053
	Leaf_avg	0.2920	0.0001	rAUDPC-in	0.1737	0.2701
	Bulbing	-0.0424	0.2076			
Thrips-day	Intercept	-25.9853	0.0003	Intercept	-1.5792	0.5568
	rAUDPCin	11.4373	0.004	Leaf color	0.0532	0.1274
	leaves_avg	0.9907	<.0001	Leaf_avg	-0.1794	0.2308
	Bulbing	0.2420	0.0036	rAUDPC-in	24.6145	0.0108
	S_B	-0.0215	0.0068			

2011	**Response**	**Variable**	**Parameter Estimate**	**P-value**
	Bulb size	Intercept	-85.2059	0.0556
		Leaf color	-0.4690	0.1838
		Leaf_avg	5.5123	<.0001
		S_B	-24.0875	<.0001
		Maturity	0.7203	<.0001
		Bulbing	-0.1183	0.3111
	Bulb weight	Intercept	-1109.5773	<.0001
		Leaf_avg	32.9279	<.0001

	S_B	-190.7231	<.0001
	Maturity	4.5724	<.0001
rAUDPC-in	Intercept	0.0858	0.0001
	rAUDPC-sv	0.1764	0.0618
	Loaf color	0.0004	0.1764
	Leaf_avg	0.0052	<.0001
rAUDPC-sv	Intercept	0.1977	<.0001
	Thrips-day	0.0073	<.0001
	Maturity	-0.0003	0.0199
Thrips-day	Intercept	-5.2750	0.0014
	Leaf_avg	0.4032	<.0001
	rAUDPC-sv	10.9166	0.0381
	S_B	-0.5321	0.0264
	Maturity	0.0120	0.0706

Model is based on Mallow's Cp model selection method in SAS (SAS v 9.3, SAS Institute Inc., NC, USA).

[a]All PI lines.

[b]All commercial cultivars and advanced breeding lines.

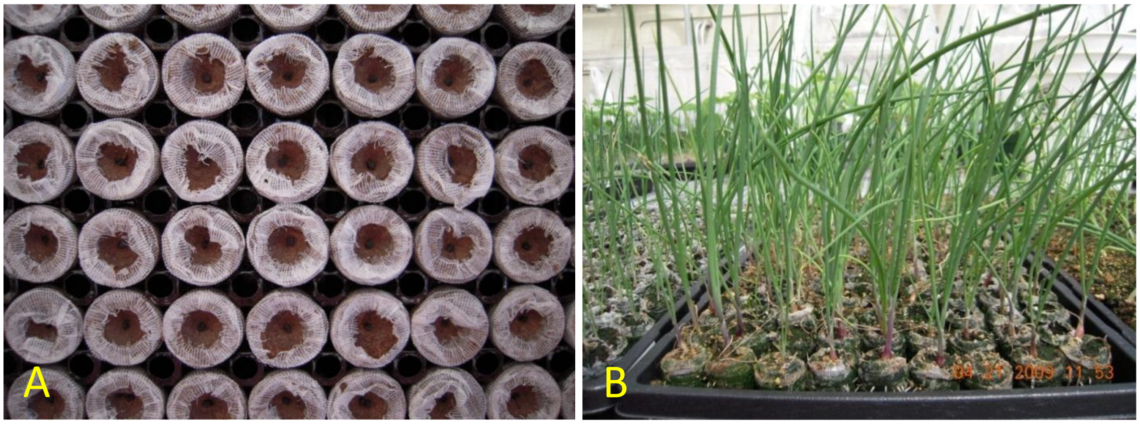

Figure II.1. **A**: Jiffy transplant pellets used to raise onion transplants in the greenhouse. **B**: Onion seedlings thinned to 1 plant/pellet in jiffy transplant pellets in the greenhouse.

Figure II.2. **A**: Production of onion transplants in nursery trays in the greenhouse. **B**: Onion transplants were routinely cut back to induce the development of robust plants with thick necks.

Figure II.3. Field preparation for onion planting in northern Colorado. **A**: deep ripping with John Deere 915 V-Ripper. **B**: disking with the John Deere 640 Disk. **C**: roller harrowing with the John Deere 970 Roller Harrow. **D**: leveling with the Eversman 2400 Land Plane. **E**: a Roto-bedder in operation. **F**: field made into beds and ready for onion planting.

Figure II.4. Field with single-line beds used for onion germplasm evaluation for resistance to IYSV and onion thrips in northern Fort Collins, Colorado, USA.

Figure II.5. **A**: Field transplanting of onion plants in northern Colorado using a 2-row mechanical transplanter. **B**: Proper placement and coverage of onion transplants in the field in northern Colorado.

Figure II.6. Cultural practices undertakened during onion germplasm evaluation for resistance to IYSV and onion thrips in northern Colorado. **A**: furrow irrigation. **B**: hoeing. **C**: hand rogueing of weeds. **D**: mechanized herbicide application.

Figure II.7. Field estimation of onion thrips (*Thrips tabaci*) population by a counting crew.

Figure II.8. Field measurement of onion leaf color using the Minolta SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

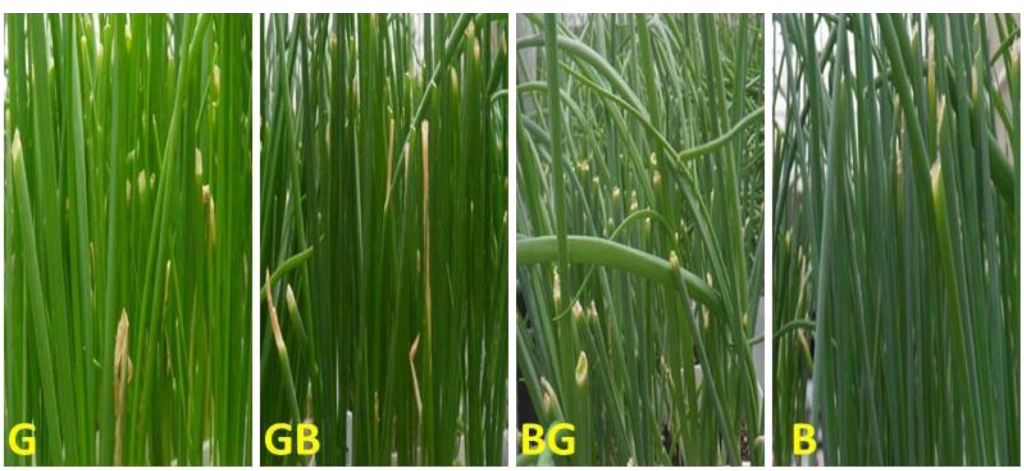

Figure II.9. Photographic representation of the visual categorization of onion leaf color into green (G), green-blue (GB), blue-green (BG) and blue (B).

Figure II.10. Photographic representation of IYSV severity based on a rating scale of 1 – 4. **A** = rating scale 1, **B** = rating scale 2, **C** = rating scale 3, **D** = rating scale 4. (D was adopted from Schwartz and du Toit, 2005).

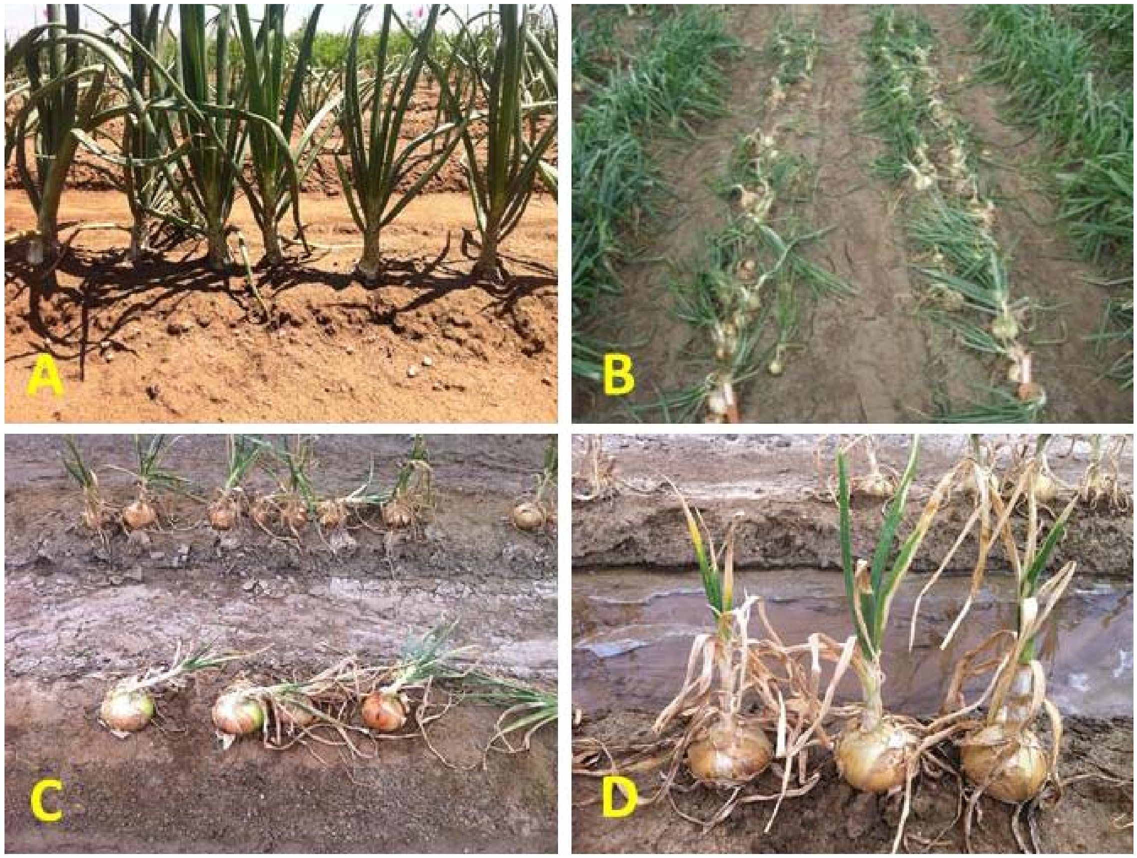

Figure II.11. Growth and developmental stages in bulb onion production. **A**: bulbing stage. **B**: cropped stage. **C**: matured onion plants after the cropping stage. **D**: maturity without a cropping stage.

Figure II.12. Size (**A**) and weight (**B**) determination of onion bulbs at harvest.

Figure II.13. Direct seeding of onion germplasm during an IYSV and onion thrips resistance evaluation in northern Colorado.

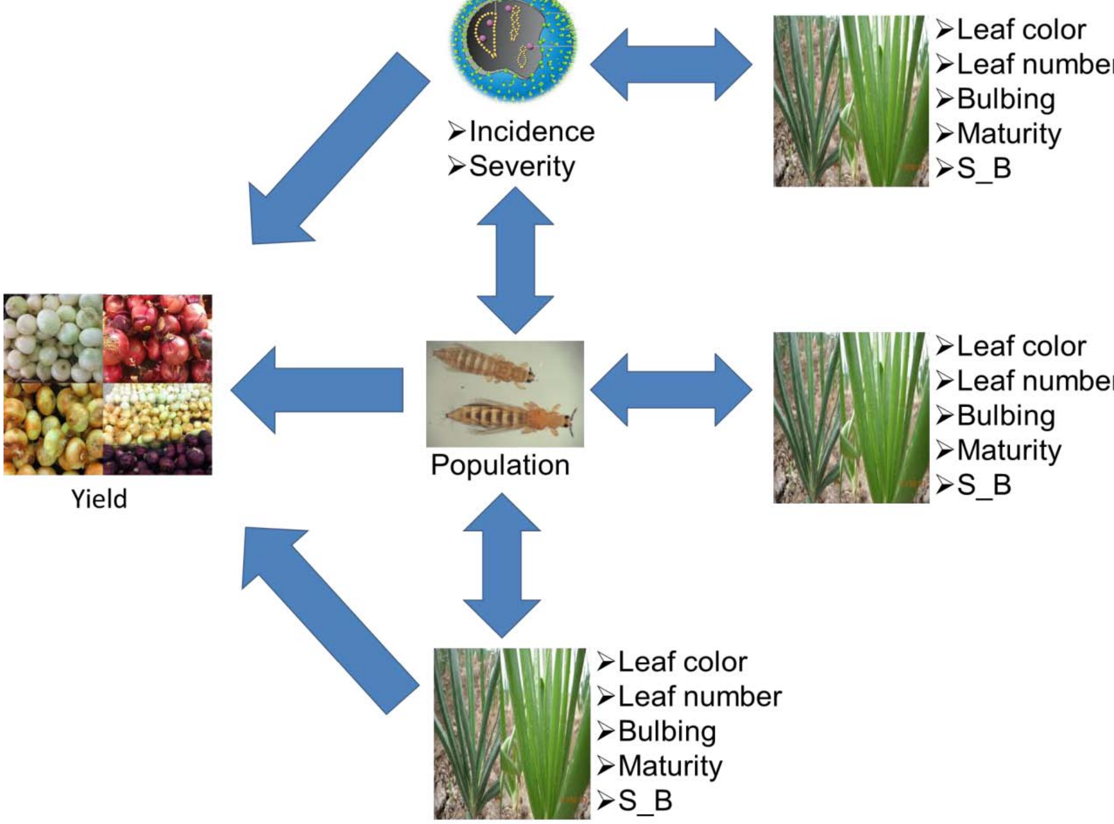

Figure II.14. Schematic representation of the research model adopted for an onion germplasm evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins. Scheme indicates that onion yield is determined by IYSV, onion thrips and inherent germplasm characteristics and the interactions between these parameters.

Figure II.15. Onion transplants severely damaged by frost (Appendix II.E)in northern Colorado, near Fort Collins, during an onion germplasm evaluation for resistance/tolerance to *Iris yellow spot virus* and/or onion thrips (*Thrips tabaci*) in 2011.

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CHAPTER III

EFFECTS OF PESTICIDES ON ONION (*ALLIUM CEPA* L.) GERMPLASM RESPONSE TO *IRIS YELLOW SPOT VIRUS* AND ONION THRIPS (*THRIPS TABACI*)

INTRODUCTION

Onion thrips (*Thrips tabaci* L.) are important economic pests in onion production systems. Their efficient transmission of *Iris yellow spot virus* (IYSV), an economically important tospovirus in the family Bunyaviridae, has further bolstered their pest status.

Although chemical control of onion thrips has varying efficiencies and comes with the disadvantages mentioned in Chapter I, it still is the primary means of management when their population reaches potentially damaging levels (Cranshaw, 2008). In western U.S., onion growers rely on insecticides to manage onion thrips, and to prevent further devastation from IYSV an even more intensive insecticide management program has been adopted (Schwartz et al., 2009). Even with the high risk associated with their use, growers still have several insecticides to choose from. With IYSV, Actigard (Syngenta Crop Protection, NC, USA), is the only chemical choice currently available for IYSV management; and resulted in a 34 % reduction in virus incidence in Colorado (Gent et al., 2004). Host plant resistance (HPR) which offers safe, reliable and cheap management of these production threats has been difficult to find in onion germplasm. As mentioned in Chapter II, the search for HPR identified 16 and 15 genotypes in 2009 and 2010, respectively, which exhibited acceptable responses to IYSV and onion thrips. Of these, 5 genotypes: PIs 258956, 264320, 546140, 546188 and 546192, were selected in both years. Focusing on just these genotypes and evaluating their responses when exposed to IYSV and onion thrips will help decipher the true resistance/tolerance status of these genotypes. The objectives of this study therefore, were to:

i. intensify the screening of these twice-selected genotypes for their response to IYSV and onion thrips.

ii. determine the effects of insecticides and Actigard on onion thrips infestation and IYSV incidence and severity on these genotypes.

MATERIALS AND METHODS

Plant Materials

Seeds of the twice-selected PIs: 258956, 264320, 546140 and 546188, in addition to Colorado 6, Talon and Salsa Red commercial onion cultivars, were planted in the greenhouse on 25 February, 2011. Seeds were sown in nursery trays (Chapter II, Fig. II.2A) using a soil-less potting mix (Fafard's Professional Custom Mix Formula, Conrad Fafard Inc. USA). Seedlings were irrigated as needed. Greenhouse environmental conditions were held at a day time temperature of 25-30^{o}C, a night time temperature of 20-25^{o}C, 60-70% relative humidity, and a photoperiod of 14 hours light and 10 hours darkness with the aid of supplemental lighting. PI 546192 was not included in this study because there wasn't sufficient seed to produce enough plants. The three commercial cultivars were included as standard checks for IYSV and onion thrips response. Plants were transplanted on 20 April, 2011 (54 days after sowing (DAS)).

Treatments and Experimental Design

Onion genotype response to IYSV and onion thrips as influenced by three treatments: untreated Control, Insecticide and Insecticide+Actigard, were investigated. The insecticide treatment involved rotation (Table III.1) of Carzol (active ingredient formetanate hydrochloride, Gowan Co. LLC, USA), Radiant (active ingredient spinetoram; Dow AgroSciences, USA) and Movento (active ingredient spirotetramat; Bayer CropScience, USA) insecticides at application rates of 2.75, 2.75 and 1.20 g/L, respectively. For the Insecticide+Actigard treatment, 0.12 g/L of Actigard (active ingredient acibenzolar-S-methly; Syngenta Crop Protection, NC, USA) was added to each insecticide mentioned above. Pesticides were manually applied using a CO_2 pressurized back pack sprayer and handheld spray boom with one flat-fan nozzle per bed.

The experimental location, field preparation, transplanting and cultural practices for this experiment are the same as described in Chapter II. Briefly, the field was deep ripped, disked, roller harrowed, leveled and made into beds using a GPS-mounted John Deere 7820 (IVT) tractor (Deere & Company, USA) with attachments for the respective operations. After leveling, a dry blend of N: P: K fertilizer was applied at a rate of 72:18:0 kg/acre, respectively. Onion bulbs and volunteer onion plants heavily infected with IYSV and onion thrips from the 2010 growing season were incorporated thoroughly throughout the field during field preparation and served as a source of primary inoculum for the season. A plot measured 3.7 m with 0.9 m spreader rows between them. Plants of White Cloud onion cultivar were planted in the spreader rows and served as an immediate barrier to chemical drift unto untreated plants or plots. Seedlings were transplanted using a 2-row MT 1000 transplanter (Mechanical Transplanter Co., USA) mounted on a John Deere 4710 tractor. Transplanting was carried out to a depth of approximately 5 cm and a within row spacing of approximately 8 cm. Field was furrow irrigated when needed and weed control was rigorously undertaken by both physical/mechanical (hoeing and hand rogueing) and chemical means.

The experiment was set up in a randomized split-plot design with four replications. Pesticide treatment was the main-plot factor and the seven onion genotypes were the sub-plot factor.

Data Collection

Growth and development monitoring, onion thrips counts, IYSV evaluation and yield assessment were the same as described in their respective sections in Chapter II. Three leaf counts were carried out on 21 July (92 DAP), 4 August (106 DAP) and 18 August (120 DAP). All leaves on a plant were counted with the exception of those exhibiting more than 60% leaf senescence. Leaf count was carried out on all plants/entry/treatment/replication. There were four onion thrips population estimates on 11 July (82 DAP), 18 July (89 DAP), 3 August (105 DAP) and 17 August (119 DAP). Both adults and larvae on 10 arbitrarily selected plants/entry/treatment/replication were counted. Counting was stopped when plant neck and leaves began to open and onion thrips abundance decreased significantly. Both IYSV incidence and severity rating were carried out on the same day on 29 July (100 DAP), 5 August (107 DAP), 12 August (114 DAP) and 19 August (121 DAP). However, there was one addition severity rating on 26 August (128 DAP). IYSV incidence was determined by taking the percentage of symptomatic plants/entry/treatment/replication. Severity of infection was assessed on all plants/entry/treatment/replication based on a rating scale of 1 – 4 (Schwartz and du Toit, 2005). Plants were continually monitored for bulbing, cropping/topping and maturity growth stages. Plants were considered matured when more than 50% of the foliage had senesced after cropping, or when 60% or more of plants had more than 50% of their foliage senesced in entries that did not crop. Harvesting was done by hand pulling of plants and cutting the tops and roots off the bulbs using a pair of shears.

Statistical Analysis

Onion thrips population was expressed in cumulative thrips-day and was determined as:

$$\sum_{i=1}^{n} [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

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

IYSV response expressed as relative area under the disease progress curve (rAUDPC) by dividing area under the disease progress curve (AUDPC) by the total area of the graph as described in Chapter II. AUDPC was calculated as:

$$\sum_{i=1}^{n} [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

where x_i is incidence or severity of IYSV at time t_i and n is the total number of observations.

The MIXED procedure in SAS (SAS v. 9.3., SAS Institute Inc., NC, USA) was used for data analysis. The REG and CORR SAS procedures were used in regression and correlation analyses, respectively, as described in Chapter II.

RESULTS

Although three insecticides were used in this experiment, this was for rotational purposes only and not for comparison between the insecticides.

Seasonal Leaf Growth and Development

Leaf growth and development was significantly different ($P < 0.0001$) among the genotypes on all counting days. In general, leaf number remained the same in all genotypes at ≈ 9 leaves/plant throughout the season (Table III.2). However, PI 546188 had the most of 10.1 leaves/plant seasonal average, with PI 546140 having the lowest of 6.6 leaves/plant.

The pesticide treatments did not significantly affect seasonal average leaf development ($P = 0.2180$), however, between 106 and 120 DAP, Instecticide+Actigard had more leaf growth and development than Insecticide in all genotypes.

There were significant Genotype-x-Treatment interactions ($P < 0.0001$) in which the two pesticide treatments promoted more leaf development in Colorado 6 and Salsa Red commercial cultivars but suppressed leaf development in PI 546140. In PI 258956, Insecticide significantly suppressed leaf development (Table III.2).

Seasonal Dynamics of Onion Thrips (*Thrips tabaci*) Population

Four onion thrips population estimations were carried out from 82 to 119 DAP (Table III.3). In all entries, population reached its highest at 89 DAP and then declined and was lowest at 119 DAP, the last estimation day. Genotypes had significantly different ($P < 0.001$) thrips population throughout the season with a highest seasonal average of 16.6 thrips/plant in Salsa Red and a lowest of 3.6 thrips/plant in PI 546140; with a corresponding highest and lowest thrips-day of 1.9 and 0.7 thrips/plant/ day, respectively.

Even though their numbers were lower, the pesticide treatments did not significantly reduce onion thrips population (P = 0.1711) (both seasonal average and thrips-day). Both thrips-day and seasonal average were in the increasing order of Insecticide, Insecticide+Actigard and Control, with thrips-day values of 1.1, 1.3 and 1.4 thrips/plant/day, respectively. Between the two pesticide treatments, Insecticide always had lower thrips population than Insecticide+Actigard. Between 89 and 105 DAP thrips population in both pesticide treatments remained similar, however, the population dropped from 20.9 thrips/plant to 9.6 thrips/plant in the untreated control.

There were no significantly different (P = 0.1295) Genotype-x-Treatment interactions in general, however, pesticides significantly reduced thrips-day in PI 546140. Although not significantly different from Control, Insecticide had a significantly lower thrips-day than with Actigard in PI 258956.

Seasonal Dynamics of *Iris yellow spot virus* (IYSV) Incidence and Severity

Four and five IYSV incidence (Table III.4) and severity (Table III.5) evaluations were, respectively, undertaken between 100 and 121 DAP (incidence) and 100 and 128 DAP (severity). Virus incidence increased throughout the season from an overall mean of 53 % at 100 DAP to 100% at 121 DAP. There were no significant differences between genotypes on individual evaluation days, however, there were significant genotype differences (P < 0.0001) in terms of area under the disease progress curve for virus incidence (AUDPC-in) and relative AUDPC-in (rAUDPC-in). rAUDPC-in was highest at 0.156 in PI 546188 and lowest at 0.089 in PI 546140.

Treatment effect was not significant in general throughout the season with a corresponding non-significant ($P = 0.1115$) rAUDPC-in, however, rAUDPC-in was significantly higher in Insecticide+Actigard (0.147) than in the untreated Control (0.13).

There were no significant Genotype-x-Treatment interactions throughout the season, and the interaction wasn't significant ($P = 0.7269$) in rAUDPC-in either. However, in PI 546140, Insecticide+Actigard significantly increased rAUDPC-in compared to both Insecticide and Control.

Just as was observed for virus incidence, infection severity also increased with time from an overall mean of 1.5 at 100 DAP to 3.9 at 128 DAP (Table III.5; only up to 121 DAP is shown on the table). There were no consistent significant differences between genotypes and between treatments on individual evaluation days, however, differences in average severity and rAUDPC for severity (rAUDPC-sv) were significant in both genotypes and 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 treatments. rAUDPC-sv was highest in Talon and lowest in PI 546140, with values of 0.169 and 0.097, respectively.

Both average severity and rAUDPC-sv were significantly lower in untreated Control than in the pesticide treatments. The two pesticide treatments were not significantly different from each other although Actigard resulted in a slightly lower infection severity than insecticide alone.

There were no overall significantly different Genotype-x-Treatment interactions in all aspects of infection severity; however, in both PI 258956 and Colorado 6, Insecticide resulted in higher infection severity than in the untreated Control.

Days to Bulbing and Maturity

PI 546140 was first to bulb and to reach maturity at 92 and 111 DAP, respectively, while Colorado 6 was last to bulb and last to mature at 113 and 148 DAP, respectively (Table III.6). The genotypes were significantly different ($P < 0.0001$) in both bulbing and maturity dates.

There were no significant treatment effects on time to bulbing ($P = 0.5479$) and maturity ($P = 0.4898$), however, there was a significant ($P = 0.0160$) Genotype-x-Treatment interaction with days to maturity. Insecticide+Actigard reduced time to maturity by ≈ 6 days in PI 258956 than did Insecticide, but delayed maturity by the same margin in PI 546140.

Onion Bulb Yield

The genotypes were significantly different in both bulb size ($P < 0.0001$) and bulb weight ($P < 0.0001$) with Colorado 6 having the largest bulbs of 84.7 mm/bulb and a corresponding highest bulb weight of 304.2 g/bulb. The lowest yield was produced by PI 546140 with 44.8 mm/bulb and 43.1 g/bulb size and weight, respectively (Table III.6).

Treatments had no significant effects on bulb size ($P = 0.4418$) and bulb weight ($P = 0.4116$), however, yield was in the increasing order of Control, Insecticide and Insecticide+Actigard (Table III.6).

The overall interaction between genotypes and treatments was not significantly different for bulb size (P = 0.0.906) and bulb weight (P = 0.1636) even though in PI 258956, Insecticide+Actigard promoted heavier bulb development than Insecticide, and in PI 264320, Actigard treated plants produced significantly heavier bulbs than Control and Insecticide plants.

Model Selection for *Iris yellow spot virus* (IYSV) Response, Onion Thrips (*Thrips tabaci*) Population and Onion Bulb Yield

Because the pesticide treatments did not significantly affect the experiment, correlation and regression analyses were carried out using the combined data instead of a separate analysis for the three treatments. Table III.7 represents the Pearson's correlation coefficients of the various variables in this experiment and how they interact to predict each other. The research model applied in Chapter II was also adopted for this experiment to determine predictors of thrips population, IYSV responses and onion bulb yield as influenced by pesticide applications (Table III.8).

The model (Table III.8) indicates that thrips population determines IYSV incidence but does not determine infection severity. IYSV infection severity, rather than just incidence, was the predictor of bulb yield. Thrips population negatively affected bulb weight but not bulb size.

DISCUSSION

In germplasm evaluations to identify particular phenotypes, multiple evaluations are always encouraged and also, where possible, under different climatic conditions. This provides the stringency necessary to guarantee the reliability of the selected phenotype (Brar et al., 1993).

The multiple evaluation criterion was fulfilled in this experiment in which the genotypes had been previously screened and selected in 2009 and 2010 (Chapter II). In addition to the current year's study, the climatic condition that prevailed at the experimental field over the three years was anything but similar, even to receiving sub-zero temperatures soon after seedlings were transplanted in the year (2011) of the study reported here. Thus, the response of these genotypes to IYSV and onion thrips under these varying environmental stress conditions testifies to their resistance/tolerance.

Host plant resistance to insects comes in three categories: tolerance, antibiosis and antixenosis (Smith, 2005). The very low thrips population and IYSV incidence and severity in PI 546140 could be due to its relatively short maturation time (matured at a time when bulbing had just started in the other genotypes (Table III.6) and its relatively fewer leaves (Table III.2). Leaves of this genotype were thick, short and circular and its canopy was more opened than in the other genotypes. Its leaf thickness was the reason why its field leaf color could not be measured earlier (Chapter II, Appendix A, Table 6). This leaf architecture may have created the antixenotic phenotype that deters onion thrips as has already been reported in other studies (Coudriet et al., 1979; Jones et al., 1935; Loges et al., 2004). These characteristics, however, resulted in PI 546140 having the lowest yield as there wasn't enough time for bulb filling from assimilates produced by the limited leaf area (Brewster, 1994; Campbell and Reece, 2008). This suggests a trade-off between bulb yield and tolerance/resistance to onion thrips and IYSV.

Contrary to PI 546140, PIs 258956, 264320 and 546188 had higher IYSV incidence and severity, and higher thrips infestation than the commercial standard Colorado 6; yet produced yields comparable to the commercial standard (Table III.6). They had phenology very similar to Colorado 6, unlike PI 546140. Colorado 6 was categorized as resistant to onion thrips for possessing antibiosis or antixenosis or both (Diaz-Montano et al., 2010). This may suggest that these PIs possess similar defenses against thrips and IYSV. Both Salsa Red and Talon sustained higher IYSV severity and thrips infestation and also produced lower yields than the 3 PIs. This is a further testament to the selected genotypes' tolerance/resistance to IYSV and onion thrips.

Why the pesticide treatments did not provide any thrips and IYSV control is not exactly known. Actigard is a plant activator and must be used at the right time to activate plant's natural defense mechanisms. Because it has no curative activity, it must be applied before the inception of infection (Syngenta, 2012). Thus, its gross failure to curtail IYSV infection could be due, in part, to an untimely application when the plants had already been infected. The first Actigard application was carried out at 85 DAP, 15 days before the first IYSV evaluation (Tables III.1 and III.4). IYSV evaluation began at first sighting of symptomatic plants. Since infection can be symptomless and latent for some time (Hogenhout et al., 2008; Whitfield et al., 2005), it is probable that the Actigard treatment was applied after plants had been infected.

Insecticide (whether conventional or microbial) management of onion thrips is the single most widely used control strategy in most onion production systems. With the right choice of insecticide chemistry, it is currently one of the most reliable control measures to significantly subdue thrips population to prevent economic injuries (Cranshaw, 2006; Diaz-Montano et al., 2011; Hammon, 2004). Why the insecticides used in this study did not provide effective control of onion thrips can only be speculated. Unlike Actigard which has no direct activity against the pathogen but offers preventative control through induction of systemic acquired resistance (SAR), the insecticides have direct lethal activity on onion thrips (Dow AgroSciences, 2012; Gowan, 2012) and should have provided significant control. Timing of application and both mode of application and application rate were chosen to ensure efficient plant coverage and control. Although thrips reside in onion leaf crevices not easily reached by insecticides (Cranshaw, 2008), this alone cannot be the reason for the total failure as, Movento for example, provides a 2-way systemicity 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) resulted in a 17-26 % increase in thrips population than in untreated checks. Reduced-risk/microbial insecticides (e.g., spinosad alternated with azadirachtin) on the other hand significantly reduced thrips abundance (Schwartz et al., 2009). Could it be that conventional insecticides are losing their efficacy in controlling thrips in Colorado? Should a surfactant have been added to the treatments? It could be argued that the size of the experiment wasn't big enough to measure insecticide effectiveness.

The study reported here is subsidiary to the study in Chapter II. One objective of this study was to focus research efforts on the 4 twice-selected onion germplasms from Chapter II. Three (PIs 258956, 264320 and 546188) of the 4 genotypes proved to be better that Salsa Red and Talon commercial cultivars and their tolerance/resistance to IYSV and onion thrips was comparable to the commercial standard Colorado 6. The inclusion of these genotypes in the onion translational genomics project has been validated by this study. The search for genotypes better than Colorado 6 should continue so that the goal of sustaining U.S. onion production by delivering resistance to IYSV and onion thrips may be fulfilled.

Table III.1. Rotation of insecticides used in onion germplasm response to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci* L) in northern Colorado, near Fort Collins.

Date (2011)	**Insecticide and Application Rate**	**Active Ingredient**
7 July (85 DAP)	Carzol @ 2.75 g/L	Formetanate hydrochloride
21 July (92 DAP)	Radiant @ 2.75 g/L	Spinetoram
28 July (99 DAP)	Movento @ 1.2 g/L	Spirotetramat
4 August (106 DAP)	Carzol @ 2.75 g/L	Formetanate hydrochloride
12 August (114 DAP)	Radiant @ 2.75 g/L	Spinetoram
18 August (120 DAP)	Movento @ 1.2 g/L	Spirotetramat

The Insecticide+Actigard treatment consisted of 0.12 g/L of Actigard added to each insecticide and applied on the same day as the insecticide treatment.

Table II I.2. Effects of pesticides on leaf growth a nd de velopment in transplanted onion germplasms during field e valuation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2011.

Genotype*	**Treatment****	**Leaves-92** (leaves/plant) (mean ± SE)	**Leaves-106** (leaves/plant) (mean ± SE)	**Leaves-120** (leaves/plant) (mean ±SE)	**Average** (leaves/plant) (mean ±SE)
258956	Control	9.7 ± 0.4x	9.0 ± 0.3x	8.1 ± 0.5x	8.9 ± 0.3x
	Insecticide	8.1 ± 0.4y	7.5 ± 0.3y	7.6 ± 0.6x	7.7 ± 0.3y
	Insecticide+Actigard	9.6 ± 0.4 x	9.0 ± 0.3 x	8.9 ± 0.6x	9.2 ± 0.3x
	Genotype mean	*9.1 ± 0.4a*	*8.5 ± 0.3a*	*8.2 ± 0.6a*	*8.6 ± 0.3a*
264320	Control	10.0 ± 0.4 x	9.4 ± 0.3 x	9.8 ± 0.5x	9.8 ± 0.3x
	Insecticide	10.5 ± 0.4 x	9.8 ± 0.3 x	8.7 ± 0.5x	9.7 ± 0.3x
	Insecticide+Actigard	10.6 ± 0.4 x	9.8 ± 0.3 x	9.9 ± 0.5x	10.0 ± 0.3x
	Genotype mean	*10.3 ± 0.4b*	*9.7 ± 0.3b*	*9.5 ± 0.5a*	*9.8 ± 0.3b*
546140	Control	7.7 ± 0.3 x	5.8 ± 0.3 x	N/A	7.0 ± 0.3x
	Insecticide	7.1 ± 0.3 x	5.4 ± 0.3 x	N/A	6.6 ± 0.3xy
	Insecticide+Actigard	7.0 ± 0.4 x	5.2 ± 0.3 x	N/A	6.2 ± 0.3y
	Genotype mean	*7.3 ± 0.3c*	*5.5 ± 0.3c*	*N/A*	*6.6 ± 0.3c*
546188	Control	9.5 ± 0.3 x	10.4 ± 0.3 x	10.1 ± 0.5x	9.8 ± 0.3x
	Insecticide	10.4 ± 0.4 x	10.7 ± 0.3 x	9.8 ± 0.5x	10.2 ± 0.3x
	Insecticide+Actigard	9.8 ± 0.4 x	10.4 ± 0.3 x	9.9 ± 0.5x	10.2 ± 0.3x
	Genotype mean	*9.9 ± 0.4d*	*10.5 ± 0.3d*	*9.9 ± 0.5c*	*10.1 ± 0.3b*
Colorado 6	Control	7.5 ± 0.5 x	9.1 ± 0.4 x	9.4 ± 0.8x	8.5 ± 0.4x
	Insecticide	7.9 ± 0.5 x	9.2 ± 0.4 x	10.3 ± 0.7x	9.1 ± 0.4xy
	Insecticide+Actigard	8.7 ± 0.5 x	9.6 ± 0.5 x	11.1 ± 0.7x	10.0 ± 0.4y
	Genotype mean	*8.0 ± 0.5e*	*9.3 ± 0.4b*	*10.3 ± 0.7bc*	*9.2 ± 0.4d*
Salsa Red	Control	7.9 ± 0.4 x	9.5 ± 0.3 x	6.9 ± 0.6x	7.8 ± 0.3x
	Insecticide	9.2 ± 0.4 y	9.5 ± 0.3 x	6.4 ± 0.6x	8.7 ± 0.3y
	Insecticide+Actigard	9.1 ± 0.4 y	9.9 ± 0.4 x	6.9 ± 0.6x	8.9 ± 0.3y
	Genotype mean	*8.7 ± 0.4f*	*9.6 ± 0.3b*	*6.7 ± 0.6d*	*8.5 ± 0.3a*

Talon	Control	8.9 ± 0.3 x	8.5 ± 0.3 x	6.9 ± 0.6x	8.4 ± 0.3x
	Insecticide	8.6 ± 0.4 x	8.0 ± 0.3 x	7.1 ± 0.6x	8.1 ± 0.3x
	Insecticide+Actigard	8.7 ± 0.3 x	8.6 ± 0.3 x	8.2 ± 0.6x	8.8 ± 0.3x
	Genotype mean	*8.7 ± 0.3f*	*8.4 ± 0.3a*	*7.4 ± 0.6df*	*8.4 ± 0.3a*
	Grand mean	**8.9 ± 0.4**	**8.8 ± 0.3**	**8.7 ± 0.6**	**8.7 ± 0.3**
Main-Plot Effect*					
	Control	8.7 ± 0.3r	8.8 ± 0.1rs	8.6 ± 0.3rs	8.6 ± 0.2r
	Insecticide	8.8 ± 0.3r	8.6 ± 0.1r	8.3 ± 0.3r	8.6 ± 0.2r
	Insecticide+Actigard	9.1 ± 0.3r	8.9 ± 0.2s	9.2 ± 0.3s	9.0 ± 0.2r

*Genotype means are separated by letters a - f. Genotypes with the same letters within a column are not significantly different from each other.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different from each other.

***Main-plot effects are separated by letters r and s. Treatments with the same letters within a column are not significantly different from each other.

N/A indicates genotype matured before counting was carried out.

Numbers following '-' indicate days after planting (DAP) on which counting was carried out.

Table III.3. Effects of pesticides on seasonal dynamics of onion thrips (*Thrips tabaci*) population in transplanted onion germplasms during field evaluation for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips in northern Colorado, near Fort Collins, in 2011.

Genotype*	**Treatment****	**Thrips-82** (Thrips/plant) (mean ± SE)	**Thrips-89** (Thrips/plant) (mean ± SE)	**Thrips-105** (Thrips/plant) (mean ± SE)	**Thrips-119** (Thrips/plant) (mean ± SE)	**Average** (Thrips/plant) (mean ± SE)	**Thrips-day** (thrips/plant/day) (mean ± SE)
258956	Control	7.9 ± 1.6x	22.2 ± 2. 76x	7.0 ± 2.2x	2.5 ± 1.2x	10.3 ± 1.2x	1.3 ± 0.2xy
	Insecticide	9.3 ± 1.6x	12.3 ± 2.8y	13.8 ± 2.2y	1.8 ± 1.2x	9.2 ± 1.2x	1.0 ± 0.2x
	Insecticide+Actigard	15.0 ± 1.6y	15.3 ± 2.8xy	11.5 ± 2.3y	2.2 ± 1.2x	11.5 ± 1.2x	1.4 ± 0.2y
	Genotype mean	*10.7 ± 1.6a*	*16.6 ± 2.8a*	*10.8 ± 2.3a*	*2.1 ± 1.2a*	*10.4 ± 1.2a*	*1.2 ± 0.2a*
264320	Control	13.4 ± 1.6x	25.9 ± 2.8x	7.4 ± 2.2x	3.5 ± 1.2x	12.6 ± 1.2x	1.4 ± 0.2x
	Insecticide	10.7 ± 1.6x	16.8 ± 2.8y	10.9 ± 2.2x	1.3 ± 1.2x	9.9 ± 1.2x	1.1 ± 0.2x
	Insecticide+Actigard	20.9 ± 1.6y	16.6 ± 2.8y	10.7 ± 2.2x	2.6 ± 1.2x	12.7 ± 1.2x	1.4 ± 0.2x
	Genotype mean	*15.0 ± 1.6b*	*19.8 ± 2.8b*	*9.7 ± 2.2ab*	*2.4 ± 1.2ab*	*11.7 ± 1.2b*	*1.3 ± 0.2a*
546140	Control	4.8 ± 1.6x	6.9 ± 2.8x	3.8 ± 3.6x	0.2 ± 1.5x	4.9 ± 1.2x	1.0 ± 0.2x
	Insecticide	3.5 ± 1.6x	4.6 ± 2.8x	3.6 ± 2.9x	0.3 ± 1.5x	3.4 ± 1.2x	0.5 ± 0.2y
	Insecticide+Actigard	3.0 ± 1.6x	4.0 ± 2.8x	2.4 ± 3.2x	0.3 ± 1.4x	2.7 ± 1.2x	0.4 ± 0.2y
	Genotype mean	*3.8 ± 1.6c*	*5.2 ± 2.8c*	*3.3 ± 3.2d*	*0.3 ± 1.5a*	*3.6 ± 1.2c*	*0.7 ± 0.2b*
546188	Control	10.3 ± 1.6x	22.6 ± 2.8x	7.8 ± 2.3x	3.9 ± 1.2x	11.1 ± 1.2x	1.2 ± 0.2x
	Insecticide	10.0 ± 1.6x	18.5 ± 2.8x	13.4 ± 2.2xy	2.7 ± 1.2x	11.1 ± 1.2x	1.2 ± 0.2x
	Insecticide+Actigard	9.5 ± 1.6x	15.5 ± 2.8x	17.8 ± 2.2y	3.1 ± 1.2x	11.5 ± 1.2x	1.2 ± 0.2x
	Genotype mean	*9.9 ± 1.6a*	*18.9 ± 2.8ab*	*13.0 ± 2.2ac*	*3.3 ± 1.2abc*	*11.2 ± 1.2ab*	*1.2 ± 0.2a*
Colorado 6	Control	4.6 ± 2.3x	13.2 ± 3.5x	8.6 ± 3.2x	9.7 ± 1.7x	8.9 ± 1.5x	1.1 ± 0.2x
	Insecticide	6.1 ± 2.3x	11.7 ± 3.5x	11.5 ± 2.9xy	2.9 ± 1.6y	7.9 ± 1.5x	0.9 ± 0.2x
	Insecticide+Actigard	7.3 ± 2.4x	16.9 ± 3.6x	17.8 ± 3.0y	3.6 ± 1.7y	11.3 ± 1.6x	1.2 ± 0.2x
	Genotype mean	*6.0 ± 2.3c*	*13.9 ± 3.5ae*	*12.6 ± 3.1ab*	*5.4 ± 1.7c*	*9.4 ± 1.5a*	*1.1 ± 0.2a*

Salsa Red	Control	8.4 ± 1.7x	32.1 ± 2.8x	17.5 ± 2.3x	16.2 ± 1.2x	17.2 ± 1.2x	1.9 ± 0.2x
	Insecticide	12.0 ± 1.6x	20.8 ± 2.8y	23.3 ± 2.2y	2.9 ± 1.2y	14.8 ± 1.2x	1.6 ± 0.2x
	Insecticide+Actigard	9.2 ± 1.6x	23.9 ± 2.8y	31.5 ± 2.2z	7.4 ± 1.2z	17.9 ± 1.2x	1.9 ± 0.2x
	Genotype mean	*9.8 ± 1.6a*	*25.6 ± 2.9d*	*24.1 ± 2.2e*	*8.8 ± 1.2e*	*16.6 ± 1.2d*	*1.9 ± 0.2c*
Talon	Control	12.6 ± 1.6x	23.7 ± 2.8x	14.8 ± 2.2x	7.3 ± 1.2x	14.6 ± 1.2x	1.6 ± 0.2x
	Insecticide	8.8 ± 1.6x	15.7 ± 2.8y	22.5 ± 2.2y	5.1 ± 1.2xy	12.9 ± 1.2x	1.4 ± 0.2x
	Insecticide+Actigard	9.9 ± 1.6x	16.4 ± 2.8y	19.2 ± 2.2xy	4.0 ± 1.2y	12.5 ± 1.1x	1.4 ± 0.2x
	Genotype mean	*10.4 ± 1.6a*	*18.6 ± 2.8ab*	*18.9 ± 2.2f*	*5.5 ± 1.2cd*	*13.4 ± 1.1e*	*1.5 ± 0.2d*
	Grand mean	**9.4 ± 1.7**	**16.9 ± 2.9**	**13.2 ± 2.5**	**4.0 ± 1.3**	**10.9 ± 1.3**	**1.3 ± 0.2**
Main-Plot Effect* **							
	Control	8.9 ± 0.7rs	20.9 ± 2.0r	9.6 ± 1.4r	6.2 ± 0.5r	11.4 ± 0.9r	1.4 ± 0.1r
	Insecticide	8.6 ± 0.7r	14.3 ± 2.0s	14.2 ± 1.4s	2.4 ± 0.5s	9.9 ± 0.9r	1.1 ± 0.1r
	Insecticide+Actigard	10.7 ± 0.7s	15.5 ± 2.0rs	15.9 ± 1.4s	3.3 ± 0.5s	11.5 ± 0.9r	1.3 ± 0.1r

*Genotype means are separated by letters a - f. Genotypes with the same letters within a column are not significantly different from each other.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different from each other.

***Main-plot effects are separated by letters r and s. Treatments with the same letters within a column are not significantly different from each other.

Numbers following '-' indicate days after planting (DAP) on which counting was carried out.

Table III.4. Effects of pesticides on incidence of *Iris yellow spot virus* (IYSV) in transplanted onion germplasms during field evaluation for their resistance/tolerance to IYSV and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2011.

Genotype* and Treatment**	**IYSV-100** (%) (mean ± SE)	**IYSV-107** (%) (mean ± SE)	**IYSV-114** (%) (mean ± SE)	**IYSV-121** (%) (mean ± SE)	**IYSV-avg** (%) (mean ± SE)[k]	**AUDPC-in** (%.day) (mean ± SE)[p]	**rAUDPC-in** (mean ± SE)[q]
258956							
Control	50.4 ± 9.3x	87.7 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	84.5 ± 4.2x	1840.1 ± 94.8x	0.152 ± 0.008x
Inst	53.3 ± 9.3x	74.4 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	81.9 ± 4.2x	1757.8 ± 94.8x	0.145 ± 0.008x
Inst+Act	49.7 ± 9.3x	90.6 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	85.1 ± 4.2x	1858.2 ± 94.8x	0.154 ± 0.008x
Genotype mean	*51.1 ± 9.3a*	*84.2 ± 8.0a*	*100.0 ± 2.9a*	*100.0 ± 0.0a*	*83.8 ± 4.2a*	*1818.7 ± 94.8a*	*0.15 ± 0.008a*
264320							
Control	49.1 ± 9.3x	88.0 ± 8.0x	97.5 ± 2.9x	100.0 ± 0.0x	83.7 ± 4.2x	1820.7 ± 94.8x	0.151 ± 0.008x
Inst	65.8 ± 9.3x	89.1 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	88.7 ± 4.2x	1904.1 ± 94.8x	0.157 ± 0.008x
Inst+Act	59.1 ± 9.3x	90.6 ± 8.0x	95.0 ± 2.9x	100.0 ± 0.0x	86.2 ± 4.2x	1855.8 ± 94.8x	0.153 ± 0.008x
Genotype mean	*58.0 ± 9.3a*	*89.2 ± 8.0a*	*97.5 ± 2.9a*	*100.0 ± 0.0a*	*86.2 ± 4.2ab*	*1860.2 ± 94.8a*	*0.154 ± 0.008a*
546140							
Control	49.6 ± 9.3x	80.8 ± 8.0x	98.5 ± 3.4x	N/A	75.1 ± 4.2x	914.4 ± 94.8x	0.08 ± 0.008x
Inst	47.4 ± 9.3x	84.8 ± 8.0x	99.8 ± 3.4x	N/A	75.3 ± 4.2x	934.6 ± 94.8x	0.082 ± 0.008x
Inst+Act	50.7 ± 9.3x	97.2 ± 8.0x	100.0 ± 2.9x	N/A	82.6 ± 4.2x	1208.1 ± 94.8y	0.106 ± 0.008y
Genotype mean	*49.2 ± 9.3a*	*87.6 ± 8.0a*	*99.4 ± 3.2a*	N/A	*77.7 ± 4.2ac*	*1019.1 ± 94.8b*	*0.089 ± 0.008b*
546188							
Control	60.8 ± 9.3x	90.6 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	87.8 ± 4.2x	1896.9 ± 94.8x	0.157 ± 0.008x
Inst	64.3 ± 9.3x	93.2 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	89.4 ± 4.2x	1927.5 ± 94.8x	0.159 ± 0.008x

Inst+Act	50.2 ± 9.3x	91.3 ± 8.0x	97.7 ± 2.9x	100.0 ± 0.0x	84.8 ± 4.2x	1848.4 ± 94.8x	0.153 ± 0.008x
Genotype mean	*58.4 ± 9.3a*	*91.7 ± 8.0ab*	*99.2 ± 2.9a*	*100.0 ± 0.0a*	*87.3 ± 4.2ad*	*1890.9 ± 94.8ac*	*0.156 ± 0.008a*
Colorado 6							
Control	48.8 ± 9.3x	79.2 ± 8.0x	83.8 ± 2.9x	100.0 ± 0.0x	77.9 ± 4.2x	1661.0 ± 94.8x	0.137 ± 0.008x
Inst	53.1 ± 9.3x	75.0 ± 8.0x	100.0 ± 2.9y	100.0 ± 0.0x	82.0 ± 4.2x	1760.9 ± 94.8x	0.146 ± 0.008x
Inst+Act	58.3 ± 9.3x	81.3 ± 8.0x	100.0 ± 2.9y	100.0 ± 0.0x	84.9 ± 4.2x	1822.9 ± 94.8x	0.151 ± 0.008x
Genotype mean	*53.4 ± 9.3a*	*78.5 ± 8.0ac*	*94.6 ± 2.9b*	*100.0 ± 0.0a*	*81.6 ± 4.2a*	*1748.3 ± 94.8ad*	*0.145 ± 0.008a*
Salsa Red							
Control	48.7 ± 9.3x	76.3 ± 8.0x	94.4 ± 2.9x	100.0 ± 0.0x	79.9 ± 4.2x	1715.8 ± 94.8x	0.142 ± 0.008x
Inst	38.5 ± 9.3x	91.3 ± 8.0xy	100.0 ± 2.9x	100.0 ± 0.0x	82.4 ± 4.2x	1823.5 ± 94.8x	0.151 ± 0.008x
Inst+Act	57.8 ± 9.3x	100.0 ± 8.0y	100.0 ± 2.9x	100.0 ± 0.0x	89.4 ± 4.2x	1952.1 ± 94.8x	0.161 ± 0.008x
Genotype mean	*48.3 ± 9.3a*	*89.2 ± 8.0a*	*98.1 ± 2.9ab*	*100.0 ± .00a*	*83.9 ± 4.2a*	*1830.5 ± 94.8a*	*0.151 ± 0.008a*
Talon							
Control	52.9 ± 9.3x	82.6 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	83.9 ± 4.2x	1813.4 ± 94.8x	0.15 ± 0.008x
Inst	56.2 ± 9.3x	89.9 ± 8.0x	94.7 ± 2.9x	100.0 ± 0.0x	85.2 ± 4.2x	1839.3 ± 94.8x	0.152 ± 0.008x
Inst+Act	47.8 ± 9.3x	88.6 ± 8.0x	100.0 ± 2.9x	100.0 ± 0.0x	84.1 ± 4.2x	1837.5 ± 94.8x	0.152 ± 0.008x
Genotype mean	*52.3 ± 9.3a*	*87.1 ± 8.0a*	*98.2 ± 2.9a*	*100.0 ± 0.0a*	*84.4 ± 4.2ae*	*1830.1 ± 94.8a*	*0.151 ± 0.008a*
Grand mean	**53.0 ± 9.3**	**86.8 ± 8.0**	**98.2 ± 3.0**	**100.0 ± 0.0**	**83.6 ± 4.2**	**1714.0 ± 94.8**	**0.142 ± 0.008**
Main-Plot Effect* **							
Control	51.5 ± 3.9r	83.6 ± 3.1r	96.3 ± 1.6r	100.0 ± 0.0r	81.8 ± 1.8r	1666.1 ± 41.6r	0.138 ± 0.003r
Inst	54.1 ± 3.9r	85.4 ± 3.1r	99.2 ± 1.6r	100.0 ± 0.0r	83.6 ± 1.8r	1706.8 ± 41.6rs	0.142 ± 0.003rs
Inst+Act	53.4 ± 3.9r	91.4 ± 3.1r	99.0 ± 1.6r	100.0 ± 0.0r	85.3 ± 1.8r	1769.0 ± 41.6s	0.147 ± 0.003s

*Genotype means are separated by letters a - f. Genotypes with the same letters within a column are not significantly different from each other.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different from each other.

***Main-plot effects are separated by letters r and s. Treatments with the same letters within a column are not significantly different from each other.

Numbers following ‘-’ indicate days after planting (DAP) on which evaluation was carried out.

N/A indicates genotype matured before evaluation was carried out.

Inst = Insecticide treatment. Inst+Act = Insecticide+Actigard treatment.

[k]Seasonal average of IYSV incidence.

[p]Area under the disease progress curve for IYSV incidence.

[q]Relative area under the disease progress curve for IYSV incidence.

Table III.5. Effects of pesticides on severity of *Iris yellow spot virus* (IYSV) infection in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2010.

Genotype* and Treatment**	**Sev-100** (mean ± SE)	**Sev-107** (mean ± SE)	**Sev-114** (mean ± SE)	**Sev-121** (mean ± SE)	**Sev-avg** (mean ± SE)[k]	**AUDPC-sv** (mean ± SE)[p]	**rAUDPC-sv** (mean ± SE)[q]
258956							
Control	1.3 ± 0.5x	2.3 ± 0.3x	3. 0 ± 0.2x	3.0 ± 0.3x	2.7 ± 0.1x	76.1 ± 4.0x	0.149 ± 0.009x
Inst	3.3 ± 0.5x	2.3 ± 0.3x	3.3 ± 0.2x	3. 8 ± 0.3y	3.3 ± 0.1y	89.3 ± 4.0y	0.189 ± 0.009y
Inst+Act	1.0 ± 0.5x	2.5 ± 0.3x	3.0 ± 0.2x	3.3 ± 0.3xy	2.8 ± 0.1x	78.8 ± 4.0x	0.154 ± 0.009x
Genotype mean	*1.8 ± 0.5a*	*2.3 ± 0.3a*	*3.1 ± 0.2a*	*3.3 ± 0.3a*	*2.9 ± 0.1a*	*81.4 ± 4.0a*	*0.164 ± 0.000a*
264320							
Control	1.3 ± 0.5x	2.5 ± 0.3xy	3.0 ± 0.2x	3.3 ± 0.3x	2.8 ± 0.1x	79.6 ± 4.0x	0.156 ± 0.009x
Inst	1.5 ± 0.5x	3.0 ± 0.3x	3.3 ± 0.2x	3.8 ± 0.3x	3.1 ± 0.1x	89.3 ± 4.0x	0.174 ± 0.009x
Inst+Act	1.8 ± 0.5x	2.3 ± 0.3y	3.3 ± 0.2x	3.3 ± 0.3x	2.9 ± 0.1x	81.4 ± 4.0x	0.159 ± 0.009x
Genotype mean	*1.5 ± 0.5a*	*2.6 ± 0.3ab*	*3.2 ± 0.2ab*	*3.4 ± 0.3ac*	*2.9 ± 0.1ab*	*83.4 ± 4.0ab*	*0.163 ± 0.000ab*
546140							
Control	1.5 ± 0.5x	2.0 ± 0.3x	2.7 ± 0.3x	N/A	2.0 ± 0.1x	24.5 ± 4.0x	0.087 ± 0.009x
Inst	1.8 ± 0.5x	2.3 ± 0.3x	2.7 ± 0.3x	N/A	2.2 ± 0.1x	27.1 ± 4.0x	0.096 ± 0.009x
Inst+Act	1.5 ± 0.5x	2.0 ± 0.3x	2.3 ± 0.2x	N/A	1.9 ± 0.1x	27.1 ± 4.0x	0.109 ± 0.009x
Genotype mean	*1.6 ± 0.5a*	*2.1 ± 0.3ac*	*2.5 ± 0.3c*	*N/A*	*2.0 ± 0.1c*	*26.3 ± 4.0c*	*0.097 ± 0.000c*
546188							
Control	1.5 ± 0.5x	2.6 ± 0.3x	3.0 ± 0.2x	3.3 ± 0.3x	2.9 ± 0.1x	81.4 ± 4.0x	0.159 ± 0.009x
Inst	1.5 ± 0.5x	2.5 ± 0.3x	3.5 ± 0.2x	3.5 ± 0.3x	3.0 ± 0.1x	85.8 ± 4.0x	0.168 ± 0.009x
Inst+Act	1.5 ± 0.5x	2.8 ± 0.3x	3.5 ± 0.2x	3.5 ± 0.3x	3.1 ± 0.1x	87.5 ± 4.0x	0.171 ± 0.009x

Genotype mean	*1.5 ± 0.5a*	*2.6 ± 0.3abd*	*3.3 ± 0.2abd*	*3.4 ± 0.3ac*	*3.0 ± 0.1abd*	*84.9 ± 4.0abd*	*0.166 ± 0.000abd*
Colorado 6							
Control	1.5 ± 0.5x	1.6 ± 0.3x	2.3 ± 0.2x	3.5 ± 0.3x	2.6 ± 0.1x	70.9 ± 4.0x	0.138 ± 0.009x
Inst	1.5 ± 0.5x	2.5 ± 0.3y	3.3 ± 0.2y	3.5 ± 0.3x	2.9 ± 0.1x	83.1 ± 4.0y	0.174 ± 0.009y
Inst+Act	1.3 ± 0.5x	2.5 ± 0.3y	3.0 ± 0.2y	3.3 ± 0.3x	2.8 ± 0.1x	79.6 ± 4.0xy	0.156 ± 0.009xy
Genotype mean	*1.4 ± 0.5a*	*2.2 ± 0.3ac*	*2.8 ± 0.2abce*	*3.4 ± 0.3ac*	*2.8 ± 0.1abe*	*77.9 ± 4.0abe*	*0.156 ± 0.000abde*
Salsa Red							
Control	1.5 ± 0.5x	2.0 ± 0.3x	3.0 ± 0.2x	3.5 ± 0.3x	2.7 ± 0.1x	77.0 ± 4.0x	0.175 ± 0.009x
Inst	1.0 ± 0.5x	2.5 ± 0.3x	3.0 ± 0.2x	3.5 ± 0.3x	2.8 ± 0.1x	80.5 ± 4.0x	0.157 ± 0.009x
Inst+Act	1.5 ± 0.5x	2.3 ± 0.3x	3.3 ± 0.2x	3.5 ± 0.3x	2.9 ± 0.1x	82.3 ± 4.0x	0.161 ± 0.009x
Genotype mean	*1.3 ± 0.5a*	*2.3 ± 0.3abcd*	*3.1 ± 0.2abde*	*3.5 ± 0.3ac*	*2.8 ± 0.1abde*	*79.9 ± 4.0abde*	*0.164 ± 0.000abde*
Talon							
Control	1.3 ± 0.5x	2.1 ± 0.3x	3.3 ± 0.2x	3.5 ± 0.3x	2.8 ± 0.1x	80.5 ± 4.0x	0.157 ± 0.009x
Inst	1.8 ± 0.5x	2.9 ± 0.3y	3.3 ± 0.2x	3.8 ± 0.3x	3.1 ± 0.1x	89.3 ± 4.0x	0.174 ± 0.009x
Inst+Act	1.5 ± 0.5x	2.5 ± 0.3xy	3.5 ± 0.2x	4.0 ± 0.3x	3.1 ± 0.1x	89.3 ± 4.0x	0.174 ± 0.009x
Genotype mean	*1.5 ± 0.5a*	*2.5 ± 0.3abd*	*3.3 ± 0.2abd*	*3.8 ± 0.3bc*	*3.0 ± 0.1abdf*	*86.3 ± 4.0abdf*	*0.169 ± 0.000abde*
Grand mean	**1.5 ± 0.5**	**2.4 ± 0.3**	**3.1 ± 0.3**	**3.5 ± 0.3**	**2.8 ± 0.1**	**74.3 ± 4.0**	**0.154 ± 0.000**
Main-Plot Effect* **							
Control	1.4 ± 0.2r	2.2 ± 0.1r	2.9 ± 0.1r	3.3 ± 0.1r	2.6 ± 0.1r	70.0 ± 2.1r	0.146 ± 0.004r
Inst	1.8 ± 0.2r	2.6 ± 0.1s	3.2 ± 0.1r	3.6 ± 0.1r	2.9 ± 0.1s	77.8 ± 2.1s	0.162 ± 0.004s
Inst+Act	1.4 ± 0.2r	2.4 ± 0.1rs	3.1 ± 0.1r	3.5 ± 0.1r	2.8 ± 0.1s	75.1 ± 2.1s	0.155 ± 0.004s

A fifth severity rating was undertaken at 128 DAP. Data is shown because almost all genotypes and treatments scored a rating of 4.

*Genotype means are separated by letters a - f. Genotypes with the same letters within a column are not significantly different from each other.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different from each other.

***Main-plot effects are separated by letters r and s. Treatments with the same letters within a column are not significantly different from each other.

Numbers following '-' indicate days after planting (DAP) on which evaluation was carried out.

N/A indicates genotype matured before evaluation was carried out.

Inst = Insecticide treatment. Inst+Act = Insecticide+Actigard treatment. Sev = Severity.

[k]Seasonal average of IYSV severity.

[p]Area under the disease progress curve for IYSV severity.

[q]Relative area under the disease progress curve for IYSV severity.

Table III.6. Effects of pesticides on development and yield of transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2009.

Genotype*	Treatment**	Bulbing (DAP) (mean ± SE)	Maturity (DAP) (mean ± SE)	Size (mm/bulb) (mean ± SE)	Weight (g/bulb) (mean ± SE)
258956	Control	102.8 ± 2.6x	136.3 ± 1.8xy	81.0 ± 2.0x	250.5 ± 12.9x
	Insecticide	106.5 ± 2.6x	139.5 ± 1.8x	76.3 ± 2.1x	214.3 ± 13.7y
	Insecticide+Actigard	104.5 ± 2.6x	133.8 ± 1.8y	81.1 ± 2.1x	249.7 ± 13.7x
	Genotype mean	*104.6 ± 2.6a*	*136.5 ± 1.8a*	*79.5 ± 2.1a*	*238.1 ± 13.4a*
264320	Control	100.3 ± 2.6x	138.3 ± 1.8x	81.7 ± 2.0x	241.3 ± 12.7x
	Insecticide	99.3 ± 2.6x	136.3 ± 1.8x	82.7 ± 2.0x	249.1 ± 12.5x
	Insecticide+Actigard	101.0 ± 2.6x	134.0 ± 1.8x	86.9 ± 2.1x	288.4 ± 13.0y
	Genotype mean	*100.2 ± 2.6b*	*136.2 ± 1.8ab*	*83.7 ± 2.0b*	*259.6 ± 12.7b*
546140	Control	92.0 ± 2.6x	106.0 ± 1.8x	43.8 ± 1.8x	37.2 ± 10.8x
	Insecticide	92.0 ± 2.6x	110.8 ± 1.8x	42.9 ± 1.9x	41.0 ± 11.6x
	Insecticide+Actigard	92.0 ± 2.6x	116.3 ± 1.8y	47.8 ± 2.1x	51.2 ± 13.0x
	Genotype mean	*92.0 ± 2.6c*	*111.0 ± 1.8c*	*44.8 ± 1.9c*	*43.1 ± 11.8c*
546188	Control	102.0 ± 2.6x	142.3 ± 1.8x	82.2 ± 2.0x	284.7 ± 12.9x
	Insecticide	99.3 ± 2.6x	138.3 ± 1.8x	83.3 ± 2.0x	295.9 ± 12.8x
	Insecticide+Actigard	101.5 ± 2.6x	137.8 ± 1.8x	81.4 ± 2.2x	287.5 ± 14.0x
	Genotype mean	*100.9 ± 2.6abd*	*139.4 ± 1.8d*	*82.3 ± 2.1bd*	*289.4 ± 13.2d*
Colorado 6	Control	118.8 ± 2.6x	148.0 ± 1.8x	83.1 ± 3.3x	293.3 ± 22.2x
	Insecticide	112.3 ± 2.6xy	148.0 ± 1.8x	86.5 ± 2.9x	323.3 ± 19.3x
	Insecticide+Actigard	107.8 ± 2.6y	148.0 ± 1.8x	84.6 ± 2.8x	296.0 ± 18.3x
	Genotype mean	*112.9 ± 2.6e*	*148.0 ± 1.8e*	*84.7 ± 3.0bde*	*304.2 ± 19.9de*
Salsa Red	Control	105.3 ± 2.6x	135.0 ± 1.8x	63.9 ± 2.2x	132.1 ± 14.0x

	Insecticide	103.5 ± 2.6x	134.5 ± 1.8x	68.8 ± 2.1x	152.9 ± 13.6x
	Insecticide+Actigard	105.3 ± 2.6x	131.8 ± 1.8x	69.1 ± 2.1x	160.3 ± 13.3x
	Genotype mean	*104.7 ± 2.6adf*	*133.8 ± 1.8abf*	*67.3 ± 2.1f*	*148.4 ± 13.7f*
Talon	Control	106.5 ± 2.6x	131.3 ± 1.8x	59.8 ± 1.9x	112.4 ± 12.1x
	Insecticide	107.0 ± 2.6x	133.0 ± 1.8x	55.0 ± 2.2x	95.5 ± 13.8x
	Insecticide+Actigard	105.3 ± 2.6x	130.5 ± 1.8x	60.5 ± 2.1x	121.2 ± 13.2x
	Genotype mean	*106.3 ± 2.6af*	*131.6 ± 1.8f*	*58.5 ± 2.1g*	*109.7 ± 13.0g*
	Grand mean	**103.1 ± 2.6**	**133.8 ± 1.8**	**71.5 ± 2.2**	**198.9 ± 14.0**
Main-Plot Effect* **					
	Control	103.9 ± 1.0r	133.9 ± 0.7r	70.8 ± 1.4r	193.1 ± 7.9r
	Insecticide	102.8 ± 1.0r	134.3 ± 0.7r	70.8 ± 1.4r	196.0 ± 7.8r
	Insecticide+Actigard	102.5 ± 1.0r	133.1 ± 0.7r	73.1 ± 1.4r	207.7 ± 7.8r

*Genotype means are separated by letters a - f. Genotypes with the same letters within a column are not significantly different from each other.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different from each other.

***Main-plot effects are separated by letters r and s. Treatments with the same letters within a column are not significantly different from each other.

Table III.7. Effects of pesticides on Pearson's correlation coefficients for *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) response in transplanted onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2011.

	Leaf_avg	**Thrips-day**	**rAUDPC_in[p]**	**rAUDPC_sv[q]**	**Bulbing**	**Maturity**	**Bulb size**	**Bulb weight**
Leaf_avg	1	0.50272	0.39271	0.70460	0.79262	0.67772	0.60434	0.33321
		0.02020	0.07820	0.00040	<.00010	0.00070	0.00370	0.13990
Thrips-day	0.50272	1	0.96166	0.51481	0.75660	0.63375	0.67626	0.45370
	0.02020		<.00010	0.01690	<.00010	0.00200	0.00080	0.03880
rAUDPC_in[p]	0.39271	0.96166	1	0.37091	0.61017	0.48021	0.51832	0.37931
	0.07820	<.00010		0.09790	0.00330	0.02760	0.01610	0.08990
rAUDPC_sv[q]	0.70460	0.51481	0.37091	1	0.81250	0.64436	0.62461	0.10555
	0.00040	0.01690	0.09790		<.00010	0.00160	0.00250	0.64890
Bulbing	0.79262	0.75660	0.61017	0.81250	1	0.86085	0.88466	0.57089
	<.0001	<.0001	0.00330	<.0001		<.0001	<.0001	0.00690
maturity	0.67772	0.63375	0.48021	0.64436	0.86085	1	0.94499	0.52873
	0.00070	0.00200	0.02760	0.00160	<.00010		<.00010	0.01370
Bulb size	0.60434	0.67626	0.51832	0.62461	0.88466	0.94499	1	0.58135
	0.00370	0.00080	0.01610	0.00250	<.00010	<.00010		0.00570
Bulb weight	0.33321	0.45370	0.37931	0.10555	0.57089	0.52873	0.58135	1
	0.13990	0.03880	0.08990	0.64890	0.00690	0.01370	0.00570	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[p]Relative area under the disease progress curve for IYSV incidence.

[q]Relative area under the disease progress curve for IYSV severity.

Table III.8. Effects of pesticides on predictors of onion thrips (*Thrips tabaci*) population, *Iris yellow spot virus* (IYSV) incidence and severity and yield of onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2011.

Response	Variable	Parameter Estimate	P-value
Thrips-day	Intercept	-5.08379	0.0005
	rAUDPC_in[p]	8.04363	<.0001
	Leaf_avg	-0.22900	0.3232
	Bulbing	55.76864	0.0006
rAUDPC-in[p]	Intercept	0.64673	<.0001
	Thrips-day	0.11437	<.0001
	Bulbing	-4.52729	0.0017
rAUDPC-sv[q]	Intercept	63.27165	<.0001
	rAUDPC_in[p]	-2.07569	0.249
	Bulbing	160.65528	<.0001
Bulb size	Intercept	0.03318	0.4988
	rAUDPC_sv[q]	-0.00083	0.2579
	Leaf_avg	-0.00524	0.0356
	Bulbing	0.66952	0.0034
	Maturity	0.05087	<.0001
Bulb weight	Intercept	191.80827	<.0001
	rAUDPC_sv[q]	-1.78406	0.0001
	Thrips-day	-0.34245	0.3155
	Bulbing	450.04409	<.0001

[p]Relative area under the disease progress curve for IYSV incidence.

[q]Relative area under the disease progress curve for IYSV severity.

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CHAPTER IV

TEMPORAL AND LOCALIZED DYNAMICS OF *IRIS YELLOW SPOT VIRUS* WITHIN TISSUES OF INFECTED ONION PLANTS

INTRODUCTION

Following its first identification on onion (*Allium cepa* L.) in Brazil in 1981, *Iris yellow spot virus* (IYSV) (family *Bunyaviridae*, genus *Tospovirus*) has emerged as a worldwide threat to the economic production of food and ornamental hosts (24). In the U.S., the virus was first confirmed on onion in the Pacific Northwest in 1989, and has since spread to several important onion producing states (16). Symptoms of IYSV appear as chlorotic or necrotic, straw-colored to white, dry, elongate or spindle-shaped lesions along the scape, with lesions frequently more numerous at mid- to lower portions of the scape. Some lesions have 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 completely girdling the scape (16). Straw-colored, lenticular-shaped lesions appear on leaves, with lesions having green centers or alternating rings of green and straw-colored tissues. No symptoms, however, have been found associated with bulbs (16, 23).

Edible allium crops and some cut flower and potted ornamental species including alstroemeria (*Alstroemeria sp.*), chrysanthemum (*Chrysanthemum sp.*), iris (*Iris hollandica*) and lisianthus (*Eustoma grandiflorum*) are the most economically important crops identified as hosts of IYSV (13). Infections result in loss in quantity and/or quality of produce depending on the host species. Infections at early stages of crop growth often result in severe stunting of entire plants and in a substantial decrease in plant stand leading to considerable yield losses; however, infections at later stages may still cause significant losses in yield and quality of produce (9, 23, 29). In all its host incidences, onion crops have been particularly affected. In bulb onion, significant losses occur in the form of reduced bulb size, significantly reducing the percentage of colossal and jumbo grade bulbs in susceptible cultivars. This is a result of affected plants not developing fully, and poorly storing assimilates. Overall yield losses of 1- 10% or more are frequently reported in Colorado, USA (15, 16, 27). On individual farms, yield losses ranged from undetectable to 100% (14). Quality losses may occur in green onions and other allium species which are harvested young for their fresh, green and succulent leaves. In such production systems, symptomatic plants will be rendered unsalable, leading to losses in marketable yield. In seed onion production systems, infected scapes often lodge leading to umbel rot and loss, which in turn leads to significant seed loss (8, 12, 16, 17, 25). In its ornamental hosts, losses in aesthetics (quality) and quantity are frequently common (13).

Several species of thrips transmit tospoviruses in a circulative propagative manner. IYSV is currently known to be transmitted exclusively by the polyphagous onion thrips (*Thrips tabaci* L.); however, limited transmission by tobacco thrips (*Frankliniella fusca*) has recently been confirmed in Georgia (31). First or second instar larvae acquire the virus by feeding on infected plants, and become viruliferous and infective for the rest of their lives. The virus is non-transmissible if acquired by adult thrips that did not originally acquire the virus at the larval stage (18, 21, 22, 33). The onion thrips vector damages plants by disrupting the leaf surface and removing mesophyll cell contents, thus reducing photosynthetic capacity of infested plants, with subsequent yield loss (2, 10).

Although the passage and replication of this virus in its onion thrips vector (18, 33) and the spatial and temporal distribution in an onion field (15, 28) have been described, little is known of the distribution of the virus within its plant hosts. This is due in part to the lack of an efficient mechanical inoculation procedure to infect onion with IYSV (3, 30). In leek (*Allium porrum*), IYSV was localized in patches of infection found mainly in the middle and top subsections of unfurled leaves, but infrequently in their bases. No detections were made in furled leaves, basal plates or roots (29). In onion, virus was detected in all segments of infected leaves even though the distribution was not uniform. Also, higher concentrations were found consistently in internal leaves and in leaf segments close to the bulb. Just as in leeks, no virus was detected in bulbs and roots of infected onion plants (19).

The objectives of the present study were to determine the distribution of IYSV within infected leaves of resistant and susceptible onion cultivars, and also its distribution within tissues of naturally infected onion plants from the field.

MATERIALS AND METHODS

Seasonal Dynamics of IYSV Titer in Infected Onion Plants

Seeds of the IYSV-field resistant Colorado 6 and IYSV-susceptible Talon onion cultivars were planted in nursery trays at the Colorado State University's greenhouse facility at Fort Collins, Colorado, using soil-less mix (Fafard's Professional Custom Mix Formula, Conrad Fafard, Inc. USA) as the growth medium. After emergence and three weeks of growth, seedlings were thinned to keep those at the same growth stage and of equal height and size. After three weeks of further growth, seedlings were transferred into 2 liter pots at 2 plants/pot (one plant was used for another study not reported here), and pots were kept in 75 cm x 75 cm x 115 cm bug dorms with 34 x 9 cm^2 mesh counts and a 680 µm mesh aperture (BugDorm Store, Megaview Inc, Taiwan). The same soil mix used for raising the seedlings was used. Irrigation was provided by an automated drip system (Orbit Irrigation Products, Inc., USA) that supplied 150 ml of water every other day.

The effects of three treatments; Healthy Control (HC), IYSV Only (V) and Thrips + IYSV (TV), were investigated. These treatments were allocated to three bug dorms, and 10 pots of each cultivar were randomly placed in each bug dorm. This arrangement ensured that plants of the two cultivars were subjected to the same environmental conditions and pest/pathogen pressure within a bug dorm. Pots of each cultivar were assigned numbers from 1 to 10. Viruliferous larvae and adult thrips were transferred to bug dorms of the IYSV Only and Thrips + IYSV treatments such that there were approximately 5 thrips/plant. However, with the IYSV Only treatment, thrips transfer was carried out five days earlier. This provided sufficient time for virus transmission. After successful virus transmission as confirmed by double antibody sandwich enzyme-linked immuno-sorbent assay (DAS ELISA) (15), the thrips were killed off the plants by application of a combination of Movento (active ingredient spirotetramat; Bayer CropScience, KS, USA), Regent (active ingredient fipronil; BASF Corp, NC, USA) and Radiant (active ingredient spinetoram; Dow AgroSciences LLC, IN, USA) insecticides at manufacturer's recommended application rates of 0.39, 0.39 and 0.63 ml/L respectively. IYSV Only treatment was assigned on 55 days after sowing (DAS), whereas Thrips + IYSV treatment was assigned on

60 DAS. The experiment was carried out in a randomized complete block design with two replications.

The oldest leaf of six plants per cultivar per treatment was randomly selected and used for serological detection of IYSV on a biweekly basis starting from 56 DAS to 126 DAS. Selection of the six plants was based on a randomization process in which numbers 1 to 10 were written on 10 paper slips and placed in a bag. Six paper slips were blindly drawn, one at a time, from the bag, and their numbers were correspondingly used to select six plants for sampling. Entire leaves were divided into top, middle and base sections (Fig. IV.2), and each section was further divided into 0.3 g subsamples for testing by DAS ELISA.

IYSV Distribution among Leaves of Naturally Infected Onion Plants from the Field

In 2010, 21 IYSV infected (and symptomatic) transplanted onion plants at 6-9 leaf stage (pre-bulb) (Fig. IV.1A) and 20 plants at 13 and over leaf stage (post-bulb) (Fig. IV.1B) of susceptible cultivar Charismatic were sampled from an onion field in northern Colorado, near Fort Collins. Leaves of pre-bulb plants were gently peeled back all the way to the basal plate such that the leaf included the furled portion (neck) (Fig. IV.2). Plants were separated into bulb scales (dead outermost leaves surrounding the bulb region), leaves (consisting of the blade (unfurled) and neck portions), basal plates and roots (Fig. IV.2). With the post-bulb plants, only leaf blades were tested; no neck, bulb scales, basal plate, bulb or roots were included; as in a preliminary experiment, these tissues were consistently negative for the virus. Two 1.0 g leaf blade and one 1.0 g neck (pre-bulb plants only) tissue segments were sampled from each leaf for IYSV detection. With symptomatic leaves, samples were taken from healthy tissues surrounding the necrotic regions, whereas leaf base tissues close to the bulb were sampled (19) in non-symptomatic leaves. Basal plate and root tissues were divided into 0.5 g samples.

IYSV Distribution within Tissues of Naturally Infected Onion Plants from the Field

Sixty symptomatic pre-bulb transplanted onion plants of susceptible cultivar Granero were sampled from an onion field at the same location as 2010 during the 2011 growing season. Plants were separated into the same sections as in 2010, however, leaf blades were divided into top, middle and base sections and neck segments were divided into neck_1 and neck_2 (Fig. IV.2). Roots were divided into root_1 and root_2 (Fig. IV.2). One 1.0 g sample was taken from each leaf segment, whereas basal plates and roots were divided into 0.5 g samples for serological testing for IYSV.

Serological Detection and Quantification of IYSV Titer Using DAS ELISA

Plant samples were frozen in liquid nitrogen and ground to a fine powder with a mortar and pestle (15), after which serology was carried out on the ground samples using the Agdia DAS ELISA kit and following manufacturer's protocol (Agdia Inc, USA). The ELx 800 Universal Micro-plate Reader (Bio-Tek Instruments Inc. VT, USA) was used to read absorbance values at 405 nm. Tissues were considered **positive** for IYSV if their absorbance values were equal to or higher than **two times** the values of healthy negative controls, and **highly positive** if their absorbance values were equal to or higher than **three times** the values of healthy negative controls.

Statistical Analysis

The general linear model procedure (PROC GLM) in SAS (SAS v.9.2, SAS Institute Inc., NC, USA) was used for statistical analysis of the seasonal dynamics data. Significant differences between cultivar and treatment means were determined using the adjusted Tukey's studentized range test at a 0.05 probability level.

RESULTS

Seasonal Dynamics of IYSV Titer in Infected Onion Plants

Leaves of cultivars Colorado 6 and Talon subjected to 3 treatments were divided in top, middle and base sections, and each section was tested on a biweekly basis for IYSV using DAS ELISA. There was significant difference ($P < 0.0001$) between Colorado 6 and Talon in virus titer across treatments, however, the difference was only at 98 DAS at which time the virus titer was significantly ($P < 0.0001$) higher in Talon than in Colorado 6. There was no significant difference ($P > 0.05$) between the two cultivars on any other sampling day (Fig. IV.3). Seasonal mean virus titer, however, was significantly ($P = 0.0031$) higher in Talon than in Colorado 6.

The treatments were significantly different ($P < 0.0001$) from each other, with virus titer in the increasing order of HC, V and TV in both cultivars. In both cultivars, virus titer of TV was significantly higher ($P < 0.0001$) than in V and HC from 70 DAS onwards except at 98 DAS in Colorado 6 when treatments were not significantly different ($P > 0.05$). V was not significantly different from HC ($P > 0.05$) in either cultivar until after 98 DAS onwards in Colorado 6 (P =

0.0001) and 84 DAS onwards in Talon (P = 0.0001), when titer was significantly higher in V than in HC (Fig. IV.3).

There were significant cultivar x treatment interactions in which titer was significantly (P = 0.0022) higher in Talon than in Colorado 6 for treatment TV. However, the interactions were not significantly different between cultivars for both HC and V, with P = 0.9995 and P = 0.9181, respectively, for the interactions.

The 3 leaf sections were not significantly different (P = 0.3449) from each other over time except at 98 DAS when titer was significantly higher in base section than in top section (P = 0.0486), but not significantly higher than in middle section (P = 0.1470). Middle and top sections were not significantly different (P = 1.000) at 98 DAS. However, seasonal mean virus titers were significantly different (P = 0.0004), with top and middle sections not significantly different from each other (P = 0.6811); but both significantly different from base sections. Base sections had the highest seasonal mean virus titer, followed by top, then middle sections (Fig. IV.4). There was no significant treatment x section (P = 0.0716) or cultivar x section (P = 0.9380) interaction.

In general, virus titer increased in all treatments, leaf sections and cultivars over time except at 98 DAS in Colorado 6 when titer substantially declined (Figures IV.3 and IV.4).

IYSV Distribution among Leaves of Naturally Infected Onion Plants from the Field

In 2010, virus titer in pre-bulb plants steadily increased from a highly positive 0.71 in Leaf 1 (oldest leaf) to a highly positive 1.18 in Leaf 4, after which values declined steadily to a highly positive 0.72 in Leaf 8. Leaf 9 (youngest leaf), together with bulb scale, neck, basal plate and root tissues tested negative for the virus (Table IV.1). IYSV was not detected in neck tissues except in the neck of Leaf 1 (oldest leaf) where highly positive levels were detected. All leaves of post-bulb plants were highly positive for the virus, however, unlike the pre-bulb stage, virus titer distribution was considerably non-uniform, with no apparent trend (Table IV.1).

In 2011, all leaves tested positive for IYSV, however, Leaves 3, 4 and 9 were highly positive. All non-green tissues were negative for the virus (Table IV.2). The frequency of IYSV detection increased from 55% in the oldest leaf (Leaf 1) to 90% in Leaf 5 after which it declined to 40% in Leaf 9 (youngest leaf). The frequency of detection of highly positive leaves increased with leaf age up to Leaf 4, and then remained fairly constant at approximately 43% for Leaves 5, 6 and 8. Leaf 7 had the lowest highly positive detection of 29%. Leaf 9 was highly positive in the two plants where virus was detected (Table IV.2).

Leaves were categorized by age into older, intermediate and younger groups. In both years, pre-bulb plants exhibited a similar trend in which virus titer was highest in intermediate leaves, followed by older and then younger leaves; with average OD values of 0.98, 0.83 and 0.56, respectively, in 2010 (Table IV.1); and 0.718, 0.675 and 0.672, respectively, in 2011 (Table IV.2). In post-bulb plants, virus titer was in the increasing order of intermediate, younger and older leaves; with average OD values of 2.44, 2.11 and 2.09, respectively (Table IV.1).

IYSV was detected in the top, middle, base and neck_1 sections of leaves. Virus was not detected in neck_2 and root segments. Virus titer increased from a highly positive 0.73 in top sections to a highly positive 0.93 in middle sections, declined to a highly positive 0.77 in base sections and finally to a positive 0.70 in neck_1 (Fig. IV.5).

The frequency of virus detection (Table IV.3) decreased from 33% in top sections to 24% in each of the middle and base sections, and to 19% in neck_1. Highly positive sections were more frequently detected in the top and middle sections of Leaves 3 – 8 whereas for base sections, highly positive detections were more frequent in Leaves 2 – 5, and Leaves 1 – 4 for neck sections. Leaves 6 – 8 had more highly positive than positive tissues in their top and middle sections; Leaf 5 in top, middle and base sections; Leaves 3 and 4 in top, middle, base and neck_1 sections; Leaf 2 in base and neck_1 sections; and Leaf 1 in neck_1 section (Table IV.3). Highly positive samples were obtained from the base and neck_1 of Leaves 1 and 2; top, middle and base of Leaf 5; top and middle of Leaves 6, 7 and 8; and from any section of Leaves 3 and 4.

Isolated/patchy detections in only one section per leaf (single) occurred 62% in top, 4% in middle, 22% in base and 12% in neck_1 sections (Table IV.4). Detection in two adjacent sections (double) was highest in top-middle, followed by base-neck_1 and then middle-base sections with frequencies of 42, 33 and 25%, respectively. Top-middle-base sections had 74% triple detections and middle-base-neck_1 sections had 26%. Detections with at least one negative section between two positive sections (spaced detections (SD)) occurred 17 times and IYSV was detected in all leaf sections (entire leaf (EL)) in 105 leaves (Table IV.4). More than 60% of all single detections were found in leaf tops, 41% in top-middle double and 74% in top-middle-base triple (Table IV.4). It should be noted, however, that although virus was more frequently found in leaf tops (33%) than in middle and base sections (24% each) (Table IV.3), virus titer was higher in middle and base sections than in top sections (Fig. IV.5).

DISCUSSION

Host plant resistance is an important component in the integrated management of plant pathogens. The field resistance (tolerance) of Colorado 6 was manifested in this greenhouse study where IYSV level in V (IYSV Only) did not reach highly positive levels at any time during the plant cycle, whereas highly positive levels were exceeded in the susceptible Talon after 98 DAS. Virus level in both TV (Thrips+IYSV) and V declined steeply in Colorado 6 between 84 and 98 DAS, whereas levels kept increasing in Talon (Fig. IV.3). This decline is due to a natural phenomenon with virus infections in which virus replication rapidly increases and then subsides in host plants. However, tolerant hosts are better able to capitalize on this phenomenon to significantly reduce virus replication than do susceptible hosts (20). IYSV level reached its highest in both cultivars at 126 DAS (the last sampling day of the cycle) indicating that virus replication continues as long as there is a susceptible host and physiologically active tissues are available. This was also observed in the field plants in which virus titer was higher in post-bulb plants than in pre-bulb plants for all leaves (Table IV.1). The overwhelmingly significant difference in virus titer between TV and V in both cultivars throughout the cycle is a further emphasis on the indispensability of vector control in the integrated management of vector-borne diseases, especially in this pathosystem in which the virus is transmitted and disseminated solely by the vector.

Unlike most tospoviruses, IYSV is known to cause localized infection in which the virus moves less systemically (4, 24). If systemic movement is expected, virus titer in one leaf section would progressively decline while another leaf section increased over the same time period (32). In this study, no such trend was observed, instead, virus titer within each leaf section increased independent of other sections over time (Fig. IV.4), indicating localized infection. Plant viruses are biotrophic pathogens and it would be expected that as onion leaves age and senesce from leaf tips down towards leaf bases, virus titer should accordingly move ahead of the senescing front. This should result in titer decline in leaf tops and increases in other leaf sections, especially, during the latter part of the season. This was indicated in Colorado 6 in which IYSV titer in leaf top sections declined after 112 DAS in TV (Fig. IV.4). Talon, on the other hand, still sustained active virus replication in leaf tops late in the season, a testament to its susceptibility to the virus.

Cell-to-cell movement through plasmodesmata rather than through the phloem stream can explain some of the virus movement in infected plants. However, this movement is highly limited as only 8-10 cells (1 mm) can be travelled in a day (1). Thus, the intimate association of the virus with its thrips vectors is the primary means of virus introduction and dispersal in infected plants. The indication that virus levels are highest at leaf bases re-enforces the strong reliance of IYSV on its vector for both within and between plant spread. This is because on infested onion hosts, thrips are found mostly inhabiting the narrow spaces between the inner leaves and leaf bases near the neck. Thus, virus build up in these sites is a result of replication in the vector and multiple inoculations via vector feeding as well as *in planta* replication. This result is consistent with the results by Kritzman et al. (19) who found the highest virus titers in leaf segments close to onion bulbs. Under field conditions, thrips reside in deep tight folds at leaf bases as an escape from predators. This habit has been attributed as a basic association for inner leaves and leaf bases having highest IYSV titers (7, 19). In this greenhouse study in which onion thrips were kept in bug dorms predominantly free of predators, they should have moved freely along all leaves and all leaf sections to result in a fairly uniform distribution of IYSV. Instead, the field scenario and virus localization were still observed.

Unlike Figure IV.4 which depicts the seasonal phenomenon of IYSV titer and distribution, Figure IV.5 is a demonstration of within tissue dynamics at a moment in time during the season. It represents virus distribution on a single sampling date that may occur on Figure 4 under field conditions. In all leaves tested, neck_1 contained some amount of green (chlorophyll) pigmentation (Fig. IV.2). As mesophyll cells contain plants' chlorophyll (6) and onion thrips feed on mesophyll cell contents (2, 10, 32), the IYSV positive status of neck_1 could be due to direct virion deposition resulting from the limited vector feeding that occurs in this section. The fact that all non-green tissues tested negative suggest that onion thrips feed only on chlorophyll-containing cells. The rare occurrence or complete absence of IYSV in onion bulbs, basal plates and roots could be explained by the lack of vector feeding in these tissues. This also explains the IYSV-positive status of the neck region of Leaf 1 in 2010 (Table IV.1). Early-season leaves of pre-bulb plants are usually shorter and they usually have smaller neck sections than later-season leaves. This usually resulted in the entire neck section being used for virus detection. In bigger leaves, neck samples were taken more towards the basal plate (chlorophyll-free sections) and this explains why IYSV was not detected in the necks of Leaves 2 – 9. This observation necessitated the dividing of neck regions into two sections in the 2011 study.

The absence of virus in dead leaves and bulb scales could be due to the biotrophic pathogenicity of viruses as they require live host cells to provide the physiological machinery for their replication. If infection occurred early in the season, it is conceivable that these dead leaves and scales were once inhabited by the virus. An efficient translocation system will therefore be required to move the virus from old dying leaves to younger live ones to prevent virus perishing with dying tissues. This phenomenon may also explain why older leaf group of post-bulb plants had the lowest virus titer. In pre-bulb plants, younger leaf group would have the lowest virus titer because, as mentioned earlier, virus concentration declines in leaves that develop after Leaf 4. The continuous migration of virus from older leaves coupled with the limited virus translocation to younger leaves explains why intermediate leaves had the highest virus titer.

All leaves of post-bulb plants testing highly positive may be explained by the fact that the plants had been in the field long enough for virus build up and viruliferous vector inoculations on all leaves. All the leaves exhibited signs of thrips feeding and hence, potential for virus inoculation. With this, it can be said that it is only a matter of time before the pre-bulb plants end up with the same fate as the post-bulb plants. In pre-bulb plants, there seems to be a trend of IYSV distribution among leaves of infected plants. Among all fully expanded leaves, virus concentration increases from the first leaf up to Leaf 4 and then declines in subsequent leaves so that newly emerged leaves are virus-free for some period of time. This trend was observed in both years of the study. In 2011, however, the youngest leaf (Leaf 9) tested highly positive (Table IV.2). It should be noted; however, that only five plants had a ninth leaf and that only two of those contained the virus. Thus the very small sample size should be taken into consideration when making assertions about the virus status of the youngest leaves on infected pre-bulb plants.

The above mentioned trend contradicts a previous study in which higher IYSV concentrations were consistently found in internal (younger) leaves (19). Only eight plants and only five leaves per plant were used in that study. No mention was made of plants' age or the number of leaves per plant from which the five leaves were selected. On more advanced post-bulb plants, youngest leaves, as mentioned earlier, would be expected to contain high virus titer because they would be one of the most preferred feeding sites for the vector as most of the other older leaves would be getting too fibrous or senescing (5). In this study, if Leaves 3 – 7 of post-bulb plants (Table IV.1) are used to represent Kritzman et al.'s (19) chosen leaves, then Leaves 6 and 7 (internal leaves) would contain the highest IYSV concentration. If, on the other hand, Leaves 6 – 10 are selected, then Leaves 6, 7 and 8 (external leaves) would contain the highest virus titer.

On symptomatic leaves, samples taken from regions surrounding the symptom will likely provide a reliable indication of the IYSV status of plants. In symptomless plants, however, Tables IV.3 and IV.4 provide information on which leaves and what sections of those leaves are more likely to enhance IYSV detection. This information is very useful in situations where very large samples of symptomless plants (e.g., (11)) need to be tested and using all the samples will be very expensive and time consuming. In both years in pre-bulb plants, Leaves 3 and 4 had the highest IYSV titer (Tables IV.1 and IV.2) and also the highest possibility of obtaining highly positive samples (Table IV.3). For field sampling for IYSV detection, Leaves 3 – 5 of pre-bulb plants are very likely to provide a good indication of virus status as 77 – 90% of the plants sampled will be positive for the virus if the plants are infected. It is interesting to note that in pre-bulb plants in both years (and even in post-bulb plants to some extent) virus titer in Leaf 1 was the lowest among the leaves even though, from personal observations, they are usually first to express field symptoms. As mentioned above, this could be due to virus migration/translocation from old senescing leaves to younger ones, eventually resulting in their complete absence in dead leaves and bulb scales. This should be taken into consideration in studies where onion germplasms are evaluated for resistance to IYSV as virus incidence (plants expressing symptoms) alone may not be a good indicator of germplasm response to IYSV. In such studies, severity of infection (26), coupled with other yield and agronomic parameters, should be considered.

Information on virus distribution within infected plants is a vital resource in IYSV studies, especially in detecting infected but symptomless plants (hosts). This information is also a very important tool in the quarantine control of IYSV as symptomless plant materials are frequently moved across state and international borders. Even though there is lack of a distinct trend in virus distribution among leaves of infected plants, the detailed information provided by this study will aid in the faster, more efficient and more reliable screening of plant materials to ascertain their IYSV status in germplasm evaluations, epidemiological studies and quarantine controls.

Table IV.1. Distribution of *Iris yellow spot virus* (IYSV) among tissues of naturally infected onion plants from the field in northern Colorado in 2010 as determined by DAS ELISA.

	Pre-bulb Stage		**Post-bulb Stage**	
Leaf Age[a]	**Blade[b]**	**Neck[b]**	**Leaf Age[a]**	**Blade[b]**
1[x]	0.71**	0.46**	1[x]	1.96**
2[x]	0.76**	0.27	2[x]	2.05**
3[x]	1.01**	0.29	3[x]	1.77**
4[y]	1.18**	0.17	4[x]	2.39**
5[y]	0.95**	0.22	5[x]	2.26**
6[y]	0.81**	0.17	6[y]	2.53**
7[z]	0.76**	0.16	7[y]	2.97**
8[z]	0.72**	0.30	8[y]	2.78**
9[z]	0.21	0.17	9[y]	1.47**
Bulb Scales	0.26	-	10[z]	1.89**
Basal Plate	0.24	-	11[z]	2.51**
Roots	0.16	-	12[z]	2.34**
			13[z]	1.69**

[a] Leaf age from oldest (Leaf 1) to youngest (Leaf 9 in Pre-bulb and Leaf 13 in Post-bulb). Leaves were characterized into three distinct groups in which:

[x]indicates older leaf group, with average OD value of 0.83 in pre-bulb and 2.09 in post-bulb plants.

[y]indicates intermediate leaf group, with average OD value of 0.98 in pre-bulb and 2.44 in post-bulb plants.

[z]indicates younger leaf group, with average OD value of 0.56 in pre-bulb and 2.11 in post-bulb plants.

[b] Values are mean optical densities (OD) of plant samples at 405 nm absorbance.

** indicates highly positive samples.

Table IV.2. Distribution of *Iris yellow spot virus* (IYSV) among tissues of naturally infected pre-bulb onion plants from the field in northern Colorado in 2011 as determined by DAS ELISA.

		Frequency of Detection (%)			Total
Leaf Age[a]	Optical Density (A_{405} nm)[b]	Positive[c]	Highly Positive[c]	Total Detection[d]	Plants Tested
1^x	0.485*	73 (24)	27 (9)	55 (33)	60
2^x	0.624*	47 (16)	53 (18)	57 (34)	60
3^x	0.916**	37 (19)	63 (32)	85 (51)	60
4^y	0.819**	35 (16)	65 (30)	77 (46)	60
5^y	0.700*	59 (32)	41 (22)	90 (54)	60
6^y	0.635*	54 (22)	46 (19)	68 (41)	60
7^z	0.599*	71 (24)	29 (10)	67 (34)	51
8^z	0.658*	57 (8)	43 (6)	54 (14)	26
9^z	0.759**	0 (0)	100 (2)	40 (2)	5
Basal Plate	0.327	0 (0)	0 (0)	0 (0)	60
Roots	0.275	0 (0)	0 (0)	0 (0)	60
Dead Leaf	0.281	0 (0)	0 (0)	0 (0)	42
Bulb Scales	0.275	0 (0)	0 (0)	0 (0)	49

[a]Leaf age from oldest (Leaf 1) to youngest (Leaf 9). Leaves were characterized into three distinct groups in which:

^{x}indicates older leaf group, with average OD value of 0.67.

^{y}indicates intermediate leaf group, with average OD value of 0.718.

^{z}indicates younger leaf group, with average OD value of 0.672.

[b] Values are mean optical densities (OD) of plant samples at 405 nm absorbance.

[c]Percent of positive and highly positive tissues out of the total number of plants in which IYSV was detected. Values in parenthesis are the number of positive or highly positive plants in which IYSV was detected.

[d] Percent of plants in which IYSV was detected out of the total number of plants tested. Values in parenthesis are the number of plants in which IYSV was detected out of the total number of plants tested.

** indicates highly positive for IYSV.

* indicates positive for IYSV.

Table IV.3. Frequency of *Iris yellow spot virus* detection within leaves of naturally infected pre-bulb onion plants from the field in northern Colorado in 2011 as determined by DAS ELISA.

Leaf Age[a]	**Top**		**Middle**		**Base**		**Neck_1**	
	Positive (%)	*Highly Positive (%)*	*Positive (%)*	*Highly Positive (%)*	*Positive (%)*	*Highly Positive (%)*	*Positive (%)*	*Highly Positive (%)*
1[x]	15	2	17	2	17	15	13	[17]
2[x]	19	7	16	9	9	[15]	9	[15]
3[x]	8	[12]	12	[13]	8	[20]	6	[20]
4[y]	5	[19]	10	[18]	6	[22]	5	[13]
5[y]	10	[17]	9	[20]	12	[19]	7	6
6[y]	16	[24]	10	[22]	13	5	10	2
7[z]	17	[33]	7	[14]	7	10	7	5
8[z]	20	[27]	0	[13]	7	13	13	7
9[z]	20	20	20	0	20	0	20	0
Average	15	18	11	13	11	13	10	9
Total	33		24		24		19	

[a]Leaf age from oldest (Leaf 1) to youngest (Leaf 9). Leaves were characterized into three distinct groups in which:

[x]indicates older leaf group.

[y]indicates intermediate leaf group.

[z]indicates younger leaf group.

Samples are positive for IYSV if their absorbance value at 405 nm is equal to or higher than 2X that of a negative control or highly positive if the absorbance value is equal to or higher than 3X that of the negative control.

Numbers in brackets indicate leaf sections with more highly positive than positive detections.

Table IV.4. *Iris yellow spot virus* detection in isolated sections in leaves of naturally infected pre-bulb onion plants from the field in 2011 as determined by DAS ELISA.

	SINGLE				DOUBLE			TRIPLE			
Leaf Age[a]	*T*	*M*	*B*	*N*	*TM*	*MB*	*BN*	*TMB*	*MBN*	SD	EL
1[x]	0	0	1	3	0	0	9	8	0	0	9
2[x]	5	0	2	7	3	5	2	5	2	2	22
3[x]	1	0	2	2	3	4	12	1	5	4	23
4[y]	0	0	5	0	4	2	3	15	7	5	12
5[y]	4	2	9	0	8	3	0	11	4	3	11
6[y]	19	2	0	0	11	4	0	9	0	2	11
7[z]	25	0	0	0	4	2	0	3	0	1	10
8[z]	8	0	3	0	0	0	0	0	0	0	5
9[z]	0	0	0	0	0	0	0	0	0	0	2
Total	62	4	22	12	33	20	26	52	18	17	105
Frequency (%)	62	4	22	12	42	25	33	74	26	-	-

[a]Leaf age from oldest (Leaf 1) to youngest (Leaf 9). Leaves were characterized into three distinct groups in which:

[x]indicates older leaf group.

[y]indicates intermediate leaf group.

[z]indicates younger leaf group.

T = top leaf section. M = middle leaf section. B = base leaf section. N = neck_1 leaf section.

Single = number of times IYSV was detected only once in a leaf.

Double = number of IYSV detections in two adjacent leaf sections.

Triple = number of IYSV detections in three adjacent leaf sections.

SD = Spaced-Detection (number of IYSV detections with at least one negative section between positive sections).

EL = Entire Leaf (IYSV detection in all leaf sections).

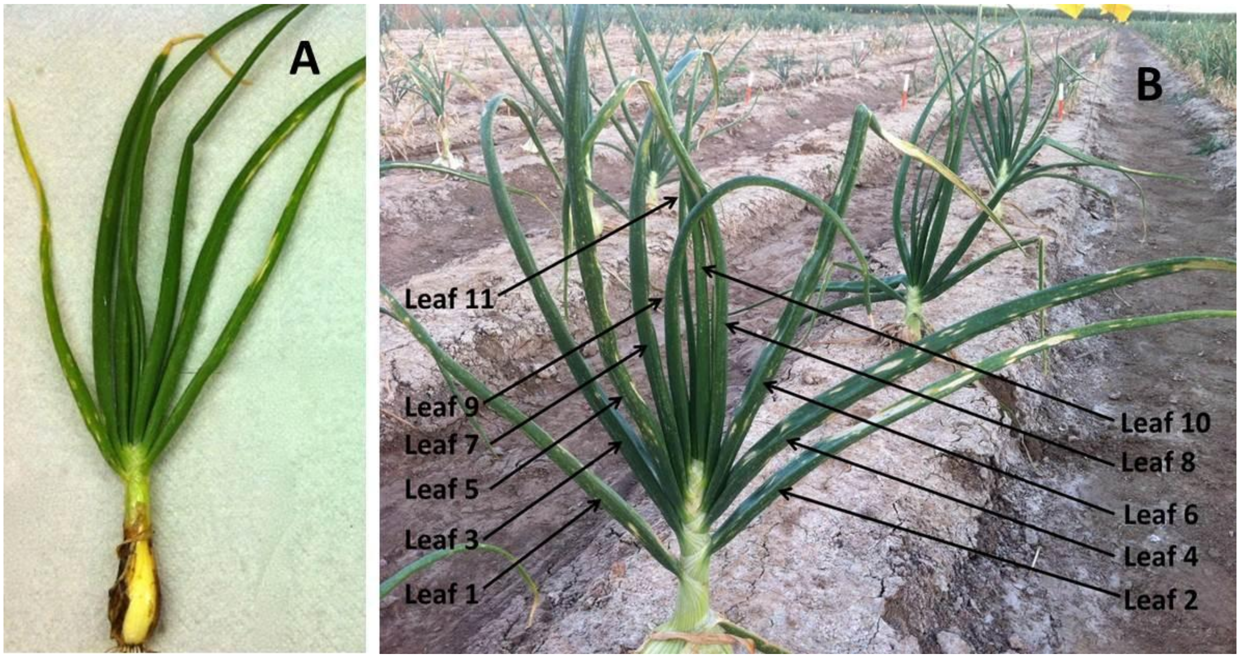

Figure IV.1. Onion plants showing symptoms of *Iris yellow spot virus* (IYSV) infection. **A**: Pre-bulb onion plant(s) showing symptoms of IYSV infection. **B**: Infected post-bulb plant in the field in northern Colorado, near Fort Collins. Leaf age is indicated by leaf numbers in which Leaf 1 indicates the oldest leaf and Leaf 11 the youngest leaf.

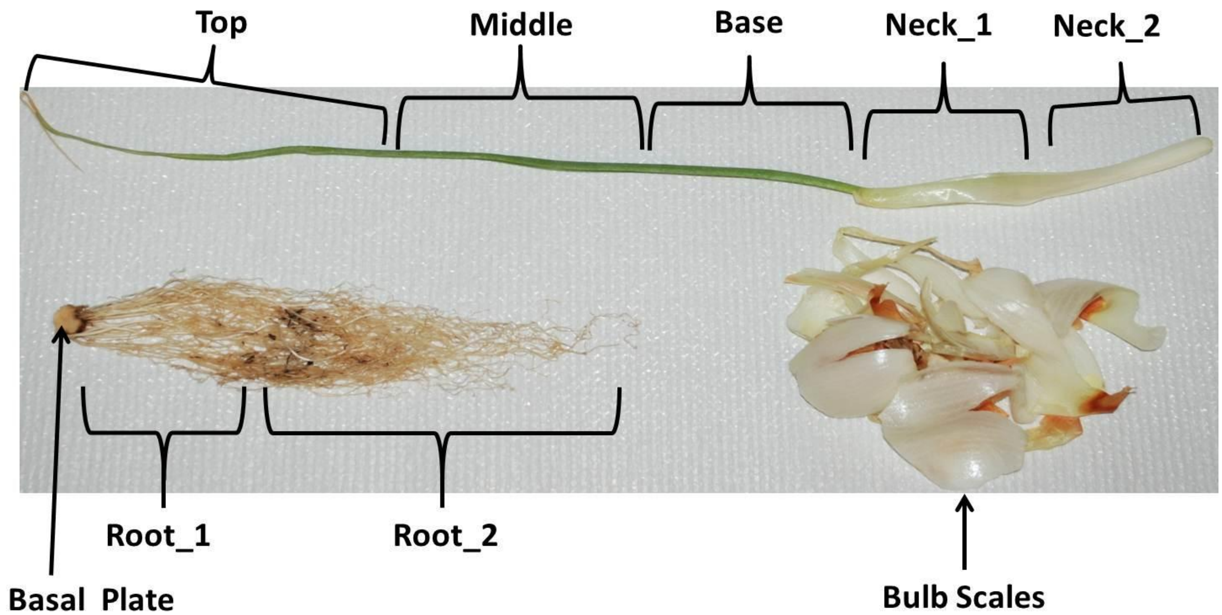

Figure IV.2. Pictorial representation of an onion leaf, bulb scales, basal plate and roots. Leaf is divided into leaf blade (top, middle and base) and neck (neck_1 and neck_2) sections; and roots into root_1 and root_2 sections.

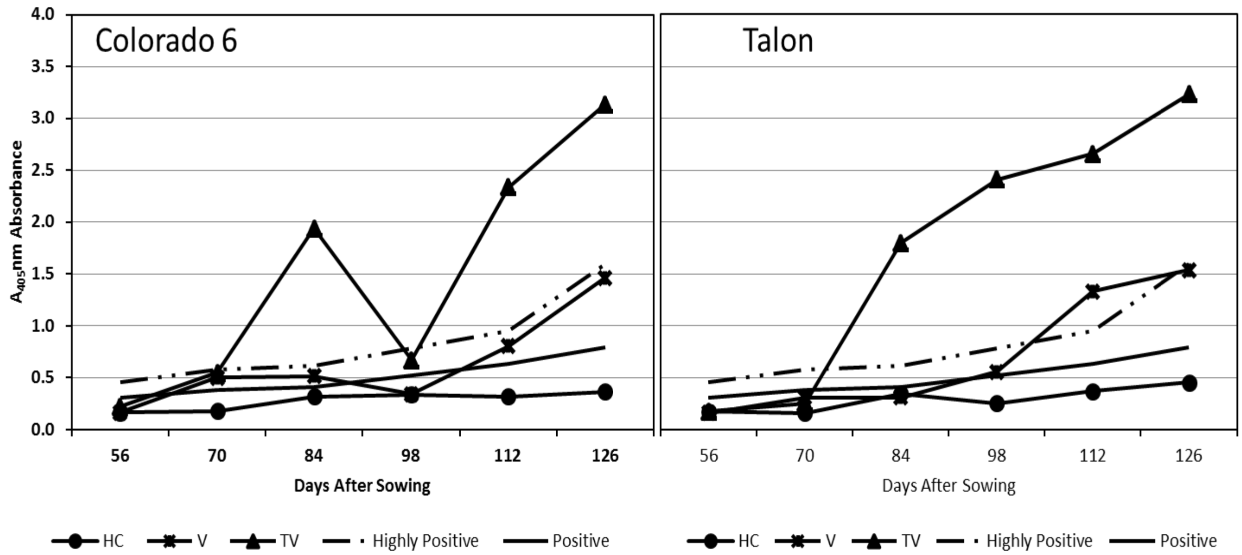

Figure IV.3. Graphical representation of the level of *Iris yellow spot virus* (IYSV) in leaf tissues of Colorado 6 and Talon onion cultivars subjected to 3 treatments; Healthy Control (HC), IYSV Only (V) and Thrips+IYSV (TV) as determined by DAS ELISA. Samples are positive for IYSV if their absorbance value at 405 nm is equal to or higher than 2X that of a negative control (solid line) or highly positive if the absorbance value is equal to or higher than 3X that of the negative control (dash-dot-dot line).

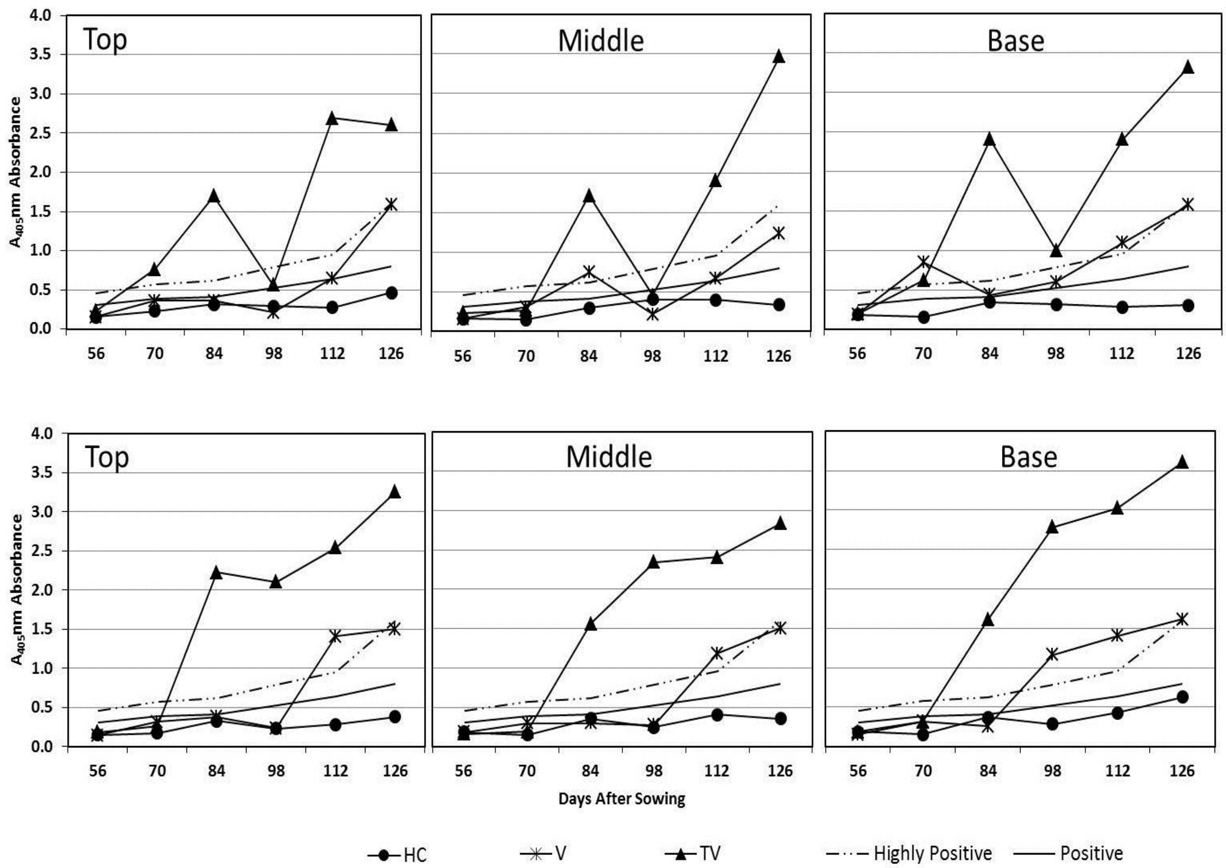

Figure IV.4. Graphical representation of the level of *Iris yellow spot virus* (IYSV) in leaf tissues of Colorado 6 (upper panel) and Talon (lower panel) onion cultivars subjected to 3 treatments; Healthy Control (HC), IYSV Only (V) and Thrips+IYSV (TV) as determined by DAS ELISA. Leaf tissues were divided into top, middle and base sections. Samples are positive for IYSV if their absorbance value at 405 nm is equal to or higher than 2X that of a negative control (solid line) or highly positive if the absorbance value is equal to or higher than 3X that of the negative control (dash-dot-dot line).

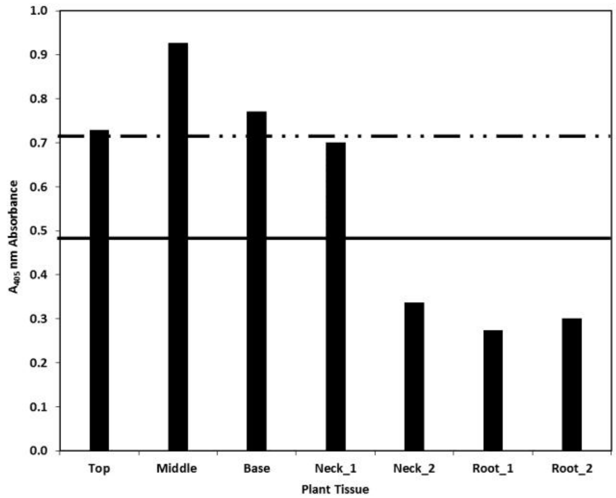

Figure IV.5. Graphical representation of *Iris yellow spot virus* titer in leaf and root tissues of naturally infected pre-bulb plants from the field in 2011 as determined by DAS ELISA. Samples are positive for IYSV if their absorbance value at 405 nm is equal to or higher than 2X that of a negative control (solid line) or highly positive if the absorbance value is equal to or higher than 3X that of the negative control (dash-dot-dot line).

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CHAPTER V

EFFECTS OF *IRIS YELLOW SPOT VIRUS* AND ONION THRIPS (*THRIPS TABACI*) ON GROWTH, PHYSIOLOGY AND PRODUCTIVITY OF ONION (*ALLIUM CEPA*)

INTRODUCTION

Photosynthesis is a basic function of green plants that enables them to transform light energy into chemical energy, ultimately providing nearly all the energy utilized in all living cells, plant or animal (Campbell and Reece, 2008). Thus, any factor that adversely affects photosynthesis will also indirectly affect all other biochemical processes as these processes expend the energy provided by photosynthesis (Raven et al., 2005). In their production of leaf spots, blights, viral mosaics, defoliation, chlorosis and stunting, plant pathogens reduce photosynthesis through the reduction in the availability of photosynthetic surface. These symptoms significantly affect chloroplasts, hence the chlorophyll contents of leaves, and result in their degeneration. Other pathogens affect photosynthesis through the activity of their toxins and enzymes. Vascular pathogens affect photosynthesis through their effects on stomata which eventually results in the deprivation of the photosynthetic machinery of water and CO_2 (Agrios, 2005).

The polyphagous onion thrips (*Thrips tabaci* L.) damages plants by disrupting the leaf surface and removing mesophyll cell contents, thus reducing the photosynthetic capacity of infested plants, leading to yield loss (Dai et al., 2009). Besides this physical damage, they transmit the devastating and widespread tospovirus, *Iris yellow spot virus* (IYSV; family *Bunyaviridae*) in onion (Gent et al., 2006). Reductions in bulb size and yield due to IYSV infection vary in relation to host resistance, infection timing and other factors, and have been found to range from undetectable to 100% (Gent and Schwartz, 2008; Schwartz et al., 2002). The physiological processes affected by the virus that result in such yield losses are currently unknown. It has always been stipulated that it is difficult to obtain firm data on the actual losses due to viruses themselves (Waterworth and Hadidi, 1998). However, plant gas exchange processes provide a critical foundation for explaining the relationship between plants and their stressors (Peterson, 2001). The objectives of this study were to provide information on the potential yield losses due to IYSV and its vector, and to separate the effects of the two pathogens by investigating their effects on the growth, physiology and productivity of three onion cultivars.

MATERIALS AND METHODS

The Colorado State University greenhouse facility was used for these experiments from 2009 to 2012. Two types of experiments were carried out to investigate effects of IYSV and onion thrips on gas exchange and plant productivity. Gas exchange experiments involved the use of 2 plants/pot; one plant was designated 'GR' and was assigned for weekly destructive growth rate measurements, and the other, designated 'FY', was used for gas exchange measurements and was also reserved for final bulb yield analysis. Gas exchange experiments were carried out in 2009, 2011 and 2012. Plant productivity experiments involved the use of 1 plant/pot and were carried out in 2010 and 2011.

Plant Material and Experimental Design

In the 2009 gas exchange experiment, seeds of IYSV-field resistant Colorado 6 and IYSV-susceptible Talon onion cultivars were planted in nursery trays (Fig. V.1A) in the greenhouse on 3 April using soil-less mix growth medium (Fafard's Professional Custom Mix Formula, Conrad Fafard, Inc. USA). After emergence and three weeks of growth, seedlings were thinned to keep those at the same growth stage and of equal height and size.

After three weeks (42 days after sowing (DAS)) of further growth, seedlings were transferred to 2 liter pots at 2 plants/pot (Fig. V.1B) and pots were kept in 75 cm x 75 cm x 115 cm bug dorms with 34 x 9 cm^2 mesh counts and a 680 μm mesh aperture (BugDorm Store, Megaview Inc., Taiwan) (Fig. V.2). The same soil mix used for raising the seedlings was used. Ten pots of each cultivar were randomly placed in each bug dorm.

In 2010, a plant productivity experiment was carried out in which seeds of Colorado 6 and Talon were treated with Maxim MZ (SD) (active ingredient fludioxonil) (Syngenta Crop Protection Inc., NC, USA) and sown in nursery trays on 24 August, transferred to 4 liter pots on 27 September (34 DAS) at a rate of 3 plants/pot and then thinned to 1 plant/pot on 28 October (65 DAS).

In 2011, one gas exchange experiment and one plant productivity experiment were run concurrently. In the gas exchange experiment, seeds of Colorado 6 and Talon were treated with Maxim MZ (SD) and direct-seeded in 4 liter pots filled with steam sterilized soil-less mix at a rate of 5 seeds/pot (Fig. V.3A) on 17 February. After germination and emergence, seedlings were thinned to 2 plants/pot on 3 April (45 DAS). For the plant productivity experiment, seeds of Salsa Red, an IYSV-susceptible onion cultivar, in addition to Colorado 6 and Talon, were treated with Maxim MZ (SD) and direct-seeded in 4 liter pots at a rate of 5 seeds/pot using steam sterilized soil-less mix on 3 March. Seedlings were thinned to 1 plant/pot on 1 May (59 DAS).

An additional gas exchange experiment was carried out towards the end of 2011 and continued into 2012 (hereafter referred to as the 2012 gas exchange experiment). Seeds of Salsa Red, Colorado 6 and Talon were treated with Maxim MZ (SD) and direct-seeded as described above on 17 October. Seedlings were thinned to 2 plants/pot on 2 December (46 DAS).

In the 2010-2012 experiments, plants were kept in bug dorms with the same dimensions as used in 2009 but with a 150 x 150 size mesh instead of the 96 x 26 size mesh used in 2009. Due to the increased pot size, there were 8 pots/cultivar/bug dorm in the 2010 plant productivity and the 2011 gas exchange experiments. There were 5 pots/cultivar/bug dorm in the 2011 plant productivity and 2012 gas exchange experiments due to the increased pot size and the inclusion of Salsa Red. Pots were assigned Arabic numbers and were randomly placed in the bug dorms in a randomized complete block design with two replications in the gas exchange experiments and three replications in the plant productivity experiments. Irrigation was provided by an automated drip system (Orbit Irrigation Products, Inc., USA) (Fig. V.3B) that supplied water when needed.

Establishment of Inoculum Source

Two onion thrips colonies were established on onion plants prior to the start of the study. One colony consisted of IYSV- free onion thrips maintained on IYSV-free onion plants and the other consisted of IYSV-infected onion thrips reared on IYSV-infected onion plants. The two colonies were kept in bug dorms in separate greenhouses to prevent IYSV contamination of the virus-free colony.

Treatments and Treatment Allocation

The effects of four (2009) and five (2010-2012) treatments were investigated. Treatments were:

1. Healthy Control (HC)
2. Thrips Only (T)
3. IYSV Only (V)
4. Thrips+IYSV (TV)
5. Spray (S) (2010-2012)

These treatments were randomly allocated to four bug dorms in 2009 and five bug dorms in 2010-2012. This set up ensured that plants were subjected to the same environmental conditions and pest/pathogen pressure within a bug dorm.

With the Thrips Only treatment, both larva and adult thrips from the IYSV-free colony were transferred by aspiration (Fig. V.4A) to the bug dorms such that there were ≈5 thrips/plant. With both IYSV Only and Thrips+IYSV treatments, viruliferous larva and adult thrips from the IYSV-infected colony were transferred by aspiration to their respective bug dorms also at an infestation rate of ≈5 thrips/plant. However, with the IYSV Only treatment, thrips transfer was carried out a week earlier to give enough time for virus transmission. After successful virus transmission as confirmed by double antibody sandwich enzyme-linked immuno-sorbent assay (DAS ELISA) (Gent et al., 2004), thrips were killed off the plants by application (Fig. V.4B) of a combination of Movento (active ingredient spirotetramat; Bayer CropScience, USA), Regent (active ingredient fipronil; BASF Corp., NC, USA) and Radiant (active ingredient spinetoram; Dow AgroSciences, USA) insecticides at manufacturer's recommended application rates of 0.39, 0.39 and 0.63 ml/L, respectively. The same insecticides were applied to the Spray treatment in 2010-

2012 on the day of treatment allocations to serve as a control for the IYSV Only treatment. Plants of Healthy Control were kept clean of thrips and free of IYSV.

In 2009, the IYSV Only treatment was assigned on 28 May (55 DAS) whereas the other treatments were assigned on 4 June (62 DAS). IYSV Only treatment was assigned on 24 November (92 DAS) and the other treatments on 1 December (99 DAS) in 2010. During the 2011 studies, IYSV Only was assigned on 20 May (92 DAS) whereas the other treatments were allocated on 26 May (98 DAS) in the gas exchange experiment. For the plant productivity experiment, IYSV Only was allocated on 2 June (91 DAS) and the other treatments on 10 June (99 DAS). For the 2012 gas exchange experiment, IYSV Only was assigned on 20 January (95 DAS) and the other treatments on 26 January (101 DAS).

Growth Rate Measurements

Plant growth rate was assessed in the 2009 and 2011 gas exchange experiments using leaf biomass of GR plants. The oldest leaf of GR plants was excised at the junction of the leaf base and sheath and oven-dried in a Precision Gravity Convection Incubator (GCA Corp., USA) held at 65-70^{o}C until they attained a constant weight.

In 2009, leaf biomass sampling for growth rate measurement started at 57 DAS and continued on a weekly basis until 132 DAS. The oldest leaf of all 10 GR plants/cultivar/treatment was excised as described above. Four leaves were randomly selected based on a randomization process in which numbers 1 to 10 were written on 10 paper slips and placed in a bag. Four paper slips were blindly drawn, one at a time, from the bag, and their numbers were correspondingly used to select four leaves for analysis. The remaining six leaves were used in the study reported in Chapter IV.

In 2011, the oldest leaf of all eight GR plants was used for leaf biomass determination in the gas exchange experiment, starting at 98 DAS and continued on a weekly basis until 154 DAS.

Number of leaves/plant was also used as an indicator of growth rate in the two 2011 experiments. Leaves were counted for all FY plants of the gas exchange experiment and for all plants of the plant productivity experiment. All leaves were included in the count except the oldest, senesced ones (Fig. V.5). Leaf counting started at 78 and 89 DAS, respectively, for the gas exchange and plant productivity experiments, and continued on a biweekly basis until 123 and 131 DAS, respectively, for the two experiments.

Growth rate analysis was not carried out in 2010 and 2012.

Days to bulbing, cropping and maturity were monitored in the 2011 experiments.

Gas Exchange Measurements

Gas exchange processes were monitored by measuring net photosynthesis (*A*), stomatal conductance (g_s) and intercellular CO_2 concentration (C_i). These parameters were obtained from measurements of CO_2 uptake half way along the youngest, fully expanded leaves using a portable photosynthesis system, LI-COR 6400 infra-red gas analyzer (IRGA), with an attached leaf fluorometer chamber (Fig. V.6) (Li-Cor Inc., NE, USA). Measurements were made at 400 $\mu molmol^{-1}$ CO_2, a block temperature of 25^oC and at a photosynthetically active radiation (PAR) of 1000 $\mu molm^{-2}s^{-1}$. Measurements were taken using FY plants of the gas exchange experiments in 2009 and 2012.

In 2009, measurements were taken on 5 randomly selected FY plants/cultivar/treatment on a weekly basis starting at 57 DAS until 106 DAS. In 2012, measurements were taken on 3 randomly selected FY plants/cultivar/treatment beginning at 91 DAS until 147 DAS on a biweekly basis. Selection of plants for measurement was randomized as described previously.

Gas exchange measurements were not carried out in 2010 and 2011.

Light Response Curve

This was measured once in 2009 and twice in the 2011 and 2012 gas exchange experiments using the same LI-COR 6400 photosynthesis system with the fluorometer leaf chamber attachment (Fig. V.6). In 2009, light response curve was determined for 4 randomly selected FY plants/cultivar/treatment at 127 DAS. CO_2 uptake half way along the youngest fully expanded leaf was measured at 1200 (first measurement), 900, 600, 450, 300, 200, 100 and 0 (last measurement) $\mu molm^{-2}s^{-1}$ PARs at a constant CO_2 concentration of 400 $\mu molmol^{-1}$ and a block temperature of 25^oC. In 2011 and 2012, measurements were taken at 1500 (first measurement), 1200, 900, 500, 200 and 0 (last measurement) $\mu molm^{-2}s^{-1}$ PARs at a constant CO_2 concentration of 400 $\mu molmol^{-1}$ and a block temperature of 25^oC on 3 randomly selected FY plants/cultivar/treatment. Measurements were taken at 78 (early season) and 138 DAS (late season) in 2011, and 112 (early season) and 151 DAS (late season) in 2012.

Virus Titer Measurements Using DAS ELISA

Besides using DAS ELISA to confirm virus transmission to the IYSV Only treatments, leaf tissues were sampled from all treatments for serological IYSV detection. These tests were carried out to verify that the virus status of treatments was maintained. DAS ELISA was performed using the Agdia DAS ELISA kit (Agdia Inc., USA) and following manufacturer's protocol after the tissues had been frozen in liquid nitrogen and ground to a fine powder with a mortar and pestle (Gent et al., 2004). The ELx 800 Universal Micro-plate Reader (Bio-Tek Instruments Inc. VT, USA) was used to read absorbance values at 405 nm. Tissues were considered positive for IYSV if their absorbance values were equal to or greater than two times the values of healthy negative controls, and highly positive if their absorbance values were equal to or greater than three times the values of healthy negative controls.

Virus Detection Using Reverse Transcription Polymerase Chain Reaction (RT-PCR)

Verification of virus status of experimental units was also assessed using RT-PCR. Total RNA was extracted from leaf tissues using the Spectrum Plant Total RNA Kit (Sigma Life Science, Sigma-Aldrich Co., MO, USA) and following manufacturer's instructions. After extraction, RNA yield was quantified with the NanoDrop 1000 spectrophotometer v. 3.7.0 (Thermo Fisher Scientific, Inc., DE, USA) and concentrations equalized in all samples before use in RT-PCR. Reverse transcription for complementary DNA (cDNA) synthesis was carried out using M-MLV RT from Invitrogen (Life Technologies, Carlsbad, CA, USA) and reactions were run using the 48 x 0.2 ml reaction module of Peltier Thermal Cycler (PTC) 200 DNA Engine (M J Research Inc., Waltham, MA, USA). 1µl 10mM dNTP mix and 1µl random hexamers were mixed with 10 µl of the extracted RNA and incubated at 65^{o}C for 5 min. Then 4, 2 and 1 µl, respectively, of 5X First-Strand Buffer, 0.1M DTT and RNase Out were added and ran at 37^{o}C for 2 min after which 1 µl M-MLV reverse transcriptase was added and ran at 25^{o}C for 10 min, 37^{o}C for 50 min and 70^{o}C for 15 min to complete the cDNA synthesis. cDNA synthesis was quickly followed by PCR performed on the IYSV nucleocapsid (N) gene using Au-R (5'-CTTGGAGGGATTCTTGGGTTTAG-3') and Au-F (5'AGGGTAAAAGCTTCAGAAATCGAGA-3') as the reverse and forward primer sets, respectively, that amplify 792 bp fragment of the N gene. Nad2 primer sets (nad2-F (5'-GGACTCCTGACGTATACGAAFFATC-3') and nad2-R (5'-AAACAACGCTTGTAAGGAGTCC-3')) were used as control primers in the PCR reaction. PCR was performed in 20 µl reactions consisting of 2 µl of 20 ng cDNA, 0.4 mM dNTP mix, 1.2 µl 50mM $MgCl_2$, 0.5 µl of each primer, 2 µl of 10X PCR Reaction Buffer and 13.3 µl of nuclease free water. The PTC-200 DNA Engine was configured to run the PCR reaction at an initial step of 94^{o}C for 3 min followed by denaturation at 94^{o}C for 45 secs, annealing at 55^{o}C for 30 secs and extension at 72^{o}C for 90 secs. Denaturation, annealing and extension processes were repeated 40 times, followed by a final extension step at 72^{o}C for 10 min.

The final PCR products were analyzed by 1% agarose gel electrophoresis in Tris/Acetic Acid/EDTA (TAE) buffer stained with ethidium bromide. The Power Pac 300 power supply (Bio-Rad Laboratories Inc., USA) was used for the electrophoresis, and was run at 75 V for 30 – 40 min. The GeneRuler 100bp Plus DNA ladder (Fermentas Inc., Glen Burnie, MD, USA) was used as a size standard. DNA bands were visualized using the Gel Logic 100 High Performance UV trans-illuminator (UVP LLC, USA) and photographed using Kodak 1D v. 3.6.3 imaging system (Kodak Scientific Imaging Systems, CT, USA).

Harvesting

Plants were harvested when more than 50% of their foliage had senesced after cropping.

Gas Exchange Experiments

Only the FY plants were harvested for yield assessment in the gas exchange experiments. Bulb size (diameter) was measured at the mid-section of the bulb using a digital vernier caliper (Swiss Precision Instruments Inc.) (Fig. V.7A). Bulb weight was determined with an Ohaus Precision weighing scale (Ohaus Corporation, USA) (Fig. V.7B). Bulbs of the 2012 gas exchange experiment were not harvested.

Plant Productivity Experiment

These experiments were executed to determine the effects of IYSV and onion thrips on both bulb yield and the pattern of biomass partitioning. At harvest, plants were separated into root, bulb and shoot sections (Fig. V.8). Size and fresh weight of bulbs were determined as described above for bulb yield assessment. Bulb, root and shoot sections were then oven-dried at 65-70^{o}C until they attained a constant weight. Root samples were dried in a Precision Gravity Convection Incubator (GCA Corp. USA) whereas bulb and shoot sections were dried in a Despatch oven (Despatch Oven Co. NJ, USA).

Statistical Analysis

The MIXED procedure in SAS (SAS v. 9.3., SAS Institute Inc., NC, USA) was used for data analysis. Significant differences between cultivar and treatment means were determined using adjusted Tukey's studentized range test at a 0.05 probability level. All tabular and graphical presentations were modeled in Microsoft Excel (Microsoft Office v 2010. Microsoft Corporation, USA).

RESULTS

Plant Gas Exchange

In 2009, there was no significant difference ($P > 0.05$) in net photosynthesis (*A*) between Colorado 6 and Talon on individual measurement days except at 71 DAS when *A* was significantly higher ($P < 0.0001$) in Colorado 6 than in Talon (Fig. V.9A). Seasonal mean *A* was, however, significantly higher ($P < 0.0001$) in Colorado 6 than in Talon, with a value of 2.4 $\mu molCO_2\ m^{-2}s^{-1}$ difference between the two cultivars. Even though there were some significant differences between the treatments on some measurement days, no treatment was consistently higher than the rest throughout the study period, and the overall seasonal mean was not significantly different ($P = 0.4200$) (Figures V.9B and V.10). In general, *A* decreased with time in both cultivars and all treatments, and there was no significant cultivar-x-treatment interaction ($P = 0.4256$).

Similarly, there was no significant cultivar or treatment difference for stomatal conductance (g_s) on individual measurement days (Fig. V.11); however, mean g_s was significantly higher ($P < 0.0001$) in Colorado 6 than in Talon. Among the treatments, mean g_s was significantly higher ($P = 0.001$) in HC than in the other treatments, however, the other treatments were not significantly different ($P > 0.05$) from each other (Fig. V.11). No one treatment or cultivar had a consistently higher intercellular CO_2 content (C_i) throughout the study period (Fig. V.12). Seasonal mean C_i was not significantly different between the treatments ($P = 0.2804$), but was significantly higher ($P = 0.0074$) in Colorado 6 than in Talon. In general, g_s decreased (Fig. V.11) whereas C_i increased (Fig. V.12) with time and there were no significant cultivar-x-treatment interactions in either parameter.

A regression of *A* on g_s (Fig. V.13) indicated that *A* in Talon was more dependent on g_s ($R^2 = 0.4419$) than was *A* in Colorado 6 ($R^2 = 0.3498$). Among the treatments, dependence of *A* on g_s was highest in V ($R^2 = 0.7195$) and lowest in TV ($R^2 = 0.0826$).

In 2012, the pattern of *A* in cultivars and treatments was just as that observed in 2009, with no cultivar or treatment consistently higher than the others on all study days (Figures V.14 and V.15). Seasonal mean *A* was significantly higher in Colorado 6 than in Talon ($P = 0.0399$), however, there was no significant difference between Colorado 6 and Salsa Red ($P = 0.6895$) or between Salsa Red and Talon ($P = 0.2324$). Among the treatments, seasonal mean *A* was in the decreasing order of T, V, HC, S and TV, with values of 14.5, 13.5, 13.2, 12.2 and 11.0 $\mu molCO_2m^{-2}s^{-1}$, respectively. TV was not significantly different from S ($P = 0.4254$), but was significantly different from all other treatments ($P < 0.05$). T was not significantly different from HC and V ($P = 0.3264$ and 0.6298, respectively), but was significantly different from S ($P = 0.0117$). HC, S and V were not significantly different ($P > 0.05$) from each other.

Dependence of *A* on g_s was in the increasing order of Colorado 6, Salsa Red and Talon, with R^2 values of 0.0003, 0.0743 and 0.1118, respectively (Fig. V.16). Among the treatments, there was a negative relationship between *A* and g_s for both HC and S, however, a positive relationship was observed for T, TV and V, with R^2 values of 0.1103, 0.0392, 0.0097, 0.5385 and 0.7571, respectively (Fig. V.16).

Light Response Curve

In 2009, light saturation point (LSP, the light intensity at which any further increase in intensity does not result in an increase in the rate of photosynthesis) was between 200 and 400 $\mu molm^{-2}s^{-1}$ in both cultivars and in all treatments, except for V in Talon where it was between 100 and 200 $\mu molm^{-2}s^{-1}$ (Fig. V.17). At the LSP, *A* was highest in T and lowest in V in both cultivars. In Colorado 6, light compensation point (LCP, light intensity at which the rates of photosynthesis and respiration are equal) as indicated by the y-intercept of the curves below 0 $\mu molCO_2\ m^{-2}s^{-1}$) indicated net loss of O_2 was highest at 4.7 $\mu molO_2\ m^{-2}s^{-1}$ in HC and lowest in TV at 0.23 $\mu molO_2\ m^{-2}s^{-1}$. In Talon, net loss of O_2 was ≈1.7 $\mu molO_2\ m^{-2}s^{-1}$ for both T and TV, and ≈2.6 $\mu molO_2\ m^{-2}s^{-1}$ for both HC and V. In general, *A* was higher in Colorado 6 than in Talon ($P < 0.0001$) across all PARs and was in the increasing order of V, HC, TV and T among the treatments for all PARs.

Two light response curves were measured in 2011 at 78 and 138 DAS, dubbed early and late response curves, respectively. In both Colorado 6 and Talon, LSP was reached at PAR >500 $\mu molm^{-2}s^{-1}$ in the early response curves in all treatments (Fig. V.18). *A* was generally higher in Talon than in Colorado 6, and there was not much difference between the treatments. LCP was not reached in all treatments or cultivars. In the late season measurement, *A* was generally higher in Colorado 6 than in Talon for all treatments (Fig. V.19). In both cultivars, *A* was in the decreasing order of S, HC, V, T and TV for the treatments. An LSP of 500 μmolm^{-2}s^{-1} was observed for all treatments in Talon, and for T and TV in Colorado 6. For HC, S and V in Colorado 6, LSP was 900 μmolm^{-2}s^{-1}. LCP was reached for T and TV in Colorado 6, and for HC, T and TV in Talon.

For all treatments and cultivars, early season *A* was higher than late *A* (Figures V.18 and V.19).

In 2012, there was little difference between early and late season *A*, however, *A* was generally higher in Talon than in Colorado 6 and Salsa Red in both early (Fig. V.20) and late (Fig. V.21) season measurements. In the early season measurements, *A* reached a saturation point in all treatments and cultivars at 500 μmolm^{-2}s^{-1} PAR. V in Colorado 6 and Talon, and S in Talon reached LCPs, with net loss of O_2 of 0.15, 0.67 and 0.9 μmolO_2 m^{-2}s^{-1}, respectively. Within the cultivars, no one treatment was higher than the others at all PARs.

In the late season measurements, there were significant differences between the treatments in all cultivars (Fig. V.21). LSP was reached at 500 μmolm^{-2}s^{-1} in all treatments and cultivars. At this and higher PARs, *A* was lowest for both T and TV, and highest for HC, S and V in Colorado 6 (Fig. 21A). LCP was reached in all treatments and net O_2 loss was highest for both T and TV at 5.1 and 4.3 μmolO_2 m^{-2}s^{-1}, respectively, and lowest for V at 0.08 μmolO_2 m^{-2}s^{-1}. In Salsa Red, *A* was below 0 μmolCO_2 m^{-2}s^{-1} for both T and TV at all PARs (Fig. 21B). Treatments S and V had nearly the same response curves, with their *A* slightly lower than in HC. LCP was reached in all treatments. In Talon (Fig. V.21C), the response curve for TV was below 0 μmolCO_2 m^{-2}s^{-1} for all PARs just as was observed in Salsa Red (Fig. V21B). Treatments T and V had nearly the same response curves which were higher than in TV. HC and S had a similar response curve although *A* was higher in HC than in S at all PARs.

Plant Growth Rate

There was no significant difference between Colorado 6 and Talon on all sampling days ($P > 0.05$) throughout the study period in 2009 (Fig. V.22). Growth rate increased from a genotype average of 0.04 g/leaf at 56 DAS to 0.25 g/leaf at 124 DAS, and then declined slightly to 0.23 g/leaf on the last sampling day (131 DAS). Seasonal mean growth rate, however, was significantly higher ($P < 0.0001$) in Colorado 6 than in Talon.

There were no significant differences ($P > 0.05$) between the treatments at 56 DAS and 96 DAS. At 103 DAS, however, HC was significantly higher than TV ($P = 0.0024$) and T ($P = 0.0008$). HC was not significantly different from V, and V, T and TV were not significantly different from each other ($P > 0.05$). Between 110 and 131 DAS, growth rate was significantly higher ($P < 0.0001$) in HC than in the other treatments in both cultivars. During the same period, growth rate was not significantly different ($P > 0.05$) between T and TV in Talon; however, in Colorado 6, growth rate was significantly higher ($P < 0.05$) in V than in both T and TV. Treatments T and TV were not significantly different ($P > 0.05$) in Talon. Seasonal mean growth rate was in the decreasing order of HC, V, TV and T, with all treatments significantly different ($P < 0.001$) from each other except T and TV that were not significantly different ($P = 0.5809$). There was no significant cultivar-treatment interaction ($P = 0.1839$).

In 2011, growth rate increased in all treatments and cultivars until 140 DAS after which growth declined (Fig. V.23). There were significant cultivar ($P < 0.001$) and treatment ($P < 0.001$)

differences as well as significant cultivar-treatment interactions ($P = 0.0045$). Seasonal mean growth rate was in the decreasing order of S, HC, V, T and TV, with values of 0.171, 0.169, 0.159, 0.159 and 0.137 g/week, respectively. Growth rate was significantly higher in Colorado 6 than in Talon ($P < 0.0001$), with values of 0.173 and 0.145 g/week, respectively. Treatment S was not significantly different from HC ($P = 0.0811$) but was significantly higher ($P < 0.05$) than in T, TV and V. Treatment HC was significantly different from TV ($P < 0.0001$) but not from T and V ($P = 0.0839$ and 0.0995, respectively). Treatments T and V were not significantly different from each other ($P = 0.9337$), but both were significantly different from TV ($P = 0.0090$ and 0.0007, respectively).

Of the cultivar-treatment interactions, HC, S, and TV were significantly higher in Colorado 6 than in Talon ($P = 0.0005$, < 0.0001 and < 0.0001, respectively), however, the difference between the two cultivars was not significantly different for T and V (Fig. V.23), with p-values of 0.1458 and 0.4302, respectively.

Leaf number increased throughout the study period in all treatments and cultivars in the 2011 gas exchange experiment (Table V.1). There was no significant cultivar difference until 123 DAS when leaf number was significantly higher in Colorado 6 than in Talon ($P = 0.0006$). There were significant differences between treatments in Colorado 6 throughout the study period, however, in Talon, significant treatment differences were observed only at 78 and 92 DAS.

Time to bulbing and maturity (Table V.1) were significantly shorter in Talon than in Colorado 6, with values of $P = 0.0007$ for bulbing and $P < 0.0001$ for maturity. Treatments S and T were first and last to bulb, respectively, in Colorado 6, whereas S and TV were, respectively, first and last to bulb in Talon. There were no significant differences between the treatments for days to maturity in both cultivars except in Talon, in which TV and V were significantly different from each other but not from the other treatments.

In the plant productivity experiment in 2011, leaf number increased in all cultivars and treatments over time (Table V.2). The three cultivars were significantly different from each other on all evaluation days except at 117 DAS when all cultivars had ≈11 leaves/plant. Talon had the highest leaf number between 89 and 117 DAS, with Colorado 6 having the highest at 131 DAS (last counting day). The five treatments were significantly different from each other within Colorado 6 except at 89 and 117 DAS, when all treatments had nearly the same number of leaves/plant. Treatments were significantly different on all days in Talon, and on all days in Salsa Red except at 117 DAS.

The cultivars were significantly different from each other in their bulbing, cropping and maturity days (Table V.2). Talon was first to bulb, crop and mature, followed by Salsa Red and lastly Colorado 6. In Colorado 6, the treatments significantly affected time to bulbing but not cropping or maturity. In Talon, treatments significantly affected maturity but not bulbing or cropping. Days to bulbing, cropping and maturity were affected by all treatments in Salsa Red.

Onion Bulb Yield

There was no cultivar difference for either bulb weight ($P = 0.9081$) or bulb size ($P = 0.0742$) in 2009 (Fig. V.24). However, there was significant treatment difference for bulb weight ($P < 0.0001$) and bulb size ($P < 0.0001$). HC had the highest bulb weight of 57.94 g/bulb, followed by V with 36.77 g/bulb, T with 20.12 g/bulb and finally TV with 13.99 g/bulb. HC also had the largest bulb size of 45.0 mm/bulb, followed by V, then T and finally by TV with sizes 41.1 mm/bulb, 34.8 mm/bulb and 30.7 mm/bulb, respectively.

The two cultivars were not significantly different in 2010 for either bulb weight ($P = 0.7871$) or bulb size ($P = 0.4629$) (Fig. V.25), just as was observed in 2009. The treatments were, however, significantly different from each other for both bulb weight ($P = 0.0004$) and bulb size ($P = 0.0463$). Bulb weight was significantly lower in T than in HC, but not significantly different from S and V. Weight was not significantly different between HC, S and V (Fig. V.25A). Bulb size was significantly lower in TV than in HC, S and V but not in T. Size was not significantly different between HC, S, T and V (Fig. V.25B).

In the 2011 gas exchange experiment, the two cultivars were not significantly different for bulb size ($P = 0.8916$), but were significantly different for bulb weight ($P = 0.0168$). The significant difference occurred only in TV in which bulbs of Colorado 6 were significantly heavier than bulbs of Talon (Fig. V.26A). The five treatments were significantly different in their effects on bulb weight ($P = 0.0053$) and bulb size ($P < 0.0001$). Bulb weight was lowest in TV, followed by T, V, S and then HC, with values of 45.5, 48.9, 49.6, 55.6 and 64.2 g/bulb, respectively. Bulb size also followed the same order as bulb weight, with values of 48.1, 49.5, 50.1, 51.2 and 56.5 mm/bulb, respectively (Fig. V.26B).

In the 2011 plant productivity experiment, there were significant cultivar and treatment differences for both bulb weight and size (Fig. V.27). For weight, the cultivars were significantly different ($P < 0.0001$), with Colorado 6 having the highest bulb weight in all treatments. Salsa Red and Talon were significantly different from each other for HC and V treatments but not for S, T and TV treatments. Bulbs of Salsa Red were generally heavier than bulbs of Talon. The treatments significantly affected bulb weight ($P < 0.0001$), with HC having the highest mean weight of 84.4 g/bulb, followed by S, V, TV and T, with values of 63.3, 55.4, 48.1 and 46.8 g/bulb, respectively.

In terms of bulb size, there was a significant cultivar difference ($P < 0.0001$) in which treatments HC, S and T, were not significantly different between Colorado 6 and Salsa Red, but the two were both significantly bigger than bulbs of Talon (Fig. V.27B). All three cultivars had nearly the same size for TV, whereas for V, Colorado 6 had significantly bigger bulbs than Talon but not Salsa Red; and Salsa Red and Talon had nearly the same bulb size. Between the treatments, bulb size was significantly higher in HC than in the other treatments. Treatments S and TV were not significantly different from each other, but were significantly different from both T and V. Treatments T and V were not significantly different from each other.

Biomass Partitioning Pattern

The plant productivity experiments in 2010 and 2011 were used to study plant biomass partitioning pattern.

In the 2010 study, biomass partitioning was not significantly influenced by the treatments ($P > 0.05$); however, the two cultivars were significantly different in their partitioning patterns (Table V.3). Colorado 6 significantly partitioned more biomass to root ($P = 0.0045$) and shoot ($P = 0.0001$) growth and development than Talon, however, biomass allocated for bulb yield was significantly higher ($P < 0.0001$) in Talon than in Colorado 6, with values of 67.2 and 50.4 %, respectively.

In 2011, biomass portioning in Colorado 6 was not significantly ($P > 0.05$) affected by the five treatments, however, in Salsa Red, biomass allocations to roots was significantly higher in T and TV than in HC. In Talon, a significantly higher proportion of total biomass was partitioned for root development in TV than in HC. A significantly higher amount of biomass was apportioned for shoot development in T than in HC in both Salsa Red and Talon (Table V.4). In all three cultivars, biomass allocated to bulb yield was highest in HC than in T, TV and V, even in Colorado 6 in which biomass partitioning was unaffected by the treatment. Between the cultivars, biomass allocation to root development was nearly the same for both Colorado 6 and Talon, but was significantly higher ($P = 0.0104$) in Salsa Red. Biomass partitioning to shoots was significantly different ($P < 0.0001$) in all cultivars, with 25.3, 22.3 and 17.7 % allocated, respectively, in Colorado 6, Salsa Red and Talon. In terms of bulb yield, the three cultivars were significantly different ($P = 0.0001$) in which both Colorado 6 and Salsa Red allocated 65.6 and 66.7 % of their total biomass, respectively, whereas Talon assigned 73.6 % of its biomass to bulb yield (Table V.4).

DISCUSSION

Plant growth and development depend on several factors including temperature, light, water and nutrition and how these factors interrelate in the absence of any biotic stresses (Brewster, 1994; Gifford and Evans, 1981). If these conditions are optimal for a given plant species, increased growth rate is a direct result of elevated net photosynthesis (Anderson et al. 1995; Boardman 1977; Bowes, 1991; Walters 2005). If provided with the same environmental conditions, plants of the same species usually do not exhibit significant differences in their net photosynthesis (Rowland et al., 2005; van Gestel et al., 2005). The 2009 and 2012 gas exchange experiments (Figures V.9 and V.14) revealed that the higher growth rate in Colorado 6 than in Talon (Figures V.22 and V.23) could, in part, be due to its slightly higher net photosynthesis. This is particularly true considering the fact that the treatments did not impose significant differential effects on net photosynthesis in both cultivars. During the gas exchange measurements, chlorotic and severely damaged sections of candidate leaves were avoided. This may explain why net photosynthesis was not consistently higher in any one treatment throughout the study period. Thus, any yield losses resulting from thrips infestation is a direct consequence of reduced leaf chlorophyll content and not altered chlorophyll efficiency. This may also explain why net photosynthesis was least dependent on stomatal conductance for the thrips treatments (Figures V.13 and V.16) as the excessive wounding of leaves through feeding resulted in loss of functional integrity of stomatal guard cells. The loss of guard cell functional integrity could be partly responsible for the low net photosynthetic response to light in the thrips treatments in the 2011 and 2012 late season light response curves (Figures V.19 and V.21). This is because if leaf gas exchange is not coordinated by stomata (because they are closed to prevent excessive water loss), leaf O_2 levels are elevated. At such elevated O_2 levels, cells undergo photorespiration at the expense of photosynthesis (Drake et al., 1997; Long, 1991; Wheeler et al., 2004). Both Figures V.19 and V.21 provide evidence of the inception of photorespiration as the y-intercept of the thrips treatments were less than 0 $\mu molCO_2\ m^{-2}s^{-1}$. Such values indicate uptake, instead of release, of O_2.

Unlike thrips, viruses do not affect photosynthesis through direct removal of chlorophyll. Instead, they affect the process through physiological and molecular alterations of host processes using mechanism that are largely unknown or are not well understood (Culver and Padmanabha, 2007). Such altered host physiology in turn decreases photosynthesis through decrease in chlorophyll content per leaf, chlorophyll efficiency and leaf area per plant (Agrios, 2005). As loss of chlorophyll content (through expression of viral chlorotic and necrotic symptoms) and leaf area per plant (through stunting, leaf drops and reduced leaf area exposure to light) do not apply in this experiment, decreased chlorophyll efficiency could explain the lower light response curves of the virus treatments in Talon (Figures V.19 and V.21) and Salsa Red (Fig. V.21). These results are confirmed by previous studies in which reduction in photosynthesis due to virus infections were attributed to a general reduction in the efficiency and content of photosystem II (Arias et al., 2003; Bertamini et al., 2004; Cabaleiro et al., 1999; Clover et al., 1999).These figures reveal the tolerance of Colorado 6 and the susceptibility of Talon and Salsa Red to the virus.

Thus, the reduced chlorophyll content due to thrips feeding and the decreased efficiency of the remaining chlorophyll resulted in the synergistic effect that significantly reduced net photosynthesis in the TV treatments. This in turn is responsible for the significantly reduced bulb yields in the TV treatments (Table V.5, Figures V.24-V.27).

Tomato spotted wilt virus (TSWV) infection of peanut resulted in significant reductions in transpiration (Rowland et al., 2005). In this study, Figures V.13 and V.16 indicate that net photosynthesis significantly depended on stomatal conductance in V than in the other treatments. Stomatal conductance is a measure of plant transpiration, thus, indicating that IYSV infection of onion results in increased transpiration. As TSWV and IYSV are closely related viruses, it would be expected that they would exert similar physiological effects on their hosts. This notwithstanding, the above referenced study was carried out in the field and there could be factor(s) other than TSWV that limited transpiration.

The progressive decline in net photosynthesis throughout the study period (Figures V.9 and V.14) was further reaffirmed by the early and late season light response curves in 2011 and 2012 (Figures V.18-V.21), as the early season curves were generally higher than the late season curves. The gradual decline could be due to a natural phenomenon in which crops prepare to senesce or over-season towards the end of the growth cycle (Campbell and Reece, 2005; Rowland et al., 2005). It should be noted that unlike in the 2011 curves, the early and late season curves in 2012 were not significantly different for HC and S treatments. This resulted because the two measurements were taken only 39 days apart, whereas the 2011 measurements were 60 days apart. The 2009 light response curve is not referred to in this discussion because no early season measurement was taken with which to compare the late season curves.

The difference in growth rate and net photosynthesis in the course of the study period did not translate into significant bulb yield differences between the cultivars. For both bulb weight and size, there were no significant differences between Colorado 6 and Talon in 2009 and 2010. Talon is susceptible to IYSV, whereas Colorado 6 possesses field tolerance. As host plant resistance is an integral component of plant disease management, failure of Colorado 6 to out-yield Talon instigated further investigation. This led to the study of biomass partitioning pattern and the inclusion of Salsa Red in the subsequent experiments. It was hypothesized that in the gas exchange experiments, cultivar differences were not attained partly due to intense competition between plants as there were 2 plants per pot. To offset this effect, 1 plant per pot was used in the plant productivity experiments. Although the change in plant density resulted in higher yields (e.g., Fig V.26 versus Fig. V.27), it did not result in significant cultivar difference in terms of bulb size for the IYSV and thrips treatments (Fig. V.27B). In terms of bulb weight, however, significant cultivar differences were attained in which Colorado 6 out-yielded both Salsa Red and Talon (Fig. V.27A). It should be noted, however, that in both HC and S treatments, Colorado 6 out-yielded Salsa Red and Talon. The question therefore is asked if the cultivar differences attained was due to Colorado 6's tolerance or to some other undetected factor(s). The non-significant cultivar differences could be due to the limitations imposed by potted greenhouse experiments (Arp, 1991) and the limited number of plants involved in the study.

Talon completed its growth cycle relatively faster than the other cultivars (Tables V.1 and V.2), and had a relatively shorter bulb-filling duration. This, coupled with its susceptibility to IYSV and onion thrips, usually should result in reduced yield (Brewster, 1994). The biomass partitioning study revealed that Talon produced yields comparable to the tolerant Colorado 6 due, in part, to its allocation of a significantly high proportion of its total biomass to bulb yield (Tables V.3 and V.4). This high harvest index of Talon was attained in both 2010 and 2011, and may also account for the non-significant yield differences between the two cultivars in 2009 (Fig. V.24).

Table V.5 summarizes the yield losses due to IYSV and onion thrips in the 2010 and 2011 plant productivity experiments. Even though the table suggests thrips infestation resulted in higher yield losses than IYSV infection, Figures V.25-V.27 indicate that losses due to their separate infections were not significantly different from each other, and that the most yield loss occurred only when the two are present in TV. Their combined effect resulted in 46-60 % bulb weight and 18-38 % bulb size losses in 2010. In 2011, 14-18 % bulb weight, and 36-48 % bulb size losses resulted from their combined infection. In both years, yield losses were higher in Colorado 6 than in Talon, however, losses were higher in Salsa Red than in Colorado 6 in 2011. The lower yield loss in Talon could be due to its relatively shorter maturation time and its higher harvest index as mentioned above. The table also indicates that effects of IYSV and onion thrips vary from year to year even for the same cultivar. In 2010, they caused a higher loss in bulb weight than bulb size in both cultivars; however, in 2011 they caused a higher reduction in bulb size than bulb weight in all 3 cultivars.

Generally, it is accepted that of the various plant pathogen classes, viruses rank second only to fungi with respect to the disease losses they cause. This notwithstanding, crop/economic losses due to viruses are frequently difficult to assess/quantify (Matthews, 1992; Waterworth and Hadidi, 1998). Estimation of crop/economic losses becomes even more difficult and complicated in arthropod-vectored viruses in which separation of vector damage from that due to the virus is frequently impossible under field conditions. In this study, estimation of yield losses due to IYSV and onion thrips as separate yield limiting factors was undertaken. Although this greenhouse study may not necessarily mirror field conditions (Matthews, 1992), information on potential yield losses is provided. Although the IYSV Only treatment may not occur in nature, it may be prevalent in field situations in which early crop infestation by viruliferous thrips is followed by extensive thrips control. Infected plants will then be subjected to physiological drawbacks which invariably will affect yield. The combined effects of IYSV and onion thrips in TV resulted in significant yield losses and as TV is what occurs naturally in onion fields, this may explain the reduced percentage of colossal and jumbo sized onion bulbs reported in USA (Gent and Schwartz, 2008; Gent et al., 2004; Schwartz et al., 2002). These studies have confirmed the economic importance of the IYSV-onion thrips-onion pathosystem to the onion industry and the urgent need for an efficient and safe IPM program for this pathosystem. Host plant resistance, although shown in this study to have little effect, can still be an integral component of an IPM program as the field tolerance of Colorado 6 may have been lost in this study owing to the enclosed and high pathogen pressure conditions under which these greenhouse studies were carried out.

Table V.1. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on leaf growth and development, and phenology of onion cultivars in the gas exchange experiment in 2011.

Genotype	Treatment	**Leaf-78** Mean ± SE*	**Leaf-92** Mean ± SE*	**Leaf-109** Mean ± SE*	**Leaf-123** Mean ± SE*	**Bulbing** Mean ± SE**	**Maturity** Mean ± SE**
Colorado 6	Healthy Control	5.5 ± 0.7w	7.0 ± 0.7w	8.6 ± 0.9w	10.8 ± 1.0w	118.0 ± 15.6xz	169.1 ± 8.6x
	Spray	5.8 ± 0.8wx	7.6 ± 0.7x	9.4 ± 0.8x	11.8 ± 1.3wx	108.3 ± 9.4x	164.4 ± 6.2x
	Thrips Only	5.3 ± 0.6wy	7.0 ± 0.9wy	9.2 ± 0.7wx	11.1 ± 0.9wxy	129.9 ± 11.9y	169.8 ± 10.5x
	Thrips+IYSV	5.3 ± 0.8wy	6.8 ± 0.7wyz	8.9 ± 0.9wx	10.6 ± 1.2wy	112.1 ± 19.6xz	166.3 ± 11.8x
	IYSV Only	5.4 ± 0.7wxy	7.5 ± 1.0wxy	8.8 ± 0.9wx	10.8 ± 1.4wy	119.7 ± 13.5z	166.3 ± 10.2x
	Genotype Mean	***5.5 ± 0.7a***	***7.2 ± 0.8a***	***9.0 ± 0.8a***	***11.0 ± 1.2a***	***117.6 ± 14.0a***	***167.2 ± 9.5a***
Talon	Healthy Control	5.8 ± 0.9w	7.3 ± 1.1w	9.3 ± 1.7w	10.6 ± 1.7w	112.1 ± 19.0x	155.3 ± 12.7x
	Spray	5.6 ± 0.8wx	6.8 ± 0.9wx	8.7 ± 1.0w	9.8 ± 1.1w	101.5 ± 10.4y	154.7 ± 12.5x
	Thrips Only	5.3 ± 0.7wxy	7.3 ± 0.5wxy	8.8 ± 0.7w	10.0 ± 1.5w	110.9 ± 17.6xy	157.2 ± 13.6x
	Thrips+IYSV	5.6 ± 1.1wxy	6.9 ± 0.5wxy	8.8 ± 0.8w	10.0 ± 1.1w	113.7 ± 17.8x	159.9 ± 13.0xy
	IYSV Only	5.8 ± 0.9wxy	7.4 ± 0.9wy	9.2 ± 0.8w	10.4 ± 1.2w	108.8 ± 14.0xy	153.7 ± 10.6xz
	Genotype Mean	***5.6 ± 0.9a***	***7.2 ± 0.8a***	***8.9 ± 1.0a***	***10.2 ± 1.3b***	***109.4 ± 15.8b***	***156.1 ± 12.5b***

*Number of leaves/plant.

**Days after sowing.

Number following leaf "-" indicates days after sowing (DAS) on which leaves were counted.

Genotype means are separated by letters 'a' and 'b'. Genotypes with the same letters within a column are not significantly different at P = 0.05.

Treatment means are separated by letters w - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different at P = 0.05.

Table V.2. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on leaf growth and development, and phenology of onion cultivars in the plant productivity experiment in 2011.

Genotype	Treatment	Leaf-89 Mean ± SE*	Leaf-103 Mean ± SE*	Leaf-117 Mean ± SE*	Leaf-131 Mean ± SE*	Bulbing Mean ± SE**	Cropping Mean ± SE**	Maturity Mean ± SE**
Colorado 6	Healthy Control	4.8 ± 0.7w	8.4 ± 0.9w	11.0 ± 0.9w	13.5 ± 1.0w	146.3 ± 13.8w	161.1 ± 6.7w	188.8 ± 5.0w
	Spray	5.2 ± 0.6w	8.8 ± 1.1wx	11.2 ± 1.1w	12.5 ± 1.8wx	139.0 ± 13.4x	160.8 ± 7.8w	185.4 ± 8.1w
	Thrips Only	5.1 ± 0.7w	8.6 ± 0.9wxy	11.3 ± 0.8w	12.8 ± 1.2wx	148.5 ± 11.0wy	N/A	182.0 ± 0.0w
	Thrips+IYSV	4.9 ± 0.5w	8.1 ± 1.0wy	10.8 ± 0.7w	12.1 ± 1.7xy	146.2 ± 13.3wyz	155.0 ± 8.7w	185.4 ± 7.3w
	IYSV Only	4.9 ± 0.6w	7.8 ± 0.9z	10.9 ± 0.7w	13.2 ± 1.1wxy	155.6 ± 7.7yu	169.0 ± 0.0w	186.0 ± 8.3w
Genotype Mean		***5.0 ± 0.6a***	***8.3 ± 1.0a***	***11.0 ± 0.9a***	***12.8 ± 1.4a***	***147.1 ± 11.9a***	***161.5 ± 5.8a***	***185.5 ± 5.7a***
Salsa Red	Healthy Control	5.3 ± 0.6w	9.1 ± 1.0w	10.7 ± 1.3w	12.2 ± 2.2w	126.5 ± 10.3w	145.9 ± 13.6w	165.9 ± 17.8w
	Spray	5.8 ± 0.4x	9.1 ± 0.7w	10.9 ± 0.9w	10.6 ± 1.5x	125.8 ± 6.6wx	142.7 ± 9.3wx	158.2 ± 13.1x
	Thrips Only	5.4 ± 0.6wx	9.1 ± 0.7w	10.9 ± 1.1w	10.9 ± 1.0x	125.0 ± 8.7wx	133.0 ± 4.5xy	161.0 ± 17.5wx
	Thrips+IYSV	5.3 ± 0.5wx	8.7 ± 0.6wx	10.6 ± 1.1w	10.0 ± 2.4x	126.1 ± 8.1wxy	135.0 ± 5.8xyu	158.9 ± 18.3wx
	IYSV Only	5.5 ± 0.5wx	9.3 ± 0.9wy	11.1 ± 1.2w	10.7 ± 1.8x	132.2 ± 17.5wy	146.6 ± 19.3wxz	158.3 ± 14.7x
Genotype Mean		***5.5 ± 0.5b***	***9.1 ± 0.8b***	***10.8 ± 1.1a***	***10.9 ± 1.8b***	***127.1 ± 10.2b***	***140.6 ± 10.5b***	***160.5 ± 16.3b***
Talon	Healthy Control	5.9 ± 0.5w	10.5 ± 0.8w	11.9 ± 0.9w	11.5 ± 0.8w	115.1 ± 8.4w	131.5 ± 8.4w	149.8 ± 9.0w
	Spray	5.8 ± 0.4wx	10.0 ± 0.5wx	10.8 ± 0.6x	10.0 ± 0.8x	115.0 ± 7.6w	133.6 ± 4.9w	146.6 ± 6.0wx
	Thrips Only	5.7 ± 0.6wx	10.1 ± 0.6wxy	11.1 ± 1.2xy	10.5 ± 1.6xy	118.9 ± 7.7w	130.9 ± 5.2w	141.0 ± 5.6x
	Thrips+IYSV	5.6 ± 0.5wx	9.6 ± 0.8xyz	11.1 ± 1.1xy	9.3 ± 1.0xz	114.1 ± 5.5w	128.8 ± 3.5w	140.4 ± 4.3x
	IYSV Only	5.5 ± 0.6x	9.3 ± 0.7z	10.1 ± 1.0xz	9.1 ± 0.7xz	119.0 ± 5.0w	132.1 ± 3.9w	143.1 ± 5.1wx
Genotype Mean		***5.7 ± 0.5c***	***9.9 ± 0.7c***	***11.0 ± 1.0a***	***10.1 ± 1.0c***	***116.4 ± 6.9c***	***131.4 ± 5.2c***	***144.2 ± 6.0c***

*Number of leaves/plant.

**Days after sowing.

Number following leaf “-” indicates days after sowing (DAS) on which leaves were counted.

Genotype means are separated by letters a-c. Genotypes with the same letters within a column are not significantly different at P = 0.05.

Treatment means are separated by letters w-z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different at P = 0.05.

N/A indicates genotype did not crop.

Table V.3. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on biomass partitioning pattern of onion cultivars in the plant productivity experiment in 2010.

Genotype*	**Treatment****	**Root (%)** Mean ± SE	**Shoot (%)** Mean ± SE	**Bulb (%)** Mean ± SE
Colorado 6	Healthy Control	7.3 ± 2.1x	32.6 ± 2.3x	60.1 ± 4.4x
	IYSV Only	7.2 ± 1.7x	46.4 ± 6.9x	46.4 ± 8.1x
	Spray	8.3 ± 2.0x	45.7 ± 5.4x	46.0 ± 6.9x
	Thrips+IYSV	6. 8 ± 4.5x	43.4 ± 9.9x	49.7 ± 5.3x
	Thrips Only	8.2 ± 1.2x	42.1 ± 10.3x	49.7 ± 11.4x
Genotype Mean		***7.5 ± 2.3a***	***42.1 ± 7.0a***	***50.4 ± 7.2a***
Talon	Healthy Control	4.4 ± 1.9x	26.3 ± 8.7x	69.3 ± 9.0x
	IYSV Only	4.3 ± 0.7x	29.5 ± 4.6x	66.2 ± 4.0x
	Spray	5.2 ± 3.0x	30.2 ± 8.1x	64.5 ± 11.0x
	Thrips+IYSV	2.2 ± 0.8x	30.0 ± 9.9x	67.9 ± 10.6x
	Thrips Only	7.8 ± 2.5x	24.0 ± 6.4x	68.1 ± 7.9x
Genotype Mean		***4.8 ± 1.8b***	***28.0 ± 7.6b***	***67.2 ± 8.5b***

*Genotype means are separated by letters a and b. Genotypes with the same letters within a column are not significantly different at P = 0.05.

**Treatment means are separated by letters x-z within genotypes. Treatments with the same letters in the same column within a genotype are not significantly different at P = 0.05. Treatment comparisons should not be made between genotypes.

Table V.4. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on biomass partitioning pattern of onion cultivars in the plant productivity experiment in 2011.

Genotype*	Treatment**	Root (%) Mean ± SE	Shoot (%) Mean ± SE	Bulb (%) Mean ± SE
Colorado 6	Healthy Control	8.5 ± 2.5x	24.6 ± 2.6x	66.9 ± 4.4x
	Spray	9.4 ± 3.2x	23.7 ± 1.4x	66.9 ± 1.7x
	Thrips Only	8.8 ± 0.3x	27.0 ± 3.2x	64.2 ± 3.5x
	Thrips+IYSV	9.9 ± 1.9x	26.4 ± 6.4x	63.7 ± 6.6x
	IYSV Only	8.7 ± 1.5x	24.7 ± 1.8x	66.6 ± 0.8x
Genotype Mean		***9.0 ± 1.9.0a***	***25.3 ± 3.1a***	***65.6 ± 3.4a***
Salsa Red	Healthy Control	8.8 ± 0.7x	20.3 ± 3.0x	70.9 ± 3.7x
	Spray	9.5 ± 2.1x	19.1 ± 0.6xy	71.4 ± 2.8x
	Thrips Only	13.6 ± 1.1y	27.0 ± 5.3z	59.4 ± 6.1y
	Thrips+IYSV	12.3 ± 2.6y	20.5 ± 3.3xy	67.2 ± 5.9x
	IYSV Only	11.1 ± 1.4xy	24.5 ± 1.9xz	64.5 ± 3.4xy
Genotype Mean		***11.1 ± 1.6b***	***22.3 ± 2.8c***	***66.7 ± 4.4a***
Talon	Healthy Control	6.4 ± 1.9x	15.1 ± 0.4x	78.5 ± 2.3x
	Spray	8.3 ± 0.2xy	18.7 ± 0.9xy	73.1 ± 0.6xy
	Thrips Only	9.3 ± 4.0xy	21.2 ± 8.5y	69.4 ± 11.9y
	Thrips+IYSV	10.4 ± 0.2y	16.6 ± 3.4xy	73.0 ± 3.3xy
	IYSV Only	9.5 ± 0.5xy	16.7 ± 5.1xy	73.8 ± 4.6xy
Genotype Mean		***8.8 ± 1.4a***	***17.7 ± 3.7b***	***73.6 ± 4.5b***

*Genotype means are separated by letters a - c. Genotypes with the same letters within a column are not significantly different at P = 0.05.

**Treatment means are separated by letters x - z within genotypes. Treatment comparisons should not be made between genotypes. Treatments with the same letters within a genotype are not significantly different at P = 0.05.

Table V.5. Percent yield loss due to *Iris yellow spot virus* and onion thrips (*Thrips tabaci)* infection in three onion cultivars.

		Colorado 6		Talon		Salsa Red	
Year	**Treatment**	**Weight (%)***	**Size (%)***	**Weight (%)***	**Size (%)***	**Weight (%)***	**Size (%)***
2010	V	25.8	18.9	0.0	0.0	N/A	N/A
	T	31.6	22. 2	17.0	8.3	N/A	N/A
	TV	59.8	38.3	46.3	18.7	N/A	N/A
2011							
	V	9.0	27.4	17.6	45.6	9.5	34.8
	T	14.5	42.8	16.9	43.0	16.4	47.1
	TV	15.6	42.3	14.1	36.2	17.7	48.2

N/A indicates Salsa Red was not included in the 2010 study.

*Yield loss figures were obtained using the formula $[(HC_{yield} - T_{yield})/HC_{yield}]*100$: where HC is healthy control and T is treatment.

Yield data were obtained from data combined from the plant productivity (1 plant/pot) experiments in 2010 and 2011 (Figures V.25 and V.27).

Plant productivity experiment was not conducted in 2009, hence no yield loss information is provided for 2009.

Figure V.1. Onion seedlings were raised in nursery trays (A) and later transferred to pots at 2 plants/pot and kept in bug dorms (B) in the greenhouse.

Figure V.2. The set of bug dorms used for the greenhouse experiment. Each bug dorm represents a treatment.

Figure V.3. Onion seeds were direct-seeded in 4 liter pots and seedlings (A) were later thinned to 2 plants/pot (B). Note the irrigation stake (yellow arrow in 'B') that supplied water to the plants.

Figure V.4. Using an aspirator, onion thrips were removed from their colonies and transferred to their respective bug dorms (A). After successful virus transmission, insecticides were applied to the IYSV Only treatment to kill off onion thrips (B). The same insecticides were applied to the Spray treatments in 2010-2012.

Figure V.5. The oldest and senesced leaves (yellow arrows) of plants were not included in growth rate assessment using number of leaves/plant.

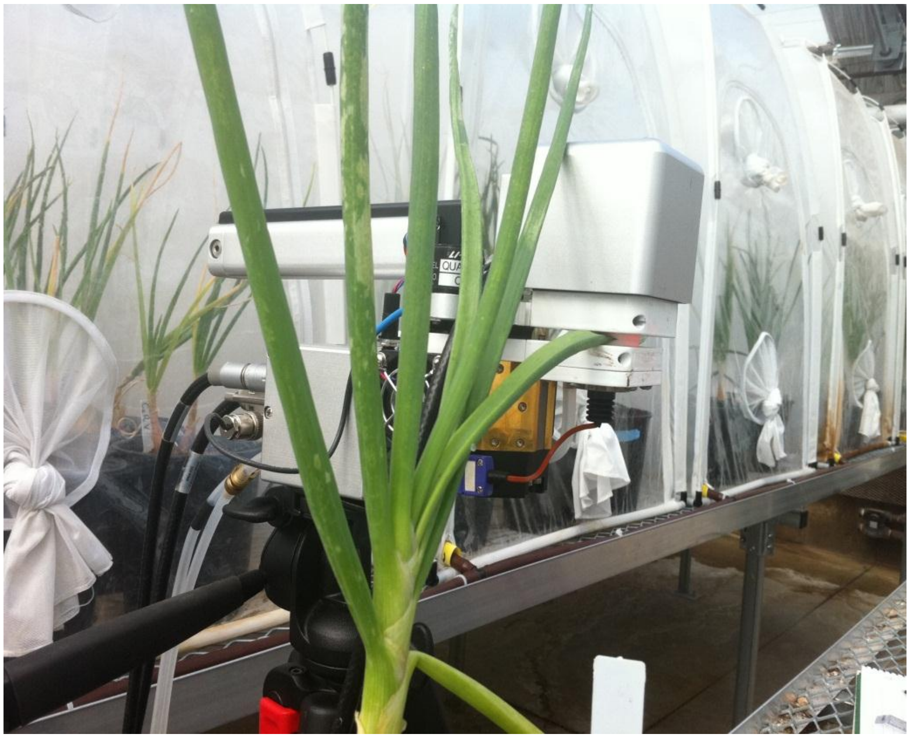

Figure V.6. Gas exchange measurement of an onion plant using a LI-COR 6400 IRGA portable photosynthesis system with an attached leaf fluorometer chamber.

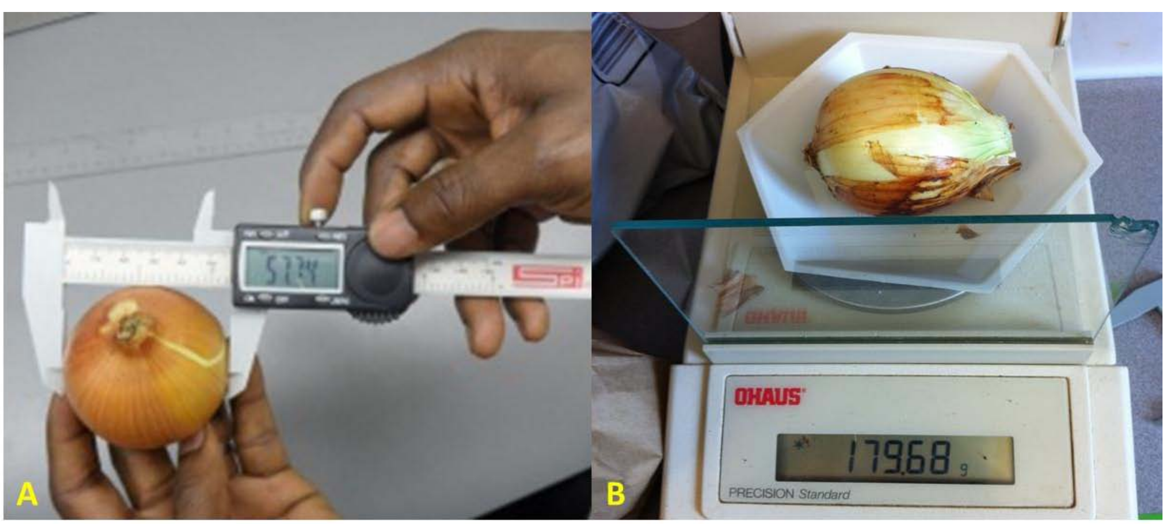

Figure V.7. Size (A) and weight (B) measurements of onion bulbs at harvest.

Figure V.8. At harvest, plants were separated into shoot (not show), bulb and root sections to determine the pattern of biomass partitioning in the plant productivity experiments.

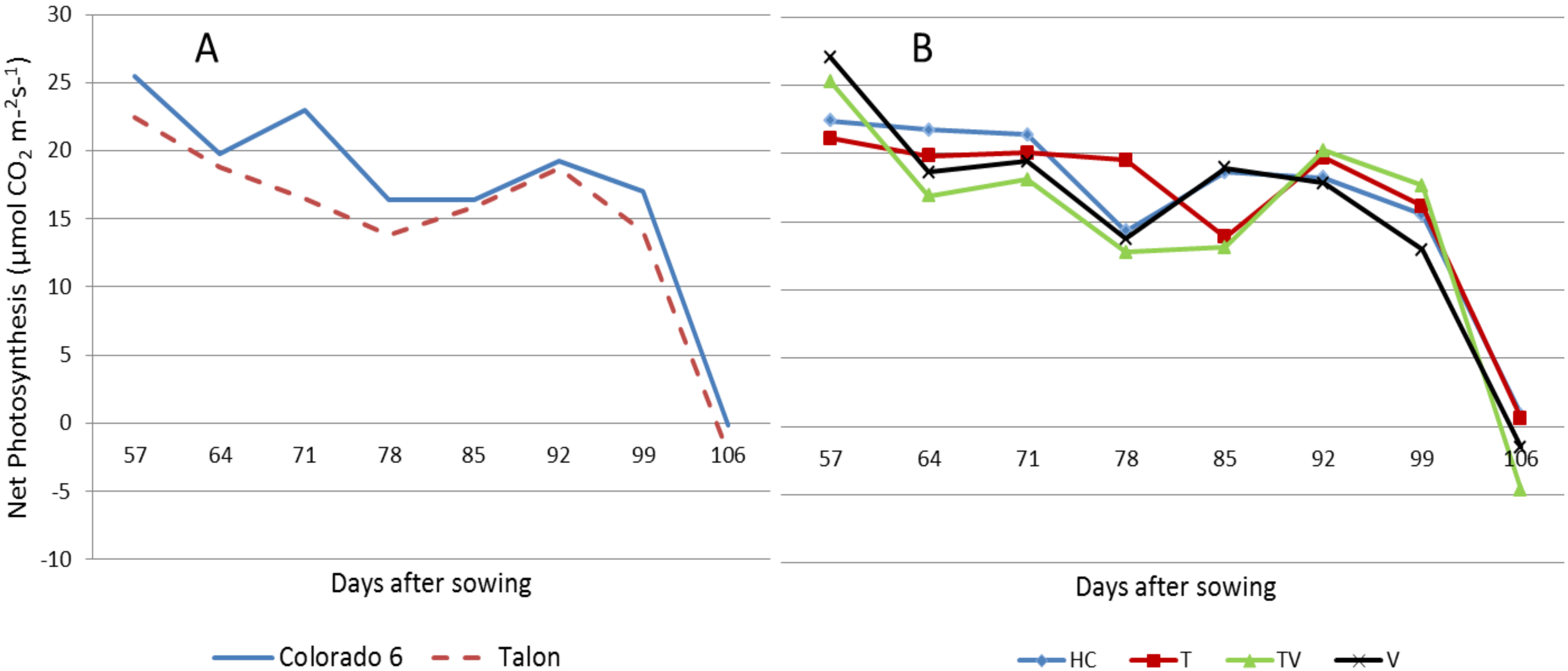

Figure V.9. Net photosynthesis of Colorado 6 and Talon onion cultivars (A) as influenced by four *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) treatments (B) in 2009.

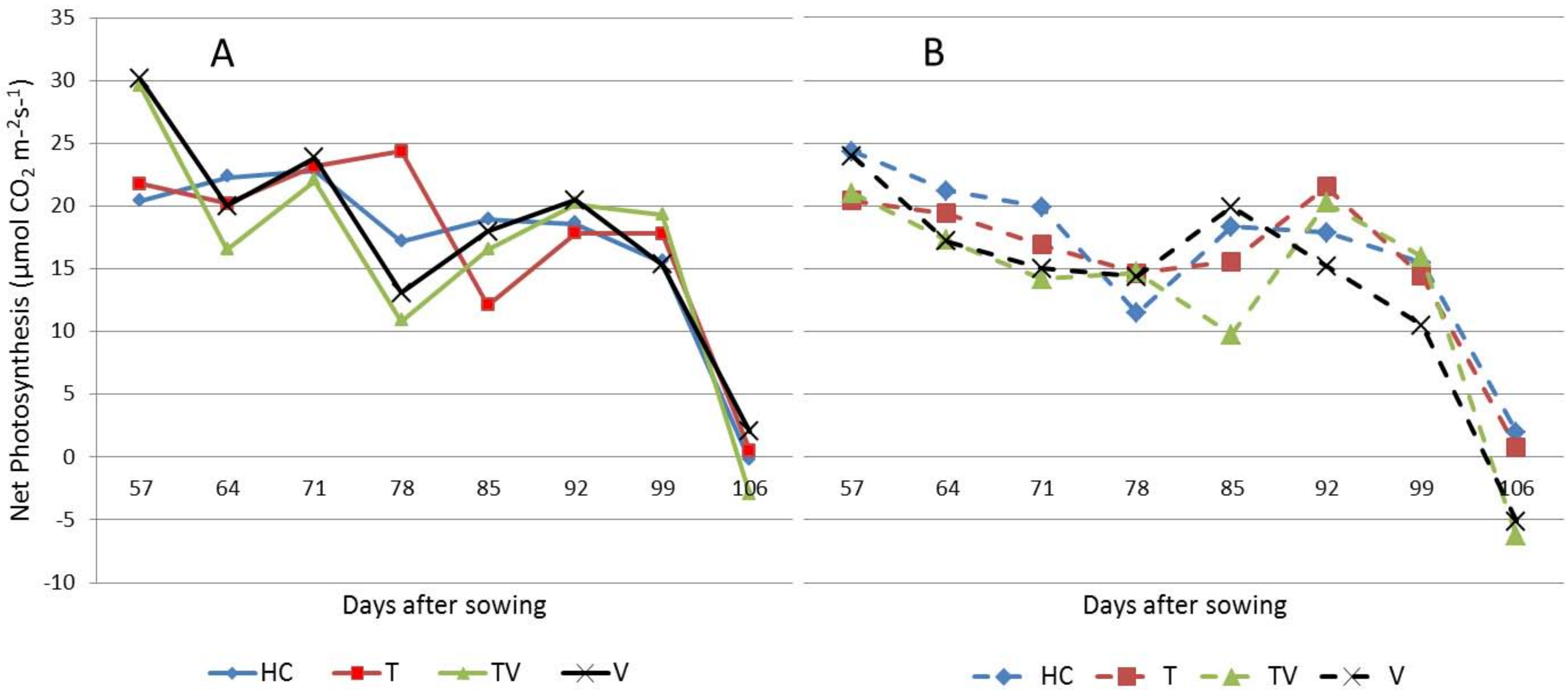

Figure V.10. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on net photosynthesis of Colorado 6 (A) and Talon (B) onion cultivars in 2009.

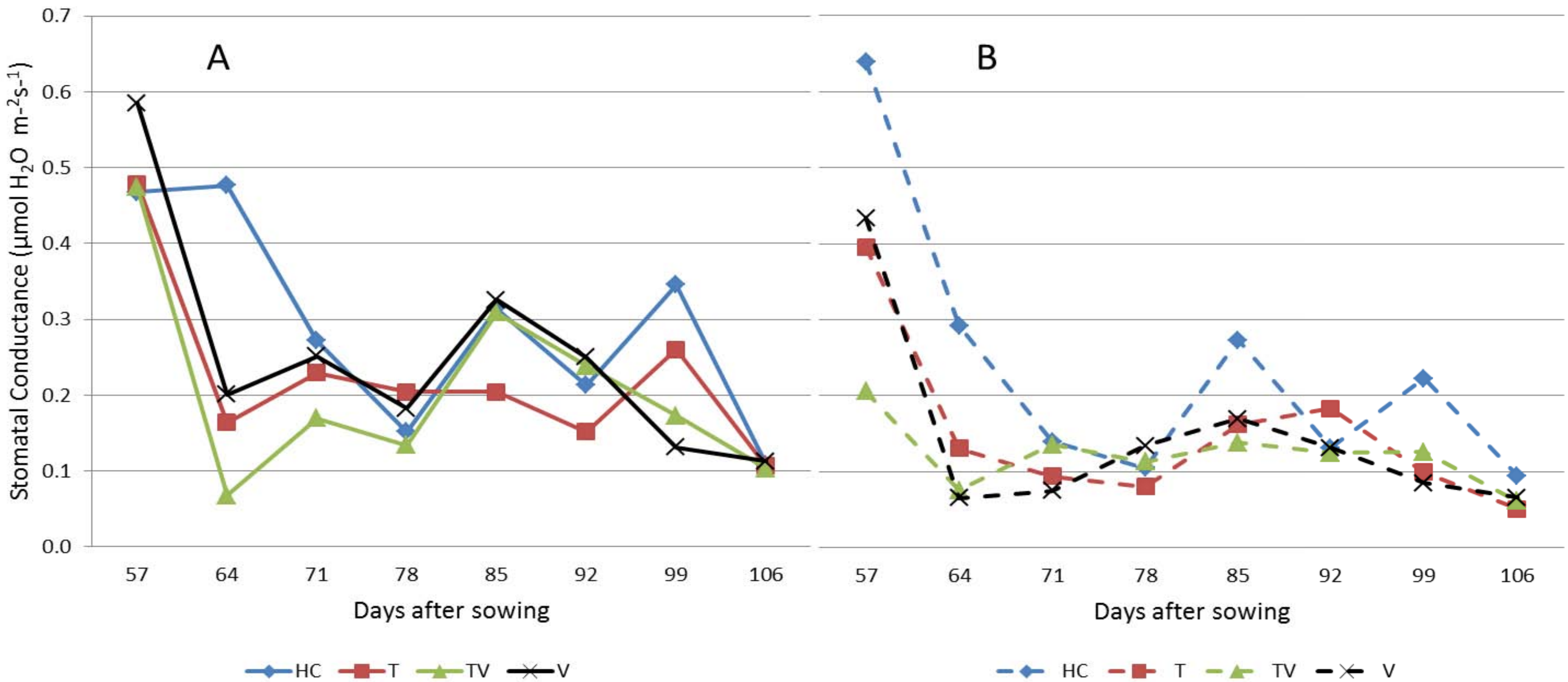

Figure V.11. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on stomatal conductance of Colorado 6 (A) and Talon (B) onion cultivars in 2009.

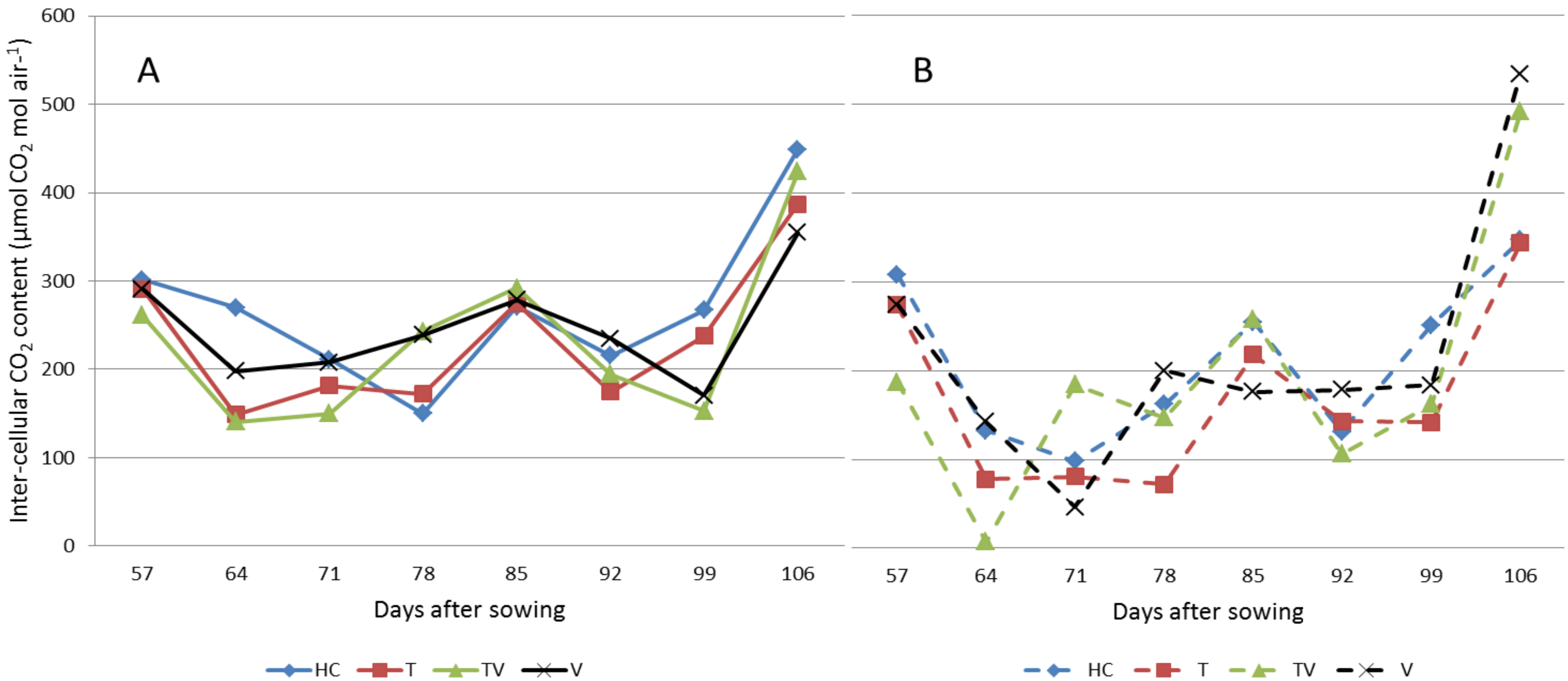

Figure V.12. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on inter-cellular CO_2 content of Colorado 6 (A) and Talon (B) onion cultivars in 2009.

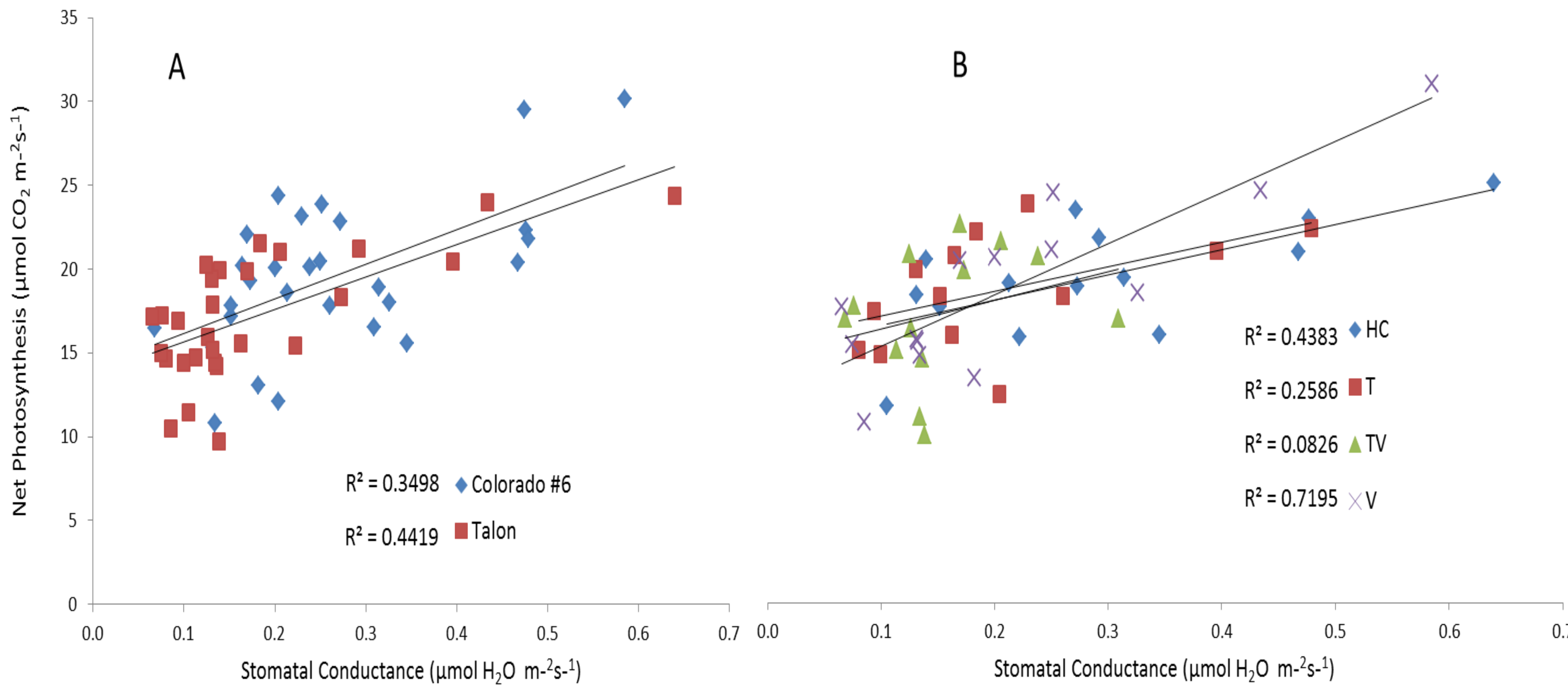

Figure V.13. Relationship between net photosynthesis and stomatal conductance of onion cultivars (A) as influenced by four *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) treatments (B) in 2009.

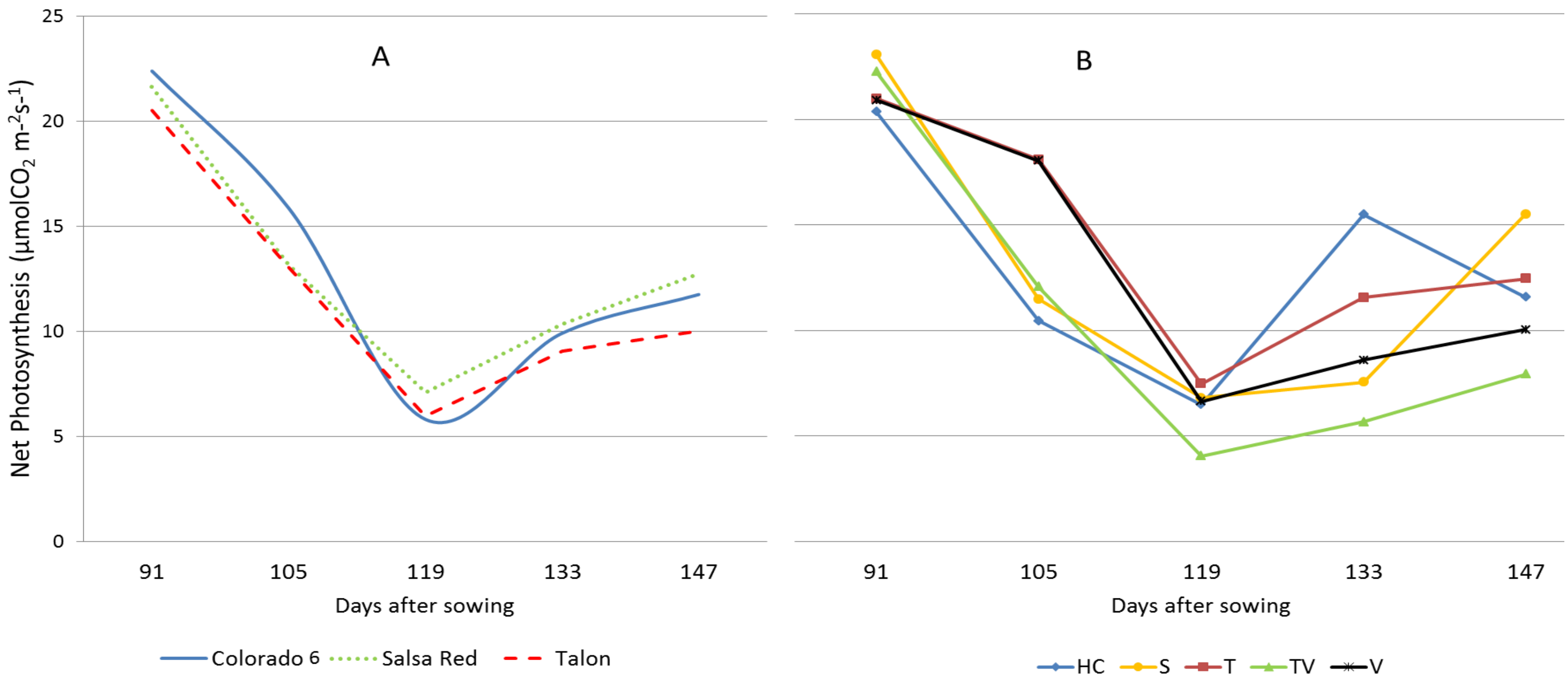

Figure V.14. Net photosynthesis of onion cultivars (A) as influenced by five *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) treatments (B) in 2012.

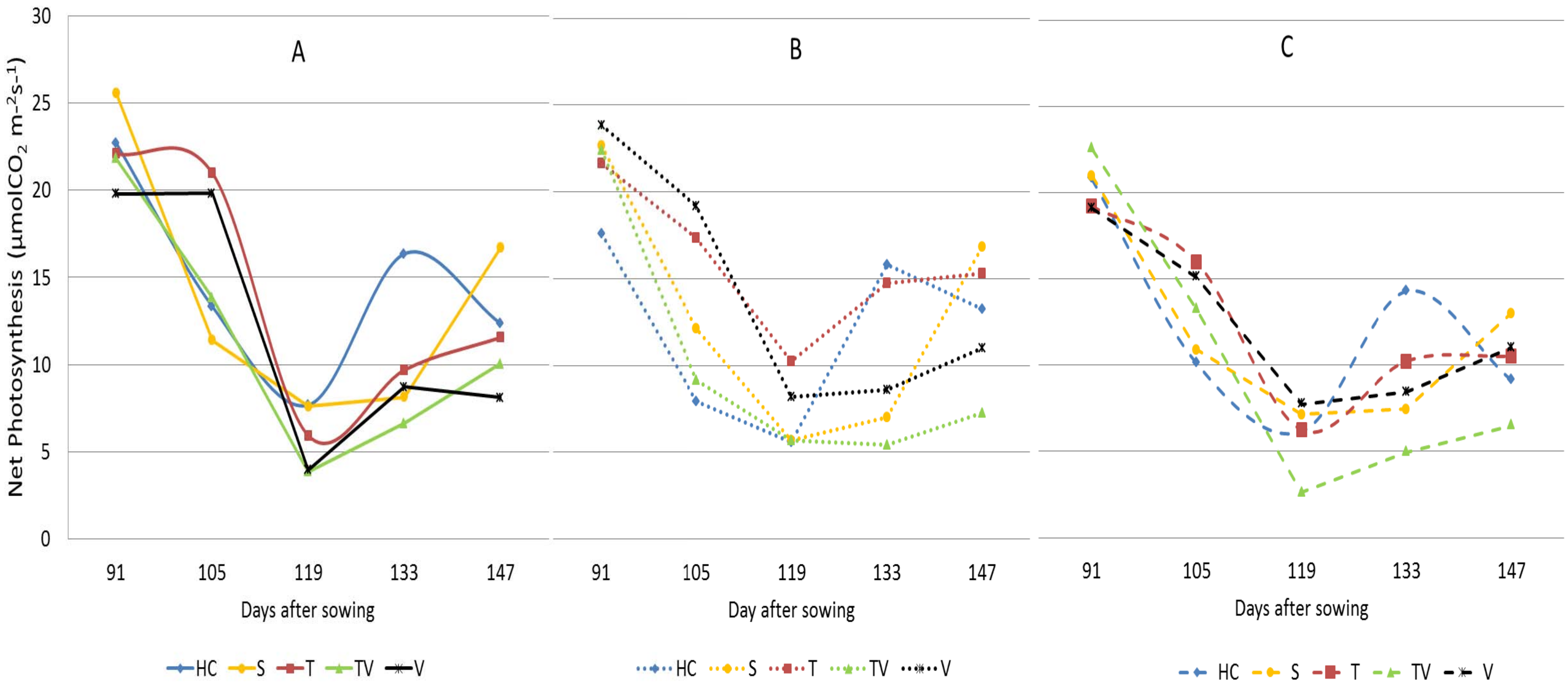

Figure V.15. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on net photosynthesis of Colorado 6 (A), Salsa Red (B) and Talon (C) onion cultivars in 2012.

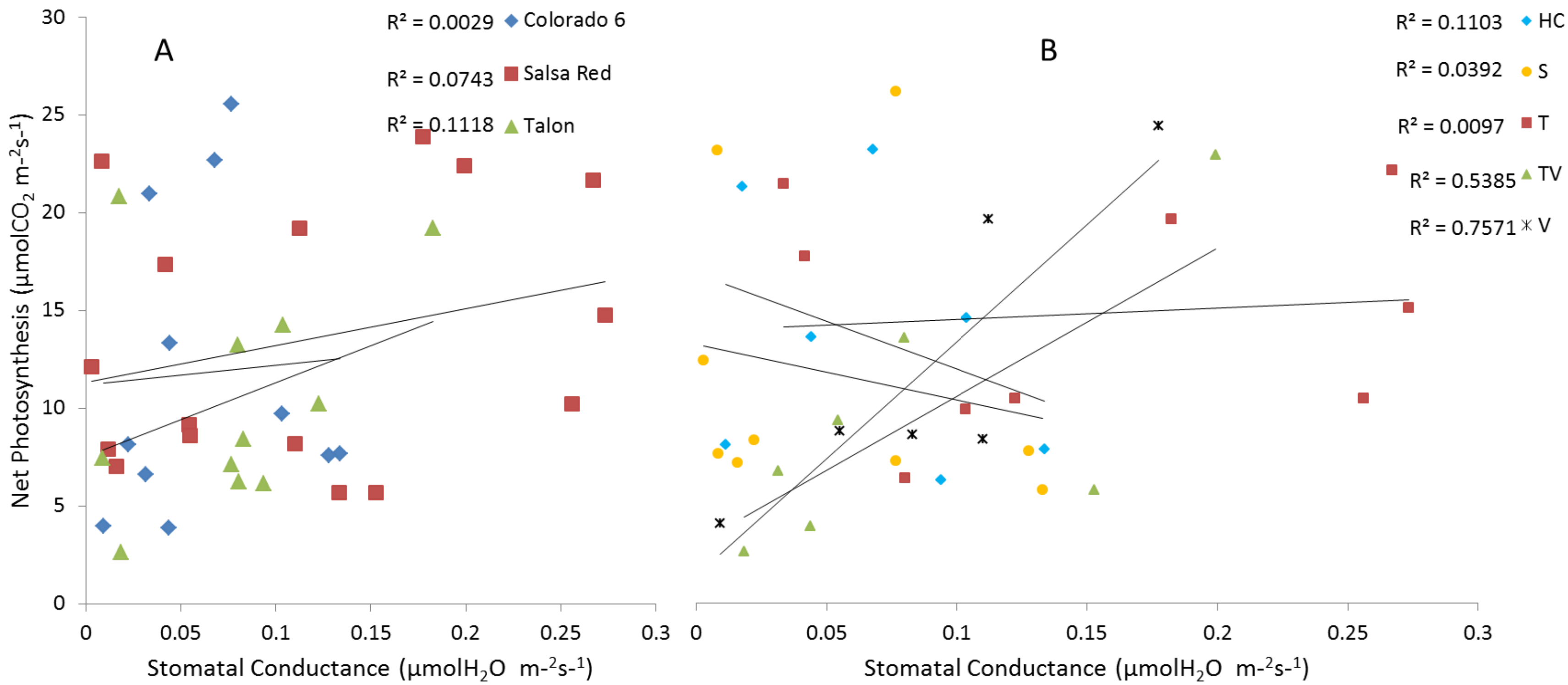

Figure V.16. Relationship between net photosynthesis and stomatal conductance of onion cultivars (A) as influenced by five *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) treatments (B) in 2012.

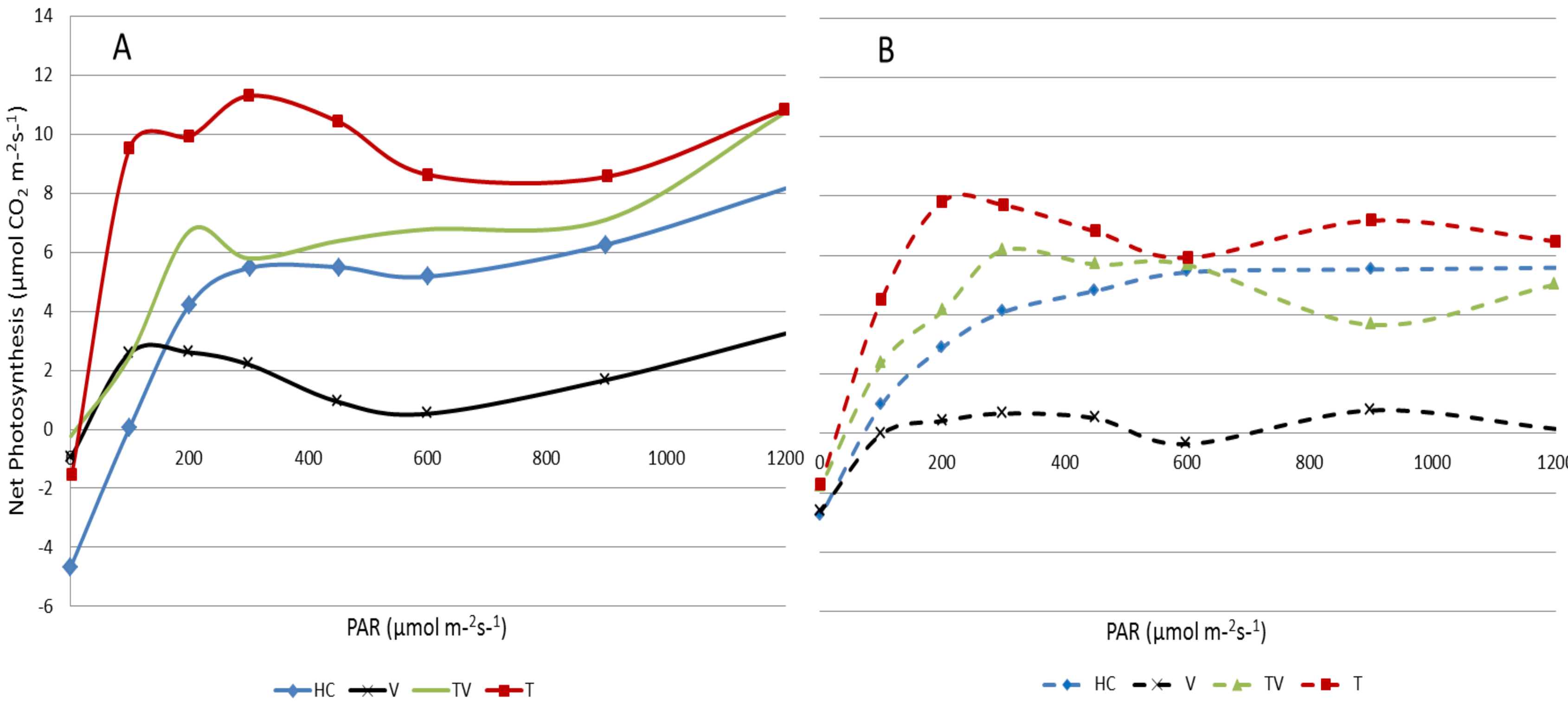

Figure V.17. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on the light response curves of Colorado 6 (A) and Talon (B) onion cultivars in 2009.

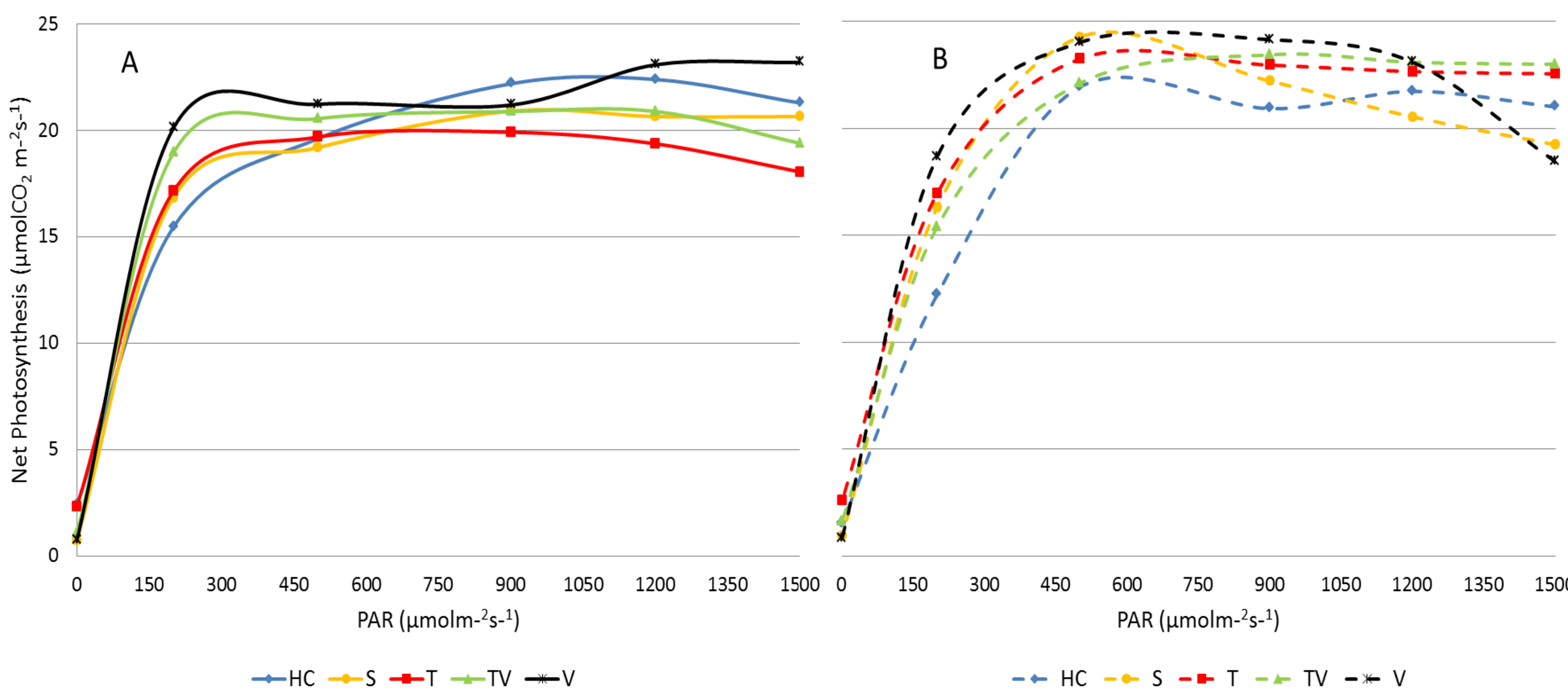

Figure V.18. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on the light response curves of Colorado 6 (A) and Talon (B) onion cultivars at 78 DAS (early season) in 2011.

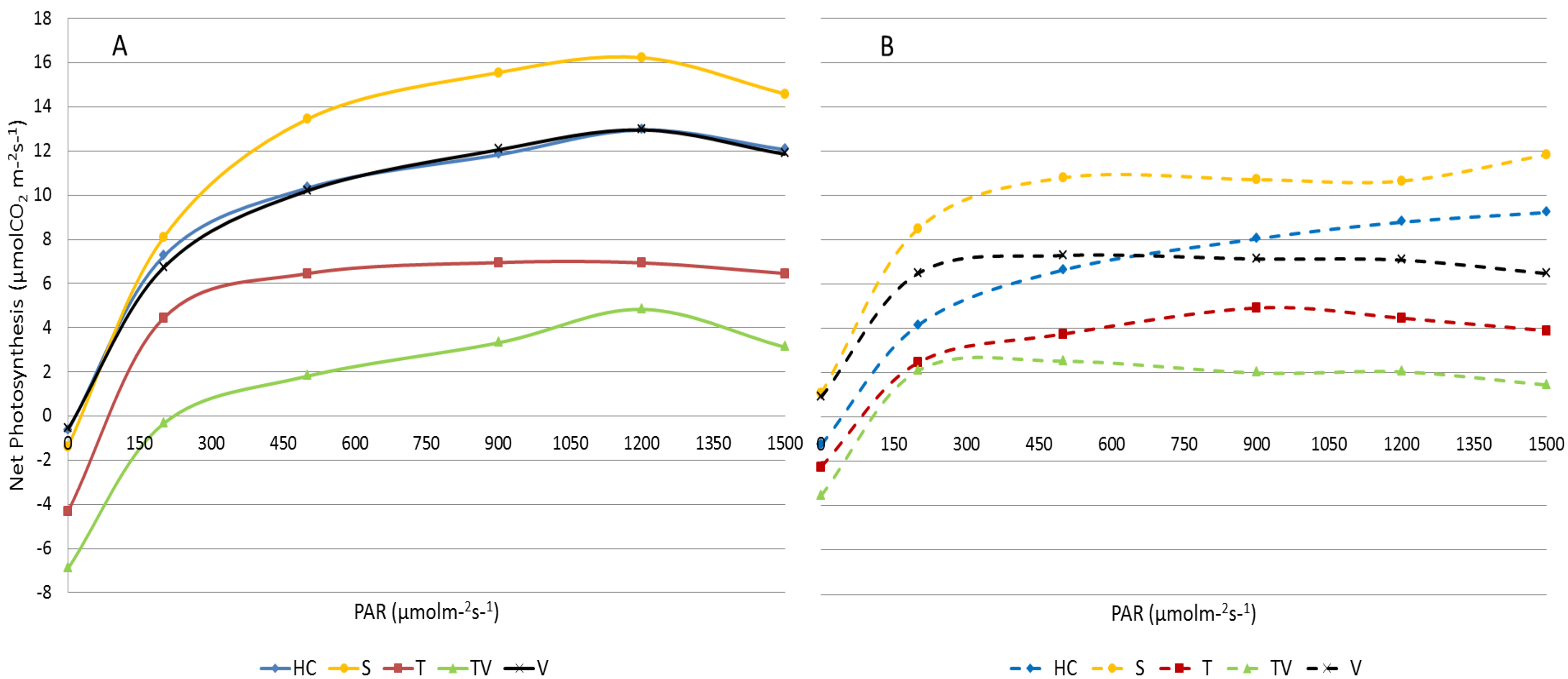

Figure V.19. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on the light response curves of Colorado 6 (A) and Talon (B) onion cultivars at 138 DAS (late season) in 2011.

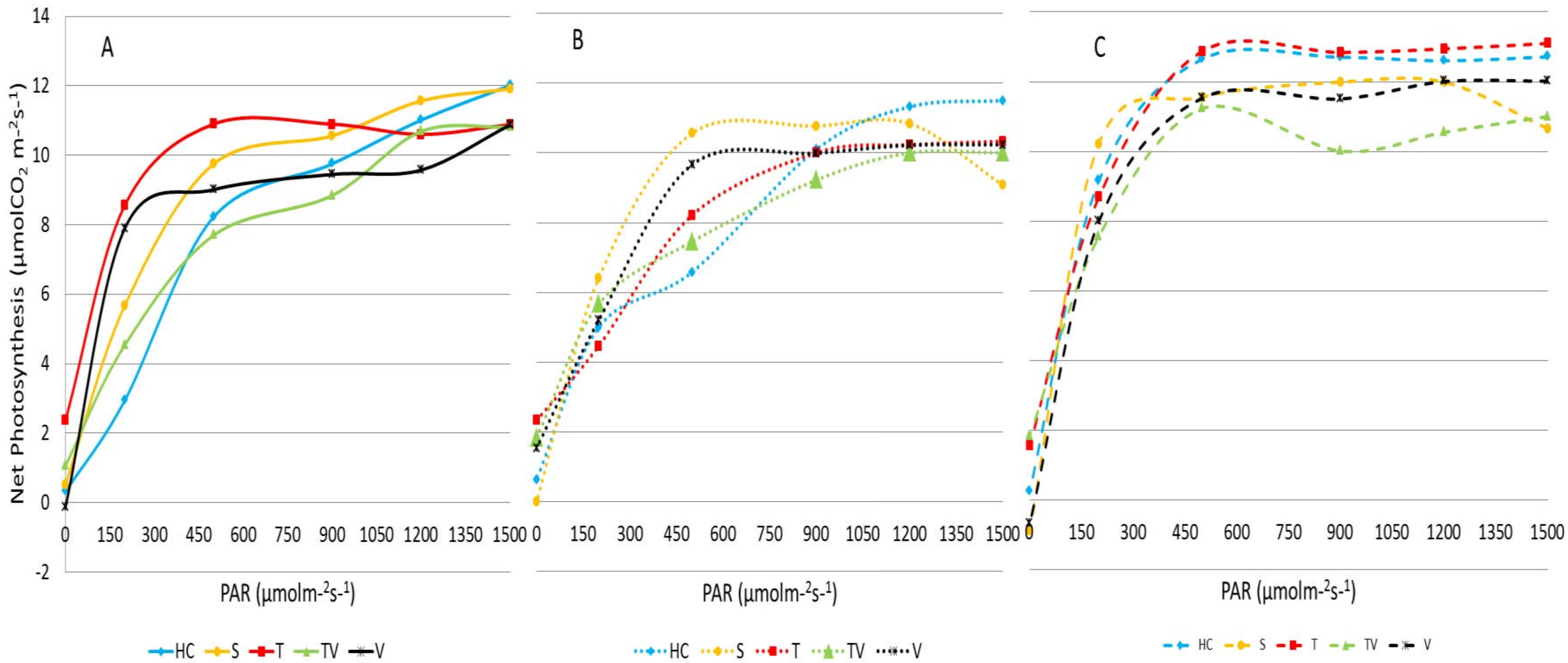

Figure V.20. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on the light response curves of Colorado 6 (A), Salsa Red (B) and Talon (C) onion cultivars at 112 DAS (early season) in 2012.

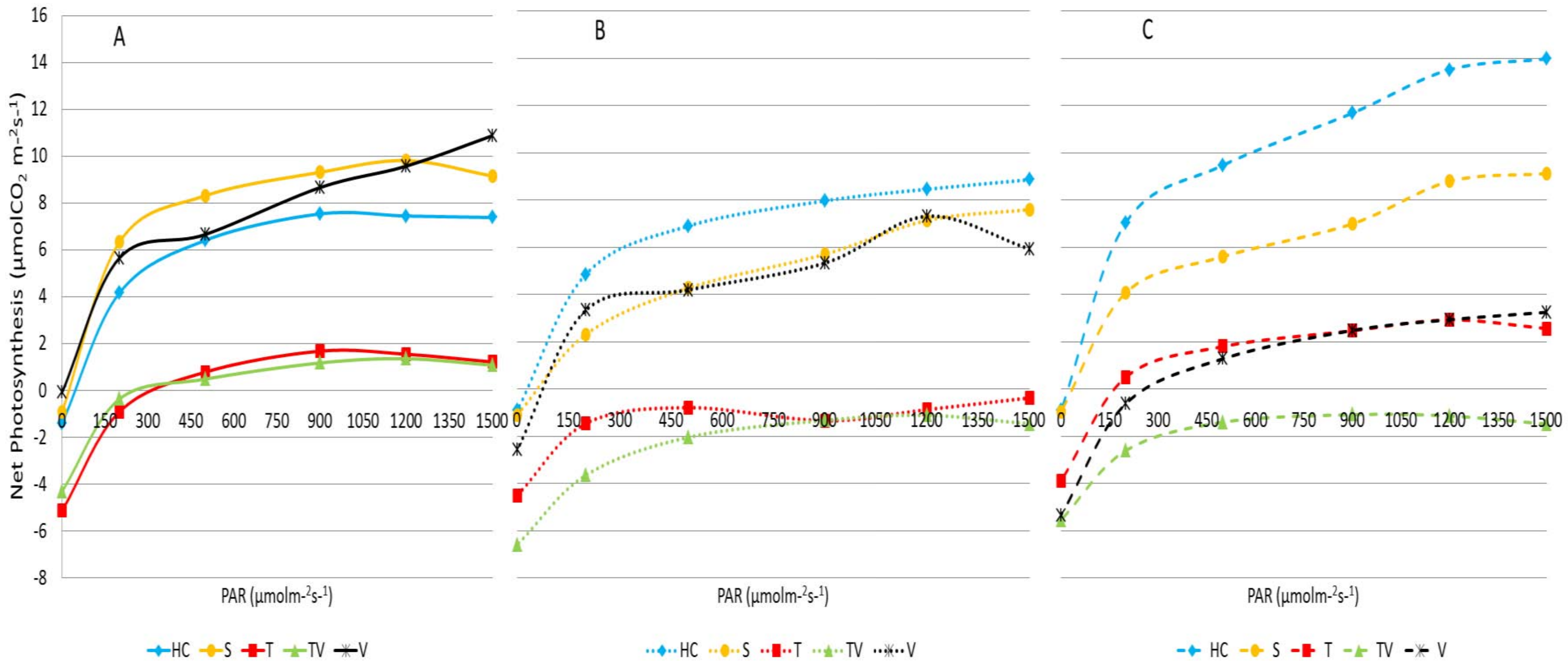

Figure V.21. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on the light response curves of Colorado 6 (A), Salsa Red (B) and Talon (C) onion cultivars at 151 DAS (late season) in 2012.

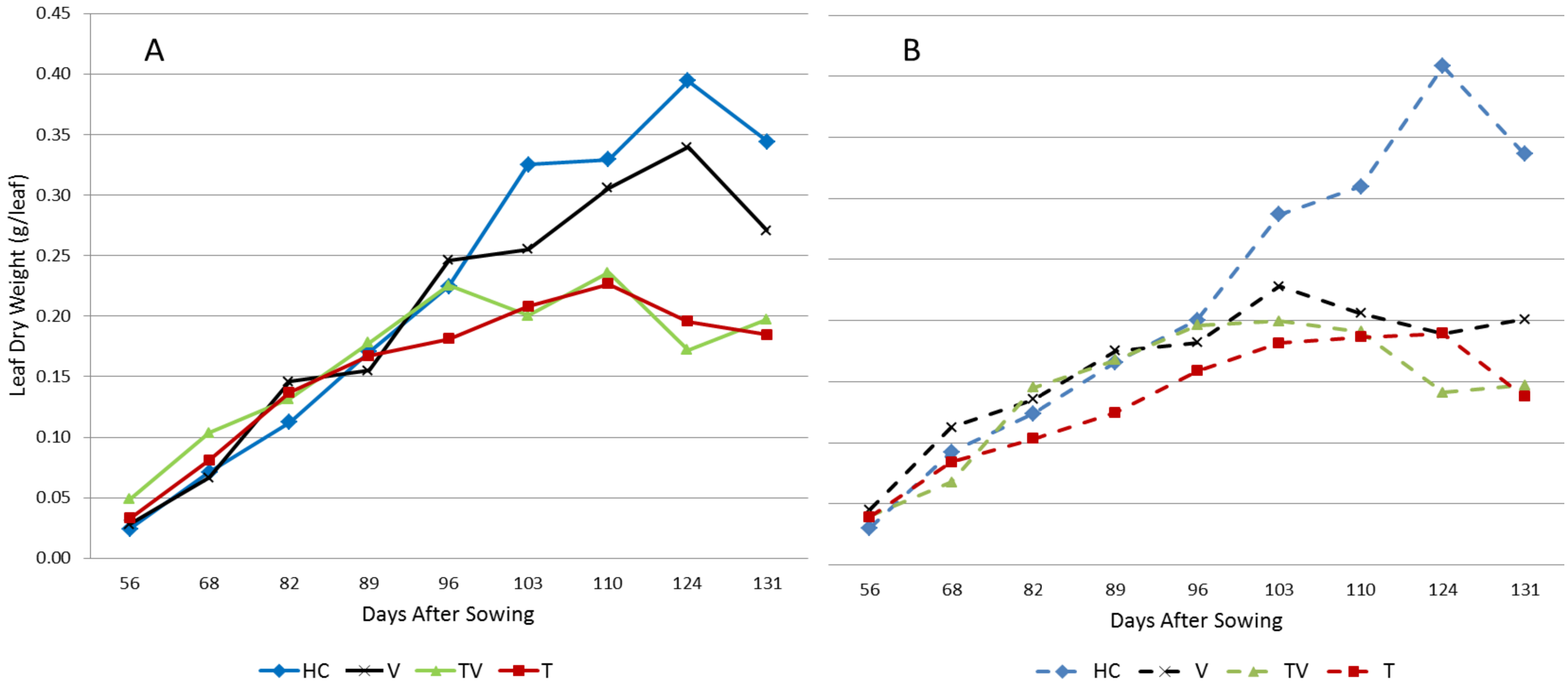

Figure V.22. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on growth rate of Colorado 6 (A) and Talon (B) onion cultivars in 2009.

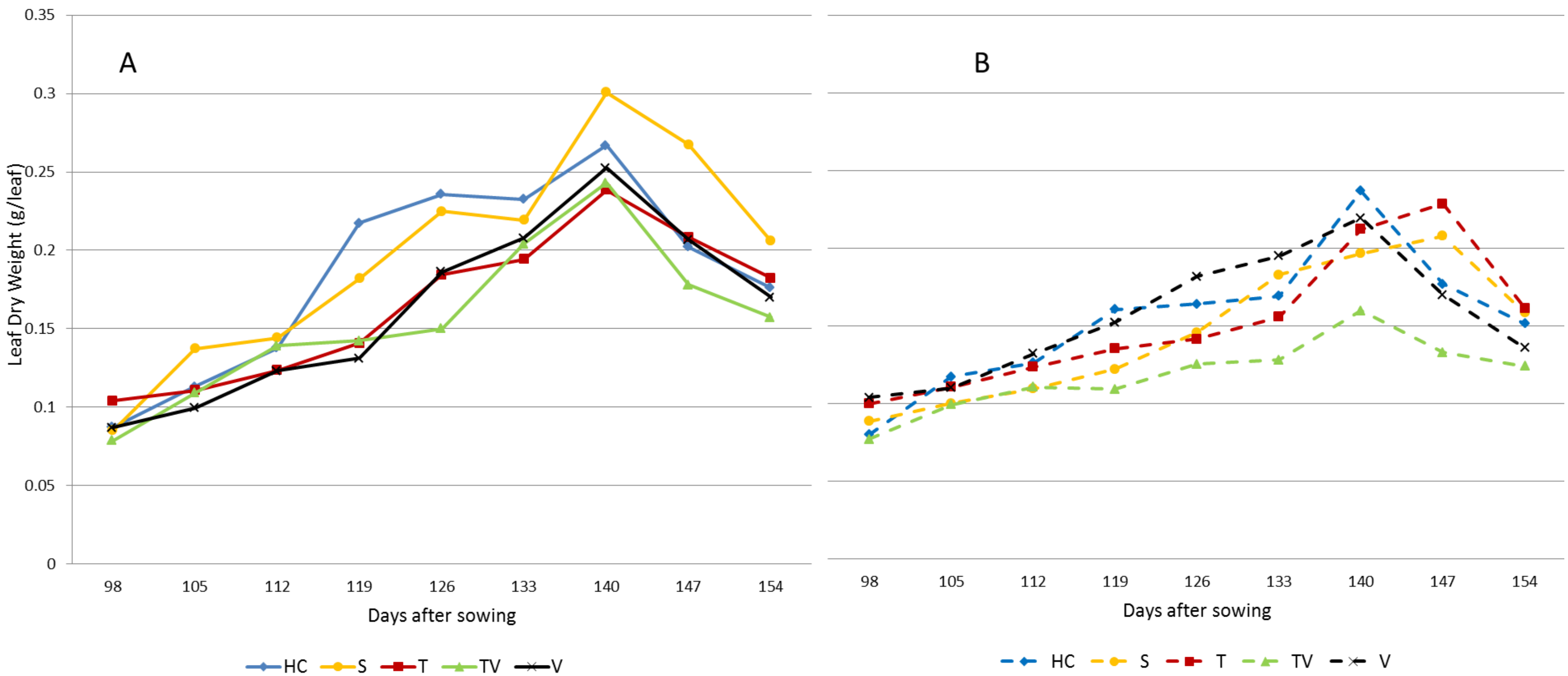

Figure V.23. Effects of *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) on growth rate of Colorado 6 (A) and Talon (B) onion cultivars in the 2011 gas exchange experiment.

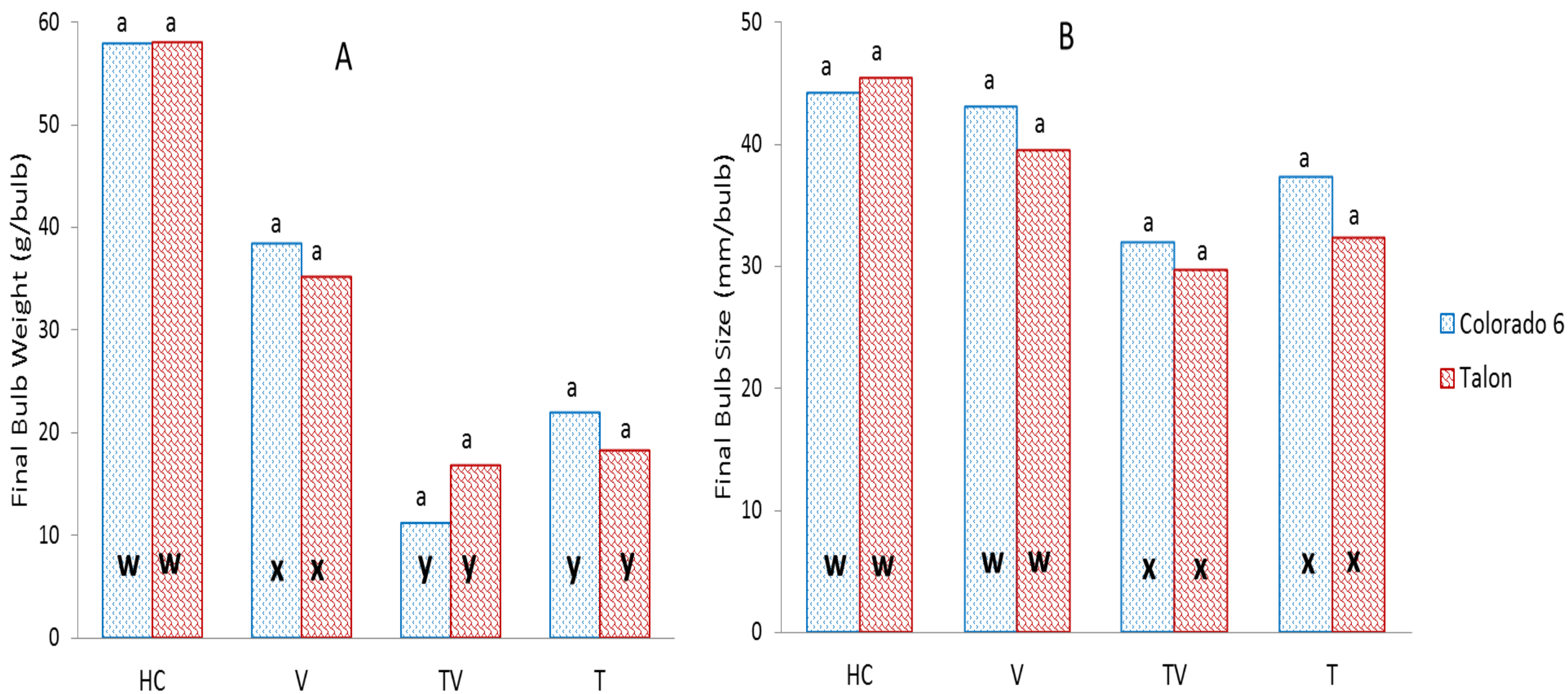

Figure V.24. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on final bulb weight (A) and size (B) of onion cultivars in the gas exchange experiment in 2009. Treatment means are separated by letters w-y. Treatments with the same letter are not significantly different at P = 0.05. Genotype means are separated by letters a and b within treatments. Genotypes with the same letters within a treatment are not significantly different at P = 0.05.

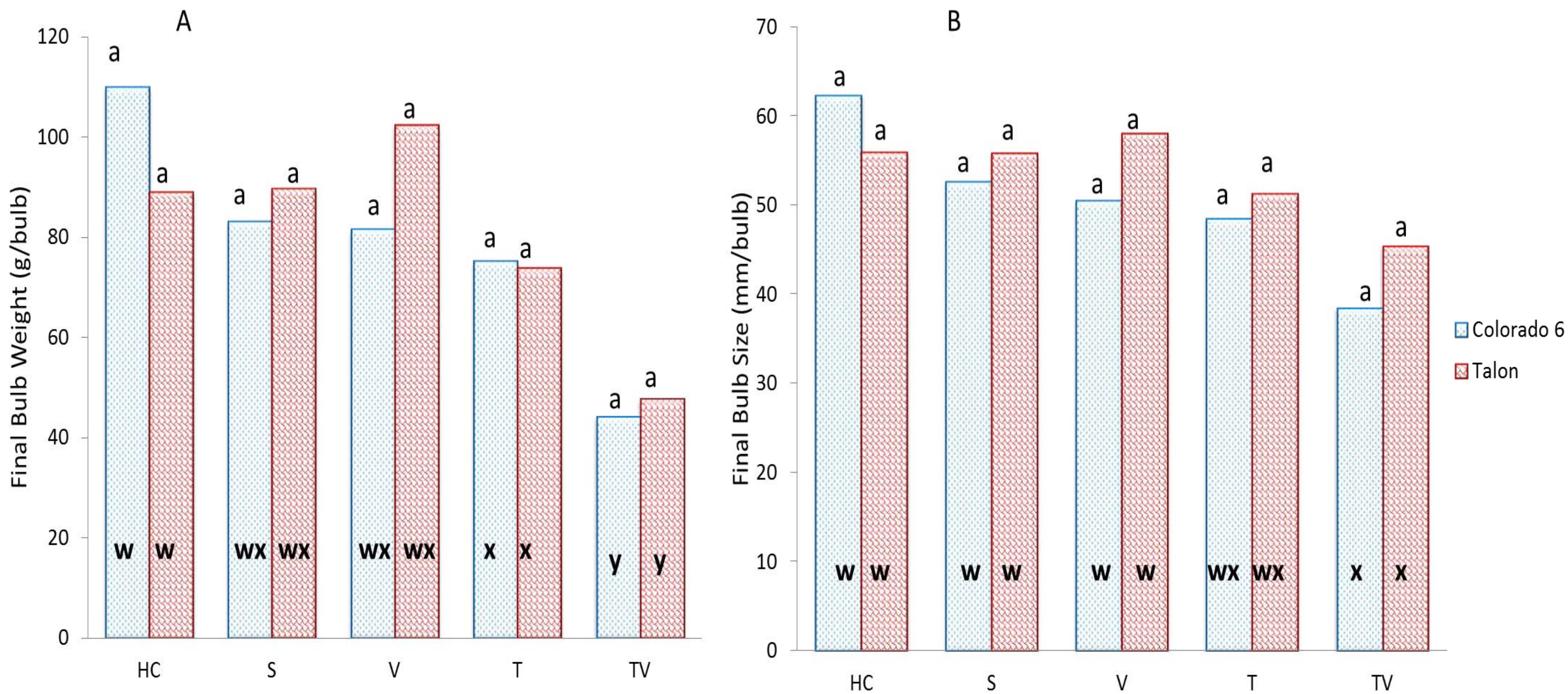

Figure V. 25. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on final bulb weight (A) and size (B) of onion cultivars in the plant productivity experiment in 2010. Treatment means are separated by letters w-y. Treatments with the same letter are not significantly different at P = 0.05. Genotype means are separated by letters a and b within treatments. Genotypes with the same letter within a treatment are not significantly different at P = 0.05.

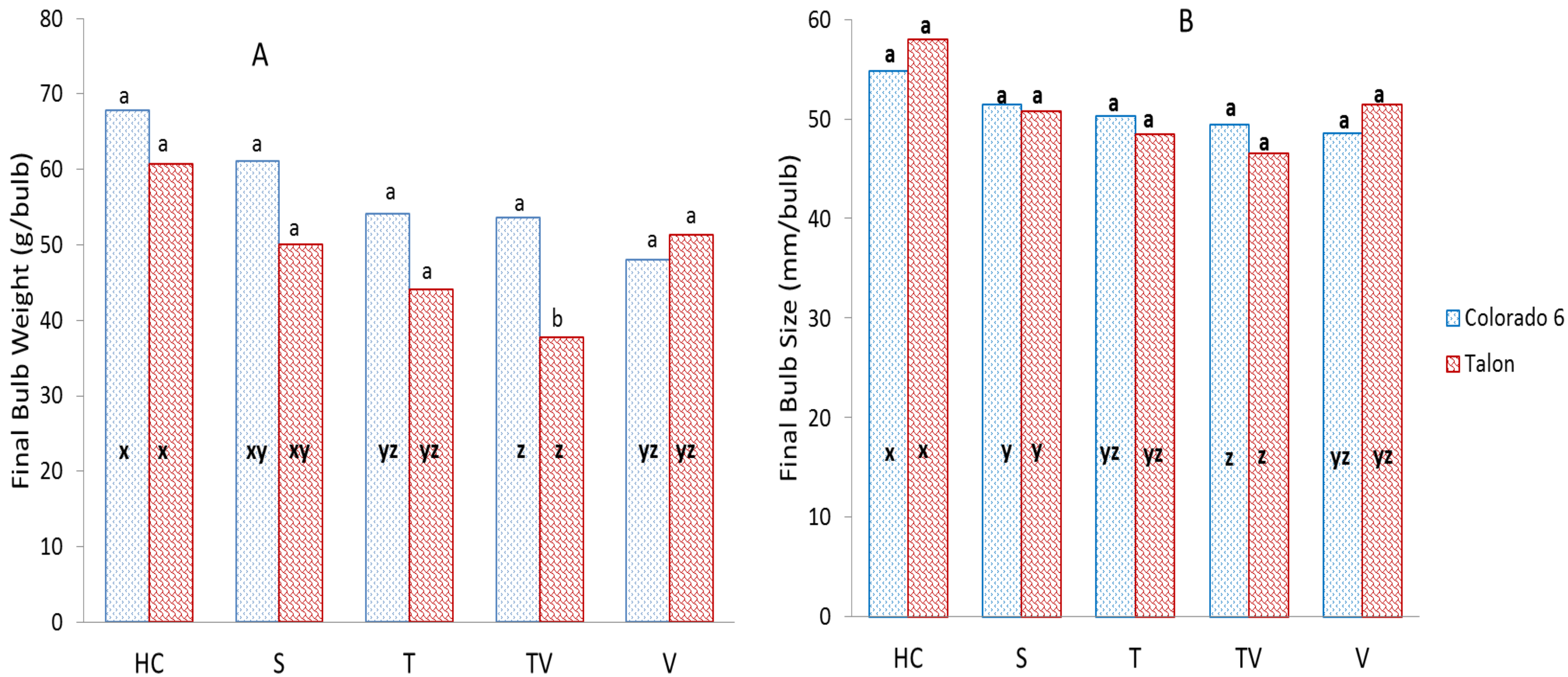

Figure V.26. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on final bulb weight (A) and size (B) of onion cultivars in the gas exchange experiment in 2011. Treatment means are separated by letters x-z. Treatments with the same letter are not significantly different at P = 0.05. Genotype means are separated by letters a and b within treatments. Genotypes with the same letters within a treatment are not significantly different at P = 0.05.

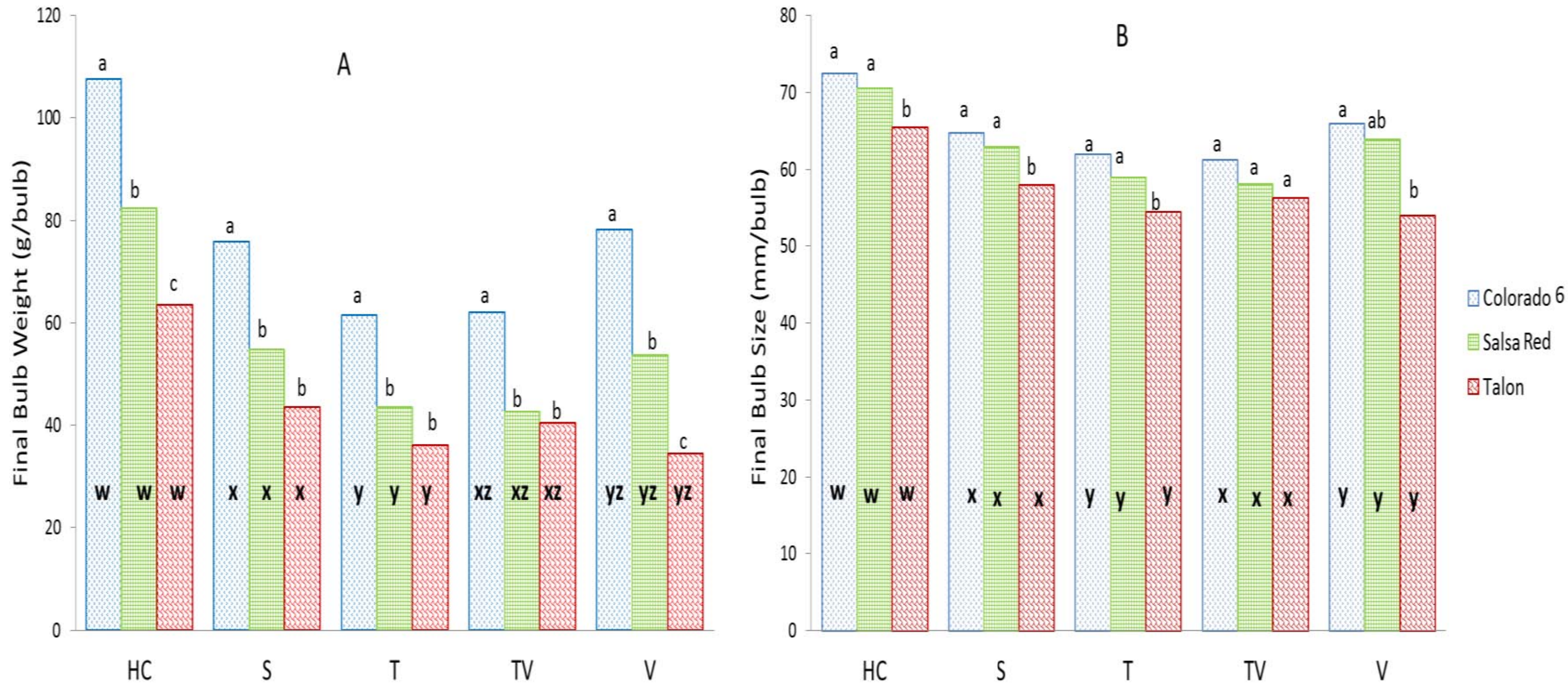

Figure V.27. Effects of *Iris yellow spot virus* and onion thrips (*Thrips tabaci*) on final bulb weight (A) and size (B) of onion cultivars in the plant productivity experiment in 2011. Treatment means are separated by letters w-z. Treatments with the same letter are not significantly different at P = 0.05. Genotype means are separated by letters a-c within treatments. Genotypes with the same letter within a treatment are not significantly different at P = 0.05.

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CHAPTER VI

OVERALL CONCLUSIONS

Onion (*Allium cepa* L.) is the most economically important monocot outside of the grasses. It is the third most valuable vegetable crop in the USA (following only lettuce and tomato), and the second most valuable vegetable in the world (following only tomato). Onion thrips (*Thrips tabaci*), a cosmopolitan and polyphagous insect, infests and damages onion crops grown between sea level and 2,000 m. Its feeding on onion leaves results in the development of silvery leaf spots that turn into white blotches as a result of the removal of mesophyll cell contents. This affects the photosynthetic capabilities of infested leaves and also interferes with the transportation of nutrients to bulbs. In recent years, onion thrips has emerged as the principal vector of the economically important *Iris yellow spot virus* (IYSV, family *Bunyaviridae*), one of only three tospoviruses found in the USA. In bulb onion, IYSV infection causes significant losses in the form of reduced bulb size, significantly reducing the percentage of colossal and jumbo grade bulbs in susceptible cultivars. Total yield losses of 1 - 10% or more are frequently reported in Colorado, whereas losses in individual fields ranged from insignificant to 100% of the crop or its value. No viricide is currently available for controlling IYSV other than partial mitigation by the use of acibenzolar-S-methyl, and conventional insecticides used for controlling onion thrips have become ineffective in most regions due to the development of resistant thrips populations. Any attempt to significantly reduce the economic impact of this pest/pathogen will require a multifaceted approach designed in an IPM framework. Host plant resistance is an important foundation to the success of such approaches, and in an effort to find sources of resistance to IYSV and onion thrips, a multi-state, multi-discipline research effort with the main goal of sustaining U.S. onion production by the identification, validation and delivery of resistance to these pathogens for use by the onion industry was initiated. A large collection of onion germplasms consisting of landraces, advanced breeding lines and commercial cultivars, were evaluated for their response to IYSV and onion thrips in 2009-2011. Evaluation consisted of 137, 104 and 84 germplasms, respectively, in 2009, 2010 and 2011; and was carried out on a research field in northern Colorado, near Fort Collins, which has a history of both IYSV and onion thrips. Germplasms were evaluated for seasonal abundance of onion thrips, percent incidence of IYSV, and severity of infection. Incidence and severity were expressed in terms of relative area under the disease progress curve (rAUDPC), whereas thrips abundance was expressed as cumulative thrips-day value. Sixteen and 18 germplasms, respectively, were selected in 2009 and 2010 for exhibiting acceptable level of tolerance/resistance to the two pests. Of these, five PIs; 258956, 264320, 546140, 546188 and 546192, were selected in both 2009 and 2010 for consistent acceptable responses to IYSV and onion thrips. In 2011, 11 PIs, including two PIs (258956 and 546188) from the 2009 and 2010 evaluations, were selected. Selected germplasms were included as candidates for the onion translational genomics component of this national endeavor.

Greenhouse experiments were carried out in 2009-2012 to study the effects of IYSV and onion thrips on the growth, physiology and productivity of onion. The effects of five treatments; Healthy Control (HC), Spray (S), Thrips Only (T), IYSV Only (V) and Thrips + IYSV (TV), were investigated using IYSV-field resistant Colorado 6, susceptible Talon and susceptible Salsa Red (in 2011 and 2012 only) onion cultivars. Net photosynthesis (*A*) was not significantly different ($P > 0.05$) between cultivars on individual study days in both 2009 and 2012. However, seasonal mean *A* was significantly higher in Colorado 6 than in Talon ($P < 0.0001$) in 2009. In 2012, seasonal mean *A* was significantly higher in Colorado 6 than in Talon ($P < 0.0399$), however, there was no significant difference between Colorado 6 and Salsa Red ($P = 0.6895$) or between Salsa Red and Talon ($P = 0.2324$). Even though there were some significant differences between the treatments on some measurement days, no treatment was consistently higher than the rest throughout the study period, and the overall seasonal mean was not significantly different ($P = 0.4200$) in 2009. In 2012, seasonal mean *A* was significantly different ($P < 0.05$) and was in the decreasing order of T, V, HC, S and TV, with values of 14.5, 13.5, 13.2, 12.2 and 11.0 $\mu molCO_2 m^{-2} s^{-1}$, respectively. The cultivars had similar early season light response curves, however, late season curves were higher in Colorado 6 than in Talon in 2009 and 2010, but not in 2012. There were no significant difference between treatments in early season curves; however, curves were significantly lower in TV, V and T in late season measurements in all cultivars. In both 2009 and 2011, seasonal mean growth rate was significantly higher in Colorado 6 than in Talon ($P < 0.0001$). Among the treatments, seasonal mean growth rate was in the decreasing order of HC, V, TV and T, with all treatments significantly different ($P < 0.001$) in 2009. In 2011, seasonal mean growth rate was in the decreasing order of S, HC, V, T and TV, with values of 0.171, 0.169, 0.159, 0.159 and 0.137 g/week, respectively. There was no significant difference between Colorado 6 and Talon for bulb weight and size in 2009 and 2010. In 2011, bulb weight was significantly higher in Colorado 6 than in Salsa Red and Talon. The treatments were significant different for bulb weight and bulb size in all three years of the study. TV had the lowest yield among the treatments in all cultivars. Biomass partitioning pattern revealed that Talon significantly allocated higher proportion of its total biomass to bulb production than both Colorado 6 and Salsa Red. Yield loss analysis indicated that TV caused the highest losses in all cultivars, with 14-60% yield loss in Colorado 6, 14-46% loss in Talon, and 17-48% loss in Salsa Red.

Seasonal dynamics of IYSV titer in leaves of Colorado 6 and Talon were compared as Healthy Control (HC), IYSV ONLY (V) and Thrips+IYSV (TV) treatments in a greenhouse study of IYSV distribution within onion hosts. Virus titer for both TV and V was consistently higher in Talon than in Colorado 6. Plant leaves, divided into top, middle and base sections, showed that IYSV titer was in the increasing order of middle, top and base sections. Studies of IYSV distribution among and within tissues of naturally infected onion plants from the field revealed that in pre-bulb plants, virus titer increased from Leaf 1 to Leaf 4 after which it declined in subsequent younger leaves. Titer was highest in middle, followed by base, top, and then neck_1 leaf sections. Virus was not detected in dead leaves, bulb scales, basal plates or roots. In post-bulb plants, virus titer distribution was considerably non-uniform, with no apparent trend.

Sources of resistance to IYSV and onion thrips exist in the onion gene pool. The search for this vital tool should continue so that the sustainability of US onion industry through the use of efficient, reliable and environmentally safe IDM strategies may be achieved.

APPENDEXES

Appendix II.A

The tables in this appendix represent all the data collected on each genotype involved in the evaluation study for all three years. Each table is appropriately titled and labeled to describe its contents.

Appendix II.A.1. Leaf growth and development in transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2009.

Genotype	Leaves-71 (mean ±SE)[a]	Leaves-85 (mean ±SE)[a]	Leaves-99 (mean ±SE)[a]	Average (mean ±SE)[a]	Leaf Color (mean ±SE)[b]
124525[x]	7.5 ± 0.8	8.5 ± 0.9	10.1 ± 1.5	8.7 ± 1.1	66.8 ± 0.0
142790[x]	7.1 ± 1.3	8.1 ± 0. 2	8.3 ± 0.2	7.8 ± 0.4	N/A
164361[x]	6.7 ± 0.9	8.0 ± 1.3	11.7 ± 3.1	8.8 ± 1.8	64.3 ± 0.0
164807[x]	6.4 ± 0.5	8.0 ± 0.8	12.4 ± 1.1	8.9 ± 0.8	54.7 ± 0.0
165498[x]	7.4 ± 0.2	8.2 ± 0.1	8.8 ± 0.4	8.1 ± 0.0	68.4 ± 0.0
168962[x]	8.4 ± 1.1	9.9 ± 0.7	10.2 ± 1.5	9.5 ± 0.3	58.0 ± 0.0
168966[x]	9.6 ± 0.1	9.8 ± 0.0	9.8 ± 0.4	9.8 ± 0.1	57.4 ± 0.0
171475[x]	8.6 ± 0.0	9.1 ± 1.3	9.7 ± 0.1	9.1 ± 0.4	61.5 ± 0.0
171477[x]	7.0 ± 0.5	8.6 ± 1.2	9.2 ± 1.2	8.2 ± 1.0	57.0 ± 0.0
172701[x]	6.6 ± 0.4	7.4 ± 1.1	8.1 ± 1.6	7.4 ± 1.1	60.1 ± 0.0
172702[x]	6.5 ± 1.2	7.9 ± 0.7	9.7 ± 1.0	8.0 ± 1.0	68.8 ± 0.1
172703[x]	7.0 ± 0.8	8.9 ± 0.8	11.1 ± 0.7	9.0 ± 0.8	62.8 ± 3.6
172704[x]	7.7 ± 0.3	8.3 ± 0.4	9.2 ± 0.2	8.4 ± 0.3	69.9 ± 0.0
174018[x]	7.7 ± 0.5	9.2 ± 0.6	10.9 ± 1.2	9.3 ± 0.8	68.4 ± 0.0
174024[x]	8.0 ± 0.9	10 ± 1.1	13.2 ± 0.4	10.4 ± 0.8	65.0 ± 0.0
177242[x]	6.0 ± 0.2	8.3 ± 0.8	9.9 ± 0.1	8.0 ± 0.4	58.8 ± 0.0
179164[x]	7.7 ± 0.0	8.9 ± 1.1	9.6 ± 1.1	8.8 ± 0.8	66.7 ± 7.4
179627[x]	8.4 ± 0.0	10.2 ± 0.2	12.7 ± 0.4	10.4 ± 0.1	65.4 ± 1.1
182138[x]	7.6 ± 3.0	7.8 ± 0.6	10.2 ± 0.7	8.6 ± 1.5	62.67 ± 3
183660[x]	6.4 ± 0.6	7.6 ± 0.6	8.9 ± 0.2	7.6 ± 0.4	62.1 ± 1.7
200874[x]	7.7 ± 0.9	8.9 ± 0.5	10.4 ± 1.1	9.0 ± 0.1	65.1 ± 0.0
233186[x]	8.4 ± 0.4	9.5 ± 0.2	11.1 ± 1.1	9.6 ± 0.6	65.7 ± 0.0
246140[x]	7.0 ± 1.1	9.0 ± 0.3	11.6 ± 0.3	9.2 ± 0.4	62.0 ± 1.4
248753[x]	4.8 ± 0.9	5.5 ± 0.4	7.2 ± 0.4	5.8 ± 0.6	65.2 ± 0.6
248754[x]	6.6 ± 1.7	8.6 ± 2.2	10.7 ± 2.5	8.6 ± 2.1	57.7 ± 0.0
249899[x]	7.8 ± 0.4	10.2 ± 0.6	13.0 ± 0.5	10.3 ± 0.5	58.0 ± 0.0
251325[x]	5.3 ± 0.4	7.3 ± 0.1	9.4 ± 0.8	7.3 ± 0.4	65.9 ± 0.0
255557[x]	7.2 ± 0.1	10.0 ± 0.2	13.3 ± 1.5	10.2 ± 0.6	59.1 ± 0.0
256048[x]	4.1 ± 0.4	5.6 ± 0.6	7.7 ± 0.1	5.8 ± 0.4	67.2 ± 0.0
256049[x]	4.9 ± 0.4	6.1 ± 0.4	8.7 ± 1.0	6.6 ± 0.6	70.3 ± 0.0
258956[x]	8.3 ± 0.2	9.8 ± 0.1	12.4 ± 0.0	10.2 ± 0.1	62.2 ± 0.0
264320[x]	8.4 ± 0.2	10.6 ± 0.4	12.9 ± 0.0	10.6 ± 0.0	62.6 ± 0.0
264321[x]	8.9 ± 0.5	10.8 ± 1.3	11.8 ± 1.9	10.5 ± 1.2	64.4 ± 0.0
264631[x]	7.6 ± 0.8	9.8 ± 1.3	12.3 ± 1.2	9.9 ± 1.1	57.5 ± 0.0
264648[x]	8.0 ± 0.1	9.6 ± 0.6	11.5 ± 0.6	9.7 ± 0.4	63.0 ± 0.0
269306[x]	7.0 ± 0.3	9.4 ± 0.6	13.4 ± 0.4	9.9 ± 0.1	64.9 ± 0.0
271039[x]	7.7 ± 0.6	8.8 ± 0.2	10.7 ± 0.4	9.0 ± 0.4	63.8 ± 0.0
273211[x]	7.4 ± 0.8	9.0 ± 0.3	11.3 ± 0.6	9.2 ± 0.6	64.4 ± 0.0

274780[x]	7.0 ± 0.2	8.2 ± 0.6	9.5 ± 1.3	8.2 ± 0.7	66.2 ± 0.0
287540[x]	6.0 ± 0.2	7.1 ± 0.5	8.0 ± 0.4	7.0 ± 0.3	65.4 ± 0.0
288073[x]	7.7 ± 0.4	8.3 ± 0.1	10.4 ± 0.8	8.8 ± 0.1	67.1 ± 0.0
288270[x]	6.1 ± 0.2	7.2 ± 1.2	8.7 ± 2.6	7.3 ± 1.3	68.0 ± 0.0
288272[x]	5.7 ± 1.2	5.8 ± 1.2	6.0 ± 1.1	5.9 ± 1.2	69.7 ± 0.0
288902[x]	5.7 ± 0.0	7.3 ± 0.5	9.0 ± 0.4	7.3 ± 0.3	56.0 ± 0.0
288903[x]	6.9 ± 1.1	10.1 ± 2.1	13.5 ± 2.9	10.2 ± 2.1	60.2 ± 0.0
288908[x]	5.7 ± 0.5	7.0 ± 0.6	9.5 ± 0.4	7.4 ± 0.5	72.0 ± 0.0
288909[x]	8.9 ± 0.3	9.5 ± 0.1	9.4 ± 0.0	9.3 ± 0.1	62.6 ± 0.0
289689[x]	6.4 ± 0.1	6.8 ± 0.7	6.8 ± 0.7	6.7 ± 0.5	72.1 ± 0.0
289690[x]	8.9 ± 0.4	1.00 ± 0.1	11.3 ± 0.8	10.1 ± 0.5	65.7 ± 0.0
293756[x]	6.3 ± 0.1	8.5 ± 0.4	12.5 ± 0.9	9.1 ± 0.2	66.6 ± 0.0
318886[x]	8.4 ± 0.4	9.8 ± 0.0	11.1 ± 0.3	9.7 ± 0.0	57.0 ± 0.0
321385[x]	6.3 ± 0.1	7.9 ± 0.4	11.0 ± 0.6	8.4 ± 0.4	69.4 ± 0.8
342943[x]	6.7 ± 0.0	8.2 ± 0.2	9.4 ± 0.9	8.1 ± 0.4	67.4 ± 1.6
343049[x]	8.6 ± 0.3	9.1 ± 0.6	9.5 ± 1.1	9.1 ± 0.7	60.5 ± 0.0
344392[x]	8.3 ± 0.5	10.4 ± 0.4	11.7 ± 0.1	10.1 ± 0.3	63.7 ± 0.0
391509[x]	7.7 ± 1.1	11.3 ± 2.1	15.6 ± 1.8	11.5 ± 1.7	66.5 ± 0.0
430371[x]	5.1 ± 0.3	4.6 ± 0.2	3.7 ± 0.3	4.5 ± 0.2	N/A
433330[x]	7.0 ± 0.4	8.2 ± 0.1	10.8 ± 0.4	8.7 ± 0.4	65.2 ± 0.0
433332[x]	7.5 ± 0.2	8.5 ± 0.3	10.7 ± 0.4	8.9 ± 0.3	63.9 ± 0.0
546096[x]	6.3 ± 0.1	7.6 ± 0.1	9.4 ± 0.8	7.8 ± 0.2	68.6 ± 0.0
546100[x]	8.3 ± 0.9	9.2 ± 0.7	11.8 ± 0.5	9.8 ± 0.8	70.6 ± 0.0
546101[x]	6.9 ± 1.4	8.9 ± 0.6	11.3 ± 0.7	9.1 ± 0.9	68.3 ± 2.1
546106[x]	6.8 ± 1.3	8.1 ± 0.4	10.1 ± 0.1	8.3 ± 0.6	66.5 ± 6.6
546115[x]	8.7 ± 0.3	10.5 ± 1.3	11.9 ± 1.6	10.4 ± 0.8	58.8 ± 0.4
546140[x]	8.5 ± 0.2	8.4 ± 0.7	8.2 ± 0.5	8.3 ± 0.3	61.5 ± 6.9
546162[x]	7.7 ± 0.8	9.1 ± 0.7	10.7 ± 0.8	9.2 ± 0.8	52.8 ± 0.0
546174[x]	6.0 ± 0.8	8.6 ± 1.2	11.2 ± 1.5	8.6 ± 1.1	60.7 ± 0.0
546188[x]	8.5 ± 0.6	10.1 ± 0.1	12.9 ± 0.2	10.5 ± 0.4	59.8 ± 0.0
546192[x]	7.7 ± 1.8	9.9 ± 0.7	13.1 ± 1.3	10.2 ± 1.3	65.3 ± 0.0
546201[x]	4.5 ± 0.3	6.1 ± 0.3	8.8 ± 0.1	6.5 ± 0.2	68.5 ± 0.0
639911[x]	3.6 ± 1.4	6.9 ± 0.3	9.7 ± 0.0	6.8 ± 0.4	70.7 ± 0.0
639912[x]	6.1 ± 0.0	8.2 ± 0.1	10.2 ± 0.2	8.2 ± 0.1	62.3 ± 0.0
639913[x]	8.4 ± 0.5	9.3 ± 0.0	9.6 ± 0.2	9.1 ± 0.1	64.8 ± 0.0
639914[x]	6.1 ± 0.0	7.4 ± 0.0	10.0 ± 0.0	7.9 ± 0.0	68.1 ± 0.0
639915[x]	8.6 ± 0.2	10.5 ± 1.4	13.3 ± 2.2	10.8 ± 1.3	64.4 ± 1.7
639916[x]	9.2 ± 0.2	11.8 ± 1.1	15.4 ± 1.7	12.1 ± 1.0	63.6 ± 0.0
239633-1[x]	3.5 ± 0.0	5.0 ± 0.0	7.5 ± 0.0	5.3 ± 0.0	76.1 ± 0.0
239633-2[x]	7.5 ± 0.1	10.3 ± 0.8	15.7 ± 1.6	11.2 ± 0.8	64.8 ± 0.9
G32590[x]	7.0 ± 0.0	9.5 ± 0.0	11.5 ± 0.0	9.3 ± 0.0	67.2 ± 0.0
G32787[x]	7.2 ± 1.1	9.8 ± 0.3	12.6 ± 0.1	9.9 ± 0.5	68.6 ± 0.7
x mean	**7.1 ± 0.5**	**8.6 ± 0.6**	**10.6 ± 0.8**	**8.7 ± 0.6**	64.3 ± 0.5

OLYS05N5[y]	6.0 ± 1.3	8.0 ± 0.8	10.9 ± 1.6	8.3 ± 1.2	70.9 ± 0.7
Colorado 6[z]	8.2 ± 0.1	9.4 ± 0.8	12.0 ± 0.9	9.9 ± 0.6	68.4 ± 0.6
Cometa[z]	8.3 ± 1.0	9.7 ± 0.1	11.9 ± 0.6	10 ± 0.6	67.9 ± 0.5
Mt. Blanc[z]	9.1 ± 0.8	10.0 ± 1.0	10.6 ± 1.8	9.9 ± 1.2	63.1 ± 0.0
Salsa Red[z]	9.4 ± 1.8	10.3 ± 0.6	10.5 ± 0.1	10.1 ± 0.4	63.5 ± 0.0
z mean	**8.7 ± 0.9**	**9.8 ± 0.7**	**11.2 ± 0.8**	**9.9 ± 0.7**	**65.7 ± 0.3**
Grand mean	**7.3 ± 0.9**	**8.8 ± 0.7**	**10.9 ± 1.1**	**9.0 ± 0.8**	**67.0 ± 0.5**
Tukey's (0.05)	3.4	3.4	4.7	3.4	6.6

[a]Number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken on 99 DAP with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[x]PI line.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

N/A indicates there was no suitable candidate leaf for measurement. This happened if leaves were too thick to fit in the chlorophyll meter.

Appendix II.A.2. Leaf growth and development in directly seeded onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2009.

Genotype	Leaves-71 (mean ±SE)[a]	Leaves-85 (mean ±SE)[a]	Leaves-99 (mean ±SE)[a]	Average (mean ±SE)[a]	Leaf Color (mean ±SE)[b]
EX 16529[y]	5.8 ± 0.9	7.1 ± 0. 4	10.3 ± 0.3	7.7 ± 0.6	73.2 ± 1.8
NUN7606ON[y]	5.9 ± 0.7	6.8 ± 0.6	9.7 ± 1.2	7.4 ± 0.8	67.6 ± 2.7
OLRH08-9[y]	5.3 ± 0.2	6.7 ± 0.4	9.5 ± 0.5	7.1 ± 0.2	63 ± 3.6.0
OLYS03-207[y]	5.6 ± 0.6	7.5 ± 0.4	10.6 ± 1.1	7.9 ± 0.7	65.9 ± 0.1
OLYS03-209[y]	5.4 ± 0.6	6.6 ± 0.2	10.5 ± 0.8	7.5 ± 0.1	68.9 ± 0.4
OLYS05N5[y]	5.4 ± 0.3	6.8 ± 0.4	9.6 ± 0.1	7.2 ± 0.1	68.9 ± 4.9
OLYX00-23[y]	5.9 ± 0.6	7.3 ± 0.1	10.7 ± 0.1	8.0 ± 0.4	63.8 ± 2.5
OLYX06-25[y]	5.4 ± 0.1	7.0 ± 0.5	10 ± 0.8	7.5 ± 0.5	67.5 ± 0.8
y mean	**5.6 ± 0.5**	**7.0 ± 0.4**	**10.1 ± 0.5**	**7.5 ± 0.4**	**67.3 ± 2.1**
Abilene[z]	5.5 ± 0.1	7.6 ± 0.2	10.3 ± 0.4	7.8 ± 0.1	66.7 ± 1.5
Arcero[z]	5.6 ± 0.3	7.2 ± 0.6	9.6 ± 0.3	7.5 ± 0.4	67.1 ± 4.7
Calibra[z]	5.8 ± 0.9	7.1 ± 0.2	10.8 ± 0.3	7.9 ± 0.2	62.1 ± 3.7
Charismatic[z]	5.0 ± 0.0	6.4 ± 0.5	8.9 ± 0.4	6.7 ± 0.3	67.0 ± 2.7
Colorado 6[z]	5.2 ± 0.5	7.0 ± 0.3	10.2 ± 0.6	7.4 ± 0.3	69.1 ± 5.1
Cometa[z]	5.3 ± 0.1	6.7 ± 0.4	9.2 ± 1.0	7.0 ± 0.4	67.1 ± 5.5
Crockett[z]	5.8 ± 0.1	7.2 ± 0.6	10.7 ± 0.3	7.9 ± 0.4	69.5 ± 0.8
Damascus[z]	6.0 ± 0.5	7.2 ± 0.5	10.1 ± 1.1	7.7 ± 0.7	67.5 ± 1.2
Delgado[z]	5.9 ± 0.4	7.6 ± 0.1	11.1 ± 0.5	8.2 ± 0.4	64.2 ± 4.9
Denali[z]	5.0 ± 0.4	6.2 ± 1.2	8.2 ± 1.3	6.5 ± 0.9	69.7 ± 2.5
Desperado[z]	5.4 ± 0.8	6.9 ± 0.7	10.2 ± 0.9	7.5 ± 0.8	63.6 ± 0.4
Granero[z]	5.5 ± 0.3	7.1 ± 0.4	10.4 ± 0.1	7.7 ± 0.1	67.9 ± 2.0
Gunnison[z]	5.6 ± 0.1	7.2 ± 0.5	10.3 ± 0.5	7.7 ± 0.4	65.8 ± 3.8
Harmony[z]	5.3 ± 0.7	7.0 ± 0.4	10.1 ± 0.7	7.4 ± 0.6	66.3 ± 0.4
Joaquin[z]	5.4 ± 0.0	6.7 ± 0.0	10.2 ± 0.0	7.4 ± 0.0	69.0 ± 0.0
Legand[z]	5.0 ± 0.4	7.3 ± 0.9	10.1 ± 0.1	7.5 ± 0.5	63.2 ± 3.4
Marquett[z]	6.0 ± 0.2	7.4 ± 0.4	10.5 ± 0.1	7.9 ± 0.3	60.2 ± 5.6
Mesquite[z]	5.3 ± 0.0	6.8 ± 0.4	9.8 ± 0.7	7.3 ± 0.4	65.5 ± 4.9
Milestone[z]	5.5 ± 0.0	7.4 ± 0.0	9.8 ± 0.0	7.5 ± 0.0	63.8 ± 2.1
Monarcho[z]	5.5 ± 0.1	7.2 ± 0.4	9.7 ± 0.2	7.4 ± 0.3	67.8 ± 0.6
Montero[z]	5.5 ± 0.3	7.2 ± 0.2	10.3 ± 1.2	7.6 ± 0.4	69.8 ± 1.9
Oro Blanco[z]	5.8 ± 0.6	7.6 ± 0.5	11.6 ± 0.4	8.3 ± 0.1	67.0 ± 0.9
Ovation[z]	5.6 ± 0.6	7.7 ± 0.1	10.5 ± 0.3	8.0 ± 0.4	66.8 ± 1.3
Pulsar[z]	5.0 ± 0.3	6.3 ± 0.8	9.7 ± 0.8	7.0 ± 0.6	61.1 ± 0.3
Ranchero[z]	5.7 ± 0.3	7.2 ± 0.0	10.4 ± 0.2	7.7 ± 0.0	71.4 ± 1.5
Red Bull[z]	5.5 ± 0.7	7.4 ± 0.2	10.3 ± 0.2	7.7 ± 0.4	66.9 ± 2.4

Red Flare[z]	5.3 ± 0.4	6.9 ± 0.3	10.3 ± 0.8	7.5 ± 0.5	67.8 ± 3.5
Red Wing[z]	6.2 ± 0.2	7.5 ± 0.2	10.3 ± 0.2	8.0 ± 0.1	67.3 ± 2.3
Ruby Ring[z]	5.4 ± 0.3	6.5 ± 0.6	9.6 ± 0.4	7.1 ± 0.4	65.7 ± 0.1
Salsa Red[z]	5.5 ± 0.5	7.0 ± 0.1	9.5 ± 0.9	7.3 ± 0.6	62.4 ± 0.8
Sarape Café[z]	5.5 ± 0.2	6.9 ± 0.1	9.9 ± 0.2	7.4 ± 0.1	62.7 ± 4.0
Sedona[z]	5.8 ± 0.4	7.5 ± 0.4	10.7 ± 0.2	8.0 ± 0.1	66.1 ± 1.0
Sp. Medallion[z]	5.8 ± 0.1	7.4 ± 0.1	11.2 ± 0.1	8.1 ± 0.1	68.8 ± 4.1
Swale[z]	5.3 ± 0.1	6.8 ± 0.9	9.8 ± 1.3	7.3 ± 0.8	68.1 ± 6.2
T-433[z]	4.9 ± 0.1	6.5 ± 0.1	9.5 ± 0.5	7.0 ± 0.2	65.6 ± 1.1
Talon[z]	6.3 ± 0.2	8.0 ± 0.2	11.3 ± 0.8	8.5 ± 0.3	67.9 ± 0.8
Tamara[z]	5.3 ± 1.1	7.3 ± 0.0	10.5 ± 0.7	7.7 ± 0.6	62.7 ± 1.2
Tequila[z]	5.4 ± 0.3	7.3 ± 0.8	10.4 ± 1.5	7.7 ± 0.9	67.2 ± 1.5
Tioga[z]	4.9 ± 0.1	6.8 ± 0.8	9.9 ± 0.2	7.2 ± 0.2	64.6 ± 0.5
Vantage[z]	5.8 ± 0.4	7.6 ± 0.4	10.7 ± 1.3	8.0 ± 0.6	67.8 ± 8.3
Vaquero[z]	5.3 ± 0.6	7.0 ± 0.1	10.1 ± 0.2	7.5 ± 0.4	68.8 ± 3.5
Vision[z]	5.4 ± 0.3	7.1 ± 0.6	10.1 ± 0.1	7.5 ± 0.3	62.2 ± 0.1
White Cloud[z]	5.7 ± 0.4	7.6 ± 0.0	10.4 ± 0.3	7.9 ± 0.2	67.2 ± 2.0
White Wing[z]	6.1 ± 0.3	7.6 ± 0.4	11.0 ± 0.8	8.2 ± 0.2	63.5 ± 3.0
z mean	**5.5 ± 0.3**	**7.1 ± 0.4**	**10.2 ± 0.5**	**7.6 ± 0.4**	**66.2 ± 2.5**
Grand mean	**5.6 ± 0.4**	**7.1 ± 0.4**	**10.1 ± 0.5**	**7.6 ± 0.4**	**66.8 ± 2.3**
Tukey's (0.05)	1.9	2.0	2.9	1.9	13.1

[a]Number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken on 118 DAS with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.3. Leaf growth and development in transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2010.

Genotype	**Leaves-64** (mean ± SE)[a]	**Leaves-77** (mean ± SE)[a]	**Leaves-90** (mean ±SE)[a]	**Leaves-106** (mean ±SE)[a]	**Average** (mean ±SE)[a]	**Leaf Color**[c] (mean ±SE)[b]	**Leaf Color**[d] (mean ±SE)[b]
124525[x]	4.4 ± 0.5	4.6 ± 0.6	4.2 ± 0.5	3.2 ± 0.5	4.1 ± 0.0	62.1 ± 0.9	61.5 ± 1.7
164807[x]	4.7 ± 1.0	6.5 ± 1.1	8.0 ± 1.9	8.4 ± 2.2	6.9 ± 1.6	55.3 ± 0.4	54.7 ± 3.2
165498[x]	5.5 ± 1.1	6.4 ± 1.8	6.5 ± 0.2	5.9 ± 0.4	6.1 ± 0.7	54.3 ± 0.2	55.0 ± 1.0
168962[x]	7.5 ± 0.5	8.8 ± 0. 4	9.9 ± 1.7	9.6 ± 1.3	8.9 ± 0.8	58.8 ± 0.9	57.0 ± 1.0
168966[x]	5.0 ± 0.1	6.9 ± 0.7	10.0 ± 0.1	11.7 ± 0.1	8.4 ± 0.1	55.9 ± 1.0	53.1 ± 4.2
171475[x]	6.5 ± 0.6	7.6 ± 0.5	10.0 ± 0.2	11.1 ± 2.3	8.8 ± 0.3	59.3 ± 1.3	60.8 ± 0.7
171477[x]	4.9 ± 0.0	6.0 ± 0.4	7.5 ± 0.4	7.5 ± 2.0	6.5 ± 0.7	55.3 ± 0.6	54.5 ± 0.4
172701[x]	5.5 ± 0.1	6.3 ± 0.2	7.5 ± 0.0	7.1 ± 0.6	6.6 ± 0.1	58.4 ± 0.3	53.0 ± 0.5
172702[x]	5.5 ± 0.1	6.6 ± 1.2	7.9 ± 3.2	7.5 ± 4.1	6.9 ± 2.2	54.4 ± 2.3	57.5 ± 0.1
172703[x]	5.5 ± 0.2	7.3 ± 0.3	9.3 ± 1.0	9.0 ± 0.3	7.8 ± 0.4	58.2 ± 0.6	57.5 ± 0.2
172704[x]	6.0 ± 0.4	6.7 ± 0.1	7.0 ± 0.1	5.3 ± 0.2	6.2 ± 0.1	59.2 ± 1.7	55.6 ± 0.1
174018[x]	6.1 ± 0.1	7.1 ± 0.0	8.5 ± 0.4	7.5 ± 0.0	7.3 ± 0.1	57.2 ± 1.0	55.4 ± 0.6
174024[x]	6.1 ± 0.3	7.7 ± 0.6	10.0 ± 0.1	10.2 ± 0.6	8.5 ± 0.1	54.8 ± 0.7	53.6 ± 1.6
177242[x]	7.0 ± 0.0	8.0 ± 0.0	8.4 ± 0.0	9.5 ± 0.0	8.2 ± 0.0	59.3 ± 1.6	59.3 ± 2.9
179627[x]	6.6 ± 0.1	8.1 ± 1.1	10.2 ± 2.4	8.9 ± 1.6	8.4 ± 1.3	57.6 ± 0.0	52.6 ± 1.3
182138[x]	6.2 ± 0.3	7.4 ± 0.6	9.0 ± 0.8	9.5 ± 1.0	8.0 ± 0.2	57.4 ± 0.6	56.8 ± 2.5
200874[x]	8.1 ± 0.2	8.7 ± 0.9	8.3 ± 1.5	7.9 ± 2.8	8.2 ± 1.3	63.2 ± 0.5	61.1 ± 1.1
233186[x]	6.6 ± 0.0	8.4 ± 0.1	10.2 ± 0.8	10.1 ± 1.8	8.8 ± 0.6	60.1 ± 1.5	60.2 ± 0.6
248753[x]	3.5 ± 0.1	3.7 ± 0.4	3.4 ± 0.6	3.5 ± 1.0	3.5 ± 0.0	54.8 ± 3.5	54.3 ± 2.4
248754[x]	4.6 ± 0.1	5.1 ± 0.6	5.5 ± 0.9	4.9 ± 0.6	5.0 ± 0.6	56.1 ± 1.9	51.8 ± 5.8
249899[x]	5.9 ± 0.3	7.5 ± 0.4	8.4 ± 0.6	9.0 ± 0.2	7.7 ± 0.4	58.3 ± 0.0	56.9 ± 0.0
251325[x]	4.2 ± 0.1	5.7 ± 0.3	6.2 ± 1.3	5.5 ± 1.2	5.4 ± 0.7	54.1 ± 3.9	56.8 ± 3.1
255557[x]	5.0 ± 0.4	6.5 ± 1.0	8.9 ± 1.6	10.7 ± 1.1	7.8 ± 1.0	63.0 ± 0.5	56.3 ± 2.8
258956[x]	6.5 ± 0.1	8.2 ± 0.6	10.4 ± 0.2	18.7 ± 9.8	10.9 ± 2.7	58.6 ± 1.8	53.9 ± 1.0
264320[x]	6.1 ± 0.1	8.0 ± 0.4	10.4 ± 0.8	12.2 ± 0.6	9.1 ± 0.5	59.8 ± 0.2	57.9 ± 1.2

264648[x]	5.9 ± 0.8	6.8 ± 0.8	8.8 ± 0.7	9.9 ± 0.1	7.8 ± 0.5	57.9 ± 1.8	53.6 ± 0.2
271039[x]	4.7 ± 0.6	5.4 ± 0.1	5.5 ± 0.6	5.5 ± 1.2	5.3 ± 0.6	58.1 ± 0.1	57.5 ± 4.4
274780[x]	4.2 ± 0.3	5.6 ± 0.6	6.6 ± 1.7	5.2 ± 1.6	5.4 ± 1.1	55.8 ± 1.0	53.6 ± 0.3
288073[x]	4.7 ± 0.5	5.9 ± 0.1	7.1 ± 0.0	7.2 ± 0.2	6.2 ± 0.1	55.2 ± 0.6	57.7 ± 2.0
288270[x]	5.0 ± 0.1	6.9 ± 0.2	8.4 ± 0.3	9.2 ± 0.2	7.3 ± 0.1	64.1 ± 0.3	58.0 ± 1.9
288272[x]	2.7 ± 0.3	3.5 ± 0.7	3.8 ± 1.0	3.1 ± 0.9	3.3 ± 0.6	59.2 ± 3.6	57.3 ± 1.9
288902[x]	4.9 ± 0.6	5.6 ± 0.1	5.8 ± 0.0	4.7 ± 0.7	5.3 ± 0.4	56.9 ± 0.7	53.5 ± 2.6
288903[x]	6.1 ± 0.1	7.4 ± 0.4	9.5 ± 0.9	10.6 ± 1.7	8.4 ± 0.8	60.8 ± 0.7	56.8 ± 0.0
288908[x]	4.9 ± 0.2	6.1 ± 0.4	7.2 ± 0.1	6.4 ± 0.2	6.2 ± 0.1	63.5 ± 1.4	60.7 ± 2.1
288909[x]	6.1 ± 0.4	7.4 ± 0.1	8.3 ± 0.0	5.7 ± 0.7	6.9 ± 0.1	62.5 ± 0.2	58.4 ± 1.4
289689[x]	5.6 ± 0.1	6.0 ± 0.1	5.8 ± 0.4	3.8 ± 0.4	5.3 ± 0.3	60.1 ± 1.7	55.7 ± 0.7
289690[x]	6.5 ± 0.8	8.5 ± 0.2	9.7 ± 0.3	9.5 ± 0.6	8.5 ± 0.5	59.9 ± 1.2	58.2 ± 0.0
344392[x]	6.1 ± 0.4	7.3 ± 0.2	8.5 ± 0.7	7.9 ± 2.4	7.4 ± 0.7	59.7 ± 1.3	57.7 ± 0.4
433330[x]	6.3 ± 0.4	7.1 ± 1.2	9.1 ± 0.9	8.6 ± 0.5	7.7 ± 0.5	55.0 ± 1.3	55.0 ± 1.3
433332[x]	5.9 ± 0.2	6.5 ± 0.4	7.2 ± 0.0	7.7 ± 0.3	6.8 ± 0.1	57.1 ± 0.7	55.7 ± 0.2
546096[x]	7.0 ± 0.0	8.5 ± 0.1	10.1 ± 0.2	8.3 ± 1.2	8.4 ± 0.3	60.2 ± 1.4	58.1 ± 1.5
546100[x]	6.6 ± 0.5	8.2 ± 0.6	10.6 ± 0.6	11.3 ± 0.0	9.2 ± 0.4	62.4 ± 0.7	60.2 ± 0.5
546101[x]	7.0 ± 0.6	8.8 ± 0.1	11.2 ± 0.5	12.5 ± 0.5	9.8 ± 0.1	60.5 ± 0.8	60.6 ± 2.3
546106[x]	6.6 ± 0.2	7.9 ± 0.1	9.7 ± 0.8	9.9 ± 0.1	8.5 ± 0.2	60.7 ± 1.9	60.8 ± 3.2
546115[x]	5.9 ± 0.1	7.2 ± 0.8	9.5 ± 0.4	9.5 ± 1.0	8.0 ± 0.0	59.8 ± 3.8	62.3 ± 0.7
546140[x]	5.4 ± 0.4	7.2 ± 1.0	7.3 ± 0.4	7.0 ± 0.8	6.7 ± 0.6	60.3 ± 1.9	65.8 ± 1.4
546162[x]	6.3 ± 0.0	8.3 ± 0.1	9.9 ± 0.6	9.7 ± 0.8	8.5 ± 0.4	57.0 ± 2.7	55.7 ± 1.3
546174[x]	6.2 ± 0.4	8.3 ± 0.4	10.3 ± 0.1	10.7 ± 0.4	8.8 ± 0.1	60.6 ± 1.3	58.6 ± 1.2
546188[x]	6.5 ± 0.3	8.2 ± 0.7	10.1 ± 0.6	10.6 ± 0.2	8.8 ± 0.5	59.7 ± 0.6	60.6 ± 0.8
546192[x]	7.1 ± 0.1	8.3 ± 0.1	10.9 ± 0.6	12.0 ± 0.4	9.6 ± 0.2	61.5 ± 0.2	63.5 ± 2.5
639911[x]	6.6 ± 0.1	8.3 ± 0.1	10.6 ± 0.3	13.0 ± 0.6	9.6 ± 0.1	63.2 ± 3.1	60.7 ± 0.4
639912[x]	6.8 ± 0.1	8.9 ± 0.3	11.3 ± 1.4	12.6 ± 2.3	9.9 ± 1.0	64.2 ± 0.0	62.1 ± 0.4
639913[x]	6.7 ± 0.5	8.0 ± 0.2	9.1 ± 0.8	8.3 ± 1.5	8.0 ± 0.4	62.3 ± 1.0	60.3 ± 3.6
639915[x]	6.7 ± 0.1	8.6 ± 0.3	11.0 ± 0.6	12.2 ± 1.7	9.6 ± 0.2	63.4 ± 0.2	62.0 ± 2.2
639916[x]	6.7 ± 0.4	8.1 ± 0.1	10.8 ± 0.4	12.5 ± 0.3	9.5 ± 0.1	61.8 ± 0.1	62.7 ± 0.0

903-1 [x]	6.7 ± 0.5	8.5 ± 0.4	10.4 ± 0.4	11.0 ± 0.2	9.1 ± 0.4	57.3 ± 0.2	60.8 ± 0.3
904-1 [x]	6.7 ± 0.4	8.9 ± 0.6	10.9 ± 0.2	11.9 ± 0.1	9.6 ± 0.4	60.3 ± 0.3	58.5 ± 2
905-1[x]	6.5 ± 0.7	8.3 ± 0.0	10.0 ± 0.3	10.8 ± 0.2	8.9 ± 0.2	61.6 ± 0.2	62.4 ± 1.5
x mean	***5.9 ± 0.3***	***7.2 ± 0.4***	***8.6 ± 0.7***	***8.8 ± 1.0***	***7.6 ± 0.5***	***59.1 ± 1.1***	***57.8 ± 1.5***
OLYO5N5[y]	6.9 ± 0.2	9.0 ± 0.1	10.6 ± 0.3	11.8 ± 0.2	9.5 ± 0.2	56.9 ± 0.8	58.8 ± 1.7
Colorado 6[z]	7.4 ± 0.2	9.3 ± 0.1	11.2 ± 0.4	12.4 ± 0.1	10.1 ± 0.1	60.1 ± 0.0	57.2 ± 2.9
Salsa Red[z]	7.2 ± 0.2	8.5 ± 0.4	10.8 ± 0.8	10.5 ± 1.0	9.2 ± 0.4	60.9 ± 0.4	55.6 ± 0.1
Vantage[z]	7.7 ± 0.2	9.8 ± 0.6	11.9 ± 0.1	11.6 ± 0.1	10.2 ± 0.2	61.9 ± 0.7	60.2 ± 0.4
z mean	***7.4 ± 0.2***	***9.2 ± 0.4***	***11.3 ± 0.4***	***11.5 ± 0.4***	***9.8 ± 0.2***	***61.0 ± 0.4***	***57.7 ± 1.1***
Grand mean	**6.7 ± 0.2**	**8.5 ± 0.3**	**10.2 ± 0.5**	**10.7 ± 0.5**	**9.0 ± 0.3**	**59.0 ± 0.8**	**58.1 ± 1.4**
Tukey's (0.05)	1.7	2.5	3.8	7.4	3.0	6.2	8.2

[a]Number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Measured in the greenhouse at 79 days after sowing (DAS).

[d]Measured in the field at 84 days after planting (DAP) (or 176 DAS).

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Table II.4. Leaf growth and development in directly seeded onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2010.

Genotype	**Leaves-76** (mean ± SE)[a]	**Leaves-90** (mean ± SE)[a]	**Leaves-104** (mean ±SE)[a]	**Leaves-118** (mean ±SE)[a]	**Average** (mean ±SE)[a]	**Leaf Color**[c] (mean ±SE)[b]
903-1 [x]	5.3 ± 0.2	6.9 ± 0.6	8.3 ± 0.7	8.4 ± 0.8	7.2 ± 0.6	67.5 ± 0.6
904-1 [x]	5.7 ± 0.4	7.9 ± 0.6	9.4 ± 0.8	10.7 ± 1.5	8.4 ± 0.8	67.0 ± 2.1
905-1 [x]	5.5 ± 0.4	7.2 ± 0.9	8.5 ± 1.1	9.0 ± 1.5	7.5 ± 1.0	63.9 ± 2.1
x mean	***5.5 ± 0.3***	***7.3 ± 0.7***	***8.7 ± 0.9***	***9.4 ± 1.3***	***7.7 ± 0.8***	***66.13 ± 1.6***
6001 [y]	5.3 ± 0.1	7.2 ± 0.1	9.3 ± 0.1	9.9 ± 1.1	7.9 ± 0.2	62.0 ± 0.4
6022 [y]	5.4 ± 0.1	7.7 ± 0.3	9.4 ± 0.3	10.3 ± 0.8	8.2 ± 0.3	60.0 ± 3.7
16535 [y]	5.1 ± 0.2	7.3 ± 0.1	9.7 ± 0.1	9.8 ± 0.1	8.0 ± 0.1	64.3 ± 3.0
18495 [y]	5.3 ± 0.8	7.3 ± 0.7	9.5 ± 0.4	9.3 ± 0.2	7.8 ± 0.4	60.9 ± 0.6
EX-14593 [y]	5.3 ± 0.2	6.9 ± 0.2	8.1 ± 0.1	8.0 ± 0.1	7.0 ± 0.0	62.2 ± 1.1
NUN7006ON [y]	5.1 ± 0.1	7.3 ± 0.4	9.0 ± 0.3	10.0 ± 0.6	7.9 ± 0.4	63.4 ± 0.1
NUN7007ON [y]	5.2 ± 0.2	7.1 ± 0.3	8.9 ± 0.1	10.2 ± 0.4	7.9 ± 0.1	59.8 ± 0.7
NUN7009ON [y]	5.4 ± 0.1	7.5 ± 0.3	9.5 ± 0.1	10.6 ± 0.4	8.2 ± 0.0	59.9 ± 4.7
NUN7606ON [y]	5.4 ± 0.2	7.5 ± 0.1	9.3 ± 0.1	10.4 ± 0.1	8.1 ± 0.0	61.0 ± 4.1
OLYS06-25 [y]	5.0 ± 0.2	6.5 ± 0.3	8.8 ± 0.4	9.2 ± 0.5	7.4 ± 0.1	61.2 ± 0.0
R-5978 [y]	5.2 ± 0.4	7.0 ± 0.5	8.0 ± 0.1	7.7 ± 0.4	7.0 ± 0.1	62.9 ± 0.9
SBO-5288 [y]	5.3 ± 0.1	7.5 ± 0.2	9.3 ± 0.2	10.8 ± 0.7	8.2 ± 0.3	59.7 ± 2.5
SBO-5419 [y]	5.7 ± 0.1	7.7 ± 0.0	9.5 ± 0.2	10.4 ± 0.3	8.3 ± 0.1	65.3 ± 4.0
SBO-5420 [y]	5.5 ± 0.1	7.5 ± 0.4	9.1 ± 0.1	10.1 ± 0.5	8.0 ± 0.3	61.8 ± 1.6
SBO-5508 [y]	5.6 ± 0.2	7.7 ± 0.2	9.3 ± 0.1	10.5 ± 0.1	8.2 ± 0.1	63.9 ± 1.6
SBO-5599 [y]	5.0 ± 0.1	7.1 ± 0.2	9.4 ± 0.4	10.2 ± 0.5	7.9 ± 0.4	61.0 ± 3.9
SN-626[y]	4.8 ± 0.3	6.3 ± 0.1	7.6 ± 0.1	8.4 ± 0.3	6.8 ± 0.2	60.6 ± 1.0
y mean	***5.3 ± 0.2***	***7.2 ± 0.3***	***9.0 ± 0.2***	***9.8 ± 0.4***	***7.8 ± 0.2***	***61.8 ± 2.0***
Advantage[z]	4.6 ± 0.3	7.2 ± 0.3	8.9 ± 0.2	9.8 ± 0.7	7.6 ± 0.4	61.3 ± 2.6
Bello Blanco[z]	4.9 ± 0.5	6.8 ± 0.0	8.3 ± 1.3	8.6 ± 1.0	7.1 ± 0.4	64.7 ± 1.0

Belmar[z]	5.4 ± 0.4	7.7 ± 0.5	9.6 ± 0.1	9.9 ± 0.4	8.2 ± 0.1	64.8 ± 0.3
Bradley[z]	5.2 ± 0.6	7.0 ± 0.4	9.0 ± 0.1	9.1 ± 0.0	7.5 ± 0.3	61.1 ± 1.8
Brundage[z]	5.1 ± 0.4	6.7 ± 0.6	8.8 ± 0.8	9.8 ± 0.2	7.6 ± 0.5	63.9 ± 0.6
Calibra[z]	5.3 ± 0.3	7.5 ± 1.1	9.2 ± 0.2	9.7 ± 1.0	7.9 ± 0.6	59.9 ± 2.4
Colorado 6[z]	4.9 ± 0.3	7.1 ± 0.3	9.1 ± 0.2	9.7 ± 0.6	7.7 ± 0.3	62.1 ± 0.4
Cometa[z]	4.7 ± 0.0	6.7 ± 0.1	8.7 ± 0.2	8.7 ± 0.1	7.2 ± 0.1	66.2 ± 1.8
Crockett[z]	5.3 ± 0.8	7.2 ± 0.7	8.9 ± 0.1	9.9 ± 0.1	7.8 ± 0.4	63.3 ± 0.3
Genesis[z]	5.4 ± 0.1	7.4 ± 0.0	9.1 ± 0.3	8.3 ± 0.4	7.5 ± 0.0	62.6 ± 0.6
Granero[z]	5.2 ± 0.1	7.3 ± 0.1	9.5 ± 0.2	10.5 ± 0.2	8.1 ± 0.1	62.9 ± 0.1
Gunnison[z]	5.4 ± 0.4	7.2 ± 0.6	8.7 ± 0.0	9.3 ± 0.6	7.6 ± 0.1	62.6 ± 0.1
Joaquin[z]	5.9 ± 0.4	8.1 ± 0.4	10.3 ± 0.5	10.9 ± 0.9	8.8 ± 0.5	63.7 ± 5.6
Mesquite[z]	5.1 ± 0.3	7.2 ± 0.4	9.3 ± 0.4	9.8 ± 0.8	7.9 ± 0.5	59.7 ± 0.4
Morpheus[z]	4.9 ± 0.2	7.1 ± 0.4	8.9 ± 0.2	12.8 ± 3.0	8.4 ± 0.6	60.9 ± 1.2
Oracle[z]	4.8 ± 0.4	7.1 ± 0.1	9.4 ± 0.5	10.1 ± 0.7	7.8 ± 0.4	63.7 ± 1.8
Red Devil[z]	5.0 ± 0.4	6.6 ± 0.3	8.2 ± 0.1	8.3 ± 0.1	7.0 ± 0.1	62.6 ± 0.2
Salsa Red[z]	4.3 ± 0.2	6.2 ± 0.1	7.9 ± 0.4	7.9 ± 0.9	6.5 ± 0.0	64.3 ± 3.5
Swale[z]	5.1 ± 0.6	7.4 ± 0.5	9.3 ± 0.4	9.7 ± 0.1	7.9 ± 0.2	63.8 ± 1.3
Tequila[z]	4.8 ± 0.4	7.2 ± 0.1	8.9 ± 0.7	9.7 ± 0.8	7.7 ± 0.5	60.9 ± 2.3
The Rock[z]	4.7 ± 0.6	6.9 ± 0.4	9.3 ± 0.5	9.1 ± 0.7	7.5 ± 0.5	62.8 ± 0.8
White Cloud[z]	5.0 ± 0.1	7.0 ± 0.0	9.3 ± 0.2	9.8 ± 0.3	7.7 ± 0.0	65.6 ± 2.9
z mean	***5.0 ± 0.4***	***7.1 ± 0.3***	***9.0 ± 0.3***	***9.6 ± 0.6***	***7.7 ± 0.3***	***62.9 ± 1.5***
Grand mean	**5.3 ± 0.3**	**7.2 ± 0.4**	**8.9 ± 0.5**	**9.6 ± 0.8**	**7.7 ± 0.4**	**63.6 ± 1.7**
Tukey's (0.05)	1.4	1.7	1.8	3.3	1.5	9.3

[a]Number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Measured in the field at 119 DAS.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following “-” indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.5. Leaf growth and development in transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2011.

Genotype	Leaves-91 (mean ± SE)[a]	Leaves-106 (mean ± SE)[a]	Leaves-126 (mean ±SE)[a]	Average (mean ±SE)[a]	Leaf Color[d] (mean ±SE)[b]	Plant Color[c]	Leaf Color[e] (mean ±SE)[b]
574[x]	7.5 ± 1.4	10.5 ± 1.1	11.9 ± 0.6	9.9 ± 1.0	56.0 ± 3.1	GB	67.0 ± 3.3
575[x]	6.4 ± 0.6	6.4 ± 1.4	5.1 ± 0.2	6.2 ± 1.1	53.1 ± 4.1	BG	63.9 ± 3.7
577[x]	8.5 ± 0.8	9.6 ± 1.6	8.3 ± 2.5	8.8 ± 1.2	52.1 ± 4.9	B	67.8 ± 7.7
578[x]	3.7 ± 0.6	2.8 ± 1.2	3.0 ± 0.0	3.2 ± 0.7	55.0 ± 2.2	BG	N/A
579[x]	5.4 ± 0.6	5.0 ± 1.1	5.5 ± 1.4	5.2 ± 0.9	53.7 ± 3.6	BG	N/A
580[x]	5.5 ± 1.6	4.4 ± 1.0	2.8 ± 1.6	4.2 ± 1.2	55.3 ± 3.9	BG	N/A
582[x]	3.7 ± 1.2	2.2 ± 0.7	N/A	2.9 ± 1.0	57.8 ± 3.9	BG	N/A
583[x]	5.7 ± 2.5	5.8 ± 2.0	3.9 ± 0.2	5.7 ± 2.3	52.2 ± 3.7	GB	N/A
589[x]	5.9 ± 0.3	7.4 ± 0.6	9.2 ± 2.2	7.5 ± 0.8	52.0 ± 3.9	G	61.9 ± 1.1
592[x]	5.5 ± 0.4	6.0 ± 0.7	7.8 ± 1.0	6.4 ± 0.5	51.7 ± 3.4	G	57.3 ± 5.0
593[x]	4.7 ± 0.5	5.9 ± 0.3	8.7 ± 0.5	6.4 ± 0.3	55.3 ± 5.1	G	66.2 ± 2.8
594[x]	4.0 ± 1.6	3.8 ± 1.5	4.8 ± 1.3	4.2 ± 1.4	56.6 ± 4.1	G	68.2 ± 0.0
596[x]	5.3 ± 0.7	6.2 ± 0.4	5.7 ± 0.8	5.8 ± 0.2	53.6 ± 5.3	G	63.5 ± 1.2
597[x]	4.3 ± 1.8	4.8 ± 1.5	4.1 ± 1.5	4.4 ± 1.3	59.1 ± 3.9	G	49.5 ± 0.0
602[x]	7.1 ± 0.6	9.6 ± 1.8	14 ± 2.2	10.2 ± 1.3	55.0 ± 4.1	GB	66.1 ± 2.6
607[x]	7.8 ± 2.6	9.5 ± 1.5	7.5 ± 1.5	8.2 ± 1.1	56.4 ± 3.8	G	63.0 ± 2.0
615[x]	4.3 ± 1.2	4.3 ± 1.4	4.5 ± 0.7	4.1 ± 1.1	55.3 ± 2.9	G	N/A
618[x]	6.5 ± 2.1	5.6 ± 2.0	3.9 ± 0.5	5.3 ± 1.4	52.6 ± 2.8	G	64.4 ± 0.0
619[x]	7.7 ± 1.0	7.8 ± 1.4	5.0 ± 1.1	6.8 ± 1.1	55.0 ± 4.2	G	75.9 ± 5.6
620[x]	6.3 ± 0.9	6.6 ± 0.8	4.6 ± 0.3	5.8 ± 0.6	56.2 ± 3.3	B	65.2 ± 1.2
621[x]	7.6 ± 1.1	8.7 ± 0.4	7.7 ± 0.2	8.0 ± 0.5	54.4 ± 12.3	B	64.7 ± 0.8
622[x]	8.1 ± 0.8	7.5 ± 0.6	4.5 ± 1.0	6.7 ± 0.3	55.2 ± 2.8	B	62.8 ± 3.5
624[x]	5.4 ± 0.9	6.2 ± 1.2	5.2 ± 1.8	5.6 ± 0.7	55.1 ± 3.5	B	65.3 ± 2.4
628[x]	5.7 ± 0.8	5.3 ± 0.3	3.2 ± 0.9	4.9 ± 0.6	49.5 ± 3.6	BG	69.5 ± 4.5
629[x]	6.3 ± 1.3	6.4 ± 1.7	4.7 ± 1.9	5.8 ± 1.1	55.9 ± 4.8	BG	67.8 ± 4.8

632[x]	9.0 ± 0.0	12.0 ± 0.0	N/A	10.5 ± 0.0	54.4 ± 2.8	GB	N/A
634[x]	6.0 ± 0.8	8.4 ± 0.6	11.4 ± 1.1	8.6 ± 0.8	48.1 ± 3.8	G	59.2 ± 1.6
643[x]	8.8 ± 2.1	10.7 ± 1.5	11.4 ± 1.6	10.3 ± 1.7	51.3 ± 3.1	G	63.4 ± 3.8
646[x]	7.7 ± 0.6	9.8 ± 1.0	11.2 ± 1.0	9.6 ± 0.7	50.6 ± 3.1	GB	61.8 ± 4.0
648[x]	6.6 ± 1.1	9.0 ± 0.3	11.2 ± 0.2	8.9 ± 0.4	51.2 ± 4.8	GB	63.0 ± 5.9
651[x]	7.4 ± 1.9	8.8 ± 1.8	10.5 ± 2.2	8.9 ± 1.9	45.2 ± 3.2	GB	62.4 ± 4.0
654[x]	7.4 ± 1.7	9.5 ± 1.6	11.9 ± 0.7	9.6 ± 1.3	45.1 ± 3.6	GB	61.9 ± 0.9
656[x]	6.4 ± 2.7	8.4 ± 2.1	10.7 ± 1.9	8.5 ± 2.2	46.8 ± 10.6	GB	62.2 ± 1.7
658[x]	9.7 ± 0.7	11.3 ± 0.5	10.5 ± 0.5	10.5 ± 0.4	46.4 ± 3.5	GB	65.0 ± 2.5
660[x]	7.5 ± 1.8	9.7 ± 1.1	11 ± 0.5	9.4 ± 1.0	54.3 ± 3.6	GB	63.3 ± 3.7
696[x]	4.8 ± 0.8	3.6 ± 0.9	3.0 ± 0.0	4.1 ± 0.8	64.0 ± 3.8	B	N/A
700[x]	7.7 ± 0.6	7.1 ± 0.7	4.6 ± 0.6	6.5 ± 0.3	53.2 ± 3.5	BG	61.8 ± 0.0
702[x]	5.1 ± 0.8	4.4 ± 0.9	3.2 ± 0.7	4.2 ± 0.5	55.5 ± 3.1	G	N/A
706[x]	6.2 ± 0.3	5.4 ± 0.5	3.3 ± 0.4	5.3 ± 0.5	55.1 ± 3.7	GB	70.9 ± 0.0
708[x]	5.7 ± 1.1	4.5 ± 0.8	2.7 ± 0.6	4.6 ± 0.3	58.4 ± 3.1	BG	N/A
711[x]	6.1 ± 1.3	5.3 ± 1.3	3.9 ± 0.3	5.1 ± 0.8	51.3 ± 5.0	GB	67.5 ± 0.0
712[x]	5.7 ± 0.4	4.0 ± 0.8	3.0 ± 0.5	4.4 ± 0.2	62.0 ± 4.2	BG	N/A
713[x]	6.3 ± 1.5	4.5 ± 0.6	3.0 ± 0.0	5.3 ± 1.0	56.7 ± 3.7	BG	N/A
718[x]	5.6 ± 1.6	4.7 ± 0.2	3.4 ± 0.8	4.8 ± 0.9	58.2 ± 3.7	BG	61.7 ± 4.8
719[x]	6.0 ± 2.2	5.4 ± 0.5	6.1 ± 0.6	5.9 ± 0.9	61.6 ± 2.7	BG	70.3 ± 0.0
753[x]	7.2 ± 1.2	7.7 ± 0.7	4.1 ± 1.5	6.3 ± 0.4	51.1 ± 3.7	GB	50.9 ± 0.0
759[x]	5.2 ± 1.6	4.2 ± 1.5	4.6 ± 2.3	4.7 ± 1.6	62.5 ± 3.4	B	N/A
765[x]	5.6 ± 1.2	7.9 ± 0.5	10.1 ± 0.8	7.9 ± 0.5	49.8 ± 4.1	GB	67.4 ± 1.7
768[x]	7.2 ± 1.9	9.4 ± 1.8	10 ± 2.2	8.8 ± 1.9	44.5 ± 3.6	GB	65.9 ± 4.4
769[x]	5.5 ± 1.1	7.4 ± 0.9	9.9 ± 0.1	7.2 ± 1.0	50.2 ± 4.2	BG	65.7 ± 4.8
172702[x]	5.4 ± 1.4	4.7 ± 2.2	4.1 ± 0.9	4.7 ± 1.2	52.6 ± 4.7	BG	65.3 ± 1.6
172703[x]	5.0 ± 1.9	4.4 ± 3.4	2.5 ± 1.0	4.4 ± 2.7	52.2 ± 3.9	BG	N/A
239633[x]	5.6 ± 1.6	8.1 ± 1.3	9.9 ± 0.9	7.9 ± 1.2	51.5 ± 3.5	G	60.2 ± 0.0
258956[x]	6.4 ± 1.9	8.8 ± 1.3	10.4 ± 1.4	8.5 ± 1.5	49.1 ± 3.8	G	60.7 ± 3.1
264320[x]	8.9 ± 0.5	10.5 ± 0.7	10.5 ± 1.5	9.9 ± 0.7	48.9 ± 3.7	GB	63.2 ± 1.9

288909[x]	6.6 ± 1.4	6.6 ± 0.8	4.1 ± 1.0	6.0 ± 0.8	50.2 ± 4.0	B	67.6 ± 0.0
289689[x]	5.8 ± 0.8	5.4 ± 0.9	3.3 ± 1.2	4.8 ± 0.9	48.6 ± 5.7	G	N/A
343049[x]	5.9 ± 1.0	5.9 ± 0.9	4.2 ± 0.9	5.3 ± 0.3	53.1 ± 12.7	B	67.1 ± 1.6
546140[x]	7.6 ± 0.6	6.2 ± 0.5	3.0 ± 0.0	6.6 ± 0.9	52.4 ± 6.1	BG	N/A
546188[x]	8.0 ± 1.7	9.7 ± 1.4	10.7 ± 0.9	9.5 ± 1.3	48.3 ± 2.5	GB	61.7 ± 3.0
546192[x]	8.0 ± 1.9	9.7 ± 2.3	10.8 ± 1.5	9.5 ± 1.8	52.4 ± 2.9	GB	65.6 ± 3.7
639911[x]	8.3 ± 0.9	9.8 ± 1.0	9.8 ± 0.7	9.3 ± 0.8	49.3 ± 3.8	B	64.9 ± 5.4
B2133C[x]	5.6 ± 1.2	7.2 ± 0.9	7.4 ± 1.0	6.7 ± 1.0	48.5 ± 4.2	GB	64.8 ± 4.5
B5336C[x]	7.0 ± 1.4	7.9 ± 1.6	12.5 ± 0.7	9.1 ± 1.2	47.8 ± 2.8	G	64.4 ± 0.0
B5351C[x]	5.9 ± 1.7	7.1 ± 1.8	8.3 ± 1.0	7.1 ± 1.5	48.4 ± 2.5	GB	62.8 ± 4.1
E203[x]	5.0 ± 1.6	4.1 ± 2.0	3.0 ± 1.3	4.0 ± 1.3	44.6 ± 2.8	BG	56.4 ± 0.0
E205[x]	5.4 ± 2.0	6.1 ± 2.0	5.0 ± 1.5	5.5 ± 1.7	48.4 ± 10.9	BG	61.2 ± 3.1
E206[x]	5.9 ± 1.5	5.6 ± 1.9	3.2 ± 0.9	4.9 ± 1.4	49.0 ± 3.2	GB	62.7 ± 3.8
E207[x]	5.6 ± 1.7	5.3 ± 1.6	3.7 ± 1.0	4.9 ± 1.3	46.1 ± 2.9	G	62.1 ± 10.8
GCA-SYN[x]	5.6 ± 2.0	7.5 ± 1.4	9.0 ± 1.2	7.3 ± 1.4	46.9 ± 3.5	BG	62.3 ± 8.5
x mean	***6.3 ± 1.3***	***6.9 ± 1.2***	***6.7 ± 1.1***	***6.7 ± 1.0***	***52.6 ± 4.2***	***-***	***-***
NUN7606ON[y]	7.8 ± 1.6	10.2 ± 1.8	11.9 ± 1.1	10.0 ± 1.5	70.9 ± 94.7	G	66.9 ± 0.8
OLYS03-207[y]	8.3 ± 1.0	10.5 ± 0.6	12 ± 0.4	10.3 ± 0.6	51.1 ± 5.4	G	70.4 ± 2.3
OLYS03-209[y]	8.1 ± 1.2	10.1 ± 1.2	11.4 ± 0.7	9.8 ± 1.0	50.7 ± 4.2	G	65.7 ± 2.7
OLYS05N5[y]	6.6 ± 2.0	8.4 ± 1.7	10.2 ± 0.9	8.4 ± 1.5	48.8 ± 3.3	GB	64.5 ± 2.4
OLYX06-25[y]	9.0 ± 1.1	10.4 ± 0.8	11.1 ± 0.4	10.2 ± 0.8	52.1 ± 3.2	G	68.9 ± 1.8
y mean	***8.0 ± 1.4***	***10.0 ± 1.2***	***11.3 ± 0.7***	***9.7 ± 1.1***	***54.7 ± 22.2***	***-***	***-***
Colorado 6[z]	6.8 ± 2.5	9.1 ± 1.7	14.5 ± 7.7	10.1 ± 3.7	49.2 ± 3.7	G	69.3 ± 5.6
Cometa[z]	7.9 ± 0.6	9.9 ± 0.4	11.1 ± 0.2	9.6 ± 0.4	50.0 ± 2.9	GB	71.9 ± 2.2
Mesquite[z]	7.2 ± 0.6	9.0 ± 0.4	10.5 ± 0.4	8.9 ± 0.3	46.3 ± 3.7	G	63.8 ± 4.4
Rumba[z]	6.9 ± 1.1	8.2 ± 1.1	7.8 ± 1.6	7.6 ± 0.9	44.9 ± 2.5	BG	63.7 ± 4.5
Salsa Red[z]	6.0 ± 1.7	7.4 ± 1.8	8.8 ± 1.6	7.4 ± 1.6	45.9 ± 5.2	G	64.1 ± 0.7
T-433[z]	8.6 ± 0.4	10.6 ± 0.4	10.5 ± 0.6	9.9 ± 0.4	51.2 ± 5.3	G	67.1 ± 0.4
Vantage[z]	6.7 ± 1.0	8.1 ± 1.3	8.5 ± 0.6	7.7 ± 0.6	49.3 ± 5.0	GB	63.6 ± 0.6

z mean	***7.2 ± 1.1***	***8.9 ± 1.0***	***10.2 ± 1.8***	***8.7 ± 1.1***	***48.1 ± 4.0***	**-**	**-**
Grand mean	**7.1 ± 1.3**	**8.6 ± 1.1**	**9.4 ± 1.2**	**8.4 ± 1.1**	**51.8 ± 10.1**	**-**	**-**
Tukey's (0.05)	4.5	4.3	5.5	3.9	15.1	-	-

[a]Number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[c]Visual categorization of plant color into green (G), green-blue (GB), blue-green (BG) and blue (B) by five independent onion researcher.

[d]Measured in the greenhouse at 61 DAS.

[e]Measured in the field at 126 DAP.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

N/A indicates genotype matured before measurement was taken. In the case of leaf color, it means there was no suitable candidate leaf for measurement. This happened if leaves were too thick to fit in the chlorophyll meter.

Appendix I I.A.6. Incidence of *Iris yellow spot virus* (IYSV) in transplanted onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2009.

Genotype	**IYSV-71** (%) (mean ± SE)	**IYSV-86** (%) (mean ± SE)	**IYSV-99** (%) (mean ± SE)	**IYSV-113** (%) (mean ± SE)	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]
124525[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
142790[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
164361[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
164807[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
165498[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
168962[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
168966[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
171475[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
171477[x]	0.0 ± 0.0	3.6 ± 5.0	3.6 ± 5.0	3.6 ± 5.0	123.2 ± 174.2	0.200 ± 0.200	2.7 ± 3.8
172701[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
172702[x]	0.0 ± 0.0	5.0 ± 7.1	5.0 ± 7.1	7.4 ± 3.7	189.2 ± 220.4	0.200 ± 0.100	4.4 ± 4.5
172703[x]	0.0 ± 0.0	0.0 ± 0.0	3.6 ± 5.0	3.6 ± 5.0	73.2 ± 103.5	0.100 ± 0.100	1.8 ± 2.5
172704[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
174018[x]	0.0 ± 0.0	2.8 ± 4.0	2.8 ± 4.0	4.8 ± 1.1	109.9 ± 115.8	0.200 ± 0.100	2.6 ± 2.3
174024[x]	4.8 ± 6.7	10.1 ± 5.9	10.1 ± 5.9	16 ± 2.3	424.8 ± 197.3	0.200 ± 0.100	10.3 ± 4.0
177242[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000± 0.000	0.0 ± 0.0
179164[x]	2.4 ± 3.4	2.4 ± 3.4	4.9 ± 0.1	4.9 ± 0.1	151.3 ± 68.9	0.300 ± 0.100	3.7 ± 1.6
179627[x]	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 4.0	2.8 ± 4.0	57.0 ± 80.5	0.100 ± 0.100	1.4 ± 2.0
182138[x]	3.4 ± 4.7	10.0 ± 4.7	10.0 ± 4.7	10.0 ± 4.7	370.0 ± 198	0.300 ± 0.000	8.4 ± 4.7
183660[x]	2.0 ± 2.8	2.0 ± 2.8	2.0 ± 2.8	2.0 ± 2.8	84.0 ± 118.8	0.200 ± 0.300	2.0 ± 2.8
200874[x]	0.0 ± 0.0	5.0 ± 7.1	5.0 ± 7.1	5.0 ± 7.1	172.5 ± 244	0.200 ± 0.200	3.8 ± 5.3

233186[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
246140[x]	3.9 ± 5.4	3.9 ± 5.4	10.7 ± 6.7	10.7 ± 6.7	300.7 ± 254.7	0.300 ± 0.100	7.2 ± 6.1
248753[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
248754[x]	0.0 ± 0.0	8.0 ± 11.3	8.0 ± 11.3	8.0 ± 11.3	276.0 ± 390.3	0.200 ± 0.200	6.0 ± 8.5
249899[x]	5.0 ± 7.1	5.0 ± 7.1	5.0 ± 7.1	5.0 ± 7.1	210.0 ± 297.0	0.200 ± 0.300	5.0 ± 7.1
251325[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
255557[x]	0.0 ± 0.0	2.3 ± 3.2	2.3 ± 3.2	9.1 ± 12.9	126.2 ± 178.4	0.100 ± 0.100	3.4 ± 4.8
256048[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
256049[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
258956[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
264320[x]	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 3.0	2.2 ± 3.0	44.6 ± 63	0.100 ± 0.100	1.1 ± 1.6
264321[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
264631[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	10.8 ± 3.5	75.8 ± 24.7	0.100 ± 0.000	2.7 ± 0.8
264648[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
269306[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
271039[x]	0.0 ± 0.0	0.0 ± 0.0	6.3 ± 8.8	6.3 ± 8.8	128.2 ± 181.2	0.100 ± 0.100	3.2 ± 4.5
273211[x]	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 4.2	3.0 ± 4.2	60.3 ± 85.3	0.100 ± 0.100	1.5 ± 2.1
274780[x]	4.6 ± 6.4	4.6 ± 6.4	4.6 ± 6.4	4.6 ± 6.4	190.9 ± 270.0	0.200 ± 0.300	4.6 ± 6.4
287540[x]	0.0 ± 0.0	2.4 ± 3.4	2.4 ± 3.4	2.4 ± 3.4	82.2 ± 116.2	0.200 ± 0.200	1.8 ± 2.5
288073[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
288270[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
288272[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.6 ± 6.4	31.8 ± 45.0	0.100 ± 0.100	1.2 ± 1.6
288902[x]	0.0 ± 0.0	4.2 ± 5.9	4.2 ± 5.9	4.2 ± 5.9	143.8 ± 203.3	0.200 ± 0.200	3.2 ± 4.5
288903[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
288908[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.4 ± 0.2	30.5 ± 1.8	0.100 ± 0.000	1.1 ± 0.1
288909[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0

289689[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
289690[x]	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 3.7	2.7 ± 3.7	54.0 ± 76.3	0.100 ± 0.100	1.3 ± 1.8
293756[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
318886[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
321385[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.2 ± 5.9	29.2 ± 41.2	0.100 ± 0.100	1.1 ± 1.5
342943[x]	4.6 ± 6.4	4.6 ± 6.4	4.6 ± 6.4	7.9 ± 1.7	214.3 ± 237.0	0.300 ± 0.200	5.4 ± 5.2
343049[x]	2.3 ± 3.2	2.3 ± 3.2	2.3 ± 3.2	2.3 ± 3.2	95.5 ± 135.0	0.200 ± 0.300	2.3 ± 3.2
344392[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
391509[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
430371[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
433330[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	22.8 ± 32.2	159.1 ± 225	0.100 ± 0.100	5.7 ± 8.1
433332[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	14.3 ± 20.2	100.0 ± 141.4	0.100 ± 0.100	3.6 ± 5.0
546096[x]	2.0 ± 2.8	2.0 ± 2.8	2.0 ± 2.8	4.0 ± 0.0	98.0 ± 99.0	0.300 ± 0.200	2.5 ± 2.1
546100[x]	0.0 ± 0.0	7.9 ± 11.2	7.9 ± 11.2	7.9 ± 11.2	272.4 ± 385.2	0.200 ± 0.200	5.9 ± 8.3
546101[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000± 0.000	0.0 ± 0.0
546106[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
546115[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.9 ± 5.4	26.9 ± 38	0.100 ± 0.100	1.0 ± 1.3.0
546140[x]	0.0 ± 0.0	0.0 ± 0.0	3.4 ± 4.7	3.4 ± 4.7	68.4 ± 96.7	0.100 ± 0.100	1.7 ± 2.3
546162[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
546174[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
546188[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
546192[x]	0.0 ± 0.0	4.2 ± 5.9	4.2 ± 5.9	4.2 ± 5.9	143.8 ± 203.3	0.200 ± 0.200	3.2 ± 4.5
546201[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
639911[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
639912[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 3.0	15.2 ± 21.5	0.100 ± 0.100	0.6 ± 0.8
639913[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
639914[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0

639915 [x]	5.6 ± 7.8	5.6 ± 7.8	5.6 ± 7.8	5.6 ± 7.8	233.4 ± 330.0	0.200 ± 0.300	5.6 ± 7.8
639916 [x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
239633-1 [x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
239633-2 [x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
G32590 [x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
G32787 [x]	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 3.0	4.4 ± 6.2	59.8 ± 84.6	0.100 ± 0.100	1.7 ± 2.3
x average	0.5 ± 0.7	1.2 ± 1.5	1.7 ± 1.9	2.8 ± 2.8	62.8 ± 71.8	0.066 ± 0.069	1.5 ± 1.7
OLYS05N5 [y]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
Colorado 6 [z]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 4.2	20.6 ± 29.1	0.100 ± 0.100	0.8 ± 1.1
Cometa [z]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 3.7	18.4 ± 26.0	0.100 ± 0.100	0.7 ± 0.9
Mt. Blanc [z]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.000 ± 0.000	0.0 ± 0.0
Salsa Red [z]	6.0 ± 8.5	8 ± 5.7	10.0 ± 2.8	12.0 ± 0.0	376.0 ± 181.0	0.300 ± 0.100	9.0 ± 4.2
z average	1.5 ± 2.1	2.0 ± 1.4	2.5 ± 0.7	4.4 ± 2.0	103.8 ± 59.0	0.100 ± 0.071	2.6 ± 1.6
Grand mean	**0.7 ± 0.9**	**1.1 ± 1.0**	**1.4 ± 0.9**	**2.4 ± 1.6**	**55.5 ± 43.6**	**0.055 ± 0.047**	**1.4 ± 1.1**
Tukey's (0.05)	9.6	13.8	15.2	24.7	543.9	0.502	12.9

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix I I.A.7. Incidence of *Iris yellow spot virus* (IYSV) in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2009.

Genotype	**IYSV-161 (%)** (mean ± SE)	**IYSV-175 (%)** (mean ± SE)	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]
EX-16529 [y]	20.0 ± 28.3	70.0 ± 14.1	630.0 ± 297.0	0.050 ± 0.014	45.0 ± 21.2
NUN7606ON [y]	30.0 ± 14.1	50.0 ± 56.6	560.0 ± 297.0	0.124 ± 0.107	40.0 ± 21.2
OLRH08-9 [y]	35.0 ± 7.1	65.0 ± 7.1	700.0 ± 0.0	0.062 ± 0.007	50.0 ± 0.0
OLYS03-207 [y]	45.0 ± 21.2	70.0 ± 14.1	805.0 ± 247.5	0.065 ± 0.007	57.5 ± 17.7
OLYS03-209 [y]	10.0 ± 14.1	60.0 ± 14.1	490.0 ± 198	0.046 ± 0.008	35.0 ± 14.1
OLYS05N5 [y]	45.0 ± 7.1	50.0 ± 0.0	665.0 ± 49.5	0.076 ± 0.006	47.5 ± 3.5
OLYX00-23 [y]	30.0 ± 14.1	8.05 ± 7.1	805.0 ± 49.5	0.054 ± 0.008	57.5 ± 3.5
OLYX06-25 [y]	31.5 ± 2.1	58.0 ± 2.8	626.5 ± 4.9	0.062 ± 0.003	44.8 ± 0.4
y average	***30.8 ± 13.5***	***63.5 ± 14.5***	***660.2 ± 142.9***	***0.067 ± 0.02***	***47.2 ± 10.2***
Abilene [z]	30.0 ± 14.1	75.0 ± 7.1	735.0 ± 148.5	0.056 ± 0.006	52.5 ± 10.6
Arcero [z]	40.0 ± 28.3	70.0 ± 28.3	770.0 ± 396.0	0.061 ± 0.008	55.0 ± 28.3
Calibra [z]	45.0 ± 7.1	60.0 ± 0.0	735.0 ± 49.5	0.070 ± 0.005	52.5 ± 3.5
Charismatic [z]	15.0 ± 21.2	50.0 ± 28.3	455.0 ± 49.5	0.060 ± 0.028	32.5 ± 3.5
Colorado 6 [z]	70.0 ± 0.0	70.0 ± 0.0	980.0 ± 0.0	0.080 ± 0.000	70.0 ± 0.0
Cometa [z]	30.0 ± 42.4	55.0 ± 21.2	595.0 ± 445.5	0.057 ± 0.024	42.5 ± 31.8
Crockett [z]	50.0 ± 0.0	75.0 ± 7.1	875.0 ± 49.5	0.067 ± 0.003	62.5 ± 3.5
Damascus [z]	30.0 ± 28.3	80.0 ± 14.1	770.0 ± 297.0	0.054 ± 0.012	55.0 ± 21.2
Delgado [z]	55.0 ± 21.2	65.0 ± 7.1	840.0 ± 99.0	0.075 ± 0.017	60.0 ± 7.1
Denali [z]	40.0 ± 14.1	55.0 ± 7.1	665.0 ± 49.5	0.070 ± 0.014	47.5 ± 3.5
Desperado [z]	65.0 ± 7.1	80.0 ± 14.1	1015.0 ± 49.5	0.073 ± 0.009	72.5 ± 3.5
Granero [z]	45.0 ± 21.2	80.0 ± 0.0	875.0 ± 148.5	0.063 ± 0.011	62.5 ± 10.6
Gunnison [z]	53.0 ± 46.7	83.0 ± 4.2	952.0 ± 356.4	0.065 ± 0.021	68.0 ± 25.5
Harmony [z]	35.0 ± 7.1	65.0 ± 21.2	700.0 ± 99.0	0.064 ± 0.012	50.0 ± 7.1
Joaquin [z]	70.0 ± 0.0	80.0 ± 0.0	1050.0 ± 0.0	0.075 ± 0.000	75.0 ± 0.0
Legand [z]	35.0 ± 7.1	65.0 ± 21.2	700.0 ± 99.0	0.064 ± 0.012	50.0 ± 7.1

Marquett[z]	45.0 ± 35.4	80.0 ± 0.0	875.0 ± 247.5	0.063 ± 0.018	62.5 ± 17.7
Mesquite[z]	40.0 ± 14.1	60.0 ± 14.1	700.0 ± 198.0	0.066 ± 0.003	50.0 ± 14.1
Milestone[z]	60.0 ± 0.0	90.0 ± 14.1	1050.0 ± 99.0	0.067 ± 0.004	75.0 ± 7.1
Monarcho[z]	30.0 ± 28.3	85.0 ± 7.1	805.0 ± 247.5	0.054 ± 0.012	57.5 ± 17.7
Montero[z]	50.0 ± 28.3	70.0 ± 14.1	840.0 ± 297.0	0.068 ± 0.011	60.0 ± 21.2
Oro Blanco[z]	40.0 ± 14.1	65.0 ± 7.1	735.0 ± 148.5	0.064 ± 0.006	52.5 ± 10.6
Ovation[z]	10.0 ± 14.1	80.0 ± 0.0	630.0 ± 99.0	0.045 ± 0.007	45.0 ± 7.1
Pulsar[z]	35.0 ± 7.1	70.0 ± 14.1	735.0 ± 148.5	0.060 ± 0.000	52.5 ± 10.6
Ranchero[z]	50.0 ± 14.1	75.0 ± 7.1	875.0 ± 49.5	0.067 ± 0.010	62.5 ± 3.5
Red Bull[z]	45.0 ± 21.2	80.0 ± 0.0	875.0 ± 148.5	0.063 ± 0.011	62.5 ± 10.6
Red Flare[z]	45.0 ± 35.4	85.0 ± 7.1	910.0 ± 198.0	0.062 ± 0.018	65.0 ± 14.1
Red Wing[z]	45.0 ± 21.2	95.0 ± 7.1	980.0 ± 198.0	0.059 ± 0.008	70.0 ± 14.1
Ruby Ring[z]	40.0 ± 0.0	70.0 ± 14.1	770.0 ± 99.0	0.063 ± 0.005	55.0 ± 7.1
Salsa Red[z]	40.0 ± 0.0	65.0 ± 7.1	735.0 ± 49.5	0.065 ± 0.003	52.5 ± 3.5
Sarape Café[z]	20.0 ± 14.1	65.0 ± 7.1	595.0 ± 148.5	0.052 ± 0.007	42.5 ± 10.6
Sedona[z]	55.0 ± 7.1	85.0 ± 7.1	980.0 ± 99.0	0.066 ± 0.001	70.0 ± 7.1
Sp. Medallion[z]	50.0 ± 28.3	85.0 ± 7.1	945.0 ± 247.5	0.063 ± 0.011	67.5 ± 17.7
Swale[z]	25.0 ± 7.1	60.0 ± 0.0	595.0 ± 49.5	0.057 ± 0.005	42.5 ± 3.5
T-433[z]	0.0 ± 0.0	50.0 ± 0.0	350.0 ± 0.0	0.040 ± 0.000	25.0 ± 0.0
Talon[z]	60.0 ± 0.0	85.0 ± 21.2	1015.0 ± 148.5	0.069 ± 0.007	72.5 ± 10.6
Tamara[z]	48.5 ± 26.2	73.5 ± 9.2	854.0 ± 118.8	0.068 ± 0.018	61.0 ± 8.5
Tequila[z]	15.0 ± 21.2	45.0 ± 21.2	420.0 ± 297.0	0.050 ± 0.014	30.0 ± 21.2
Tioga[z]	50.0 ± 14.1	80.0 ± 0.0	910.0 ± 99.0	0.065 ± 0.007	65.0 ± 7.1
Vantage[z]	45.0 ± 21.2	65.0 ± 21.2	770.0 ± 297.0	0.067 ± 0.004	55.0 ± 21.2
Vaquero[z]	35.0 ± 21.2	80.0 ± 14.1	805.0 ± 247.5	0.057 ± 0.008	57.5 ± 17.7
Vision[z]	30.0 ± 28.3	55.0 ± 7.1	595.0 ± 247.5	0.061 ± 0.018	42.5 ± 17.7
White Cloud[z]	15.0 ± 7.1	80.0 ± 0.0	665.0 ± 49.5	0.048 ± 0.004	47.5 ± 3.5
White Wing[z]	30.0 ± 14.1	75.0 ± 21.2	735.0 ± 247.5	0.056 ± 0.003	52.5 ± 17.7
z average	***40.0 ± 16.1***	***71.9 ± 9.8***	***783.2 ± 155.9***	***0.062 ± 0.009***	***55.9 ± 11.1***
Grand mean	**35.4 ± 14.8**	**67.7 ± 12.1**	**721.7 ± 149.4**	**0.065 ± 0.015**	**51.5 ± 10.7**

Tukey's (0.05)	83.1	62.2	809.4	0.078	57.8

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after sowing (DAS) on which evaluation was carried out.

Appendix I I.A.8. Incidence of *Iris yellow spot virus* (IYSV) in transplanted onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2010.

Genotype	**IYSV-84 (%)** (mean ± SE)	**IYSV-97 (%)** (mean ± SE)	**IYSV-112 (%)** (mean ± SE)	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]	**Severity (117 DAP)** (mean ± SE)[d]
124525[x]	11.1 ± 15.7	14.3 ± 20.2	10.0 ± 14.1	347.2 ± 491.0	0.150 ± 0.212	11.8 ± 16.7	0.5 ± 0.7
164807[x]	5.6 ± 7.8	22.9 ± 14.7	28.5 ± 22.6	570.5 ± 426.6	0.200 ± 0.000	19.0 ± 15.1	3.0 ± 0.0
165498[x]	7.7 ± 10.9	12.5 ± 17.7	60.0 ± 14.1	675.0 ± 424.3	0.100 ± 0.000	26.8 ± 14.2	3.0 ± 0.0
168962[x]	7.2 ± 10.1	11.3 ± 4.2	44.7 ± 27.8	539.6 ± 333.0	0.100 ± 0.000	21.1 ± 14.1	4.0 ± 0.0
168966[x]	6.7 ± 9.4	20.7 ± 1.0	32.6 ± 8.3	577.6 ± 138.0	0.200 ± 0.000	20.0 ± 6.2	4.0 ± 0.0
171475[x]	20.0 ± 14.1	25.0 ± 7.1	72.5 ± 3.5	1023.8 ± 164.4	0.100 ± 0.000	39.2 ± 5.9	3.0 ± 0.0
171477[x]	7.7 ± 10.9	21.6 ± 4.8	21.6 ± 4.8	514.2 ± 174.4	0.200 ± 0.000	17.0 ± 6.9	2.0 ± 0.0
172701[x]	7.4 ± 0.4	11.3 ± 4.2	47.5 ± 31.8	562.8 ± 182.2	0.150 ± 0.071	22.1 ± 9.3	3.0 ± 0.0
172702[x]	17.1 ± 11.2	19.7 ± 7.6	28.0 ± 19.4	595.7 ± 324.3	0.200 ± 0.000	21.6 ± 12.7	2.0 ± 1.4
172703[x]	12.9 ± 0.6	26.8 ± 2.5	58.0 ± 15.9	893.6 ± 158.8	0.100 ± 0.000	32.6 ± 6.3	3.0 ± 0.0
172704[x]	23.3 ± 10.6	32.5 ± 1.2	31.7 ± 2.3	843.2 ± 68.5	0.250 ± 0.071	29.2 ± 3.2	2.5 ± 0.7
174018[x]	16.7 ± 4.7	22.0 ± 9.3	30.0 ± 14.1	641.0 ± 267.3	0.200 ± 0.000	22.9 ± 9.4	2.5 ± 0.7
174024[x]	25.0 ± 17.7	37.5 ± 17.7	35.7 ± 20.2	955.4 ± 513.9	0.200 ± 0.000	32.7 ± 18.5	3.5 ± 0.7
177242[x]	12.5 ± 0.0	16.7 ± 0.0	16.7 ± 0.0	439.7 ± 0.0	0.200 ± 0.000	15.3 ± 0.0	3.0 ± 0.0
179627[x]	18.4 ± 2.3	24.1 ± 8.3	44.5 ± 15.8	789.8 ± 250.2	0.200 ± 0.000	29.0 ± 8.8	2.5 ± 0.7
182138[x]	3.0 ± 4.2	50.6 ± 13.3	53.6 ± 9.1	1128.9 ± 227.9	0.200 ± 0.000	35.7 ± 6.1	3.5 ± 0.7
200874[x]	14.3 ± 20.2	28.6 ± 0.0	34.3 ± 8.1	750.0 ± 70.7	0.250 ± 0.071	25.8 ± 4.0	2.5 ± 0.7
233186[x]	10.7 ± 15.1	26.8 ± 2.5	42.8 ± 3.9	765.1 ± 162.8	0.150 ± 0.071	26.8 ± 7.1	2.5 ± 0.7
248753[x]	0.0 ± 0.0	11.1 ± 0.0	12.5 ± 0.0	249.3 ± 0.0	0.200 ± 0.000	7.9 ± 0.0	1.0 ± 0.0
248754[x]	3.9 ± 5.4	8.0 ± 0.4	22.2 ± 0.0	303.8 ± 29.0	0.100 ± 0.000	11.4 ± 1.6	2.0 ± 1.4
249899[x]	8.6 ± 4.6	19.7 ± 5.4	20.9 ± 5.9	486.9 ± 150.7	0.200 ± 0.000	16.4 ± 5.3	2.0 ± 0.0
251325[x]	6.3 ± 8.8	18.1 ± 9.8	34.7 ± 13.7	553.8 ± 91.9	0.150 ± 0.071	19.7 ± 1.6	1.5 ± 0.7

255557[x]	12.9 ± 0.6	45.0 ± 7.1	51.7 ± 2.3	1101.5 ± 77.6	0.200 ± 0.000	36.6 ± 1.3	3.0 ± 0.0
258956[x]	0.0 ± 0.0	32.5 ± 5.5	90.0 ± 14.1	1129.5 ± 29.0	0.100 ± 0.000	40.9 ± 2.9	3.0 ± 0.0
264320[x]	13.9 ± 10.7	43.8 ± 8.8	70.6 ± 11.4	1231.5 ± 278.7	0.150 ± 0.071	42.7 ± 10.3	4.0 ± 0.0
264648[x]	30.7 ± 8.1	46.4 ± 14.1	60.0 ± 5.2	1297.3 ± 105.5	0.200 ± 0.000	45.7 ± 0.2	3.0 ± 0.0
271039[x]	0.0 ± 0.0	23.4 ± 9.4	45.6 ± 48.7	668.4 ± 497.3	0.200 ± 0.141	23.0 ± 19.4	1.5 ± 0.7
274780[x]	0.0 ± 0.0	18.6 ± 16.2	25.4 ± 7.6	450.4 ± 169.2	0.200 ± 0.141	14.7 ± 2.9	2.0 ± 0.0
288073[x]	21.6 ± 4.8	44.3 ± 27.3	45.0 ± 21.2	1098.3 ± 510.2	0.200 ± 0.000	37.0 ± 14.6	2.0 ± 0.0
288270[x]	11.9 ± 6.8	19.9 ± 4.5	30.0 ± 14.1	580.6 ± 125.7	0.150 ± 0.071	20.6 ± 4.0	2.5 ± 0.7
288272[x]	0.0 ± 0.0	17.4 ± 6.9	17.2 ± 4.0	371.7 ± 126.5	0.200 ± 0.000	11.5 ± 3.7	1.0 ± 0.0
288902[x]	5.6 ± 7.8	18.1 ± 9.8	18.1 ± 9.8	424.3 ± 160.1	0.250 ± 0.071	13.9 ± 4.0	1.5 ± 0.7
288903[x]	25.0 ± 0.0	54.2 ± 17.7	62.5 ± 5.9	1389.7 ± 291.7	0.200 ± 0.000	47.3 ± 7.8	2.5 ± 0.7
288908[x]	0.0 ± 0.0	45.0 ± 7.1	19.1 ± 1.3	773.2 ± 89.4	0.350 ± 0.071	21.4 ± 1.9	2.0 ± 0.0
288909[x]	17.3 ± 16.1	36.8 ± 35.3	22.2 ± 31.4	959.2 ± 598.6	0.200 ± 0.141	25.4 ± 27.6	3.0 ± 0.0
289689[x]	16.9 ± 13.9	28.6 ± 10.1	32.2 ± 25.2	751.0 ± 420.5	0.250 ± 0.071	25.9 ± 16.4	2.0 ± 0.0
289690[x]	17.8 ± 1.5	50.4 ± 8.4	50.4 ± 8.4	1197.6 ± 189.2	0.200 ± 0.000	39.5 ± 6.1	3.5 ± 0.7
344392[x]	10.0 ± 14.1	18.4 ± 2.3	20.9 ± 5.9	478.0 ± 169.1	0.200 ± 0.000	16.4 ± 7.5	2.0 ± 0.0
433330[x]	3.0 ± 4.2	44.1 ± 12.4	31.2 ± 6.4	870.7 ± 195.7	0.250 ± 0.071	26.1 ± 4.9	2.5 ± 0.7
433332[x]	13.3 ± 3.0	75.6 ± 16.9	61.3 ± 1.8	1603.5 ± 229.9	0.250 ± 0.071	50.0 ± 5.2	3.0 ± 0.0
546096[x]	45.0 ± 21.2	80.0 ± 0.0	73.2 ± 2.5	1961.6 ± 118.9	0.250 ± 0.071	66.1 ± 6.2	2.0 ± 0.0
546100[x]	0.0 ± 0.0	21.0 ± 20.8	39.8 ± 5.7	591.7 ± 249.0	0.150 ± 0.071	20.3 ± 5.0	3.0 ± 0.0
546101[x]	4.6 ± 6.4	34.3 ± 15.8	42.7 ± 16.8	829.2 ± 389.3	0.200 ± 0.000	27.2 ± 13	3.0 ± 0.0
546106[x]	0.0 ± 0.0	36.6 ± 19.0	40.4 ± 13.6	814.5 ± 368.5	0.200 ± 0.000	25.7 ± 10.8	2.0 ± 0.0
546115[x]	12.8 ± 8.6	34.3 ± 8.1	39.3 ± 1.1	856.9 ± 176.8	0.200 ± 0.000	28.8 ± 5.9	2.5 ± 0.7
546140[x]	17.8 ± 13.4	38.9 ± 22.3	39.7 ± 24.7	956.7 ± 583.8	0.200 ± 0.000	32.1 ± 20.1	2.0 ± 0.0
546162[x]	12.5 ± 17.7	34.9 ± 2.2	34.9 ± 2.2	830.4 ± 68.9	0.200 ± 0.000	27.4 ± 4.5	2.0 ± 0.0
546174[x]	11.5 ± 7.4	45.9 ± 29.5	44.3 ± 27.3	1048.6 ± 665.3	0.200 ± 0.000	33.9 ± 21.4	2.0 ± 0.0
546188[x]	3.2 ± 4.5	24.1 ± 16.4	37.5 ± 17.7	639.0 ± 333.6	0.150 ± 0.071	21.6 ± 9.9	3.5 ± 0.7
546192[x]	7.4 ± 0.4	14.9 ± 0.8	33.1 ± 18.5	504.0 ± 152.0	0.150 ± 0.071	18.5 ± 6.6	3 .0± 1.4

639911[x]	7.0 ± 1.0	35.6 ± 15	35.6 ± 15	810.2 ± 328.2	0.200 ± 0.000	26.1 ± 10.3	3.0 ± 0.0
639912[x]	9.1 ± 12.9	27.3 ± 12.9	38.2 ± 2.5	727.2 ± 77.1	0.200 ± 0.000	24.9 ± 0.9	3.0 ± 0.0
639913[x]	3.2 ± 4.5	37.5 ± 5.9	23.4 ± 9.4	720.4 ± 124.5	0.250 ± 0.071	21.4 ± 3.6	2.0 ± 0.0
639915[x]	10.9 ± 6.4	29.4 ± 23.8	39.7 ± 4.6	778.0 ± 340.6	0.200 ± 0.141	26.6 ± 8.6	2.0 ± 0.0
639916[x]	21.9 ± 13.3	37.6 ± 8.8	48.6 ± 6.7	1031.3 ± 159.2	0.200 ± 0.000	36.0 ± 5.1	3.0 ± 0.0
903-1[x]	24.3 ± 1.1	30.5 ± 9.9	42.3 ± 6.8	902.1 ± 94.4	0.200 ± 0.000	32.4 ± 1.3	3.0 ± 0.0
904-1[x]	14.3 ± 20.2	21.5 ± 10.1	45.0 ± 7.1	730.4 ± 325.7	0.150 ± 0.071	26.9 ± 12.4	3.0 ± 0.0
905-1[x]	18.8 ± 17.0	28.8 ± 2.9	55.8 ± 3.5	942.5 ± 177.9	0.150 ± 0.071	34.5 ± 7.8	3.0 ± 0.0
x average	***11.6 ± 7.5***	***30.3 ± 10.3***	***39.5 ± 11.5***	***797.6 ± 235.3***	***0.189 ± 0.037***	***27.1 ± 8.1***	***2.5 ± 0.3***
OLYO5N5[y]	5.3 ± 7.4	7.9 ± 3.7	39.5 ± 11.2	440.8 ± 184.3	0.100 ± 0.000	17.6 ± 7.4	3.5 ± 0.7
Colorado 6[z]	0.0 ± 0.0	6.7 ± 9.4	46.5 ± 0.4	441.4 ± 134.7	0.100 ± 0.000	17.7 ± 3.3	3.5 ± 0.7
Salsa Red[z]	11.0 ± 4.7	21.7 ± 19.8	52.0 ± 2.8	764.7 ± 287.3	0.150± 0.071	28.2 ± 7.2	3.0 ± 0.0
Vantage[z]	23.6 ± 33.3	30.4 ± 1.3	48.8 ± 10.7	943.0 ± 118.2	0.150 ± 0.071	34.2 ± 7.1	4.0 ± 0.0
z average	***11.5 ± 12.7***	***19.6 ± 10.2***	***49.1 ± 4.6***	***716.4 ± 180.1***	***0.133 ± 0.047***	***26.7 ± 5.9***	***3.5 ± 0.2***
Grand mean	**9.5 ± 9.2**	**19.3 ± 8**	**42.7 ± 9.1**	**651.6 ± 199.9**	**0.141 ± 0.028**	**23.8 ± 7.1**	**3.2 ± 0.4**
Tukey's (0.05)	44.9	55.5	63.3	1205	0.263	42.4	2.2

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[d]Severity was based on a rating scale of 1 – 4 (Schwartz and du Toit, 2005).

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.9a. Incidence of *Iris yellow spot virus* (IYSV) in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2010.

Genotype	**IYSV-97 (%)** (mean ± SE)	**IYSV-112 (%)** (mean ± SE)	**IYSV-122 (%)** (mean ± SE)	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]
903-1[x]	8.6 ± 1.0	15.9 ± 2.1	87.5 ± 5.1	700.2 ± 43.7	0.066 ± 0.000	37.3 ± 2.0
904-1[x]	5.9 ± 2.7	26.8 ± 12.7	94.6 ± 4.7	851.9 ± 162.9	0.074 ± 0.010	42.4 ± 4.9
905-1[x]	2.0 ± 1.0	23.4 ± 0.4	95.8 ± 2.9	787.1 ± 27.8	0.067 ± 0.000	40.4 ± 1.5
x mean	5.5 ± 1.6	22.0 ± 5.1	92.6 ± 4.2	779.7 ± 78.1	0.069 ± 0.004	40.0 ± 2.8
16535[y]	2.5 ± 0.7	19.2 ± 11.5	90.7 ± 11.2	712.3 ± 195.4	0.064 ± 0.010	37.5 ± 7.4
18495[y]	5.7 ± 1.7	19.8 ± 10.1	97.6 ± 3.4	778.1 ± 131.3	0.065 ± 0.009	41.0 ± 4.0
6001[y]	6.2 ± 2.4	14.4 ± 3.5	90.3 ± 5.3	678.6 ± 0.4	0.062 ± 0.004	37.0 ± 1.4
6022[y]	2.2 ± 1.1	17.4 ± 7.7	92.5 ± 4.5	697.2 ± 111.0	0.062 ± 0.007	37.4 ± 3.7
EX-14593[y]	14.7 ± 6.1	19.8 ± 1.0	87.6 ± 0.4	795.8 ± 35.3	0.074 ± 0.003	40.7 ± 1.8
NUN7006ON[y]	4.2 ± 2.0	22.3 ± 14.2	94.4 ± 8.0	781.4 ± 232.4	0.067 ± 0.014	40.3 ± 8.1
NUN7007ON[y]	5.0 ± 1.1	22.1 ± 11.3	95.2 ± 6.8	789.0 ± 166.4	0.068 ± 0.009	40.7 ± 5.6
NUN7009ON[y]	7.8 ± 6.3	26.2 ± 9.5	97.8 ± 3.1	875.0 ± 87.0	0.073 ± 0.005	43.9 ± 2.1
NUN7606ON[y]	4.5 ± 2.5	18.3 ± 9.9	88.6 ± 0.6	705.2 ± 108.0	0.065 ± 0.010	37.1 ± 2.7
OLYS06-25[y]	9.4 ± 7.2	17.6 ± 4.4	88.1 ± 0.9	730.9 ± 5.7	0.068 ± 0.000	38.4 ± 0.6
R-5978[y]	9.4 ± 0.6	26.9 ± 10.0	87.3 ± 7.1	843.8 ± 93.9	0.080 ± 0.015	41.2 ± 1.2
SBO-5288[y]	1.0 ± 1.5	24.4 ± 17.7	93.1 ± 2.4	778.0 ± 244.0	0.068 ± 0.020	39.5 ± 7.2
SBO-5419[y]	4.1 ± 4.6	26.4 ± 15.8	94.6 ± 2.5	833.6 ± 244.3	0.072 ± 0.019	41.7 ± 7.6
SBO-5420[y]	2.0 ± 2.8	11.6 ± 3.8	86.6 ± 0.4	593.1 ± 66.0	0.056 ± 0.006	33.4 ± 2.1
SBO-5508[y]	1.1 ± 0.8	9.2 ± 1.8	90.9 ± 5.7	578.7 ± 0.1	0.052 ± 0.003	33.8 ± 1.0
SBO-5599[y]	3.6 ± 0.2	27.9 ± 27.1	92.2 ± 11.0	837 ± 392.1	0.073 ± 0.026	41.2 ± 12.6
SN-626[y]	4.4 ± 1.1	15.3 ± 4.9	89.2 ± 7.6	670.8 ± 107.6	0.061 ± 0.005	36.3 ± 4.5
y mean	***5.2 ± 2.5***	***19.9 ± 9.7***	***91.6 ± 4.8***	***745.8 ± 130.6***	***0.067 ± 0.010***	***38.9 ± 4.3***

Advantage [z]	2.7 ± 2.5	14.7 ± 12.2	93.5 ± 3.9	671.6 ± 191.7	0.059 ± 0.014	37.0 ± 6.2
Bello Blanco [z]	4.5 ± 2.8	10.1 ± 1.5	85.9 ± 13.8	589.3 ± 29.0	0.057 ± 0.006	33.5 ± 3.2
Belmar [z]	7.5 ± 6.3	14.5 ± 0.1	89.6 ± 2.4	684.8 ± 33.3	0.063 ± 0.005	37.2 ± 1.2
Bradley [z]	8.1 ± 1.4	21.5 ± 1.7	90.9 ± 2.7	784.9 ± 18.8	0.071 ± 0.004	40.2 ± 0.1
Brundage [z]	5.3 ± 0.6	15.7 ± 3.5	88.1 ± 2.5	676.7 ± 51.8	0.063 ± 0.003	36.4 ± 1.8
Calibra [z]	7.6 ± 1.2	18.2 ± 3.1	95.8 ± 6.0	762.9 ± 59.5	0.065 ± 0.001	40.5 ± 2.6
Colorado 6 [z]	1.6 ± 0.7	6.7 ± 0.3	89.6 ± 1.7	544.0 ± 17.3	0.050 ± 0.001	32.6 ± 0.9
Cometa [z]	9.5 ± 7.6	15.1 ± 7.5	79.2 ± 14.1	656.0 ± 221.6	0.067 ± 0.011	34.6 ± 9.8
Crockett [z]	2.6 ± 2.5	20.3 ± 3.2	87.3 ± 3.4	709.7 ± 42.2	0.067 ± 0.007	36.7 ± 0.8
Genesis [z]	18.6 ± 15.6	32.8 ± 1.2	93.5 ± 5.0	1016.6 ± 127.1	0.089 ± 0.006	48.3 ± 6.5
Granero [z]	4.1 ± 0.4	13.1 ± 6.0	94.8 ± 6.0	668.1 ± 42.1	0.058 ± 0.007	37.3 ± 0.1
Gunnison [z]	2.4 ± 3.4	17.1 ± 2.0	92.0 ± 8.7	691.7 ± 43.4	0.062 ± 0.002	37.2 ± 2.5
Joaquin [z]	2.1 ± 3.0	20.6 ± 3.8	91.4 ± 2.8	730.4 ± 39.5	0.066 ± 0.002	38.0 ± 1.2
Mesquite [z]	5.8 ± 0.1	14.9 ± 0.8	76.7 ± 27.2	612.4 ± 125.6	0.067 ± 0.010	32.4 ± 8.8
Morpheus [z]	5.0 ± 1.7	23.0 ± 28.5	85.9 ± 14.7	754.7 ± 441.6	0.069 ± 0.030	38.0 ± 14.9
Oracle [z]	3.5 ± 3.6	14.6 ± 7.1	91.2 ± 4.9	664.8 ± 37.6	0.060 ± 0.007	36.4 ± 0.5
Red Devil [z]	8.5 ± 4.4	22.9 ± 4.6	84.1 ± 3.6	770.9 ± 108.3	0.075 ± 0.007	38.5 ± 4.2
Salsa Red [z]	14.6 ± 5.7	24.8 ± 8.2	91.6 ± 5.8	876.8 ± 174.1	0.078 ± 0.011	43.6 ± 6.6
Swale [z]	7.0 ± 8.5	27.7 ± 9.7	93.2 ± 2.2	865.3 ± 196.2	0.076 ± 0.015	42.7 ± 6.8
Tequila [z]	3.8 ± 2.4	11.4 ± 4.0	93.5 ± 4.2	639.5 ± 47.4	0.056 ± 0.007	36.3 ± 0.7
The Rock [z]	8.5 ± 2.5	12.5 ± 0.2	93.6 ± 1.1	688.2 ± 22.1	0.060 ± 0.001	38.2 ± 1.1
White Cloud [z]	0.6 ± 0.9	19.2 ± 3.3	89.6 ± 8.9	692.9 ± 92.7	0.063 ± 0.002	36.5 ± 4.4
z mean	***6.1 ± 3.5***	***17.8 ± 5.1***	***89.6 ± 6.6***	***716.0 ± 98.3***	***0.065 ± 0.007***	***37.8 ± 3.9***
Grand mean	**5.6 ± 2.5**	**19.9 ± 6.6**	**91.3 ± 5.2**	**747.2 ± 102.4**	**0.067 ± 0.007**	**38.9 ± 3.7**
Tukey’s (0.05)	17.6	40.1	31.7	622.5	0.044	22.1

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.9b. Severity of *Iris yellow spot virus* (IYSV) infection in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2010.

Genotype	**Severity-117** (mean ± SE)[c]	**Severity-136** (mean ± SE)[c]	**AUDPC-sv** (mean ± SE)[a]	**rAUDPC-sv** (mean ± SE)[b]	**Severity-avg** (mean ± SE)[d]
903-1[x]	3.0 ± 0.0	3.3 ± 0.4	59.4 ± 3.4	0.135 ± 0.007	3.1 ± 0.2
904-1[x]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
905-1[x]	2.3 ± 0.4	3.0 ± 0.0	49.9 ± 3.4	0.122 ± 0.008	2.6 ± 0.2
x mean	2.6 ± 0.4	3.1 ± 0.1	53.8 ± 4.5	0.128 ± 0.011	2.8 ± 0.2
16535[y]	2.8 ± 0.4	3.3 ± 0.4	57.0 ± 6.7	0.129 ± 0.001	3.0 ± 0.4
18495[y]	2.3 ± 0.4	3.0 ± 0.0	49.9 ± 3.4	0.122 ± 0.008	2.6 ± 0.2
6001[y]	2.0 ± 0.0	3.8 ± 0.4	54.6 ± 3.4	0.107 ± 0.004	2.9 ± 0.2
6022[y]	2.3 ± 0.4	3.3 ± 0.4	52.3 ± 0.0	0.119 ± 0.013	2.8 ± 0.0
EX-14593[y]	3.0 ± 0.0	3.0 ± 0.0	57.0 ± 0.0	0.140 ± 0.000	3.0 ± 0.0
NUN7006ON[y]	2.0 ± 0.7	3.5 ± 0.7	52.3 ± 13.4	0.109 ± 0.006	2.8 ± 0.7
NUN7007ON[y]	2.3 ± 0.4	3.0 ± 0.0	49.9 ± 3.4	0.122 ± 0.008	2.6 ± 0.2
NUN7009ON[y]	2.3 ± 0.4	3.3 ± 0.4	52.3 ± 6.7	0.118 ± 0.002	2.8 ± 0.4
NUN7606ON[y]	1.8 ± 0.4	3.0 ± 0.0	45.1 ± 3.4	0.111 ± 0.008	2.4 ± 0.2
OLYS06-25[y]	2.0 ± 0.0	2.8 ± 0.4	45.1 ± 3.4	0.121 ± 0.007	2.4 ± 0.2
R-5978[y]	2.8 ± 0.4	3.3 ± 0.4	57.0 ± 0.0	0.130 ± 0.014	3.0 ± 0.0
SBO-5288[y]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
SBO-5419[y]	2.3 ± 0.4	3.3 ± 0.4	52.3 ± 6.7	0.118 ± 0.002	2.8 ± 0.4
SBO-5420[y]	1.8 ± 0.4	3.0 ± 0.0	45.1 ± 3.4	0.111 ± 0.008	2.4 ± 0.2
SBO-5508[y]	2.3 ± 0.4	3.0 ± 0.0	49.9 ± 3.4	0.122 ± 0.008	2.6 ± 0.2
SBO-5599[y]	2.3 ± 0.4	3.0 ± 1.4	49.9 ± 16.8	0.127 ± 0.019	2.6 ± 0.9
SN-626[y]	2.0 ± 0.0	2.3 ± 0.4	40.4 ± 3.4	0.133 ± 0.01	2.1 ± 0.2
y mean	***2.3 ± 0.3***	***3.1 ± 0.3***	***50.7 ± 4.9***	***0.122 ± 0.008***	***2.7 ± 0.3***
Advantage[z]	2.0 ± 0.0	3.0 ± 0.0	47.5 ± 0.0	0.116 ± 0.000	2.5 ± 0.0
Bello Blanco[z]	2.0 ± 0.0	2.5 ± 0.0	42.8 ± 0.0	0.126 ± 0.000	2.3 ± 0.0
Belmar[z]	2.5 ± 0.7	3.3 ± 0.4	54.6 ± 10.1	0.123 ± 0.009	2.9 ± 0.5

Bradley [z]	2.8 ± 0.4	3.3 ± 0.4	57.0 ± 6.7	0.129 ± 0.001	3.0 ± 0.4
Brundage [z]	2.0 ± 0.0	2.8 ± 0.4	45.1 ± 3.4	0.121 ± 0.007	2.4 ± 0.2
Calibra [z]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
Colorado 6 [z]	2.0 ± 0.0	3.0 ± 0.0	47.5 ± 0.0	0.116 ± 0.000	2.5 ± 0.0
Cometa [z]	1.8 ± 0.4	2.5 ± 0.7	40.4 ± 3.4	0.122 ± 0.025	2.1 ± 0.2
Crockett [z]	2.3 ± 0.4	2.5 ± 0.0	45.1 ± 3.4	0.133 ± 0.010	2.4 ± 0.2
Genesis [z]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
Granero [z]	3.0 ± 0.0	3.5 ± 0.7	61.8 ± 6.7	0.131 ± 0.012	3.3 ± 0.4
Gunnison [z]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
Joaquin [z]	2.5 ± 0.7	3.0 ± 0.0	52.3 ± 6.7	0.128 ± 0.016	2.8 ± 0.4
Mesquite [z]	2.5 ± 0.7	2.5 ± 0.7	47.5 ± 13.4	0.140 ± 0.000	2.5 ± 0.7
Morpheus [z]	2.5 ± 0.7	3.3 ± 0.4	54.6 ± 10.1	0.123 ± 0.009	2.9 ± 0.5
Oracle [z]	2.5 ± 0.7	3.5 ± 0.7	57.0 ± 13.4	0.119 ± 0.004	3.0 ± 0.7
Red Devil [z]	2.8 ± 0.4	3.0 ± 0.0	54.6 ± 3.4	0.134 ± 0.008	2.9 ± 0.2
Salsa Red [z]	2.5 ± 0.0	3.0 ± 0.0	52.3 ± 0.0	0.128 ± 0.000	2.8 ± 0.0
Swale [z]	2.3 ± 0.4	3.3 ± 0.4	52.3 ± 6.7	0.118 ± 0.002	2.8 ± 0.4
Tequila [z]	2.5 ± 0.7	2.5 ± 0.7	47.5 ± 13.4	0.140 ± 0.000	2.5 ± 0.7
The Rock [z]	2.5 ± 0.0	3.3 ± 0.4	54.6 ± 3.4	0.124 ± 0.006	2.9 ± 0.2
White Cloud [z]	1.8 ± 0.4	2.5 ± 0.7	40.4 ± 3.4	0.122 ± 0.025	2.1 ± 0.2
z mean	***2.4 ± 0.4***	***3.0 ± 0.3***	***50.5 ± 5.8***	***0.126 ± 0.008***	***2.7 ± 0.3***
Grand mean	**2.4 ± 0.4**	**3 ± 0.2**	**51.7 ± 5.1**	**0.125 ± 0.009**	**2.7 ± 0.3**
Tukey's (0.05)	1.9	1.8	28.5	0.045	1.5

[a]Area under the disease progress curve for IYSV severity.

[b]Relative area under the disease progress curve for IYSV severity.

[c]Severity was based on a rating scale of 1 – 4 (Schwartz and du Toit, 2005).

[d]Seasonal average of IYSV severity.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following “-” indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.10a. Incidence of *Iris yellow spot virus* (IYSV) in transplanted onion germplasms during field evaluation for their resistance/tolerance to IYSV in northern Colorado, near Fort Collins, in 2011.

Genotype	**IYSV-107** **(%)** (mean ± SE)	**IYSV-120** **(%)** (mean ± SE)	**IYSV-134** **(%)** (mean ± SE)	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]
574 [x]	73.3 ± 22.6	100.0 ± 0.0	100.0 ± 0.0	2526.1 ± 146.6	0.189 ± 0.011	91.1 ± 7.5
575 [x]	43.0 ± 30.2	100.0 ± 0.0	100.0 ± 0.0	2329.5 ± 196.1	0.174 ± 0.015	81.0 ± 10.1
577 [x]	64.0 ± 9.6	91.7 ± 14.4	100.0 ± 0.0	2353.5 ± 133.3	0.176 ± 0.010	85.2 ± 1.7
578 [x]	60.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2440.0 ± 0.0	0.182 ± 0.000	86.7 ± 0.0
579 [x]	33.5 ± 23.3	100.0 ± 0.0	100.0 ± 0.0	2267.8 ± 151.7	0.169 ± 0.011	77.8 ± 7.8
580 [x]	59.0 ± 13.9	83.3 ± 28.9	100.0 ± 0.0	2208.5 ± 479.8	0.165 ± 0.036	80.8 ± 14.2
583 [x]	25.0 ± 11.3	75.0 ± 35.4	100.0 ± 0.0	187.0 ± 403.8	0.140 ± 0.030	66.7 ± 8.0
589 [x]	34.0 ± 20.1	80.3 ± 5.5	100.0 ± 0.0	2005.5 ± 202.0	0.150 ± 0.015	71.4 ± 8.4
592 [x]	44.3 ± 9.8	76.7 ± 25.2	100.0 ± 0.0	2023.2 ± 291.0	0.151 ± 0.022	73.7 ± 6.1
593 [x]	31.3 ± 18.9	83.8 ± 15.5	100.0 ± 0.0	2033.8 ± 278.6	0.152 ± 0.021	71.7 ± 9.5
594 [x]	36.5 ± 4.9	80.0 ± 28.3	100.0 ± 0.0	2017.3 ± 414.0	0.151 ± 0.031	72.2 ± 11.1
596 [x]	35.3 ± 18.0	76.3 ± 15.9	100.0 ± 0.0	1958.5 ± 260.8	0.146 ± 0.019	70.5 ± 8.6
597 [x]	33.0 ± 0.0	67.0 ± 0.0	100.0 ± 0.0	1819.0 ± 0.0	0.136 ± 0.000	66.7 ± 0.0
602 [x]	62.3 ± 4.0	91.7 ± 14.4	100.0 ± 0.0	2342.7 ± 209.2	0.175 ± 0.016	84.7 ± 5.6
607 [x]	73.3 ± 32.8	100.0 ± 0.0	100.0 ± 0.0	2526.1 ± 213.2	0.189 ± 0.016	91.1 ± 10.9
615 [x]	78.5 ± 10.6	100.0 ± 0.0	100.0 ± 0.0	2560.3 ± 68.9	0.191 ± 0.005	92.8 ± 3.5
618 [x]	46.7 ± 25.7	100.0 ± 0.0	100.0 ± 0.0	2353.3 ± 166.8	0.176 ± 0.012	82.2 ± 8.6
619 [x]	48.7 ± 16.2	100.0 ± 0.0	100.0 ± 0.0	2366.3 ± 105.1	0.177 ± 0.008	82.9 ± 5.4
620 [x]	45.5 ± 18.4	88.5 ± 14.2	100.0 ± 0.0	2190.5 ± 202.4	0.163 ± 0.015	78.0 ± 6.9
621 [x]	63.3 ± 25.5	100.0 ± 0.0	100.0 ± 0.0	2461.1 ± 165.6	0.184 ± 0.012	87.8 ± 8.5
622 [x]	53.5 ± 10.8	86.8 ± 12.6	100.0 ± 0.0	2218.9 ± 213.1	0.166 ± 0.016	80.1 ± 6.7

624[x]	38.5 ± 24.1	82.5 ± 23.6	100.0 ± 0.0	2064.0 ± 343.4	0.154 ± 0.026	73.7 ± 10.8
628[x]	36.7 ± 17.6	67.7 ± 29.3	100.0 ± 0.0	1851.8 ± 508.2	0.138 ± 0.038	68.1 ± 15.6
629[x]	57.3 ± 26.6	100.0 ± 0.0	100.0 ± 0.0	2422.7 ± 173.1	0.181 ± 0.013	85.8 ± 8.9
632[x]	100.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2700.0 ± 0.0	0.201 ± 0.000	100.0 ± 0.0
634[x]	72.3 ± 4.6	100.0 ± 0.0	100.0 ± 0.0	2520.2 ± 30.0	0.188 ± 0.002	90.8 ± 1.5
643[x]	71.5 ± 40.3	100.0 ± 0.0	100.0 ± 0.0	2514.8 ± 262.0	0.188 ± 0.020	90.5 ± 13.4
646[x]	75.0 ± 25.0	100.0 ± 0.0	100.0 ± 0.0	2537.5 ± 162.5	0.189 ± 0.012	91.7 ± 8.3
648[x]	60.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2440.0 ± 0.0	0.182 ± 0.000	86.7 ± 0.0
651[x]	55.0 ± 27.8	89.0 ± 19.1	100.0 ± 0.0	2259.0 ± 431.0	0.169 ± 0.032	81.3 ± 15.4
654[x]	55.0 ± 15.2	100.0 ± 0.0	100.0 ± 0.0	2407.5 ± 99.0	0.180 ± 0.007	85.0 ± 5.1
656[x]	58.5 ± 34.6	90.0 ± 20.0	100.0 ± 0.0	2295.3 ± 469.6	0.171 ± 0.035	82.8 ± 17.3
658[x]	61.0 ± 9.3	100.0 ± 0.0	100.0 ± 0.0	2446.5 ± 60.5	0.183 ± 0.005	87 .0± 3.1
660[x]	61.0 ± 35.5	100.0 ± 0.0	100.0 ± 0.0	2446.5 ± 231.0	0.183 ± 0.017	87.0 ± 11.8
696[x]	20.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2180.0 ± 0.0	0.163 ± 0.000	73.3 ± 0.0
700[x]	64.8 ± 10.1	88.5 ± 12.3	100.0 ± 0.0	2315.6 ± 195.4	0.173 ± 0.015	84.4 ± 6.0
702[x]	31.3 ± 5.6	83.5 ± 19.1	100.0 ± 0.0	2030.4 ± 261.6	0.152 ± 0.020	71.6 ± 6.7
706[x]	36.0 ± 9.6	93.3 ± 11.5	100.0 ± 0.0	2194.0 ± 218.0	0.164 ± 0.016	76.4 ± 7.0
708[x]	26.7 ± 5.8	90.0 ± 17.3	100.0 ± 0.0	2088.3 ± 217.5	0.156 ± 0.016	72.2 ± 5.1
711[x]	32.8 ± 16.7	87.5 ± 14.4	100.0 ± 0.0	2094.1 ± 227.9	0.156 ± 0.017	73.4 ± 7.5
712[x]	31.0 ± 2.8	80.0 ± 28.3	100.0 ± 0.0	1981.5 ± 363.5	0.148 ± 0.027	70.3 ± 8.5
713[x]	14.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2141.0 ± 0.0	0.160 ± 0.000	71.3 ± 0.0
718[x]	24.7 ± 13.6	82.3 ± 16.6	100.0 ± 0.0	1971.8 ± 180.3	0.147 ± 0.013	69.0 ± 4.3
719[x]	42.5 ± 24.7	100.0 ± 0.0	100.0 ± 0.0	2326.3 ± 160.9	0.174 ± 0.012	80.8 ± 8.2
753[x]	45.3 ± 13.7	100.0 ± 0.0	100.0 ± 0.0	2344.7 ± 88.7	0.175 ± 0.007	81.8 ± 4.6
759[x]	32.3 ± 13.3	100.0 ± 0.0	100.0 ± 0.0	2260.2 ± 86.3	0.169 ± 0.006	77.4 ± 4.4
765[x]	43.7 ± 14.4	100.0 ± 0.0	100.0 ± 0.0	2333.8 ± 93.4	0.174 ± 0.007	81.2 ± 4.8
768[x]	74.3 ± 15.0	100.0 ± 0.0	100.0 ± 0.0	2533.2 ± 97.6	0.189 ± 0.007	91.4 ± 5.0
769[x]	55.0 ± 7.1	87.5 ± 17.7	100.0 ± 0.0	2238.8 ± 284.6	0.167 ± 0.021	80.8 ± 8.2

172702 [x]	25.5 ± 12.3	79.3 ± 24.9	100.0 ± 0.0	1935.6 ± 371.0	0.144 ± 0.028	68.3 ± 10.4
172703 [x]	33.0 ± 0.0	100.0 ± 0.0	100.0 ± 0.0	2264.5 ± 0.0	0.169 ± 0.000	77.7 ± 0.0
239633 [x]	50.0 ± 24.0	83.5 ± 23.3	100.0 ± 0.0	2152.3 ± 158.7	0.161 ± 0.012	77.8 ± 0.2
258956 [x]	39.0 ± 21.5	100.0 ± 0.0	100.0 ± 0.0	2303.5 ± 139.9	0.172 ± 0.010	79.7 ± 7.2
264320 [x]	57.5 ± 9.7	100.0 ± 0.0	100.0 ± 0.0	2423.8 ± 63.4	0.181 ± 0.005	85.8 ± 3.2
288909 [x]	51.0 ± 9.5	100.0 ± 0.0	100.0 ± 0.0	2381.5 ± 62.0	0.178 ± 0.005	83.7 ± 3.2
289689 [x]	39.8 ± 26.2	91.8 ± 16.5	100.0 ± 0.0	2197.0 ± 312.2	0.164 ± 0.023	77.2 ± 11.4
343049 [x]	39.0 ± 9.2	86.5 ± 15.7	100.0 ± 0.0	2121.3 ± 269.1	0.158 ± 0.020	75.2 ± 8.2
546140 [x]	32.3 ± 12.5	90.0 ± 20.0	100.0 ± 0.0	2124.6 ± 238.1	0.159 ± 0.018	74.1 ± 5.7
546188 [x]	65.0 ± 13.9	95.0 ± 10.0	100.0 ± 0.0	2405 ± 179.5	0.179 ± 0.013	86.7 ± 6.3
546192 [x]	43.5 ± 13.9	97.3 ± 5.5	100.0 ± 0.0	2295.6 ± 143.0	0.171 ± 0.011	80.3 ± 5.8
639911 [x]	63.8 ± 24.1	100.0 ± 0.0	100.0 ± 0.0	2464.4 ± 156.8	0.184 ± 0.012	87.9 ± 8.0
B2133C [x]	30.5 ± 12.4	92.5 ± 9.6	100.0 ± 0.0	2147.0 ± 204.0	0.160 ± 0.015	74.3 ± 7.1
B5336C [x]	66.5 ± 47.4	100.0 ± 0.0	100.0 ± 0.0	2482.3 ± 307.9	0.185 ± 0.023	88.8 ± 15.8
B5351C [x]	27.0 ± 12.8	91.7 ± 14.4	100.0 ± 0.0	2113.0 ± 274.9	0.158 ± 0.021	72.9 ± 9.0
E203 [x]	28.5 ± 18.4	75.5 ± 17.4	100.0 ± 0.0	1904.5 ± 263.9	0.142 ± 0.020	68.0 ± 8.4
E205 [x]	25.3 ± 12.1	73.8 ± 25.0	100.0 ± 0.0	1859.8 ± 396.9	0.139 ± 0.030	66.3 ± 11.6
E206 [x]	56.5 ± 20.6	100.0 ± 0.0	100.0 ± 0.0	2417.3 ± 133.6	0.180 ± 0.010	85.5 ± 6.9
E207 [x]	41.5 ± 21.1	92.3 ± 9.0	100.0 ± 0.0	2215.1 ± 247.0	0.165 ± 0.018	77.9 ± 9.6
GCA_SYN [x]	56.0 ± 21.3	95.3 ± 8.1	100.0 ± 0.0	2351.0 ± 243.5	0.175 ± 0.018	83.8 ± 9.7
x mean	47.7 ± 17.5	92.0 ± 10.3	100.0 ± 0.0	2251.8 ± 221.2	0.168 ± 0.017	79.9 ± 7.9
NUN7606ON [y]	77.3 ± 27.5	100.0 ± 0.0	100.0 ± 0.0	2552.1 ± 179.0	0.190 ± 0.013	92.4 ± 9.2
OLYS03-207 [y]	74.3 ± 5.1	100.0 ± 0.0	100.0 ± 0.0	2532.6 ± 32.9	0.189 ± 0.002	91.4 ± 1.7
OLYS03-209 [y]	65.3 ± 25.1	100.0 ± 0.0	100.0 ± 0.0	2474.1 ± 163.4	0.185 ± 0.012	88.4 ± 8.4
OLYS05N5 [y]	47.3 ± 13.0	92.8 ± 14.5	100.0 ± 0.0	2259.3 ± 276.5	0.169 ± 0.021	80.0 ± 9.0
OLYX06-25 [y]	71.8 ± 24.7	100.0 ± 0.0	100.0 ± 0.0	2516.4 ± 160.3	0.188 ± 0.012	90.6 ± 8.2
y mean	67.2 ± 19.1	98.6 ± 2.9	100.0 ± 0.0	2466.9 ± 162.4	0.184 ± 0.012	88.6 ± 7.3

Colorado 6[z]	51.3 ± 17.0	97.3 ± 5.5	100.0 ± 0.0	2346.0 ± 121.3	0.175 ± 0.009	82.8 ± 5.6
Cometa[z]	65.0 ± 13.6	97.3 ± 5.5	100.0 ± 0.0	2435.4 ± 70.8	0.182 ± 0.005	87.4 ± 3.7
Mesquit[z]	62.8 ± 21.8	100.0 ± 0.0	100.0 ± 0.0	2457.9 ± 141.6	0.183 ± 0.011	87.6 ± 7.3
Rumba[z]	40.5 ± 22.9	100.0 ± 0.0	100.0 ± 0.0	2313.3 ± 148.6	0.173 ± 0.011	80.2 ± 7.6
Salsa Red[z]	57.5 ± 13.1	100.0 ± 0.0	100.0 ± 0.0	2423.8 ± 85.0	0.181 ± 0.006	85.8 ± 4.4
T-433[z]	72.3 ± 7.8	100.0 ± 0.0	100.0 ± 0.0	2519.6 ± 50.7	0.188 ± 0.004	90.8 ± 2.6
Vantage[z]	70.5 ± 8.2	95.8 ± 8.5	100.0 ± 0.0	2450.9 ± 124.5	0.183 ± 0.009	88.8 ± 3.9
z mean	60.0 ± 14.9	98.6 ± 2.8	100.0 ± 0.0	2421.0 ± 106.1	0.181 ± 0.008	86.2 ± 5.0
Grand mean	**58.3 ± 17.2**	**96.4 ± 5.3**	**100.0 ± 0.0**	**2379.9 ± 163.2**	**0.178 ± 0.012**	**84.9 ± 6.7**
Tukey's (0.05)	70.4	47.1	0.0	840.8	0.063	30.3

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.10b. Severity of *Iris yellow spot virus* (IYSV) infection in transplanted onion germplasms during field evaluation for their resistance/tolerance to IYSV and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2011.

Genotype	**Severity-107** (mean ± SE)[c]	**Severity-120** (mean ± SE)[c]	**Severity-134** (mean ± SE)[c]	**AUDPC-sv** (mean ± SE)[a]	**rAUDPC-sv** (mean ± SE)[b]	**Severity-avg** (mean ± SE)[d]
574[x]	1.3 ± 0.5	2.8 ± 0.5	4.0 ± 0.0	73.3 ± 8.4	0.137 ± 0.016	2.7 ± 0.3
575[x]	1.3 ± 0.5	2.0 ± 1.2	3.0 ± 1.2	56.1 ± 25.7	0.136 ± 0.012	2.1 ± 0.9
577[x]	1.3 ± 0.6	2.0 ± 0.0	3.0 ± 0.5	56.7 ± 1.9	0.144 ± 0.025	2.1 ± 0.1
578[x]	1.0 ± 0.0	2.0 ± 0.0	2.5 ± 0.0	51.0 ± 0.0	0.152 ± 0.000	1.8 ± 0.0
579[x]	1.0 ± 0.0	1.0 ± 0.0	2.8 ± 0.4	39.3 ± 2.5	0.107 ± 0.007	1.6 ± 0.1
580[x]	1.0 ± 0.0	1.0 ± 0.0	2.0 ± 1.0	34.0 ± 7.0	0.143 ± 0.052	1.3 ± 0.3
583[x]	1.0 ± 0.0	1.5 ± 0.7	2.8 ± 0.4	46.0 ± 7.1	0.127 ± 0.036	1.8 ± 0.1
589[x]	1.3 ± 0.6	2.0 ± 0.0	3.5 ± 0.5	60.2 ± 1.9	0.130 ± 0.019	2.3 ± 0.1
592[x]	1.0 ± 0.0	2.0 ± 0.0	3.2 ± 0.3	55.7 ± 2.0	0.132 ± 0.007	2.1 ± 0.1
593[x]	1.3 ± 0.5	1.8 ± 0.5	3.9 ± 0.3	58.9 ± 10.1	0.113 ± 0.013	2.3 ± 0.3
594[x]	1.0 ± 0.0	1.0 ± 0.0	3.3 ± 1.1	42.8 ± 7.4	0.101 ± 0.016	1.8 ± 0.4
596[x]	1.3 ± 0.5	1.5 ± 0.6	2.9 ± 0.9	48.5 ± 15.8	0.125 ± 0.01	1.9 ± 0.6
597[x]	1.0 ± 0.0	1.0 ± 0.0	2.0 ± 0.0	34.0 ± 0.0	0.127 ± 0.000	1.3 ± 0.0
602[x]	1.7 ± 0.6	2.7 ± 0.6	4.0 ± 0.0	74.8 ± 11.5	0.140 ± 0.022	2.8 ± 0.4
607[x]	2.3 ± 0.5	3.0 ± 0.0	3.8 ± 0.5	81.4 ± 5.5	0.163 ± 0.016	3.0 ± 0.3
615[x]	1.0 ± 0.0	2.0 ± 0.0	3.0 ± 1.4	54.5 ± 9.9	0.146 ± 0.044	2.0 ± 0.5
618[x]	1.0 ± 0.0	1.7 ± 0.6	3.0 ± 0.0	50.0 ± 7.8	0.124 ± 0.019	1.9 ± 0.2
619[x]	1.0 ± 0.0	2.0 ± 0.0	3.3 ± 0.6	56.8 ± 4.0	0.129 ± 0.012	2.1 ± 0.2
620[x]	1.3 ± 0.5	2.3 ± 0.5	3.1 ± 0.3	60.4 ± 8.0	0.144 ± 0.010	2.2 ± 0.3
621[x]	1.3 ± 0.5	2.5 ± 0.6	3.5 ± 0.6	66.4 ± 14.0	0.141 ± 0.008	2.4 ± 0.5
622[x]	1.5 ± 0.6	2.0 ± 0.0	3.0 ± 0.6	57.8 ± 0.3	0.148 ± 0.028	2.2 ± 0.0
624[x]	1.0 ± 0.0	1.8 ± 0.5	3.1 ± 0.3	52.0 ± 7.5	0.124 ± 0.016	2.0 ± 0.2
628[x]	1.0 ± 0.0	1.7 ± 0.6	2.3 ± 0.8	45.3 ± 13.0	0.147 ± 0.009	1.7 ± 0.4
629[x]	1.0 ± 0.0	2.0 ± 1.0	3.3 ± 0.3	56.8 ± 15.3	0.126 ± 0.025	2.1 ± 0.4
632[x]	1.0 ± 0.0	3.0 ± 0.0	4.0 ± 0.0	75.0 ± 0.0	0.140 ± 0.000	2.7 ± 0.0

634[x]	1.0 ± 0.0	2.3 ± 0.6	4.0 ± 0.0	66.0 ± 7.8	0.123 ± 0.015	2.4 ± 0.2
643[x]	1.5 ± 0.7	3.0 ± 1.4	4.0 ± 0.0	78.3 ± 23.7	0.146 ± 0.044	2.8 ± 0.7
646[x]	1.3 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	77.2 ± 3.8	0.144 ± 0.007	2.8 ± 0.2
648[x]	1.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	61.5 ± 0.0	0.115 ± 0.000	2.3 ± 0.0
651[x]	1.7 ± 0.6	2.7 ± 0.6	4.0 ± 0.0	74.8 ± 6.8	0.140 ± 0.013	2.8 ± 0.2
654[x]	1.8 ± 0.5	3.0 ± 0.0	4.0 ± 0.0	79.9 ± 3.3	0.149 ± 0.006	2.9 ± 0.2
656[x]	1.3 ± 0.5	2.8 ± 0.5	4.0 ± 0.0	73.3 ± 8.4	0.137 ± 0.016	2.7 ± 0.3
658[x]	1.5 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	78.3 ± 3.8	0.146 ± 0.007	2.8 ± 0.2
660[x]	1.0 ± 0.0	2.7 ± 0.6	4.0 ± 0.0	70.5 ± 7.8	0.132 ± 0.015	2.6 ± 0.2
696[x]	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	27.0 ± 0.0	0.201 ± 0.000	1.0 ± 0.0
700[x]	1.3 ± 0.5	2.8 ± 0.5	3.4 ± 0.5	68.9 ± 9.7	0.153 ± 0.023	2.5 ± 0.3
702[x]	1.0 ± 0.0	1.8 ± 0.5	2.8 ± 0.5	49.4 ± 10.3	0.133 ± 0.004	1.8 ± 0.3
706[x]	1.3 ± 0.6	1.7 ± 1.2	3.0 ± 0.9	52.2 ± 18.8	0.129 ± 0.022	2.0 ± 0.6
708[x]	1.0 ± 0.0	1.7 ± 0.6	3.2 ± 1.0	51.2 ± 15.0	0.122 ± 0.006	1.9 ± 0.5
711[x]	1.0 ± 0.0	1.8 ± 1.0	2.8 ± 1.2	49.4 ± 17.8	0.147 ± 0.047	1.8 ± 0.6
712[x]	1.0 ± 0.0	2.0 ± 0.0	3.3 ± 0.4	56.3 ± 2.5	0.130 ± 0.008	2.1 ± 0.1
713[x]	1.0 ± 0.0	2.0 ± 0.0	3.0 ± 0.0	54.5 ± 0.0	0.136 ± 0.000	2.0 ± 0.0
718[x]	1.0 ± 0.0	1.0 ± 0.0	3.2 ± 0.3	42.2 ± 2.0	0.100 ± 0.004	1.7 ± 0.1
719[x]	1.0 ± 0.0	2.5 ± 0.7	3.0 ± 0.0	61.3 ± 9.5	0.152 ± 0.024	2.2 ± 0.2
753[x]	2.0 ± 0.0	2.7 ± 0.6	3.3 ± 0.3	72.3 ± 7.0	0.163 ± 0.024	2.7 ± 0.2
759[x]	1.0 ± 0.0	2.0 ± 1.0	3.0 ± 1.0	54.5 ± 18	0.140 ± 0.038	2.0 ± 0.6
765[x]	1.0 ± 0.0	2.7 ± 0.6	4.0 ± 0.0	70.5 ± 7.8	0.132 ± 0.015	2.6 ± 0.2
768[x]	1.3 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	77.2 ± 3.8	0.144 ± 0.007	2.8 ± 0.2
769[x]	1.5 ± 0.7	2.5 ± 0.7	4.0 ± 0.0	71.5 ± 4.9	0.133 ± 0.009	2.7 ± 0.0
172702[x]	1.0 ± 0.0	1.5 ± 0.6	3.1 ± 1.0	48.6 ± 14.9	0.117 ± 0.007	1.9 ± 0.5
172703[x]	1.0 ± 0.0	2.0 ± 0.0	3.0 ± 0.0	54.5 ± 0.0	0.136 ± 0.000	2.0 ± 0.0
239633[x]	1.0 ± 0.0	1.5 ± 0.7	3.3 ± 0.4	49.5 ± 12.0	0.113 ± 0.015	1.9 ± 0.4
258956[x]	1.0 ± 0.0	2.7 ± 0.6	4.0 ± 0.0	70.5 ± 7.8	0.132 ± 0.015	2.6 ± 0.2
264320[x]	1.5 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	78.3 ± 3.8	0.146 ± 0.007	2.8 ± 0.2
288909[x]	1.0 ± 0.0	2.7 ± 0.6	3.5 ± 0.5	67.0 ± 8.5	0.144 ± 0.023	2.4 ± 0.3

289689 [x]	1.0 ± 0.0	2.0 ± 0.8	2.8 ± 0.6	52.8 ± 14.3	0.144 ± 0.028	1.9 ± 0.4
343049 [x]	1.0 ± 0.0	2.5 ± 0.6	3.0 ± 0.7	61.3 ± 12.2	0.154 ± 0.017	2.2 ± 0.4
546140 [x]	1.0 ± 0.0	1.8 ± 1.0	2.6 ± 0.8	48.5 ± 18.1	0.135 ± 0.012	1.8 ± 0.6
546188 [x]	1.3 ± 0.5	3.0 ± 0.0	3.9 ± 0.3	75.8 ± 4.2	0.146 ± 0.007	2.7 ± 0.2
546192 [x]	1.5 ± 0.6	2.8 ± 0.5	4.0 ± 0.0	74.9 ± 9.4	0.140 ± 0.018	2.8 ± 0.3
639911[x]	1.5 ± 0.6	2.8 ± 0.5	4.0 ± 0.0	74.9 ± 9.4	0.140 ± 0.018	2.8 ± 0.3
B2133C [x]	1.5 ± 0.6	2.8 ± 0.5	3.6 ± 0.5	72.3 ± 5.1	0.151 ± 0.021	2.6 ± 0.2
B5336C [x]	1.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	61.5 ± 0.0	0.115 ± 0.000	2.3 ± 0.0
B5351C [x]	1.3 ± 0.6	2.0 ± 0.0	4.0 ± 0.0	63.7 ± 3.8	0.119 ± 0.007	2.4 ± 0.2
E203 [x]	1.0 ± 0.0	1.3 ± 0.5	2.6 ± 0.9	41.8 ± 13.3	0.120 ± 0.008	1.6 ± 0.5
E205[x]	1.0 ± 0.0	1.8 ± 1.0	3.6 ± 0.5	55.5 ± 14.8	0.114 ± 0.022	2.1 ± 0.4
E206[x]	1.0 ± 0.0	2.3 ± 0.5	3.4 ± 0.5	60.5 ± 9.8	0.134 ± 0.007	2.2 ± 0.3
E207[x]	1.3 ± 0.5	2.0 ± 0.0	3.5 ± 0.6	59.6 ± 3.4	0.129 ± 0.018	2.3 ± 0.2
GCA_SYN [x]	1.3 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	77.2 ± 3.8	0.144 ± 0.007	2.8 ± 0.2
x mean	***1.2 ± 0.3***	***2.2 ± 0.4***	***3.3 ± 0.4***	***60.2 ± 8.8***	***0.136 ± 0.017***	***2.2 ± 0.3***
NUN7606ON [y]	1.8 ± 0.5	3.0 ± 0.0	4.0 ± 0.0	79.9 ± 3.3	0.149 ± 0.006	2.9 ± 0.2
OLYS03-207 [y]	1.8 ± 0.5	3.0 ± 0.0	4.0 ± 0.0	79.9 ± 3.3	0.149 ± 0.006	2.9 ± 0.2
OLYS03-209 [y]	1.5 ± 0.6	3.0 ± 0.0	4.0 ± 0.0	78.3 ± 3.8	0.146 ± 0.007	2.8 ± 0.2
OLYS05N5 [y]	1.0 ± 0.0	2.5 ± 0.6	4.0 ± 0.0	68.3 ± 7.8	0.127 ± 0.015	2.5 ± 0.2
OLYX06-25[y]	2.0 ± 0.8	2.5 ± 0.6	4.0 ± 0.0	74.8 ± 12.1	0.139 ± 0.023	2.8 ± 0.4
y mean	***1.6 ± 0.5***	***2.8 ± 0.2***	***4.0 ± 0.0***	***76.2 ± 6.0***	***0.142 ± 0.011***	***2.8 ± 0.2***
Colorado 6[z]	1.8 ± 0.5	2.3 ± 0.5	4.0 ± 0.0	69.8 ± 8.4	0.130 ± 0.016	2.7 ± 0.3
Cometa[z]	1.8 ± 0.5	2.5 ± 0.6	4.0 ± 0.0	73.1 ± 6.5	0.136 ± 0.012	2.8 ± 0.2
Mesquit[z]	1.3 ± 0.5	2.8 ± 0.5	4.0 ± 0.0	73.3 ± 8.4	0.137 ± 0.016	2.7 ± 0.3
Rumba[z]	1.3 ± 0.5	2.3 ± 0.5	4.0 ± 0.0	66.5 ± 10.0	0.124 ± 0.019	2.5 ± 0.3
Salsa Red[z]	1.3 ± 0.5	2.5 ± 0.6	3.9 ± 0.3	69.0 ± 11.1	0.133 ± 0.017	2.5 ± 0.4
T-433[z]	1.8 ± 0.5	3.0 ± 0.0	4.0 ± 0.0	79.9 ± 3.3	0.149 ± 0.006	2.9 ± 0.2
Vantage[z]	1.3 ± 0.5	2.8 ± 0.5	4.0 ± 0.0	73.3 ± 8.4	0.137 ± 0.016	2.7 ± 0.3
z mean	***1.5 ± 0.5***	***2.6 ± 0.5***	***4.0 ± 0.0***	***72.1 ± 8.0***	***0.135 ± 0.014***	***2.7 ± 0.3***

Grand mean	**1.4 ± 0.4**	**2.5 ± 0.4**	**3.8 ± 0.1**	**69.5 ± 7.6**	**0.138 ± 0.014**	**2.6 ± 0.3**
Tukey's (0.05)	1.6	2.0	1.8	37.6	0.067	1.3

[a]Area under the disease progress curve for IYSV severity.

[b]Relative area under the disease progress curve for IYSV severity.

[c]Severity was based on a rating scale of 1 – 4 (Schwartz and du Toit, 2005).

[d]Seasonal average of IYSV severity.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.11. Seasonal dynamics of onion thrips (*Thrips tabaci*) population in transplanted onion germplasms during field evaluation for their resistance/tolerance to onion thrips in northern Colorado, near Fort Collins, in 2009.

Genotype	**Thrips-71** (Thrips/plant) (mean ± SE)	**Thrips-86** (Thrips/plant) (mean ± SE)	**Thrips-99** (Thrips/plant) (mean ± SE)	**Average** (Thrips/plant) (mean ± SE)	**Thrips-day** (Thrips/plant/day) (mean ± SE)
124525[x]	12.3 ± 1.1	7.3 ± 1.1	3.3 ± 0.5	7.6 ± 0.9	0.8 ± 0.1
142790[x]	17.0 ± 9.9	12.5 ± 6.9	0.9 ± 0.4	10.1 ± 0.8	1.1 ± 0.1
164361[x]	7.5 ± 1.1	9.1 ± 3.3	2.9 ± 1.5	6.5 ± 2.0	0.7 ± 0.2
164807[x]	8.4 ± 7.6	12.6 ± 10.5	5.4 ± 0.8	8.8 ± 6.3	1.0 ± 0.6
165498[x]	7.1 ± 3.5	2.4 ± 2.5	0.9 ± 0.4	3.5 ± 1.9	0.4 ± 0.2
168962[x]	19.1 ± 9.9	11.6 ± 2.8	2.1 ± 2.3	10.9 ± 1.6	1.2 ± 0.2
168966[x]	21.1 ± 2.1	1.8 ± 0.8	1.0 ± 1.2	8.0 ± 1.3	0.9 ± 0.2
171475[x]	24.2 ± 1.4	3.8 ± 0.1	1.0 ± 0.5	9.7 ± 0.4	1.1 ± 0.1
171477[x]	7.0 ± 1.8	2.9 ± 2.0	1.3 ± 1.6	3.7 ± 0.6	0.4 ± 0.0
172701[x]	11.1 ± 4.6	3.0 ± 3.2	1.5 ± 0.0	5.2 ± 2.6	0.6 ± 0.2
172702[x]	12.4 ± 4.2	12.1 ± 1.1	12.2 ± 1.4	12.2 ± 0.6	1.4 ± 0.1
172703[x]	14.7 ± 5.2	10.3 ± 7.4	9.2 ± 0.3	11.4 ± 0.8	1.3 ± 0.1
172704[x]	16.1 ± 3.1	7.5 ± 6.3	2.5 ± 1.8	8.7 ± 3.7	0.9 ± 0.4
174018[x]	13.5 ± 10.6	13.2 ± 3.2	6.8 ± 6.9	11.2 ± 4.7	1.2 ± 0.6
174024[x]	16.6 ± 4.5	22.5 ± 18.4	21.3 ± 17.8	20.2 ± 10.5	2.2 ± 1.1
177242[x]	5.2 ± 4.0	13.3 ± 8.6	9.3 ± 2.3	9.2 ± 2.3	1.0 ± 0.3
179164[x]	16.8 ± 0.6	5.7 ± 1.6	1.6 ± 1.3	8.0 ± 0.3	0.9 ± 0.1
179627[x]	16.6 ± 5.1	6.1 ± 0.1	5.2 ± 5.6	9.3 ± 0.1	1.0 ± 0.0
182138[x]	11.4 ± 3.2	27.7 ± 11.4	18.6 ± 1.7	19.2 ± 3.3	2.1 ± 0.4
183660[x]	11.1 ± 0.2	3.5 ± 2.9	2.4 ± 1.9	5.6 ± 1.7	0.6 ± 0.1
200874[x]	9.4 ± 8.5	9.9 ± 4.2	3.9 ± 1.7	7.8 ± 3.6	0.9 ± 0.4
233186[x]	15.6 ± 5.6	8.5 ± 3.3	3.5 ± 1.7	9.2 ± 2.4	1.0 ± 0.3
246140[x]	16.2 ± 1.4	27.1 ± 25.0	16.9 ± 0.9	20.0 ± 8.2	2.2 ± 0.9
248753[x]	6.0 ± 1.3	2.8 ± 0.8	2.7 ± 1.1	3.8 ± 0.1	0.4 ± 0.0
248754[x]	2.9 ± 0.7	7.6 ± 3.3	6.4 ± 4.7	5.6 ± 2.5	0.6 ± 0.3
249899[x]	16.4 ± 0.1	34.0 ± 17.7	31.7 ± 20.2	27.4 ± 12.7	3.0 ± 1.3
251325[x]	5.1 ± 2.1	17.5 ± 8.6	10.8 ± 1.1	11.1 ± 4.0	1.2 ± 0.4
255557[x]	13.1 ± 3.7	15.0 ± 1.2	13.7 ± 5.3	13.9 ± 0.1	1.5 ± 0.0
256048[x]	7.5 ± 2.8	7.6 ± 1.2	16.3 ± 1.8	10.5 ± 0.8	1.2 ± 0.1
256049[x]	9.2 ± 0.6	11.6 ± 2.5	20.8 ± 2.3	13.9 ± 0.2	1.5 ± 0.0
258956[x]	18.8 ± 6.6	14.5 ± 7.6	11.8 ± 1.0	15.1 ± 4.5	1.6 ± 0.4
264320[x]	15.6 ± 9.1	12.6 ± 6.0	12.4 ± 7.8	13.5 ± 2.4	1.5 ± 0.2
264321[x]	13.0 ± 0.6	9.6 ± 2.1	3.7 ± 3.1	8.8 ± 1.9	1.0 ± 0.2
264631[x]	24.3 ± 0.5	29.5 ± 13.1	33.5 ± 4.9	29.1 ± 5.9	3.2 ± 0.6
264648[x]	22.4 ± 10.9	58.5 ± 49.1	28.7 ± 6.9	36.6 ± 22.3	3.9 ± 2.4
269306[x]	14.1 ± 1.3	21.8 ± 12.2	23.5 ± 8.3	19.8 ± 1.8	2.1 ± 0.1

271039 [x]	16.0 ± 2.0	12.5 ± 6.9	6.4 ± 4.0	11.6 ± 0.3	1.3 ± 0.1
273211 [x]	25.4 ± 4.0	18.7 ± 5.4	17.6 ± 7.1	20.5 ± 2.8	2.2 ± 0.3
274780 [x]	8.6 ± 1.5	7.5 ± 1.8	2.6 ± 1.1	6.2 ± 0.7	0.7 ± 0.1
287540 [x]	5.5 ± 2.3	7.5 ± 7.3	3.0 ± 1.7	5.3 ± 3.8	0.6 ± 0.4
288073 [x]	26.3 ± 7.2	24.7 ± 15.2	7.1 ± 7.4	19.4 ± 10.0	2.1 ± 1.1
288270 [x]	10.9 ± 0.4	8.5 ± 4.9	7.2 ± 4.7	8.9 ± 3.3	1.0 ± 0.4
288272 [x]	8.9 ± 2.7	0.8 ± 0.7	0.1 ± 0.1	3.3 ± 1.1	0.4 ± 0.1
288902 [x]	5.3 ± 1.3	14.6 ± 1.9	7.5 ± 0.7	9.1 ± 0.1	1.0 ± 0.0
288903 [x]	13.4 ± 6.4	18.5 ± 1.3	16.8 ± 11.8	16.2 ± 6.5	1.7 ± 0.7
288908 [x]	13.3 ± 2.7	9.2 ± 2.5	11.4 ± 3.3	11.3 ± 1.1	1.2 ± 0.1
288909 [x]	22.5 ± 5.4	1.6 ± 1.3	1.7 ± 2.0	8.6 ± 0.7	1.0 ± 0.1
289689 [x]	6.3 ± 2.1	0.5 ± 0.6	1.0 ± 0.0	2.6 ± 0.4	0.3 ± 0.1
289690 [x]	21.7 ± 2.3	4.9 ± 1.6	7.4 ± 6.6	11.3 ± 0.8	1.2 ± 0.1
293756 [x]	17.0 ± 0.7	7.7 ± 1.5	10.9 ± 0.0	11.9 ± 0.7	1.3 ± 0.1
318886 [x]	27.8 ± 5.1	16.1 ± 2.5	10.3 ± 4.5	18.1 ± 4.0	1.9 ± 0.4
321385 [x]	13.0 ± 0.8	15.6 ± 0.7	11.6 ± 0.1	13.4 ± 0.6	1.5 ± 0.1
342943 [x]	16.5 ± 3.3	20.0 ± 19.0	14.1 ± 2.3	16.8 ± 8.2	1.8 ± 0.8
343049 [x]	26.0 ± 1.4	3.3 ± 3.2	1.7 ± 2.1	10.3 ± 1.3	1.1 ± 0.1
344392 [x]	29.9 ± 1.6	11.6 ± 4.4	8.7 ± 4.3	16.7 ± 0.6	1.8 ± 0.1
391509 [x]	13.5 ± 0.2	8.6 ± 4.7	6.9 ± 2.6	9.6 ± 2.4	1.0 ± 0.3
430371 [x]	5.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.0	0.2 ± 0.0
433330 [x]	19.1 ± 4.8	27.8 ± 5.2	39.7 ± 5.1	28.9 ± 1.6	3.1 ± 0.1
433332 [x]	24.7 ± 1.0	21.1 ± 8.1	33.0 ± 11.5	26.3 ± 6.2	2.8 ± 0.7
546096 [x]	13.6 ± 6.2	27.9 ± 11.4	25.8 ± 0.1	22.4 ± 5.9	2.4 ± 0.6
546100 [x]	18.1 ± 6.5	12.5 ± 11.7	9.8 ± 4.2	13.5 ± 4.6	1.5 ± 0.5
546101 [x]	14.2 ± 1.1	11.4 ± 6.4	21.4 ± 0.6	15.7 ± 1.5	1.7 ± 0.1
546106 [x]	16.8 ± 7.1	25.3 ± 9.1	25.2 ± 4.5	22.4 ± 0.8	2.4 ± 0.1
546115 [x]	26.7 ± 2.4	13.7 ± 7.4	7.6 ± 5.0	16.0 ± 1.6	1.7 ± 0.1
546140 [x]	20.2 ± 2.2	2.2 ± 0.0	0.7 ± 0.2	7.7 ± 0.6	0.9 ± 0.1
546162 [x]	17.6 ± 2.9	11.7 ± 3.7	16.4 ± 0.7	15.2 ± 2.4	1.6 ± 0.3
546174 [x]	9.5 ± 10.1	17.7 ± 4.3	35.4 ± 0.0	20.8 ± 4.8	2.3 ± 0.5
546188 [x]	14.3 ± 1.6	6.6 ± 0.1	9.0 ± 2.1	10.0 ± 1.2	1.1 ± 0.1
546192 [x]	13.7 ± 8.5	9.4 ± 3.1	14.6 ± 6.2	12.6 ± 0.3	1.4 ± 0.1
546201 [x]	6.9 ± 0.9	8.4 ± 2.7	9.3 ± 1.0	8.2 ± 1.6	0.9 ± 0.1
639911 [x]	8.4 ± 0.2	13.8 ± 2.9	31.1 ± 10.4	17.7 ± 4.5	1.9 ± 0.4
639912 [x]	6.6 ± 2.5	13.8 ± 0.2	8.4 ± 4.1	9.6 ± 2.3	1.1 ± 0.2
639913 [x]	18.0 ± 6.4	3.6 ± 3.4	3.4 ± 1.5	8.3 ± 0.4	0.9 ± 0.0
639914 [x]	10.2 ± 0.0	13.6 ± 0.0	25.4 ± 0.0	16.4 ± 0.0	1.8 ± 0.0
639915 [x]	22.7 ± 1.7	13.9 ± 2.8	6.9 ± 3.0	14.5 ± 0.6	1.6 ± 0.1
639916 [x]	17.0 ± 7.6	13.9 ± 1.0	12.6 ± 2.6	14.5 ± 3.0	1.6 ± 0.4
239633-1 [x]	7.5 ± 0.0	2.0 ± 0.0	7.5 ± 0.0	5.7 ± 0.0	0.6 ± 0.0
239633-2 [x]	10.1 ± 3.0	11.2 ± 12.1	16.1 ± 6.1	12.5 ± 5.0	1.3 ± 0.6

G32590 [x]	24.5 ± 0.0	29.0 ± 0.0	8.5 ± 0.0	20.7 ± 0.0	2.2 ± 0.0
G32787 [x]	16.3 ± 4.7	18.2 ± 9.7	21.0 ± 11.0	18.5 ± 5.3	2.0 ± 0.6
x Average	***14.6 ± 3.4***	***12.7 ± 5.6***	***11.1 ± 3.4***	***12.8 ± 2.8***	***1.4 ± 0.3***
OLYS05N5 [y]	**14.5 ± 6.1**	**11.2 ± 3.2**	**7.7 ± 3.9**	**11.1 ± 2.3**	**1.2 ± 0.3**
Colorado 6 [z]	24.0 ± 2.3	8.6 ± 0.8	13.4 ± 1.8	15.3 ± 1.1	1.7 ± 0.1
Cometa [z]	19.0 ± 4.0	9.8 ± 2.3	18.3 ± 17.7	15.7 ± 6.4	1.7 ± 0.7
Mt. Blanc [z]	8.5 ± 0.6	6.4 ± 2.9	3.6 ± 1.7	6.2 ± 1.3	0.7 ± 0.1
Salsa Red [z]	19.3 ± 14.2	23.0 ± 2.5	9.4 ± 10.0	17.2 ± 2.3	1.9 ± 0.2
z Average	***17.7 ± 5.3***	***11.9 ± 2.1***	***11.2 ± 7.8***	***13.6 ± 2.8***	***1.5 ± 0.2***
Grand mean	**15.6 ± 4.9**	**11.9 ± 3.6**	**10.0 ± 5.0**	**12.5 ± 2.6**	**1.3 ± 0.3**
Tukey's (0.05)	20.8	38.5	24.0	19.2	2.1

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.12. Seasonal dynamics of onion thrips (*Thrips tabaci*) population in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to onion thrips in northern Colorado, near Fort Collins, in 2009.

Genotype	**Thrips-90** (Thrips/plant) (mean ± SE)	**Thrips-104** (Thrips/plant) (mean ± SE)	**Thrips-118** (Thrips/plant) (mean ± SE)	**Average** (Thrips/plant) (mean ± SE)	**Thrips-day** (Thrips/plant/day) (mean ± SE)
EX 16529[y]	5.9 ± 0.5	10 ± 4.9	4.9 ± 0.9	6.9 ± 1.5	0.7 ± 0.1
NUN7606ON [y]	4.3 ± 1.1	7.2 ± 0.1	3.9 ± 1.6	5.1 ± 0.8	0.6 ± 0.1
OLRH08-91 [y]	5.1 ± 2.4	6.3 ± 0.8	6.4 ± 1.0	5.9 ± 1.4	0.6 ± 0.1
OLYS03-207 [y]	4.3 ± 0.9	6.7 ± 0.6	3.6 ± 1.2	4.8 ± 0.3	0.5 ± 0.0
OLYS03-209 [y]	3.9 ± 0.1	6.7 ± 0.3	4.0 ± 1.8	4.9 ± 0.6	0.6 ± 0.1
OLYS05N5 [y]	6.8 ± 3.8	9.5 ± 2.8	3.4 ± 0.6	6.6 ± 2.3	0.7 ± 0.3
OLYX00-23 [y]	5.6 ± 1.6	9.8 ± 0.4	4.3 ± 0.8	6.5 ± 0.1	0.7 ± 0.0
OLYX06-25 [y]	3.7 ± 0.3	4.8 ± 1.5	3.9 ± 2.3	4.1 ± 0.1	0.5 ± 0.1
y Average	***5.0 ± 1.3***	***7.6 ± 1.4***	***4.3 ± 1.3***	***5.6 ± 0.9***	***0.6 ± 0.1***
Abilene[z]	6.7 ± 0.5	11.6 ± 0.6	7.5 ± 0.4	8.6 ± 0.2	0.9 ± 0.0
Arcero[z]	4.9 ± 2.6	7.5 ± 2.6	5.4 ± 0.1	5.9 ± 1.8	0.7 ± 0.2
Calibra[z]	6.6 ± 0.6	7.5 ± 0.5	4.6 ± 2.3	6.2 ± 1.1	0.7 ± 0.1
Charismatic[z]	4.1 ± 0.4	6.7 ± 1.0	2.6 ± 0.8	4.4 ± 0.7	0.5 ± 0.1
Colorado 6[z]	5.3 ± 0.7	12.5 ± 2.7	4.3 ± 0.8	7.3 ± 0.8	0.8 ± 0.1
Cometa[z]	5.1 ± 0.3	6.0 ± 5.2	3.9 ± 0.5	5.0 ± 2.1	0.6 ± 0.2
Crockett[z]	7.5 ± 0.6	14 ± 1.6	7.7 ± 2.5	9.7 ± 1.6	1.1 ± 0.2
Damascus[z]	4.4 ± 1.7	8.6 ± 3.0	5.2 ± 1.5	6.0 ± 2.1	0.7 ± 0.2
Delgado[z]	4.6 ± 2.8	10.7 ± 2.5	6.2 ± 1.3	7.1 ± 1.3	0.8 ± 0.1
Denali[z]	2.7 ± 0.6	3.5 ± 1.9	1.8 ± 0.6	2.6 ± 1.0	0.3 ± 0.1
Desperado[z]	7.6 ± 3.5	8.7 ± 3.3	5.5 ± 2.6	7.2 ± 1.4	0.8 ± 0.1
Granero[z]	5.3 ± 0.8	13.0 ± 5.8	6.2 ± 3.3	8.2 ± 1.1	0.9 ± 0.1
Gunnison[z]	5.0 ± 1.2	12.5 ± 7.3	9.3 ± 1.3	8.9 ± 2.4	1.0 ± 0.2
Harmony[z]	3.1 ± 0.7	6.6 ± 1.4	6.3 ± 0.6	5.4 ± 0.9	0.6 ± 0.1
Joaquin[z]	4.9 ± 0.0	10.3 ± 0.0	5.0 ± 0.0	6.7 ± 0.0	0.7 ± 0.0
Legand[z]	4.5 ± 2.2	7.3 ± 1.1	4.8 ± 2.7	5.5 ± 2.0	0.6 ± 0.2
Marquett[z]	8.4 ± 4.0	12.3 ± 4.8	7.5 ± 0.1	9.4 ± 2.9	1.0 ± 0.3
Mesquite[z]	4.2 ± 0.3	8.0 ± 1.1	3.9 ± 0.9	5.3 ± 0.6	0.6 ± 0.1
Milestone[z]	4.2 ± 0.0	28.0± 19.1	15.2 ± 0.0	15.8 ± 6.4	1.7 ± 0.7
Monarcho[z]	4.7 ± 0.1	9.1 ± 0.5	3.0 ± 0.5	5.6 ± 0.4	0.6 ± 0.0
Montero[z]	6.2 ± 3.1	11.4 ± 5.2	6.0 ± 2.4	7.9 ± 3.6	0.9 ± 0.4
Oro Blanco[z]	6.5 ± 2.1	15.6 ± 3.3	6.9 ± 1.9	9.6 ± 2.4	1.0 ± 0.3
Ovation[z]	4.6 ± 0.5	10.8 ± 0.6	4.7 ± 3.2	6.6 ± 0.7	0.8 ± 0.1
Pulsar[z]	5.6 ± 3.2	7.7 ± 4.8	9.4 ± 0.4	7.5 ± 2.8	0.8 ± 0.3
Ranchero[z]	5.4 ± 0.8	10.9 ± 3.2	5.5 ± 1.3	7.3 ± 0.9	0.8 ± 0.1
Red Bull[z]	5.2 ± 0.3	10.0 ± 1.1	11.8 ± 5.6	9.0 ± 2.3	1.0 ± 0.2
Red Flare[z]	5.8 ± 0.8	14.9 ± 0.4	12.9 ± 0.1	11.1 ± 0.1	1.2 ± 0.0

Red Wing[z]	6.9 ± 2.0	10.0 ± 0.9	9.3 ± 5.5	8.7 ± 0.8	1.0 ± 0.1
Ruby Ring[z]	4.9 ± 1.2	11.8 ± 1.2	11.2 ± 3.8	9.3 ± 0.5	1.0 ± 0.0
Salsa Red[z]	8.6 ± 5.9	11.4 ± 4.5	10.2 ± 0.1	10.0 ± 3.5	1.1 ± 0.4
Sarape Café	3.9 ± 1.8	7.3 ± 3.8	4.4 ± 0.4	5.2 ± 1.7	0.6 ± 0.2
Sedona[z]	5.7 ± 0.7	9.7 ± 1.0	7.8 ± 1.8	7.7 ± 0.0	0.8 ± 0.0
Sp. Medallion[z]	5.8 ± 0.2	10.5 ± 2.7	6.5 ± 0.9	7.6 ± 1.3	0.8 ± 0.1
Swale[z]	7.0 ± 2.1	11.5 ± 2.8	4.5 ± 0.2	7.6 ± 1.7	0.8 ± 0.1
T-433[z]	4.2 ± 0.5	9.0 ± 1.3	4.0 ± 2.3	5.7 ± 0.2	0.6 ± 0.0
Talon[z]	7.8 ± 3.5	12.7 ± 6.6	8.5 ± 4.9	9.6 ± 4.9	1.1 ± 0.5
Tamara[z]	5.9 ± 2.9	13.4 ± 4.4	6.0 ± 0.1	8.4 ± 2.4	0.9 ± 0.3
Tequila[z]	7.2 ± 5.0	10.7 ± 3.4	4.2 ± 1.2	7.3 ± 3.3	0.8 ± 0.4
Tioga[z]	2.7 ± 0.7	6.0 ± 1.1	5.1 ± 2.9	4.6 ± 0.8	0.5 ± 0.1
Vantage[z]	6.9 ± 2.6	10.0 ± 5.2	10.4 ± 3.5	9.1 ± 3.7	1.0 ± 0.4
Vaquero[z]	4.7 ± 2.6	11.2 ± 3.2	3.6 ± 0.4	6.5 ± 1.8	0.7 ± 0.1
Vision[z]	3.6 ± 0.9	6.9 ± 0.6	4.0 ± 1.0	4.8 ± 0.2	0.5 ± 0.0
White Cloud[z]	5.3 ± 0.8	7.2 ± 1.3	3.3 ± 1.1	5.3 ± 0.2	0.6 ± 0.1
White Wing[z]	6.6 ± 1.1	12.7 ± 0.0	6.4 ± 0.4	8.6 ± 0.5	1.0 ± 0.1
z Average	***5.5 ± 1.6***	***10.4 ± 2.9***	***6.4 ± 1.6***	***7.4 ± 1.6***	***0.8 ± 0.2***
Grand mean	**5.2 ± 1.5**	**9.0 ± 2.2**	**5.4 ± 1.4**	**6.5 ± 1.3**	**0.7 ± 0.1**
Tukey's (0.05)	8.7	17.1	8.7	8.5	0.9

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.13. Seasonal dynamics of onion thrips (*Thrips tabaci*) population in transplanted onion germplasms during field evaluation for their resistance/tolerance to onion thrips in northern Colorado, near Fort Collins, in 2010.

Genotype	**Thrips-63** (Thrips/plant) (mean ± SE)	**Thrips-83** (Thrips/plant) (mean ± SE)	**Average** (Thrips/plant) (mean ± SE)	**Thrips-day** (Thrips/plant/day) (mean ± SE)
124525[x]	7.6 ± 4.5	2.0 ± 2.3	4.8 ± 3.4	0.5 ± 0.3
164807[x]	7.1 ± 2.3	9.3 ± 2.0	8.2 ± 2.2	0.8 ± 0.2
165498[x]	9.7 ± 9. 1	3.9 ± 4.2	6.8 ± 2.4	0.7 ± 0.2
168962[x]	45.2 ± 6.2	34.9 ± 11.5	40.0 ± 2.7	4.0 ± 0.3
168966[x]	21.4 ± 1.1	43.1 ± 6.7	32.2 ± 2.8	3.2 ± 0.3
171475[x]	45.2 ± 16.2	25.7 ± 4.9	35.5 ± 10.6	3.5 ± 1.1
171477[x]	25.5 ± 3.6	30.5 ± 1.9	28.0 ± 2.8	2.8 ± 0.3
172701[x]	20.8 ± 9.4	38.0 ± 4.5	29.4 ± 2.4	2.9 ± 0.2
172702[x]	29.9 ± 11.5	30.2 ± 24	30.0 ± 17.7	3.0 ± 1.8
172703[x]	16.9 ± 4.1	45.0 ± 6.5	31.0 ± 1.2	3.1 ± 0.1
172704[x]	28.0 ± 2.1	28.0 ± 0.6	28.0 ± 0.8	2.8 ± 0.1
174018[x]	18.6 ± 5.7	20.9 ± 7.5	19.8 ± 0.9	2.0 ± 0.1
174024[x]	34.9 ± 8.8	71.4 ± 0.0	53.2 ± 4.4	5.3 ± 0.4
177242[x]	45.7 ± 0.0	15.1 ± 0.0	30.4 ± 0.0	3.0 ± 0.0
179627[x]	45.3 ± 10.3	25.3 ± 10.5	35.3 ± 10.4	3.5 ± 1.0
182138[x]	27.9 ± 1.6	67.5 ± 24.5	47.7 ± 11.5	4.8 ± 1.1
200874[x]	26.4 ± 11.8	7.9 ± 7.0	17.2 ± 9.4	1.7 ± 0.9
233186[x]	19.3 ± 5.7	30.8 ± 4.7	25.0 ± 0.5	2.5 ± 0.1
248753[x]	0.9 ± 0.1	0.6 ± 0.3	0.7 ± 0.2	0.1 ± 0.0
248754[x]	14.4 ± 1.2	5.1 ± 3.3	9.7 ± 2.2	1.0 ± 0.2
249899[x]	41.9 ± 5.6	92.5 ± 10.3	67.2 ± 8.0	6.7 ± 0.8
251325[x]	6.6 ± 1.5	16.5 ± 0.2	11.5 ± 0.8	1.2 ± 0.1
255557[x]	19.7 ± 7.3	37.0 ± 5.8	28.3 ± 6.5	2.8 ± 0.7
258956[x]	18.0 ± 10.9	44.1 ± 13.7	31.0 ± 1.4	3.1 ± 0.1
264320[x]	30.8 ± 9.0	78.4 ± 4.8	54.6 ± 6.9	5.5 ± 0.7
264648[x]	30.0 ± 8.8	69.0 ± 18.2	49.5 ± 13.5	4.9 ± 1.4
271039[x]	7.8 ± 4.0	10.4 ± 3.3	9.1 ± 0.3	0.9 ± 0.0
274780[x]	11.8 ± 1.6	9.9 ± 2.7	10.9 ± 0.6	1.1 ± 0.1
288073[x]	26.9 ± 14.7	50.5 ± 34.4	38.7 ± 24.6	3.9 ± 2.5
288270[x]	6.9 ± 0.2	42.7 ± 9.5	24.8 ± 4.9	2.5 ± 0.5
288272[x]	3.5 ± 0.2	3.3 ± 0.2	3.4 ± 0.2	0.3 ± 0.0
288902[x]	38.4 ± 10.4	36.7 ± 10.0	37.5 ± 10.2	3.8 ± 1.0
288903[x]	28.7 ± 11.5	67.2 ± 8.8	47.9 ± 10.1	4.8 ± 1.0
288908[x]	14.9 ± 4.1	34.7 ± 4.9	24.8 ± 4.5	2.5 ± 0.4
288909[x]	26.1 ± 9.9	26.2 ± 8.1	26.2 ± 0.9	2.6 ± 0.1

289689 [x]	16.8 ± 0.3	10.3 ± 3.0	13.5 ± 1.4	1.4 ± 0.1
289690 [x]	37.6 ± 4.2	21.3 ± 1.1	29.4 ± 2.7	2.9 ± 0.3
344392 [x]	38.1 ± 19.7	24.0 ± 10.4	31.1 ± 15.0	3.1 ± 1.5
433330 [x]	72.1 ± 25.9	110.5 ± 5.9	91.3 ± 15.9	9.1 ± 1.6
433332 [x]	33.8 ± 2.8	53.3 ± 15.6	43.5 ± 9.2	4.4 ± 0.9
546096 [x]	66.2 ± 24.8	89.4 ± 34.7	77.8 ± 4.9	7.8 ± 0.5
546100 [x]	34.5 ± 9.0	47.5 ± 6.2	41.0 ± 7.6	4.1 ± 0.8
546101 [x]	44.7 ± 17.2	62.5 ± 9.2	53.6 ± 4.0	5.4 ± 0.4
546106 [x]	41.5 ± 7.1	73.3 ± 3.0	57.4 ± 5.1	5.7 ± 0.5
546115 [x]	38.4 ± 15.7	72.3 ± 7.7	55.3 ± 4.0	5.5 ± 0.4
546140 [x]	30.3 ± 0.9	39.0 ± 3.2	34.6 ± 1.1	3.5 ± 0.1
546162 [x]	37.4 ± 5.4	91.1 ± 45.0	64.3 ± 25.2	6.4 ± 2.5
546174 [x]	37.0 ± 7.2	77.6 ± 19.0	57.3 ± 13.1	5.7 ± 1.3
546188 [x]	28.0 ± 7.3	45.1 ± 11.5	36.5 ± 9.4	3.7 ± 0.9
546192 [x]	35.0 ± 1.2	48.1 ± 1.2	41.5 ± 0.0	4.2 ± 0.0
639911 [x]	56.9 ± 8.2	77.1 ± 15.6	67.0 ± 3.7	6.7 ± 0.4
639912 [x]	53.6 ± 14.8	78.9 ± 3.6	66.2 ± 9.2	6.6 ± 0.9
639913 [x]	45.0 ± 4.2	59.4 ± 5.3	52.2 ± 0.5	5.2 ± 0.1
639915 [x]	60.0 ± 12.5	78.9 ± 9.3	69.4 ± 1.6	6.9 ± 0.2
639916 [x]	64.5 ± 4.5	67.3 ± 16.7	65.9 ± 10.6	6.6 ± 1.1
903-1 [x]	71.1 ± 16.6	76.2 ± 10.6	73.6 ± 3.0	7.4 ± 0.3
904-1 [x]	49.8 ± 2.3	81.0 ± 4.0	65.4 ± 3.1	6.5 ± 0.3
905-1 [x]	57.9 ± 24.0	87.7 ± 7.4	72.8 ± 8.3	7.3 ± 0.8
x Average	***31.9 ± 7.8***	***45.3 ± 8.8***	***38.6 ± 5.9***	***3.9 ± 0.6***
OLYO5N5 [y]	38.9 ± 9.1	62.8 ± 10.9	50.8 ± 10.0	5.1 ± 1.0
Colorado 6 [z]	31.8 ± 15.8	30.8 ± 7.0	31.3 ± 4.4	3.1 ± 0.4
Salsa Red [z]	51.5 ± 18.2	90.7 ± 34.6	71.1 ± 26.4	7.1 ± 2.6
Vantage [z]	66.6 ± 2.8	84.2 ± 0.1	75.4 ± 1.4	7.5 ± 0.1
z Average	***50.0 ± 12.3***	***68.6 ± 13.9***	***59.3 ± 10.7***	***5.9 ± 1.0***
Grand mean	**40.3 ± 9.7**	**58.9 ± 11.2**	**49.6 ± 8.9**	**5.0 ± 0.9**
Tukey's (0.05)	44.3	56.1	37.8	3.8

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.14. Seasonal dynamics of onion thrips (*Thrips tabaci*) population in direct-seeded onion germplasms during field evaluation for their resistance/tolerance to onion thrips in northern Colorado, near Fort Collins, in 2010.

Genotype	Thrips-70 (Thrips/plant) (mean ± SE)	Thrips-79 (Thrips/plant) (mean ± SE)	Thrips-113 (Thrips/plant) (mean ± SE)	Average (Thrips/plant) (mean ± SE)	Thrips-day (Thrips/plant/day) (mean ± SE)
903-1[x]	3.6 ± 0.2	55.5 ± 14.3	47.0 ± 3.0	35.4 ± 5.9	2.5 ± 0.4
904-1[x]	5.0 ± 0.8	45.6 ± 24.5	46.5 ± 1.3	32.4 ± 8.3	2.3 ± 0.6
905-1[x]	2.4 ± 0.4	35.7 ± 0.5	42.5 ± 3.4	26.8 ± 1.4	1.9 ± 0.1
x average	***3.7 ± 0.5***	***45.6 ± 13.1***	***45.3 ± 2.6***	***31.5 ± 5.2***	***2.2 ± 0.4***
6001[y]	2.6 ± 0.2	32.4 ± 1.7	49.2 ± 0.0	28.1 ± 0.5	2.0 ± 0.1
6022[y]	4.0 ± 1.6	34.5 ± 18.0	47.1 ± 0.0	28.5 ± 5.5	2.0 ± 0.4
16535[y]	2.1 ± 0.4	56.0 ± 12.7	32.1 ± 3.3	30.1 ± 5.4	2.1 ± 0.4
18495[y]	3.4 ± 1.2	48.9 ± 7.6	53.1 ± 1.6	35.1 ± 2.7	2.5 ± 0.2
EX-14593[y]	2.5 ± 0.0	49.3 ± 6.9	34.4 ± 3.2	28.7 ± 3.4	2.0 ± 0.3
NUN7006ON[y]	2.7 ± 0.6	24.0 ± 7.4	25.6 ± 0.0	17.4 ± 2.3	1.2 ± 0.1
NUN7007ON[y]	2.0 ± 0.6	25.0 ± 13.1	30.8 ± 0.0	19.3 ± 4.2	1.3 ± 0.3
NUN7009ON[y]	3.7 ± 1.9	25.8 ± 7.8	36.4 ± 2.1	22.0 ± 2.6	1.6 ± 0.2
NUN7606ON[y]	2.4 ± 0.1	33.8 ± 5.9	35.5 ± 3.1	23.9 ± 3.0	1.7 ± 0.2
OLYS06-25[y]	2.7 ± 0.1	23.7 ± 23.8	47.9 ± 5.5	24.8 ± 9.8	1.7 ± 0.7
R-5978[y]	2.7 ± 1.1	44.8 ± 23.6	29.3 ± 0.0	25.6 ± 7.5	1.8 ± 0.6
SBO-5288[y]	2.6 ± 1.9	30.3 ± 1.3	41.3 ± 0.6	24.7 ± 0.0	1.7 ± 0.0
SBO-5419[y]	4.8 ± 1.6	35.3 ± 5.3	40.2 ± 3.7	26.8 ± 2.5	1.9 ± 0.2
SBO-5420[y]	4.5 ± 0.2	13.7 ± 5.2	34.0 ± 1.5	17.4 ± 1.2	1.3 ± 0.1
SBO-5508[y]	4.3 ± 0.4	15.1 ± 11.2	31.4 ± 6.4	16.9 ± 5.8	1.2 ± 0.4
SBO-5599[y]	2.8 ± 1.1	52.5 ± 14.7	38.9 ± 2.2	31.4 ± 6.0	2.2 ± 0.4
SN-626[y]	2.4 ± 0.1	14.6 ± 9.8	18.5 ± 10.9	11.8 ± 6.9	0.9 ± 0.5
y average	***3.1 ± 0.8***	***32.9 ± 10.4***	***36.8 ± 2.6***	***24.3 ± 4.1***	***1.7 ± 0.3***
Advantage[z]	3.0 ± 1.3	27.9 ± 10.9	46.7 ± 0.0	25.9 ± 3.2	1.8 ± 0.3
Bello Blanco[z]	2.6 ± 0.1	49.2 ± 5.4	40 ± 13.8	30.6 ± 6.4	2.2 ± 0.5
Belmar[z]	3.4 ± 1.1	37.5 ± 28.7	41.4 ± 24.5	27.4 ± 17.4	2.0 ± 1.2
Bradley[z]	4.0 ± 0.8	46.3 ± 23.3	39.4 ± 17.5	29.9 ± 13.9	2.1 ± 1.0
Brundage[z]	2.2 ± 1.1	47.7 ± 16.7	37.4 ± 7.9	29.1 ± 8.6	2.1 ± 0.6
Calibra[z]	4.8 ± 1.6	39.2 ± 23.3	51.3 ± 0.0	31.8 ± 7.3	2.3 ± 0.5
Colorado 6[z]	2.6 ± 0.9	32.3 ± 5.0	40.3 ± 0.0	25.0 ± 1.4	1.8 ± 0.1
Cometa[z]	2.6 ± 0.5	49.1 ± 7.6	35.8 ± 1.9	29.2 ± 3.0	2.1 ± 0.2
Crockett[z]	4.7 ± 1.0	39.1 ± 3.8	38.8 ± 3.9	27.5 ± 2.3	1.9 ± 0.1
Genesis[z]	3.2 ± 0.4	70.4 ± 17.6	36.2 ± 1.8	36.6 ± 6.6	2.6 ± 0.5
Granero[z]	3.1 ± 0.1	37.2 ± 10.2	60.2 ± 2.8	33.5 ± 4.3	2.3 ± 0.3
Gunnison[z]	2.8 ± 1.8	46.7 ± 6.4	56.6 ± 0.0	35.4 ± 1.5	2.5 ± 0.1
Joaquin[z]	3.7 ± 0.2	35.6 ± 21.3	29.0 ± 2.3	22.7 ± 7.8	1.6 ± 0.6
Mesquite[z]	3.1 ± 0.4	40.5 ± 3.4	31.5 ± 0.0	25.0 ± 1.0	1.8 ± 0.1

Morpheus^{z}	2.2 ± 1.7	53.8 ± 2.2	65.0 ± 0.0	40.3 ± 0.1	2.8 ± 0.0
Oracle^{z}	3.1 ± 1.6	33.2 ± 17.0	36.2 ± 2.4	24.2 ± 7.0	1.7 ± 0.5
Red Devil^{z}	2.1 ± 0.5	40.9 ± 4.0	83.8 ± 8.6	42.2 ± 4.4	3.0 ± 0.4
Salsa Red^{z}	2.0 ± 2.0	58.7 ± 6.6	89.3 ± 2.8	50.0 ± 0.6	3.5 ± 0.0
Swale^{z}	2.9 ± 2.4	62.7 ± 0.1	32.0 ± 0.2	32.5 ± 0.8	2.3 ± 0.1
Tequila^{z}	2.5 ± 1.3	26.0 ± 16.3	37.0 ± 0.0	21.9 ± 5.0	1.6 ± 0.4
The Rock^{z}	2.7 ± 0.8	29.4 ± 3.7	53.0 ± 3.0	28.3 ± 2.5	2.0 ± 0.1
White Cloud^{z}	2.1 ± 0.1	38.6 ± 13.3	40.5 ± 4.2	27.0 ± 5.8	1.9 ± 0.4
z average	***3.0 ± 1.0***	***42.8 ± 11.2***	***46.4 ± 4.4***	***30.7 ± 5.0***	***2.2 ± 0.4***
Grand mean	**3.2 ± 0.7**	**40.5 ± 11.6**	**42.9 ± 3.2**	**28.8 ± 4.8**	**2.0 ± 0.3**
Tukey's (0.05)	4.5	56.3	25.8	24.7	1.8

^{x}PI lines.

^{y}Advanced breeding line.

^{z}Commercial cultivar.

Number following "-" indicates days after sowing (DAS) on which evaluation was carried out.

Appendix II.A.15. Seasonal dynamics of onion thrips (*Thrips tabaci*) population in transplanted onion germplasms during field evaluation for their resistance/tolerance to onion thrips in northern Colorado, near Fort Collins, in 2011.

Genotype	**Thrips-89** (Thrips/plant) (mean ± SE)	**Thrips-96** (Thrips/plant) (mean ± SE)	**Thrips-112** (Thrips/plant) (mean ± SE)	**Average** (Thrips/plant) (mean ± SE)	**Thrips-day** (Thrips/plant/day) (mean ± SE)
574[x]	34.2 ± 22.7	43.7 ± 23.4	16.2 ± 13.9	31.4 ± 13.2	4.1 ± 1.7
575[x]	5.5 ± 5.9	3.3 ± 1.9	1.4 ± 1.1	3.4 ± 2.7	0.4 ± 0.4
577[x]	10.7 ± 4.9	16.4 ± 6.6	7.1 ± 4.8	11.4 ± 2.4	1.5 ± 0.3
578[x]	2.0 ± 2.1	0.9 ± 1.3	0.9 ± 1.1	1.3 ± 1.4	0.2 ± 0.2
579[x]	4.4 ± 2.9	3.2 ± 1.8	2.8 ± 3.1	3.5 ± 0.4	0.5 ± 0.0
580[x]	5.7 ± 4.1	4.6 ± 5.1	0.6 ± 0.5	3.6 ± 2.0	0.5 ± 0.3
582[x]	0.5 ± 0.1	0.5 ± 0.2	0.3 ± 0.4	0.4 ± 0.2	0.1 ± 0.0
583[x]	1.7 ± 0.5	4.8 ± 5.4	0.8 ± 0.4	2.4 ± 1.9	0.3 ± 0.3
589[x]	6.8 ± 2.4	8.7 ± 3.1	8.5 ± 5.3	8.0 ± 1.3	1.0 ± 0.2
592[x]	8.8 ± 1.3	9.7 ± 4.3	6.1 ± 4.5	8.2 ± 3.1	1.1 ± 0.4
593[x]	5.5 ± 3.7	12.5 ± 3.9	4.4 ± 1.7	7.5 ± 2.0	1.0 ± 0.3
594[x]	2.8 ± 2.7	5.3 ± 3.2	6.3 ± 7.5	4.8 ± 3.9	0.6 ± 0.5
596[x]	5.6 ± 3.7	11.2 ± 7.2	4.8 ± 2.6	7.2 ± 3.6	0.9 ± 0.5
597[x]	2.8 ± 2.6	2.8 ± 2.7	1.2 ± 0.8	2.3 ± 1.1	0.3 ± 0.1
602[x]	18.4 ± 12.4	27.9 ± 11.5	13.5 ± 10.7	19.9 ± 10.1	2.6 ± 1.3
607[x]	13.1 ± 2.3	28.8 ± 5.1	13.2 ± 11.4	18.4 ± 3.6	2.4 ± 0.5
615[x]	1.8 ± 1.8	0.3 ± 0.3	0.5 ± 0.9	0.9 ± 0.9	0.1 ± 0.1
618[x]	4.4 ± 5.9	3.7 ± 4.5	0.4 ± 0.1	2.8 ± 3.5	0.4 ± 0.5
619[x]	6.3 ± 1.1	5.7 ± 2.3	1.9 ± 1.3	4.6 ± 1.1	0.6 ± 0.1
620[x]	16.1 ± 11.6	23.2 ± 9.4	6.8 ± 4.0	15.4 ± 7.6	2.0 ± 1.0
621[x]	11.9 ± 4.8	24.8 ± 5.3	10.1 ± 1.2	15.6 ± 2.1	2.0 ± 0.3
622[x]	19.8 ± 9.5	35.3 ± 13.6	9.0 ± 2.9	21.4 ± 7.4	2.8 ± 1.0
624[x]	4.9 ± 4.3	14.7 ± 16.8	6.8 ± 2.3	8.8 ± 7.4	1.1 ± 1.0
628[x]	3.3 ± 1.9	5.4 ± 3.3	1.2 ± 1.0	3.3 ± 1.7	0.4 ± 0.2
629[x]	7.9 ± 6.8	14.2 ± 9.1	3.8 ± 3.4	8.6 ± 4.3	1.1 ± 0.6
632[x]	51.0 ± 0.0	47.0 ± 0.0	7.0 ± 0.0	35.0 ± 0.0	4.6 ± 0.0
634[x]	9.9 ± 2.5	28.1 ± 14.1	16.5 ± 5.5	18.2 ± 4.9	2.4 ± 0.6
643[x]	26.9 ± 27.0	46.0 ± 24.6	6.5 ± 1.7	26.5 ± 17.7	3.5 ± 2.3
646[x]	17.0 ± 1.0	41.2 ± 5.7	10.7 ± 5.8	23.0 ± 2.3	3.0 ± 0.3
648[x]	8.5 ± 3.5	35.3 ± 14.6	17.4 ± 2.6	20.4 ± 6.9	2.7 ± 0.9
651[x]	32.7 ± 34.7	23.5 ± 15.1	10.3 ± 6.4	22.2 ± 18.1	2.9 ± 2.4
654[x]	11.1 ± 5.4	49.8 ± 23.2	16.0 ± 9.1	25.6 ± 6.8	3.3 ± 0.9
656[x]	14.2 ± 14.9	22.5 ± 18.4	10.2 ± 2.8	15.7 ± 10.5	2.0 ± 1.4
658[x]	31.9 ± 10.6	45.1 ± 14.5	5.1 ± 1.5	27.4 ± 7.0	3.6 ± 0.9
660[x]	10.4 ± 3.0	33.7 ± 5.9	21.5 ± 12.1	21.9 ± 4.1	2.9 ± 0.5
696[x]	2.6 ± 2.4	3.5 ± 3.5	0.4 ± 0.6	2.2 ± 2.1	0.3 ± 0.3

700 [x]	21.7 ± 19.9	16.9 ± 4.6	3.6 ± 2.6	14.1 ± 6.3	1.8 ± 0.8
702 [x]	7.2 ± 7.7	5.1 ± 1.6	1.5 ± 1.5	4.6 ± 2.8	0.6 ± 0.4
706 [x]	9.0 ± 3.5	5.6 ± 2.1	2.4 ± 0.9	5.7 ± 1.0	0.7 ± 0.1
708 [x]	3.2 ± 2.3	8.0 ± 5.4	1.9 ± 1.4	4.4 ± 2.9	0.6 ± 0.4
711 [x]	13.8 ± 13.7	13.0 ± 4.9	3.0 ± 1.7	9.9 ± 6.0	1.3 ± 0.8
712 [x]	3.1 ± 0.6	2.7 ± 2.0	0.4 ± 0.4	2.1 ± 0.8	0.3 ± 0.1
713 [x]	6.9 ± 3.6	6.5 ± 3.6	2.3 ± 1.6	5.2 ± 2.6	0.7 ± 0.3
718 [x]	3.7 ± 4.0	2.8 ± 1.6	1.4 ± 1.1	2.7 ± 1.7	0.3 ± 0.2
719 [x]	4.3 ± 5.7	10.3 ± 11.5	5.5 ± 3.5	6.7 ± 4.6	0.9 ± 0.6
753 [x]	10.6 ± 2.9	16.6 ± 1.8	2.1 ± 1.1	9.8 ± 0.5	1.3 ± 0.1
759 [x]	3.5 ± 1.8	4.6 ± 6.1	3.7 ± 4.1	3.9 ± 3.3	0.5 ± 0.4
765 [x]	9.6 ± 2.8	18.4 ± 8.6	19.9 ± 2.7	15.9 ± 4.2	2.1 ± 0.5
768 [x]	12.6 ± 11.5	24.7 ± 17.9	11.7 ± 4.0	16.3 ± 8.9	2.1 ± 1.2
769 [x]	8.9 ± 4.2	23.9 ± 13.1	11.2 ± 4.1	14.7 ± 2.1	1.9 ± 0.3
172702 [x]	4.4 ± 4.3	6.8 ± 8.8	2.2 ± 1.7	4.4 ± 4.6	0.6 ± 0.6
172703 [x]	2.5 ± 2.5	3.4 ± 6.8	0.9 ± 1.7	2.3 ± 3.6	0.3 ± 0.5
239633 [x]	9.3 ± 7.1	15.8 ± 9.7	7.4 ± 6.9	10.8 ± 7.9	1.4 ± 1.0
258956 [x]	11.0 ± 8.0	28.5 ± 13.6	7.7 ± 5.6	15.7 ± 5.4	2.1 ± 0.7
264320 [x]	19.8 ± 4.5	33.3 ± 7.9	10.0 ± 5.2	21.0 ± 4.5	2.7 ± 0.6
288909 [x]	6.1 ± 3.1	9.7 ± 6.9	2.6 ± 1.0	6.2 ± 3.1	0.8 ± 0.4
289689 [x]	3.2 ± 1.5	3.0 ± 2.8	0.4 ± 0.3	2.2 ± 1.4	0.3 ± 0.2
343049 [x]	8.0 ± 7.9	15.3 ± 9.2	5.5 ± 4.3	9.6 ± 5.6	1.2 ± 0.7
546140 [x]	7.3 ± 4.5	9.6 ± 4.8	1.0 ± 0.7	5.9 ± 3.2	0.8 ± 0.4
546188 [x]	15.5 ± 9.7	40.2 ± 17.2	7.6 ± 2.5	21.1 ± 6.0	2.8 ± 0.8
546192 [x]	14.1 ± 11.2	39.6 ± 17.7	6.5 ± 1.5	20.0 ± 9.6	2.6 ± 1.3
639911 [x]	16.6 ± 6.4	40.8 ± 6.3	15.3 ± 1.3	24.2 ± 3.9	3.2 ± 0.5
B2133C [x]	6.6 ± 4.5	17.2 ± 7.0	17.0 ± 5.0	13.6 ± 5.5	1.8 ± 0.7
B5336C [x]	4.5 ± 3.5	20.2 ± 6.8	11.8 ± 6.7	12.1 ± 1.1	1.6 ± 0.1
B5351C [x]	8.0 ± 3.6	14.8 ± 12.5	9.3 ± 4.0	10.7 ± 5	1.4 ± 0.6
E203 [x]	1.9 ± 2.5	1.4 ± 2.4	0.3 ± 0.6	1.2 ± 1.8	0.2 ± 0.2
E205 [x]	5.7 ± 5.4	10.0 ± 8.3	1.8 ± 0.7	5.8 ± 4.8	0.8 ± 0.6
E206 [x]	3.6 ± 1.4	5.0 ± 4.2	1.3 ± 0.8	3.3 ± 2.1	0.4 ± 0.3
E207 [x]	5.1 ± 3.2	9.0 ± 6.4	1.2 ± 1.7	5.1 ± 3.4	0.7 ± 0.4
GCA-SYN [x]	12.2 ± 13.4	27.3 ± 21	26.3 ± 12.5	21.9 ± 12	2.9 ± 1.6
x average	**10.1 ± 6.1**	**17.1 ± 8.1**	**6.5 ± 3.3**	**11.2 ± 4.5**	**1.5 ± 0.6**
NUN7606ON [y]	24.5 ± 20.8	38.8 ± 19.6	11.2 ± 3	24.8 ± 12.1	3.2 ± 1.6
OLYS03-207 [y]	18.2 ± 15.1	37.0 ± 4.8	7.5 ± 0.8	20.9 ± 6.1	2.7 ± 0.8
OLYS03-209 [y]	20.1 ± 5.7	34.4 ± 6.5	13.6 ± 5.5	22.7 ± 4.8	3.0 ± 0.6
OLYS05N5 [y]	11.0 ± 10.1	24.4 ± 13.3	9.5 ± 3.0	15.0 ± 8.5	2.0 ± 1.1
OLYX06-25 [y]	21.6 ± 11	32.0 ± 14.0	10.2 ± 5.1	21.3 ± 6.6	2.8 ± 0.9
y average	**19.1 ± 12.5**	**33.3 ± 11.6**	**10.4 ± 3.5**	**20.9 ± 7.6**	**2.7 ± 1.0**

Colorado 6 [z]	18.3 ± 14.2	30.2 ± 20.9	10.6 ± 3.3	19.7 ± 11.3	2.6 ± 1.5
Cometa [z]	17.9 ± 4.6	35.7 ± 5.1	17.1 ± 4.1	23.6 ± 1.7	3.1 ± 0.2
Mesquit [z]	9.2 ± 6.4	34.8 ± 12	8.8 ± 2.5	17.6 ± 5.6	2.3 ± 0.7
Rumba [z]	8.0 ± 0.7	26.7 ± 4.2	10.8 ± 9.5	15.2 ± 3.9	2.0 ± 0.5
Salsa Red [z]	11.9 ± 5.1	34.5 ± 23.7	28.0 ± 8.9	24.8 ± 12.3	3.2 ± 1.6
T-433 [z]	25.7 ± 10.5	43.5 ± 9.3	9.3 ± 3.1	26.2 ± 4.5	3.4 ± 0.6
Vantage [z]	19.8 ± 8.1	34.5 ± 14.1	23.6 ± 9.2	26.0 ± 10.4	3.4 ± 1.4
z average	**15.8 ± 7.1**	**34.3 ± 12.8**	**15.5 ± 5.8**	**21.9 ± 7.1**	**2.9 ± 0.9**
Grand mean	**15.0 ± 8.6**	**28.2 ± 10.8**	**10.8 ± 4.2**	**18.0 ± 6.4**	**2.3 ± 0.8**
Tukey's (0.05)	28.3	34.5	15.3	19.5	2.5

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Number following "-" indicates days after planting (DAP) on which evaluation was carried out.

Appendix II.A.16. Development and yield of transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2009.

Genotype	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)	**Split/Bunch** (%) (mean ± SE)
124525 [x]	90.9 ± 6.9	136.0 ± 0.0	49.3 ± 9.4	55.3 ± 0.0
142790 [x]	91.8 ± 0.6	136.0 ± 0.0	57.0 ± 1.9	3.0 ± 0.0
164361 [x]	96.2 ± 11.4	143.0 ± 0.0	25.4 ± 0.0	94.7 ± 0.0
164807 [x]	90.1 ± 5.8	143.0 ± 0.0	25.4 ± 0.0	68.4 ± 0.0
165498 [x]	90.8 ± 5.8	130.0 ± 0.0	37.0 ± 7.4	17.6 ± 0.0
168962 [x]	86.9 ± 1.3	130.0 ± 0.0	56.4 ± 3.3	4.0 ± 0.0
168966 [x]	88.6 ± 0.1	122.0 ± 0.0	52.6 ± 0.7	2.5 ± 0.0
171475 [x]	97.2 ± 0.5	122.0 ± 0.0	34.2 ± 8.1	9.4 ± 0.0
171477 [x]	92.4 ± 4.3	130.0 ± 0.0	39.1 ± 7.6	0.0 ± 0.0
172701 [x]	95.1 ± 7.4	130.0 ± 0.0	33.8 ± 10.1	2.9 ± 0.0
172702 [x]	98.2 ± 1.3	137.0 ± 0.0	50.5 ± 8.6	55.0 ± 0.0
172703 [x]	98.0 ± 8.0	136.0 ± 0.0	46.9 ± 5.6	54.8 ± 0.0
172704 [x]	86.6 ± 0.9	136.0 ± 0.0	58.2 ± 7.5	35.7 ± 0.0
174018 [x]	88.8 ± 0.7	143.0 ± 0.0	63.6 ± 1.2	47.6 ± 0.0
174024 [x]	74.9 ± 13	144.0 ± 0.0	61.1 ± 14.5	65.8 ± 0.0
177242 [x]	101.1 ± 7.8	144.0 ± 0.0	56.8 ± 11.7	70.0 ± 0.0
179164 [x]	98.3 ± 6.5	130.0 ± 0.0	37.5 ± 0.3	16.2 ± 0.0
179627 [x]	91.8 ± 4.4	137.0 ± 0.0	39.1 ± 3.7	66.7 ± 0.0
182138 [x]	107.8 ± 3.4	137.0 ± 0.0	39.5 ± 1.9	3.3 ± 0.0
183660 [x]	104.4 ± 2.4	137.0 ± 0.0	32.1 ± 3.7	18.0 ± 0.0
200874 [x]	90.8 ± 1.2	136.0 ± 0.0	47.0 ± 3.7	28.6 ± 0.0
233186 [x]	87.1 ± 0.7	130.0 ± 0.0	45.6 ± 4.2	4.4 ± 0.0
246140 [x]	104.1 ± 2.9	137.0 ± 0.0	60.2 ± 13.2	20.0 ± 0.0
248753 [x]	103.9 ± 0.1	137.0 ± 0.0	29.1 ± 5.2	59.3 ± 0.0
248754 [x]	71.9 ± 26.4	144.0 ± 0.0	37.9 ± 5.7	76.9 ± 0.0
249899 [x]	98.1 ± 15.3	144.0 ± 0.0	59.1 ± 6.3	53.8 ± 0.0
251325 [x]	102.3 ± 2.3	136.0 ± 0.0	47.5 ± 0.6	35.0 ± 0.0
255557 [x]	95.2 ± 1.7	144.0 ± 0.0	58.9 ± 4.2	78.6 ± 0.0
256048 [x]	111.8 ± 1.6	143.0 ± 0.0	44.7 ± 1.1	55.2 ± 0.0
256049 [x]	106.5 ± 6.6	143.0 ± 0.0	50.1 ± 1.0	61.5 ± 0.0
258956 [x]	86.0 ± 0.0	143.0 ± 0.0	97.1 ± 1.6	6.1 ± 0.0
264320 [x]	87.9 ± 2.7	143.0 ± 0.0	79.4 ± 6.6	20.9 ± 0.0
264321 [x]	87.3 ± 0.3	136.0 ± 0.0	84.2 ± 4.8	37.2 ± 0.0
264631 [x]	93.9 ± 4.4	144.0 ± 0.0	64.2 ± 4.0	34.8 ± 0.0

264648 x	102.4 ± 4.3	136.0 ± 0.0	54.8 ± 3.3	9.5 ± 0.0
269306 x	100.8 ± 0.6	143.0 ± 0.0	38.1 ± 2.3	66.7 ± 0.0
271039 x	92.0 ± 0.9	136.0 ± 0.0	69.8 ± 0.0	69.2 ± 0.0
273211 x	96.0 ± 0.2	143.0 ± 0.0	41.0 ± 0.8	26.3 ± 0.0
274780 x	95.0 ± 8.1	136.0 ± 0.0	51.7 ± 6.2	25.9 ± 0.0
287540 x	93.5 ± 3.6	136.0 ± 0.0	45.2 ± 8.6	34.2 ± 0.0
288073 x	99.6 ± 0.8	143.0 ± 0.0	43.9 ± 2.8	28.2 ± 0.0
288270 x	103.9 ± 4.7	143.0 ± 0.0	48.7 ± 7.6	53.6 ± 0.0
288272 x	95.3 ± 1.4	136.0 ± 0.0	56.5 ± 12.2	14.8 ± 0.0
288902 x	107.8 ± 3.4	130.0 ± 0.0	33.1 ± 3.3	0.0 ± 0.0
288903 x	106.4 ± 6.9	144.0 ± 0.0	2.5 ± 0.0	100.0 ± 0.0
288908 x	104.3 ± 1.5	143.0 ± 0.0	42.3 ± 2.3	44.7 ± 0.0
288909 x	89.9 ± 0.1	130.0 ± 0.0	76.3 ± 4.9	12.1 ± 0.0
289689 x	87.3 ± 0.7	122.0 ± 0.0	54.3 ± 4.5	0.0 ± 0.0
289690 x	86.3 ± 0.5	143.0 ± 0.0	64 ± 11.3	51.2 ± 0.0
293756 x	104.3 ± 0.3	143.0 ± 0.0	38.1 ± 0.0	86.8 ± 0.0
318886 x	91.1 ± 4.5	136.0 ± 0.0	74.3 ± 2.8	10.0 ± 0.0
321385 x	100.4 ± 3.1	137.0 ± 0.0	80.5 ± 3.8	25.0 ± 0.0
342943 x	95.9 ± 3.8	136.0 ± 0.0	71.6 ± 5.0	23.1 ± 0.0
343049 x	88.1 ± 3.0	122.0 ± 0.0	67.0 ± 9.0	4.8 ± 0.0
344392 x	91.0 ± 2.4	122.0 ± 0.0	60.7 ± 2.8	9.5 ± 0.0
391509 x	112.5 ± 0.7	143.0 ± 0.0	44.4 ± 0.0	97.2 ± 0.0
430371 x	94.0 ± 3.2	122.0 ± 0.0	45.2 ± 1.1	0.0 ± 0.0
433330 x	103.4 ± 1.8	143.0 ± 0.0	62.0 ± 4.1	10.7 ± 0.0
433332 x	100.7 ± 5.5	143.0 ± 0.0	41.0 ± 2.8	31.3 ± 0.0
546096 x	98.1 ± 1.9	143.0 ± 0.0	56.2 ± 5.6	4.2 ± 0.0
546100 x	88.7 ± 1.8	143.0 ± 0.0	94.2 ± 12.9	14.0 ± 0.0
546101 x	99.1 ± 12.4	137.0 ± 0.0	79.4 ± 10.2	6.9 ± 0.0
546106 x	100.8 ± 5.0	136.0 ± 0.0	60.1 ± 8.6	3.6 ± 0.0
546115 x	89.0 ± 1.4	136.0 ± 0.0	84.4 ± 1.6	15.6 ± 0.0
546140 x	88.4 ± 0.7	122.0 ± 0.0	63.8 ± 2.1	0.0 ± 0.0
546162 x	94.4 ± 4.0	136.0 ± 0.0	57.5 ± 8.9	0.0 ± 0.0
546174 x	105.7 ± 4.6	144.0 ± 0.0	54.2 ± 9.3	27.0 ± 0.0
546188 x	86.5 ± 0.8	144.0 ± 0.0	105.1 ± 5.8	15.8 ± 0.0
546192 x	89.4 ± 3.1	144.0 ± 0.0	103.0 ± 11.0	17.4 ± 0.0
546201 x	106.7 ± 5.2	143.0 ± 0.0	80.6 ± 16.3	27.8 ± 0.0
639911 x	109.5 ± 0.0	143.0 ± 0.0	54.6 ± 3.5	47.6 ± 0.0
639912 x	101 ± 4.7	144.0 ± 0.0	48.5 ± 8.7	50.0 ± 0.0
639913 x	87.2 ± 1.7	130 .0± 0.0	58.5 ± 0.1	16.2 ± 0.0
639914 x	101.7 ± 0.0	137.0 ± 0.0	58.7 ± 0.0	42.9 ± 0.0

639915[x]	95.8 ± 1.3	137.0 ± 0.0	66.3 ± 11.5	37.5 ± 0.0
639916[x]	87.6 ± 2.3	144.0 ± 0.0	78.6 ± 2.0	53.8 ± 0.0
239633-1[x]	113.0 ± 0.0	137.0 ± 0.0	44.4 ± 0.0	50.0 ± 0.0
239633-2[x]	106.1 ± 3.1	143.0 ± 0.0	42.9 ± 0.0	84.0 ± 0.0
G32590[x]	113.0 ± 0.0	136.0 ± 0.0	79.4 ± 0.0	0.0 ± 0.0
G32787[x]	100.1 ± 6.2	137.0 ± 0.0	61.6 ± 11.2	43.2 ± 0.0
x mean	***96.3 ± 3.6***	***137.4 ± 0***	***55.5 ± 5.0***	***33.2 ± 0.0***
OLYS05N5[y]	96.3 ± 4.2	137 .0± 0.0	88.0 ± 15.4	0.0 ± 0.0
Colorado 6[z]	93.2 ± 3.3	143.0 ± 0.0	101.1 ± 0.8	0.0 ± 0.0
Cometa[z]	95.0 ± 7.8	137.0 ± 0.0	98.4 ± 13.4	0.0 ± 0.0
Mt. Blanc[z]	88.6 ± 1.3	136.0 ± 0.0	86.3 ± 6.2	2.8 ± 0.0
Salsa Red[z]	88.6 ± 2.9	136.0 ± 0.0	76.9 ± 3.7	0 .0 ± 0.0
z mean	***91.4 ± 3.8***	***138.0 ± 0.0***	***90.7 ± 6.0***	***07 ± 0.0***
Grand mean	**94.6 ± 3.9**	**137.5 ± 0.0**	**78.1 ± 8.8**	**11.3 ± 0.0**
Tukey's (0.05)	61.3	0.0	29.6	0.0

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Appendix II.A.17. Development and yield of direct-seeded onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2009.

Genotype	**Bulbing (DAS)** (mean ± SE)	**Size (mm/bulb)** (mean ± SE)
EX-16529 ^{y}	115.0 ± 4.2	86.4 ± 2.7
NUN7606ON ^{y}	126.3 ± 2.0	82.6 ± 3.6
OLRH08-9 ^{y}	123.5 ± 2.6	70.2 ± 0.4
OLYS03-207 ^{y}	119.0 ± 1.6	77.2 ± 10.3
OLYS03-209 ^{y}	116.8 ± 3.6	71.5 ± 1.3
OLYS05N5 ^{y}	121.0 ± 1.8	73.7 ± 0.0
OLYX00-23 ^{y}	112.1 ± 5.1	85.8 ± 4.5
OLYX06-25^{y}	117.6 ± 2.5	75.7 ± 2.8
y mean	***118.9 ± 2.9***	***77.9 ± 3.2***
Abilene^{z}	112.7 ± 2.1	82.3 ± 1.3
Arcero^{z}	119.2 ± 8.6	78.8 ± 14.4
Calibra^{z}	117.6 ± 4.5	79.4 ± 0.9
Charismatic^{z}	121.1 ± 5.4	78.1 ± 4.5
Colorado 6^{z}	121.0 ± 7.8	75.6 ± 5.4
Cometa^{z}	119.3 ± 0.4	81.0 ± 12.1
Crockett^{z}	115.4 ± 1.0	83.2 ± 0.8
Damascus^{z}	121.3 ± 4.0	79.1 ± 9.4
Delgado^{z}	119.1 ± 13.2	86.1 ± 0.5
Denali^{z}	110.7 ± 2.1	89.2 ± 0.4
Desperado^{z}	116.4 ± 9.2	83.6 ± 1.3
Granero^{z}	121.4 ± 3.2	83.2 ± 11.7
Gunnison^{z}	123.7 ± 6.4	76.3 ± 12.7
Harmony^{z}	121.8 ± 9.5	77.8 ± 4.0
Joaquin^{z}	123.3 ± 0.0	78.7 ± 0.0
Legand^{z}	119.5 ± 5.8	82.3 ± 5.9
Marquett^{z}	114.1 ± 3.3	82.0 ± 15.1
Mesquite^{z}	122.9 ± 10.4	73.4 ± 4.0
Milestone^{z}	127.0 ± 0.0	82.9 ± 4.9
Monarcho^{z}	114.9 ± 2.0	79.1 ± 4.9
Montero^{z}	117.9 ± 7.4	83.2 ± 11.7
Oro Blanco^{z}	110.9 ± 0.5	102.9 ± 1.8
Ovation^{z}	113.4 ± 0.9	97.2 ± 6.3
Pulsar^{z}	126.2 ± 1.6	67.4 ± 14.4
Ranchero^{z}	115.3 ± 2.6	80.7 ± 0.9
Red Bull^{z}	122.9 ± 2.0	65.4 ± 9.9
Red Flare^{z}	120.8 ± 4.2	81.6 ± 3.1
Red Wing^{z}	123.4 ± 1.4	68.3 ± 3.2

Ruby Ring[z]	124.2 ± 1.8	60.4 ± 6.3
Salsa Red[z]	125.3 ± 8.1	71.5 ± 14.8
Sarape Café	118.4 ± 6.4	80.3 ± 20.2
Sedona[z]	114.5 ± 0.5	80.3 ± 0.4
Sp. Medallion[z]	111.7 ± 4.6	88.3 ± 0.9
Swale[z]	118.7 ± 0.0	80.4 ± 8.6
T-433[z]	121.9 ± 5.5	77.5 ± 1.8
Talon[z]	118.8 ± 1.8	79.7 ± 4.1
Tamara[z]	122.4 ± 0.6	72.8 ± 4.0
Tequila[z]	120.8 ± 7.1	81.6 ± 12.2
Tioga[z]	122.0 ± 0.2	86.7 ± 12.2
Vantage[z]	118.4 ± 9.1	81.3 ± 22.5
Vaquero[z]	122.7 ± 4.8	77.5 ± 4.5
Vision[z]	114.5 ± 5.6	74.3 ± 2.7
White Cloud[z]	113.5 ± 1.1	90.5 ± 8.5
White Wing[z]	115.0 ± 5.0	79.7 ± 10.3
z mean	**119 ± 4.1**	**80.0 ± 6.8**
Grand mean	**119.0 ± 3.5**	**79.0 ± 5.0**
Tukey’s (0.05)	21.4	35.4

All entries were harvested at 175 DAS.

[y]Advanced breeding line.

[z]Commercial cultivar.

Appendix II.A.18. Development and yield of transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2010.

Genotype	Bulbing (DAP) (mean ± SE)	Maturity (DAP) (mean ± SE)	Size (mm/bulb) (mean ± SE)	Weight (g/bulb) (mean ± SE)	Split/Bunch (%) (mean ± SE)
124525 [x]	84.9 ± 1.2	113.6 ± 1.7	29.3 ± 3.2	14.9 ± 3.9	31.1 ± 12.6
164807 [x]	84.9 ± 1.2	125.9 ± 1.3	35.1 ± 3.1	19.2 ± 1.7	80.0 ± 28.3
165498 [x]	84.0 ± 0.0	124.1 ± 5.5	35.8 ± 5.3	26.0 ± 7.2	10.0 ± 0.0
168962 [x]	84.0 ± 0.0	137.6 ± 3.9	62.9 ± 9.2	103.9 ± 33.3	40.0 ± 0.0
168966 [x]	84.0 ± 0.0	137.4 ± 4.1	49.0 ± 1.3	64.7 ± 7.1	45.0 ± 7.1
171475 [x]	84.0 ± 0.0	129.5 ± 3.2	48.0 ± 1.1	44.5 ± 3.3	51.4 ± 37.3
171477 [x]	84.0 ± 0.0	118.9 ± 0.6	42.6 ± 2.0	33.3 ± 7.5	45 .0± 7.1
172701 [x]	84.0 ± 0.0	129.5 ± 10.2	47.5 ± 1.8	70.8 ± 6.9	23.8 ± 13.5
172702 [x]	84.0 ± 0.0	127.6 ± 6.9	43.0 ± 8.5	35.3 ± 18.5	48.9 ± 40.9
172703 [x]	84.0 ± 0.0	141.2 ± 1.2	60.9 ± 2.3	81.6 ± 1.6	20.0 ± 0.0
172704 [x]	84.0 ± 0.0	118.7 ± 5.7	50.4 ± 0.1	52.2 ± 1.5	15.0 ± 7.1
174018 [x]	84.0 ± 0.0	131.7 ± 1.8	48.1 ± 1.0	48.6 ± 2.8	15.0 ± 7.1
174024 [x]	84.0 ± 0.0	133.1 ± 3.3	64.6 ± 1.2	102.1 ± 11.1	40.0 ± 14.1
177242 [x]	84.9 ± 1.2	115.3 ± 2.4	36.1 ± 1.5	20.9 ± 2.5	85.7 ± 20.2
179627 [x]	84.0 ± 0.0	118.0 ± 4.5	54.5 ± 2.0	63.9 ± 2.4	45.0 ± 7.1
182138 [x]	87.2 ± 4.5	134.3 ± 4.7	52.4 ± 3.7	72.3 ± 4.7	50 .0± 14.1
200874 [x]	84.9 ± 1.2	117.1 ± 1.6	50.4 ± 13.2	57.4 ± 33.8	71.4 ± 0.0
233186 [x]	84.0 ± 0.0	138.7 ± 1.6	58.2 ± 4.6	76.8 ± 7.4	35.0 ± 7.1
248753 [x]	84.0 ± 0.0	123.5 ± 2.2	28.0 ± 2.3	13.6 ± 4.2	25.0 ± 7.1
248754 [x]	84.0 ± 0.0	125.8 ± 1.1	40.7 ± 5.6	40.2 ± 4.4	50.0 ± 0.0
249899 [x]	91.7 ± 0.0	135.1 ± 0.0	46.7 ± 9.2	45.6 ± 18.4	40.0 ± 14.1
251325 [x]	85.7 ± 0.1	120.6 ± 0.4	34.2 ± 3.7	20.2 ± 8.3	0.0 ± 0.0
255557 [x]	87.5 ± 4.0	137.6 ± 6.2	66.8 ± 2.9	80.7 ± 25.9	60.0 ± 0.0
258956 [x]	84.0 ± 0.0	142.0 ± 0.0	100.8 ± 2.4	390.6 ± 2.6	0.0 ± 0.0
264320 [x]	85.4 ± 1.0	142.0 ± 0.0	113.6 ± 3.6	394.8 ± 12.6	5.0 ± 7.1
264648 [x]	88.9 ± 3.0	138.7 ± 4.7	64.6 ± 5.9	63.2 ± 15.2	30.0 ± 0.0
271039 [x]	85.4 ± 2.0	120.8 ± 0.8	43.3 ± 6.2	41.0 ± 14.0	11.1 ± 15.7
274780 [x]	84.0 ± 0.0	118.1 ± 3.7	43.0 ± 2.2	38.9 ± 2.2	30.0 ± 0.0
288073 [x]	95.6 ± 4.5	142.0 ± 0.0	44.5 ± 0.6	19.1 ± 4.5	26.1 ± 5.5
288270 [x]	86.1 ± 1.0	135.9 ± 1.7	64.1 ± 4.1	118.2 ± 29.3	41.7 ± 11.8
288272 [x]	86.3 ± 0.7	117.6 ± 4.4	31.4 ± 0.8	18.2 ± 2.2	8.3 ± 11.8
288902 [x]	90.2 ± 1.1	120.4 ± 0.6	28.5 ± 0.3	17.1 ± 0.1	6.3 ± 8.8
288903 [x]	90.0 ± 0.5	139.8 ± 3.1	55.8 ± 5.0	62.8 ± 14	75.0 ± 7.1
288908 [x]	87.5 ± 1.0	121.8 ± 1.2	39.5 ± 2.3	35.4 ± 0.4	15.0 ± 7.1
288909 [x]	84.0 ± 0.0	120.0 ± 0.1	60.7 ± 0.4	73.6 ± 0.4	40.0 ± 0.0
289689 [x]	84.0 ± 0.0	116.8 ± 1.0	60.3 ± 5.5	93.2 ± 22.5	10.0 ± 0.0

289690 [x]	84.0 ± 0.0	123.6 ± 0.9	73.6 ± 0.7	182.3 ± 7.7	30.0 ± 0.0
344392 [x]	84.6 ± 0.8	121.3 ± 4.0	50.8 ± 3.0	60.3 ± 7.8	22.9 ± 14.7
433330 [x]	87.9 ± 1.5	133.1 ± 4.0	55.4 ± 6.2	70.2 ± 20.2	40.0 ± 0.0
433332 [x]	90.7 ± 0.5	122.3 ± 3.2	34.2 ± 0.5	27.2 ± 8.4	7.1 ± 10.1
546096 [x]	85.1 ± 0.5	125.1 ± 1.9	59.8 ± 0.7	118.1 ± 5.1	0.0 ± 0.0
546100 [x]	84.0 ± 0.0	142.0 ± 0.0	111.3 ± 2.6	510.0 ± 2.2	0.0 ± 0.0
546101 [x]	84.0 ± 0.0	138.7 ± 1.6	91.1 ± 1.3	322.1 ± 22.0	20.0 ± 0.0
546106 [x]	84.0 ± 0.0	123.9 ± 0.0	65.0 ± 0.1	138.7 ± 0.8	10.0 ± 0.0
546115 [x]	85.4 ± 2.0	126.2 ± 6.6	75.1 ± 3.3	200.7 ± 38.3	15.0 ± 7.1
546140 [x]	84.0 ± 0.0	119.1 ± 1.2	70.2 ± 3.8	173.3 ± 26.2	0.0 ± 0.0
546162 [x]	86.1 ± 2.0	128.8 ± 0.1	66.1 ± 0.8	146.8 ± 10.3	5.0 ± 7.1
546174 [x]	85.8 ± 1.5	121.5 ± 1.3	62.2 ± 1.7	100.5 ± 1.0	15.0 ± 7.1
546188 [x]	84.4 ± 0.5	142.0 ± 0.0	106.4 ± 11	491.2 ± 3.2	0.0 ± 0.0
546192 [x]	84.0 ± 0.0	142.0 ± 0.0	106.2 ± 1.1	765.8 ± 301.9	0.0 ± 0.0
639911 [x]	86.1 ± 3.0	139.7 ± 0.2	72.8 ± 5.5	193.8 ± 12.0	30.0 ± 0.0
639912 [x]	84.7 ± 1.0	133.9 ± 5.6	60.0 ± 0.3	116.4 ± 11.4	45.0 ± 7.1
639913 [x]	84.7 ± 1.0	120.8 ± 5.9	64.1 ± 5.6	115.3 ± 19.9	7.1 ± 10.1
639915 [x]	85.1 ± 1.5	125.2 ± 8.2	65.8 ± 3.4	128.6 ± 14.0	20.0 ± 0.0
639916 [x]	85.8 ± 2.5	134.8 ± 0.8	74.5 ± 5.2	186.3 ± 15.9	20.0 ± 0.0
903-1 [x]	84.0 ± 0.0	142.0 ± 0.0	77.3 ± 1.6	232.4 ± 4.6	0.0 ± 0.0
904-1 [x]	84.0 ± 0.0	142.0 ± 0.0	86.2 ± 3.1	314.7 ± 30.7	0.0 ± 0.0
905-1 [x]	84.7 ± 0.0	142.0 ± 0.0	83.6 ± 7.9	263.0 ± 45.6	0.0 ± 0.0
x mean	***85.5 ± 0.8***	***129.3 ± 2.4***	***59.4 ± 3.4***	***127.8 ± 16.3***	***26.1 ± 6.6***
OLYO5N5 [y]	85.1 ± 1.5	142.0 ± 0.0	100.9 ± 1.5	526.6 ± 10.8	0.0 ± 0.0
Colorado 6 [z]	85.4 ± 2.0	142.0 ± 0.0	111.2 ± 0.3	683.8 ± 86.7	0.0 ± 0.0
Salsa Red [z]	85.1 ± 1.5	139.7 ± 0.9	92.3 ± 11.7	278.6 ± 8.1	0.0 ± 0.0
Vantage [z]	84.4 ± 0.5	135.9 ± 0.6	101.2 ± 5.1	452.4 ± 74.3	0.0 ± 0.0
z mean	***85.0 ± 1.3***	***139.2 ± 0.5***	***101.6 ± 5.7***	***471.6 ± 56.4***	***0.0 ± 0.0***
Grand mean	**85.2 ± 1.2**	**136.8 ± 1.0**	**87.3 ± 3.5**	**375.3 ± 27.8**	**8.7 ± 2.2**
Tukey's (0.05)	6.0	14.3	19.8	188.6	45.8

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Appendix II.A.19. Development and yield of direct-seeded onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2010.

Genotype	**Bulbing (DAS)** (mean ± SE)	**Size (mm/bulb)** (mean ± SE)	**Weight (g/bulb)** (mean ± SE)
903-1 [y]	86.9 ± 2.3	66.9 ± 3.1	151.2 ± 8.3
904-1 [y]	83.3 ± 1.3	77.7 ± 3.5	226.7 ± 8.6
905-1 [y]	85.8 ± 2.5	70.9 ± 10.2	184.8 ± 50.0
x mean	***85.3 ± 2.0***	***71.8 ± 5.6***	***187.6 ± 22.3***
6001 [y]	86.7 ± 1.3	77.8 ± 0.2	255.5 ± 17.0
6022 [y]	86.7 ± 1.8	82.5 ± 4.9	280.9 ± 33.9
16535 [y]	84.6 ± 0.6	81.9 ± 3.8	261.8 ± 28.2
18495 [y]	85.6 ± 1.7	74.7 ± 0.8	207.2 ± 8.4
EX 14593 [y]	88.5 ± 2.0	64.2 ± 4.0	136.5 ± 29.1
NUN7006ON [y]	91.0 ± 2.2	86.7 ± 6.3	339.8 ± 126.4
NUN7007ON [y]	87.4 ± 2.8	88.9 ± 0.4	377.0 ± 13.6
NUN7009ON [y]	85.9 ± 3.3	90.6 ± 0.6	398.6 ± 45.0
NUN7606ON [y]	89.9 ± 1.8	88.4 ± 6.2	338.0 ± 95.0
OLYS06-25 [y]	85.9 ± 0.1	88.2 ± 8.6	320.9 ± 69.0
R-5978 [y]	84.3 ± 1.1	59.6 ± 0.5	113.1 ± 0.5
SBO-5288 [y]	87.5 ± 2.9	85.1 ± 1.3	313.8 ± 3.5
SBO-5419 [y]	86.4 ± 1.1	86.5 ± 3.2	307.5 ± 45.5
SBO-5420 [y]	86.6 ± 0.7	87.8 ± 5.8	327.3 ± 59.8
SBO-5508 [y]	85.8 ± 1.4	90.4 ± 4.5	357.1 ± 23.2
SBO-5599 [y]	87.1 ± 3.4	90.1 ± 5.8	367.7 ± 50.0
SN-626[y]	90.2 ± 2.1	67.2 ± 6.9	162.1 ± 48.6
y mean	***87.1 ± 1.8***	***81.8 ± 3.8***	***286.2 ± 41.0***
Advantage[z]	87.4 ± 0.4	85.9 ± 5.4	331.3 ± 15.6
Bello Blanco[z]	84.2 ± 1.6	78.7 ± 5.2	256.7 ± 65.9
Belmar[z]	85.4 ± 0.5	83.8 ± 5.9	274.1 ± 67.5
Bradley[z]	86.5 ± 2.7	73.8 ± 1.3	202.5 ± 6.4
Brundage[z]	86.4 ± 3.1	88.9 ± 0.9	350.4 ± 28.8
Calibra[z]	83.6 ± 0.3	78.9 ± 7.6	241.2 ± 75.6
Colorado 6[z]	86.2 ± 0.6	90.1 ± 2.7	377.5 ± 52.2
Cometa[z]	87.5 ± 0.5	85.7 ± 4.8	292.2 ± 30.5
Crockett[z]	86.8 ± 2.9	76.1 ± 1.8	216.7 ± 4.5
Genesis[z]	85.4 ± 3.0	72.9 ± 1.6	192.1 ± 11.3
Granero[z]	88.6 ± 1.1	85.8 ± 2.7	293.2 ± 10.5
Gunnison[z]	86.3 ± 3.3	62.7 ± 1.5	124.9 ± 12.9
Joaquin[z]	85.0 ± 1.1	92.6 ± 7.4	392.7 ± 94.4
Mesquite[z]	84.8 ± 1.1	87.7 ± 5.7	358.7 ± 45.8

Morpheus[z]	87.7 ± 0.1	87.5 ± 1.6	329.6 ± 27.8
Oracle[z]	86.2 ± 1.1	88.4 ± 7.2	360.7 ± 61.1
Red Devil[z]	88.3 ± 0.3	63.1 ± 4.9	126.0 ± 29.3
Salsa Red[z]	90.1 ± 2.8	57.9 ± 4.6	96.6 ± 21.3
Swale[z]	85.5 ± 4.4	79.9 ± 4.0	246.5 ± 22.5
Tequila[z]	88.0 ± 1.1	97.2 ± 5.4	455.8 ± 75.6
The Rock[z]	87.8 ± 1.9	90.8 ± 7.6	375.0 ± 92.6
White Cloud[z]	84.9 ± 1.2	89.8 ± 10.8	918.6 ± 914.8
z mean	***86.5 ± 1.6***	***81.7 ± 4.6***	***309.7 ± 80.3***
Grand mean	**86.3 ± 1.8**	**78.5 ± 4.6**	**261.1 ± 47.9**
Tukey's (0.05)	8.4	21.4	628.7

All entries were harvested at 180 DAS.

[x]PI lines.

[y]Advanced breeding line.

[z]Commercial cultivar.

Appendix II.A.20. Development and yield of transplanted onion germplasms during field evaluation for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado, near Fort Collins, in 2011.

Genotype	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Size** (mm/bulb) (mean ± SE)	**Weight** (g/bulb) (mean ± SE)	**Split/Bunch** (%) (mean ± SE)
574 [x]	192.6 ± 6.7	239.5 ± 4.0	87.1 ± 9.0	306.1 ± 83.9	0.0 ± 0.0
575 [x]	180.4 ± 4.9	213.2 ± 11.9	33.4 ± 4.5	18.4 ± 5.3	0.0 ± 0.0
577 [x]	184.2 ± 6.0	232.5 ± 6.5	50.1 ± 1.6	37.4 ± 8.4	0.6 ± 0.4
578 [x]	182.7 ± 6.2	209.9 ± 2.2	20.9 ± 6.9	5.9 ± 5.2	0.0 ± 0.0
579 [x]	184.3 ± 5.9	213.1 ± 2.8	25.5 ± 5.3	10.0 ± 4.3	0.1 ± 0.1
580 [x]	185.8 ± 2.8	214.3 ± 2.1	33.0 ± 3.3	15.3 ± 4.4	0.0 ± 0.1
582 [x]	198.7 ± 0.0	211.0 ± 0.0	23.4 ± 4.2	3.1 ± 2.5	0.0 ± 0.0
583 [x]	186.9 ± 4.6	214.7 ± 6.3	25.2 ± 6.5	10.1 ± 3.0	0.2 ± 0.2
589 [x]	193.0 ± 3.7	230.9 ± 14.1	48.3 ± 11.7	31.6 ± 14.2	0.9 ± 0.1
592 [x]	291.3±172.5	237.9 ± 24	44.7 ± 12.7	25.5 ± 10.8	0.7 ± 0.6
593 [x]	198.8 ± 5.4	252.3 ± 8.2	53.5 ± 11.2	43.7 ± 12.8	0.6 ± 0.5
594 [x]	191.7 ± 1.0	223.5 ± 0.7	48.4 ± 18.7	51.1 ± 46.3	0.5 ± 0.7
596 [x]	193.5 ± 3.2	220.3 ± 4.4	38.7 ± 5.3	22.7 ± 1.8	0.9 ± 0.2
597 [x]	200.4 ± 7.2	241.5 ± 1.7	36.0 ± 6.7	14.7 ± 6.8	0.5 ± 0.5
602 [x]	191.2 ± 3.3	236.0 ± 0.0	85.9 ± 6.4	222.1 ± 58.7	0.9 ± 0.1
607 [x]	187.8 ± 10.6	229.0 ± 9.9	77.7 ± 12	196.5 ± 56.2	0.0 ± 0.0
615 [x]	176.0 ± 0.0	200.1 ± 2.4	35.1 ± 4.6	22.3 ± 6.8	0.0 ± 0.0
618 [x]	176.0 ± 0.0	210.3 ± 4.6	49.5 ± 16.5	42.7 ± 26.6	0.0 ± 0.0
619 [x]	177.7 ± 3.4	213.6 ± 0.8	55.4 ± 4.9	69.6 ± 7.8	0.0 ± 0.0
620 [x]	186.2 ± 2.3	219.7 ± 0.8	65.0 ± 6.2	108.4 ± 31.8	0.0 ± 0.0
621 [x]	187.7 ± 4.3	231.0 ± 2.8	63.7 ± 12.4	85.4 ± 43.8	0.5 ± 0.2
622 [x]	184.7 ± 4.4	215.5 ± 0.6	57.2 ± 5.0	58.2 ± 10.1	0.0 ± 0.0
624 [x]	191.1 ± 8.6	231.5 ± 13.3	47.2 ± 6.3	28.6 ± 6.2	0.5 ± 0.6
628 [x]	184.0 ± 8.3	209.9 ± 4.6	33.7 ± 3.5	15.5 ± 4.3	0.0 ± 0.0
629 [x]	184.9 ± 6.2	210.2 ± 7.9	36.9 ± 9.4	23.9 ± 10.4	0.1 ± 0.2
632 [x]	191.0 ± 0.0	229.0 ± 0.0	90.4 ± 0.0	214.9 ± 0.0	0.0 ± 0.0
634 [x]	190.9 ± 0.1	236.0 ± 0.0	77.8 ± 3.2	222.4 ± 28.7	0.2 ± 0.4
643 [x]	186.0 ± 7.1	236.0 ± 0.0	90.4 ± 13.3	338.2±121.6	0.0 ± 0.0
646 [x]	186.3 ± 4.8	236.0 ± 0.0	77.5 ± 4.1	196.4 ± 33.1	0.0 ± 0.0
648 [x]	190.4 ± 5.9	236.0 ± 0.0	78.7 ± 3.3	220.1 ± 31.5	0.2 ± 0.2
651 [x]	190.8 ± 5.7	235.0 ± 6.9	87.2 ± 6.3	257.1 ± 97.8	0.0 ± 0.0
654 [x]	190.4 ± 5.8	230.8 ± 3.5	76.4 ± 4.2	196.1 ± 44.5	0.0 ± 0.0
656 [x]	189.2 ± 10.2	225.4 ± 4.1	70.4 ± 8.6	178.4 ± 60.8	0.0 ± 0.0
658 [x]	180.6 ± 3.2	232.5 ± 4.0	96.0 ± 8.3	400.8 ± 63.9	0.0 ± 0.0
660 [x]	188.1 ± 9.8	232.3 ± 2.5	80.6 ± 6.4	247.1 ± 56.1	0.0 ± 0.0
696 [x]	174.6 ± 2.8	199.5 ± 1.8	30.6 ± 4.9	19.7 ± 5.8	0.0 ± 0.0

700 [x]	178.4 ± 4.7	218.1 ± 3.5	57.8 ± 4.7	93.5 ± 27.9	0.0 ± 0.0
702 [x]	179.7 ± 1.4	204.9 ± 1.9	35.2 ± 5.7	30.7 ± 11.2	0.0 ± 0.0
706 [x]	178.4 ± 1.8	209.5 ± 4.0	39.2 ± 5.0	33.6 ± 8.6	0.0 ± 0.0
708 [x]	181.6 ± 3.4	210.4 ± 4.6	36.1 ± 9.6	31.5 ± 20.0	0.0 ± 0.0
711 [x]	180.2 ± 3.3	210.8 ± 4.0	56.2 ± 36.5	37.5 ± 18.4	0.0 ± 0.0
712 [x]	178.1 ± 1.8	208.9 ± 8.4	32.6 ± 2.3	38.3 ± 34.6	0.0 ± 0.0
713 [x]	178.9 ± 2.4	202.0 ± 4.6	35.4 ± 6.5	28.3 ± 11.1	0.0 ± 0.1
718 [x]	185.2 ± 13.1	214.3 ± 15.9	37.3 ± 5.8	30.0 ± 11.5	0.0 ± 0.0
719 [x]	180.8 ± 23.2	203.1 ± 7.0	37.6 ± 8.7	32.7 ± 16.0	0.0 ± 0.0
753 [x]	182.5 ± 1.9	218.3 ± 4.0	62.3 ± 5.1	74.4 ± 15.6	0.0 ± 0.0
759 [x]	181.3 ± 2.5	206.6 ± 5.4	36.9 ± 6.8	23.1 ± 10.7	0.0 ± 0.0
765 [x]	201.9 ± 3.0	257.0 ± 0.0	47.1 ± 2.8	58.1 ± 26.2	0.9 ± 0.2
768 [x]	191.9 ± 5.7	248.7 ± 27.3	73.9 ± 13.1	196.2 ± 59.2	0.3 ± 0.5
769 [x]	192.7 ± 7.6	236.0 ± 0.0	74.3 ± 3.5	251.9 ± 45.1	0.0 ± 0.0
172702 [x]	179.8 ± 2.7	216.5 ± 5.7	29.8 ± 7.1	17.4 ± 10.0	0.0 ± 0.0
172703 [x]	183.5 ± 3.5	207.4 ± 2.3	34.1 ± 1.2	24.3 ± 10.5	0.1 ± 0.1
239633 [x]	198.0 ± 3.3	234 ± 22.6	56.4 ± 0.9	63.4 ± 1.3	1.0 ± 0.0
258956 [x]	185.3 ± 2.2	226.7 ± 8.1	77.9 ± 7.4	234.6 ± 52.5	0.0 ± 0.0
264320 [x]	186.0 ± 3.7	229.0 ± 0.0	90.4 ± 4.2	305.2 ± 25.9	0.3 ± 0.2
288909 [x]	185.3 ± 5.3	211.0 ± 5.3	48.0 ± 2.2	39.6 ± 7.1	0.0 ± 0.0
289689 [x]	176.4 ± 0.8	254.3 ± 86.7	46.2 ± 5.0	41.2 ± 12.1	0.0 ± 0.0
343049 [x]	185.1 ± 5.8	219.7 ± 4.1	48.2 ± 4.7	37.2 ± 10.7	0.0 ± 0.1
546140 [x]	176.5 ± 1.1	203.5 ± 4.3	51.0 ± 4.1	63.1 ± 17.3	0.0 ± 0.0
546188 [x]	193.0 ± 7.8	234.3 ± 3.5	81.5 ± 2.8	285.5 ± 30.9	0.0 ± 0.0
546192 [x]	194.1 ± 5.5	238.8 ± 6.7	95.0 ± 8.6	369.9 ± 60.5	0.2 ± 0.2
639911 [x]	189.3 ± 2.0	232.5 ± 2.4	59.8 ± 3.9	109.5 ± 10.2	0.6 ± 0.1
B2133C [x]	198.2 ± 5.8	240.0 ± 11.5	53.9 ± 5.9	80.5 ± 31.3	0.0 ± 0.0
B5336C [x]	194.5 ± 0.0	243.0 ± 0.0	90.3 ± 0.0	311.5 ± 0.0	0.0 ± 0.0
B5351C [x]	199.4 ± 12.8	239.5 ± 12.1	61.2 ± 8.3	114.1 ± 42.1	0.0 ± 0.0
E203 [x]	177.3 ± 2.5	216.0 ± 3.7	40.9 ± 11.4	40.5 ± 30.2	0.0 ± 0.0
E205 [x]	182.0 ± 5.5	225.5 ± 4.0	62.9 ± 9.5	122.5 ± 49.5	0.0 ± 0.0
E206 [x]	177.5 ± 2.1	216.8 ± 3.8	59.5 ± 16.3	111.6 ± 61.1	0.0 ± 0.0
E207 [x]	184.1 ± 7.7	218.5 ± 5.2	50.2 ± 13.2	67.6 ± 38.8	0.0 ± 0.0
GCA-SYN [x]	197.3 ± 10.0	234.0 ± 12.8	52.8 ± 7.4	81.1 ± 43.1	0.0 ± 0.0
x mean	***188.1 ± 7.4***	***224.0 ± 6.7***	***55.5 ± 7.3***	***106.3 ± 27.6***	***0.2 ± 0.1***
NUN7606ON [y]	196.7 ± 4.8	241.5 ± 6.4	93.6 ± 3.7	303.2 ± 46.7	0.0 ± 0.0
OLYS03-207 [y]	190.6 ± 1.4	239.5 ± 4.0	86.7 ± 4.5	364.8 ± 41.0	0.0 ± 0.0
OLYS03-209 [y]	192.7 ± 5.5	239.5 ± 7.0	89.5 ± 5.6	341.6 ± 54.1	0.0 ± 0.0
OLYS05N5 [y]	199.1 ± 9.4	238.5 ± 16.7	90.8 ± 7.2	365.0 ± 37.1	0.0 ± 0.0
OLYX06-25 [y]	189.1 ± 1.7	234.3 ± 2.9	93.0 ± 6.1	364.0± 27.6	0.0 ± 0.0
y mean	***193.6 ± 4.6***	***238.7 ± 7.4***	***90.7 ± 5.4***	***347.7 ± 41.3***	***0.0 ± 0.0***
Colorado 6 [z]	196.2 ± 9.0	246.5 ± 4.0	94.5 ± 2.5	395.2 ± 31.8	0.0 ± 0.0

Cometa^{z}	193.2 ± 5.2	243.0 ± 0.0	99.0 ± 2.9	419.3 ± 40.6	0.0 ± 0.0
Mesquite^{z}	192.9 ± 1.6	242.3 ± 1.5	90.1 ± 5.3	324.5 ± 40.2	0.1 ± 0.2
Rumba^{z}	187.4 ± 6.8	228.1 ± 1.8	61.8 ± 6.4	115.7 ± 31	0.0 ± 0.0
Salsa Red^{z}	200.7 ± 7.2	240.5 ± 11	60.5 ± 11.6	109.1 ± 50.5	0.2 ± 0.2
T-433^{z}	187.9 ± 3.7	234.3 ± 3.5	94.0 ± 7.1	387.8 ± 55.8	0.0 ± 0.1
Vantage^{z}	193.4 ± 4.2	231.3 ± 3.3	64.0 ± 4.2	130.8 ± 9.2	0.0 ± 0.0
z mean	***193.1 ± 5.4***	***238.0 ± 3.6***	***80.6 ± 5.7***	***268.9 ± 37.0***	***0.1 ± 0.1***
Grand mean	**191.6 ± 5.8**	**233.6 ± 5.9**	**75.6 ± 6.2**	**241.0 ± 35.3**	**0.1 ± 0.1**
Tukey's (0.05)	60.0	42.5	28.8	121.2	0.6

^{x}PI lines.

^{y}Advanced breeding line.

^{z}Commercial cultivar.

APPENDIX II.B

This appendix contains tables of genotypes that were selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*). The individual tables are a summary of the various parameter evaluated in this study. It is intended as a quick reference to how the selected genotypes performed. Appendix II.A should be consulted for detailed information on all evaluated genotypes.

Appendix II.B.1a. *Iris yellow spot virus* (IYSV) infection and onion thrips (*Thrips tabaci*) infestation of onion genotypes selected for their resistance/tolerance to IYSV and/or onion thrips during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2009.

Genotype	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]	**Thrips-avg** (thrips/plant) (mean ± SE)[d]	**Thrips-day** (thrips/plant/day) (mean ± SE)
172701[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.2 ± 2.6	0.6 ± 0.2
172702[x]	189.2 ± 220.4	0.2 ± 0.1	4.4 ± 4.5	12.2 ± 0.6	1.4 ± 0.1
172703[x]	73.2 ± 103.5	0.1 ± 0.1	1.8 ± 2.5	11.4 ± 0.8	1.3 ± 0.1
179627[x]	57.0 ± 80.5	0.1 ± 0.1	1.4 ± 2.0	9.3 ± 0.1	1.0 ± 0.0
258956[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	15.1 ± 4.5	1.6 ± 0.4
264320[x]	44.6 ± 63.0	0.1 ± 0.1	1.1 ± 1.6	13.5 ± 2.4	1.5 ± 0.2
288270[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.9 ± 3.3	1.0 ± 0.4
288909[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.6 ± 0.7	1.0 ± 0.1
289689[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.4	0.3 ± 0.1
343049[x]	95.5 ± 135.0	0.2 ± 0.3	2.3 ± 3.2	10.3 ± 1.3	1.1 ± 0.1
546140[x]	68.4 ± 96.7	0.1 ± 0.1	1.7 ± 2.3	7.7 ± 0.6	0.9 ± 0.1
546188[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	10.0 ± 1.2	1.1 ± 0.1
546192[x]	143.8 ± 203.3	0.2 ± 0.2	3.2 ± 4.5	12.6 ± 0.3	1.4 ± 0.1
639911[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	17.7 ± 4.5	1.9 ± 0.4
239633-1[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.7 ± 0.0	0.6 ± 0.0
239633-2[x]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.5 ± 5.0	1.3 ± 0.6
182138[w]	370.0 ± 198.0	0.3 ± 0.0	8.4 ± 4.7	19.2 ± 3.3	2.1 ± 0.4
OLYS05N5[y]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	11.1 ± 2.3	1.2 ± 0.3
Colorado 6[z]	20.6 ± 29.1	0.1 ± 0.1	0.8 ± 1.1	15.3 ± 1.1	1.7 ± 0.1
Cometa[z]	18.4 ± 26.0	0.1 ± 0.1	0.7 ± 0.9	15.7 ± 6.4	1.7 ± 0.7
Salsa Red[z]	376 .0± 181.0	0.3 ± 0.1	9.0 ± 4.2	17.2 ± 2.3	1.9 ± 0.2
Tukey's (0.05)	543.9	0.502	12.9	19.2	2.1

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[d]Seasonal average of onion thrips population.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Appendix II.B.1b. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2009.

Genotype	**Leaf-avg** (leaves/plant) (mean ± SE)[a]	**Leaf Color** (mean ±SE)[b]	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)
172701[x]	7.4 ± 1.1	60.1 ± 0.0	95.1 ± 7.4	130.0 ± 0.0	33.8 ± 10.1
172702[x]	8.0 ± 1.0	68.8 ± 0.1	98.2 ± 1.3	137.0 ± 0.0	50.5 ± 8.6
172703[x]	9.0 ± 0.8	62.8 ± 3.6	98.0 ± 8.0	136.0 ± 0.0	46.9 ± 5.6
179627[x]	10.4 ± 0.1	65.4 ± 1.1	91.8 ± 4.4	137.0 ± 0.0	39.1 ± 3.7
258956[x]	10.2 ± 0.1	62.2 ± 0.0	86.0 ± 0.0	143.0 ± 0.0	97.1 ± 1.6
264320[x]	10.6 ± 0.0	62.6 ± 0.0	87.9 ± 2.7	143.0 ± 0.0	79.4 ± 6.6
288270[x]	7.3 ± 1.3	68.0 ± 0.0	103.9 ± 4.7	143.0 ± 0.0	48.7 ± 7.6
288909[x]	9.3 ± 0.1	62.6 ± 0.0	89.9 ± 0.1	130.0 ± 0.0	76.3 ± 4.9
289689[x]	6.7 ± 0.5	72.1 ± 0.0	87.3 ± 0.7	122.0 ± 0.0	54.3 ± 4.5
343049[x]	9.1 ± 0.7	60.5 ± 0.0	88.1 ± 3.0	122.0 ± 0.0	67.0 ± 9.0
546140[x]	8.3 ± 0.3	61.5 ± 6.9	88.4 ± 0.7	122.0 ± 0.0	63.8 ± 2.1
546188[x]	10.5 ± 0.4	59.8 ± 0.0	86.5 ± 0.8	144.0 ± 0.0	105.1 ± 5.8
546192[x]	10.2 ± 1.3	65.3 ± 0.0	89.4 ± 3.1	144.0 ± 0.0	103.0 ± 11.0
639911[x]	6.8 ± 0.4	70.7 ± 0.0	109.5 ± 0.0	143.0 ± 0.0	54.6 ± 3.5
239633-1[x]	5.3 ± 0.0	76.1 ± 0.0	113.0 ± 0.0	137.0 ± 0.0	44.4 ± 0.0
239633-2[x]	11.2 ± 0.8	64.8 ± 0.9	106.1 ± 3.1	143.0 ± 0.0	42.9 ± 0.0
182138[w]	8.6 ± 1.5	62.7 ± 3.0	107.8 ± 3.4	137.0 ± 0.0	39.5 ± 1.9
OLYS05N5[y]	8.3 ± 1.2	70.9 ± 0.7	96.3 ± 4.2	137.0 ± 0.0	88 ± 15.4
Colorado 6[z]	9.9 ± 0.6	68.4 ± 0.6	93.2 ± 3.3	143.0 ± 0.0	101.1 ± 0.8
Cometa[z]	10.0 ± 0.6	67.9 ± 0.5	95.0 ± 7.8	137.0 ± 0.0	98.4 ± 13.4
Salsa Red[z]	10.1 ± 0.4	63.5 ± 0.0	88.6 ± 2.9	136.0 ± 0.0	76.9 ± 3.7
Tukey's (0.05)	3.4	6.6	61.3	0.0	29.6

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) taken with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan).

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Appendix II.B.2a. *Iris yellow spot virus* (IYSV) infection and onion thrips (*Thrips tabaci*) infestation of onion genotypes selected for their resistance/tolerance to IYSV and/or onion thrips during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2010.

Genotype	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]	**Severity** (117 DAP) (mean ± SE)	**Thrips-avg** (thrips/plant) (mean ± SE)[d]	**Thrips-day** (thrips/plant/day) (mean ± SE)
248753[x]	249.3 ± 0.0	0.200 ± 0.000	7.9 ± 0. 0	1.0 ± 0.0	0.7 ± 0.2	0.1 ± 0.0
248754[x]	303.8 ± 29.0	0.100± 0.000	11.4 ± 1.6	2.0 ± 1.4	9.7 ± 2.2	1.0 ± 0.2
258956[x]	1129.5 ± 29.0	0.100 ± 0.000	40.9 ± 2.9	3.0 ± 0.0	31.0 ± 1.4	3.1 ± 0.1
264320[x]	1231.5 ± 278.7	0.150 ± 0.071	42.7 ± 10.3	4.0 ± 0.0	54.6 ± 6.9	5.5 ± 0.7
271039[x]	668.4 ± 497.3	0.200 ± 0.141	23.0 ± 19.4	1.5 ± 0.7	9.1 ± 0.3	0.9 ± 0.0
274780[x]	450.4 ± 169.2	0.200 ± 0.141	14.7 ± 2.9	2.0± 0.0	10.9 ± 0.6	1.1 ± 0.1
288073[x]	1098.3 ± 510.2	0.200 ± 0.000	37.0 ± 14.6	2.0 ± 0.0	38.7 ± 24.6	3.9 ± 2.5
288272[x]	371.7 ± 126.5	0.2 00± 0.000	11.5 ± 3.7	1.0 ± 0.0	3.4 ± 0.2	0.3 ± 0.0
546096[x]	1961.6 ± 118.9	0.250 ± 0.071	66.1 ± 6.2	2.0 ± 0.0	77.8 ± 4.9	7.8 ± 0.5
546100[x]	591.7 ± 249.0	0.150 ± 0.071	20.3 ± 5.0	3.0 ± 0.0	41.0 ± 7.6	4.1 ± 0.8
546101[x]	829.2 ± 389.3	0.200 ± 0.000	27.2 ± 13.0	3.0 ± 0.0	53.6 ± 4.0	5.4 ± 0.4
546106[x]	814.5 ± 368.5	0.200 ± 0.000	25.7 ± 10.8	2.0 ± 0.0	57.4 ± 5.1	5.7 ± 0.5
546140[x]	956.7 ± 583.8	0.200 ± 0.000	32.1 ± 20.1	2.0 ± 0.0	34.6 ± 1.1	3.5 ± 0.1
546188[x]	639.0 ± 333.6	0.150 ± 0.071	21.6 ± 9.9	3.5 ± 0.7	36.5 ± 9.4	3.7 ± 0.9
546192[x]	504 .0± 152.0	0.150 ± 0.071	18.5 ± 6.6	3.0 ± 1.4	41.5 ± 0.0	4.2 ± 0.0
182138[w]	1128.9 ± 227.9	0.200 ± 0.000	35.7 ± 6.1	3.5 ± 0.7	47.7 ± 11.5	4.8 ± 1.1
OLYO5N5[y]	440.8 ± 184.3	0.100 ± 0.000	17.6 ± 7.4	3.5 ± 0.7	50.8 ± 10.0	5.1 ± 1.0
Colorado 6[z]	441.4 ± 134.7	0.100 ± 0.000	17.7 ± 3.3	3.5 ± 0.7	31.3 ± 4.4	3.1 ± 0.4
Salsa Red[z]	764.7 ± 287.3	0.150 ± 0.071	28.2 ± 7.2	3.0 ± 0.0	71.1 ± 26.4	7.1 ± 2.6
Vantage[z]	943.0 ± 118.2	0.150 ± 0.071	34.2 ± 7.1	4.0 ± 0.0	75.4 ± 1.4	7.5 ± 0.1
Tukey's (0.05)	1205	0.263	42.4	2.2	37.8	3.8

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[d]Seasonal average of onion thrips population.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Appendix II.B.2b. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2010.

Genotype	**Leaf-avg** (leaves/plant) (mean ± SE)[a]	**Early Leaf Color** (mean ±SE)[b]	**Late Leaf Color** (mean ±SE)[b]	**Split/Bunch** (%) (mean ± SE)	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)	**Weight Bulb** (g/bulb) (mean ± SE)
248753[x]	3.5 ± 0.0	54.8 ± 3.5	54.3 ± 2.4	25.0 ± 7.1	84.0 ± 0.0	123.5 ± 2.2	28.0 ± 2.3	13.6 ± 4.2
248754[x]	5.0 ± 0.6	56.1 ± 1.9	51.8 ± 5.8	50.0 ± 0.0	84.0 ± 0.0	125.8 ± 1.1	40.7 ± 5.6	40.2 ± 4.4
258956[x]	10.9 ± 2.7	58.6 ± 1.8	53.9 ± 1.0	0.0 ± 0.0	84.0 ± 0.0	142.0 ± 0.0	100.8 ± 2.4	390.6 ± 2.6
264320[x]	9.1 ± 0.5	59.8 ± 0.2	57.9 ± 1.2	5.0 ± 7.1	85.4 ± 1.0	142.0 ± 0.0	113.6 ± 3.6	394.8 ± 12.6
271039[x]	5.3 ± 0.6	58.1 ± 0.1	57.5 ± 4.4	11.1 ± 15.7	85.4 ± 2.0	120.8 ± 0.8	43.3 ± 6.2	41.0 ± 14.0
274780[x]	5.4 ± 1.1	55.8 ± 1.0	53.6 ± 0.3	30.0 ± 0.0	84.0 ± 0.0	118.1 ± 3.7	43.0 ± 2.2	38.9 ± 2.2
288073[x]	6.2 ± 0.1	55.2 ± 0.6	57.7 ± 2.0	26.1 ± 5.5	95.6 ± 4.5	142.0 ± 0.0	44.5 ± 0.6	19.1 ± 4.5
288272[x]	3.3 ± 0.6	59.2 ± 3.6	57.3 ± 1.9	8.3 ± 11.8	86.3 ± 0.7	117.6 ± 4.4	31.4 ± 0.8	18.2 ± 2.2
546096[x]	8.4 ± 0.3	60.2 ± 1.4	58.1 ± 1.5	0.0 ± 0.0	85.1 ± 0.5	125.1 ± 1.9	59.8 ± 0.7	118.1 ± 5.1
546100[x]	9.2 ± 0.4	62.4 ± 0.7	60.2 ± 0.5	0.0 ± 0.0	84.0 ± 0.0	142.0 ± 0.0	111.3 ± 2.6	510.0 ± 2.2
546101[x]	9.8 ± 0.1	60.5 ± 0.8	60.6 ± 2.3	20.0 ± 0.0	84.0 ± 0.0	138.7 ± 1.6	91.1 ± 1.3	322.1 ± 22
546106[x]	8.5 ± 0.2	60.7 ± 1.9	60.8 ± 3.2	10.0 ± 0.0	84.0 ± 0.0	123.9 ± 0.0	65.0 ± 0.1	138.7 ± 0.8
546140[x]	6.7 ± 0.6	60.3 ± 1.9	65.8 ± 1.4	0.0 ± 0.0	84.0 ± 0.0	119.1 ± 1.2	70.2 ± 3.8	173.3 ± 26.2
546188[x]	8.8 ± 0.5	59.7 ± 0.6	60.6 ± 0.8	0.0 ± 0.0	84.4 ± 0.5	142.0 ± 0.0	106.4 ± 11	491.2 ± 3.2
546192[x]	9.6 ± 0.2	61.5 ± 0.2	63.5 ± 2.5	0.0 ± 0.0	84.0 ± 0.0	142.0 ± 0.0	106.2 ± 1.1	765.8 ± 301.9
182138[w]	8.0 ± 0.2	57.4 ± 0.6	56.8 ± 2.5	50.0 ± 14.1	87.2 ± 4.5	134.3 ± 4.7	52.4 ± 3.7	72.3 ± 4.7
OLYO5N5[y]	9.5 ± 0.2	56.9 ± 0.8	58.8 ± 1.7	0.0 ± 0.0	85.1 ± 1.5	142.0 ± 0.0	100.9 ± 1.5	526.6 ± 10.8
Colorado 6[z]	10.1 ± 0.1	60.1 ± 0.0	57.2 ± 2.9	0.0 ± 0.0	85.4 ± 2.0	142.0 ± 0.0	111.2 ± 0.3	683.8 ± 86.7
Salsa Red[z]	9.2 ± 0.4	60.9 ± 0.4	55.6 ± 0.1	0.0 ± 0.0	85.1 ± 1.5	139.7 ± 0.9	92.3 ± 11.7	278.6 ± 8.1
Vantage	10.2 ± 0.2	61.9 ± 0.7	60.2 ± 0.4	0.0 ± 0.0	84.4 ± 0.5	135.9 ± 0.6	101.2 ± 5.1	452.4 ± 74.3
Tukey's (0.05)	3.0	6.2	8.2	45.8	6.0	14.3	19.8	188.6

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) measured with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan). Early leaf color was measured in the greenhouse at 79 DAS while late leaf color was measured in the field at 84 DAP.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Appendix II.B.3a. *Iris yellow spot virus* (IYSV) infection and onion thrips (*Thrips tabaci*) infestation of onion genotypes selected for their resistance/tolerance to IYSV and/or onion thrips during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2011.

Genotype	**AUDPC-in** (mean ± SE)[a]	**rAUDPC-in** (mean ± SE)[b]	**IYSV-avg** (%) (mean ± SE)[c]	**AUDPC-sv** (mean ± SE)[d]	**rAUDPC-sv** (mean ± SE)[e]	**Average Severity** (mean ± SE)	**Thrips-avg** (thrips/plant) (mean ± SE)[f]	**Thrips-day** (mean ± SE)[g]
620[x]	2190.5 ± 202.4	0.163 ± 0.015	78.0 ± 6.9	60.4 ± 8.0	0.144 ± 0.01	2.2 ± 0.3	15.4 ± 7.6	2.0 ± 1.0
621[x]	2461.1 ± 165.6	0.184 ± 0.012	87.8 ± 8.5	66.4 ± 14.0	0.141 ± 0.008	2.4 ± 0.5	15.6 ± 2.1	2.0 ± 0.3
634[x]	2520.2 ± 30.0	0.188 ± 0.002	90.8 ± 1.5	66.0 ± 7.8	0.123 ± 0.015	2.4 ± 0.2	18.2 ± 4.9	2.4 ± 0.6
648[x]	2440.0 ± 0.0	0.182 ± 0.000	86.7 ± 0.0	61.5 ± 0.0	0.115 ± 0.000	2.3 ± 0.0	20.4 ± 6.9	2.7 ± 0.9
656[x]	2295.3 ± 469.6	0.171 ± 0.035	82.8 ± 17.3	73.3 ± 8.4	0.137 ± 0.016	2.7 ± 0.3	15.7 ± 10.5	2.0 ± 1.4
753[x]	2344.7 ± 88.7	0.175 ± 0.007	81.8 ± 4.6	72.3 ± 7	0.163 ± 0.024	2.7 ± 0.2	9.8 ± 0.5	1.3 ± 0.1
769[x]	2238.8 ± 284.6	0.167 ± 0.021	80.8 ± 8.2	71.5 ± 4.9	0.133 ± 0.009	2.7 ± 0.0	14.7 ± 2.1	1.9 ± 0.3
258956[x]	2303.5 ± 139.9	0.172 ± 0.010	79.7 ± 7.2	70.5 ± 7.8	0.132 ± 0.015	2.6 ± 0.2	15.7 ± 5.4	2.1 ± 0.7
546188[x]	2405.0 ± 179.5	0.179 ± 0.013	86.7 ± 6.3	75.8 ± 4.2	0.146 ± 0.007	2.7 ± 0.2	21.1 ± 6.0	2.8 ± 0.8
B5336C[x]	2482.3 ± 307.9	0.185 ± 0.023	88.8 ± 15.8	61.5 ± 0.0	0.115 ± 0.000	2.3 ± 0.0	12.1 ± 1.1	1.6 ± 0.1
696[w]	2180.0 ± 0.0	0.163 ± 0.000	73.3 ± 0.0	27 ± 0.0	0.201 ± 0.000	1.0 ± 0.0	2.2 ± 2.1	0.3 ± 0.3
OLYS05N5[y]	2259.3 ± 276.5	0.169 ± 0.021	80.0 ± 9.0	68.3 ± 7.8	0.127 ± 0.015	2.5 ± 0.2	15 ± 8.5	2.0 ± 1.1
Colorado 6[z]	2346.0 ± 121.3	0.175 ± 0.009	82.8 ± 5.6	69.8 ± 8.4	0.130 ± 0.016	2.7 ± 0.3	19.7 ± 11.3	2.6 ± 1.5
Cometa[z]	2435.4 ± 70.8	0.182 ± 0.005	87.4 ± 3.7	73.1 ± 6.5	0.136 ± 0.012	2.8 ± 0.2	23.6 ± 1.7	3.1 ± 0.2
Salsa Red[z]	2423.8 ± 85.0	0.181 ± 0.006	85.8 ± 4.4	69.0 ± 11.1	0.133 ± 0.017	2.5 ± 0.4	24.8 ± 12.3	3.2 ± 1.6
Tukey's (0.05)	840.8	0.063	30.3	37.6	0.067	1.3	19.5	2.5

[a]Area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV incidence.

[c]Seasonal average of IYSV incidence.

[d]Area under the disease progress curve for IYSV severity.

[e]Relative area under the disease progress curve for IYSV severity.

[f]Seasonal average of onion thrips population.

[g]Thrips/plant/day.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

Appendix II.B.3b. Phenology, agronomic characteristics and yield of onion genotypes selected for their resistance/tolerance to *Iris yellow spot virus* (IYSV) and onion thrips (*Thrips tabaci*) during an onion germplasm evaluation in northern Colorado, near Fort Collins, in 2011.

Genotype	**Leaf-avg** (leaves/plant) (mean ± SE)[a]	**Early Leaf Color** (mean ±SE)[b]	**Late Leaf Color** (mean ±SE)[b]	**Split/Bunch** (%) (mean ± SE)	**Bulbing** (DAP) (mean ± SE)	**Maturity** (DAP) (mean ± SE)	**Bulb Size** (mm/bulb) (mean ± SE)	**Weight Bulb** (g/bulb) (mean ± SE)
620[x]	5.8 ± 0.6	56.2 ± 3.3	65.2 ± 1.2	0.0 ± 0.0	186.2 ± 2.3	219.7 ± 0.8	65.0 ± 6.2	108.4 ± 31.8
621[x]	8.0 ± 0.5	54.4 ± 12.3	64.7 ± 0.8	0.5 ± 0.2	187.7 ± 4.3	231.0 ± 2.8	63.7 ± 12.4	85.4 ± 43.8
634[x]	8.6 ± 0.8	48.1 ± 3.8	59.2 ± 1.6	0.2 ± 0.4	190.9 ± 0.1	236.0 ± 0.0	77.8 ± 3.2	222.4 ± 28.7
648[x]	8.9 ± 0.4	51.2 ± 4.8	63.0 ± 5.9	0.2 ± 0.2	190.4 ± 5.9	236.0 ± 0.0	78.7 ± 3.3	220.1 ± 31.5
656[x]	8.5 ± 2.2	46.8 ± 10.6	62.2 ± 1.7	0.0 ± 0.0	189.2 ± 10.2	225.4 ± 4.1	70.4 ± 8.6	178.4 ± 60.8
753[x]	6.3 ± 0.4	51.1 ± 3.7	50.9 ± 0.0	0.0 ± 0.0	182.5 ± 1.9	218.3 ± 4.0	62.3 ± 5.1	74.4 ± 15.6
769[x]	7.2 ± 1.0	50.2 ± 4.2	65.7 ± 4.8	0.0 ± 0.0	192.7 ± 7.6	236.0 ± 0.0	74.3 ± 3.5	251.9 ± 45.1
258956[x]	8.5 ± 1.5	49.1 ± 3.8	60.7 ± 3.1	0.0 ± 0.0	185.3 ± 2.2	226.7 ± 8.1	77.9 ± 7.4	234.6 ± 52.5
546188[x]	9.5 ± 1.3	48.3 ± 2.5	61.7 ± 3.0	0.0 ± 0.0	193.0 ± 7.8	234.3 ± 3.5	81.5 ± 2.8	285.5 ± 30.9
B5336C[x]	9.1 ± 1.2	47.8 ± 2.8	64.4 ± 0.0	0.0 ± 0.0	194.5 ± 0.0	243.0 ± 0.0	90.3 ± 0.0	311.5 ± 0.0
696[w]	4.1 ± 0.8	64.0 ±3.8	N/A	0.0 ± 0.0	174.6±2.8	199.5 ± 1.8	30.6 ± 4.9	19.7 ± 5.8
OLYS05N5[y]	8.4 ± 1.5	48.8 ± 3.3	64.5 ± 2.4	0.0 ± 0.0	199.1 ± 9.4	238.5 ± 16.7	90.8 ± 7.2	365.0 ± 37.1
Colorado 6[z]	10.1 ± 3.7	49.2 ± 3.7	69.3 ± 5.6	0.0 ± 0.0	196.2 ± 9.0	246.5 ± 4.0	94.5 ± 2.5	395.2 ± 31.8
Cometa[z]	9.6 ± 0.4	50.0 ± 2.9	71.9 ± 2.2	0.0 ± 0.0	193.2 ± 5.2	243.0 ± 0.0	99.0 ± 2.9	419.3 ± 40.6
Salsa Red[z]	7.4 ± 1.6	45.9 ± 5.2	64.1 ± 0.7	0.2 ± 0.2	200.7 ± 7.2	240.5 ± 11.0	60.5 ± 11.6	109.1 ± 50.5
Tukey's (0.05)	3.9	-	-	0.6	60.0	42.5	28.8	121.2

[a]Seasonal average of number of leaves/plant.

[b]Chlorophyll concentration index (CCI) measured with SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd. Japan). Early leaf color was measured in the greenhouse at 79 DAS whilst late leaf color was measured in the field at 84 DAP.

[w]A susceptible PI check.

[x]Selected PI lines.

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

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

N/A indicates there was no suitable candidate leaf for measurement. This happended if leaves were too thick to fit in the chlorophyll meter.

APPENDIX II.C

The CORR procedure in SAS (SAS v 9.3, SAS Institute Inc., NC, USA) was used to produce Pearson's correlation coefficients presented in the tables of this appendix. Parameter notations and meanings are the same as used in the main text.

Appendix II.C.1. Pearson's correlation coefficients for *Iris yellow spot virus* (IYS) and onion thrips (*Thrips tabaci*) responses in transplanted onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2009.

	Leaf-avg	Thrips-day	rAUDPC-in[a]	Bulbing	Maturity	Bulb size	S_B	Leaf color
Leaf-avg	1	0.3815	0.0734	-0.3631	0.2059	0.3497	0.1138	-0.3645
		0.0003	0.5045	0.0006	0.0588	0.0010	0.2996	0.0007
Thrips-day	0.3815	1	0.1364	0.2150	0.3731	0.1984	-0.0594	-0.0977
	0.0003		0.2133	0.0482	0.0004	0.0687	0.5892	0.3796
rAUDPC-in[a]	0.0734	0.1364	1	-0.1314	0.0461	0.0470	-0.1318	-0.0429
	0.5045	0.2133		0.2306	0.6753	0.6692	0.2293	0.7000
Bulbing	-0.3631	0.2150	-0.1314	1	0.2174	-0.3272	0.1979	0.2703
	0.0006	0.0482	0.2306		0.0456	0.0022	0.0695	0.0134
Maturity	0.2059	0.3731	0.0461	0.2174	1	0.0922	0.5569	0.1073
	0.0588	0.0004	0.6753	0.0456		0.4014	<.0001	0.3342
Bulb size	0.3497	0.1984	0.0470	-0.3272	0.0922	1	-0.4279	0.1292
	0.0010	0.0687	0.6692	0.0022	0.4014		<.0001	0.2445
S_B	0.1138	-0.0594	-0.1318	0.1979	0.5569	-0.4279	1	0.0583
	0.2996	0.5892	0.2293	0.0695	<.0001	<.0001		0.6004
Leaf color	-0.3645	-0.0977	-0.0429	0.2703	0.1073	0.1292	0.0583	1
	0.0007	0.3796	0.7000	0.0134	0.3342	0.2445	0.6004	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[a]Relative area under the disease progress curve for IYSV incidence.

Appendix II.C.2. Pearson's correlation coefficients for *Iris yellow spot virus* (IYS) and onion thrips (*Thrips tabaci*) responses in direct-seeded onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2009.

	Leaf-avg	Thrips-day	rAUDPC-in[a]	Bulbing	Bulb size	Leaf color
Leaf-avg	1	0.4240	-0.0382	-0.3860	0.3528	0.0057
		0.0017	0.7878	0.0047	0.0103	0.9678
Thrips-day	0.4240	1	0.0500	0.2173	-0.0301	-0.0892
	0.0017		0.7251	0.1218	0.8321	0.5293
rAUDPC-in[a]	-0.0382	0.0500	1	0.2998	-0.0295	0.0296
	0.7878	0.7251		0.0308	0.8356	0.8348
Bulbing	-0.3860	0.2173	0.2998	1	-0.6229	-0.1927
	0.0047	0.1218	0.0308		<.0001	0.1712
Bulb size	0.3528	-0.0301	-0.0295	-0.6229	1	0.2110
	0.0103	0.8321	0.8356	<.0001		0.1332
Leaf color	0.0057	-0.0892	0.0296	-0.1927	0.2110	1
	0.9678	0.5293	0.8348	0.1712	0.1332	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[a]Relative area under the disease progress curve for IYSV incidence.

Appendix II.C.3. Pearson's correlation coefficients for *Iris yellow spot virus* (IYS) and onion thrips (*Thrips tabaci*) responses in transplanted onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2010.

	Leaf-avg	Thrips-day	rAUDPC-in[a]	Severity	Bulbing	Maturity	Bulb size	Bulb weight	S_B	Leaf color
Leaf-avg	1	0.6865	-0.2687	0.7074	-0.1614	0.6489	0.7634	0.6258	-0.1023	0.3558
		<.0001	0.0347	<.0001	0.2102	<.0001	<.0001	<.0001	0.4291	0.0045
Thrips-day	0.6865	1	0.0988	0.3519	0.1831	0.4745	0.4946	0.3300	-0.2430	0.3147
	<.0001		0.4449	0.0050	0.1543	<.0001	<.0001	0.0088	0.0570	0.0127
rAUDPC-in[a]	-0.2687	0.0988	1	-0.3499	0.3171	-0.4692	-0.3828	-0.4206	0.1227	0.0285
	0.0347	0.4449		0.0053	0.0120	0.0001	0.0021	0.0007	0.3422	0.8260
Severity	0.7074	0.3519	-0.3499	1	-0.1776	0.6244	0.5963	0.4882	0.0539	0.0174
	<.0001	0.0050	0.0053		0.1673	<.0001	<.0001	<.0001	0.6774	0.8930
Bulb	-0.1614	0.1831	0.3171	-0.1776	1	0.1292	-0.2431	-0.2338	0.1046	-0.1221
	0.2102	0.1543	0.0120	0.1673		0.3170	0.0570	0.0674	0.4186	0.3446
Maturity	0.6489	0.4745	-0.4692	0.6244	0.1292	1	0.6781	0.5977	-0.1820	0.1071
	<.0001	<.0001	0.0001	<.0001	0.3170		<.0001	<.0001	0.1570	0.4073
Bulb size	0.7634	0.4946	-0.3828	0.5963	-0.2431	0.6781	1	0.9125	-0.4693	0.3692
	<.0001	<.0001	0.0021	<.0001	0.0570	<.0001		<.0001	0.0001	0.0031
Bulb weight	0.6258	0.3300	-0.4206	0.4882	-0.2338	0.5977	0.9125	1	-0.5141	0.3612
	<.0001	0.0088	0.0007	<.0001	0.0674	<.0001	<.0001		<.0001	0.0039
S_B	-0.1023	-0.2430	0.1227	0.0539	0.1046	-0.1820	-0.4693	-0.5141	1	-0.2165
	0.4291	0.0570	0.3422	0.6774	0.4186	0.1570	0.0001	<.0001		0.0909
Leaf color	0.3558	0.3147	0.0285	0.0174	-0.1221	0.1071	0.3692	0.3612	-0.2165	1
	0.0045	0.0127	0.8260	0.8930	0.3446	0.4073	0.0031	0.0039	0.0909	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[a]Relative area under the disease progress curve for IYSV incidence.

Appendix II.C.4. Pearson's correlation coefficients for *Iris yellow spot virus* (IYS) and onion thrips (*Thrips tabaci*) responses in direct-seeded onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2010.

	Leaf-avg	Thrips-day	rAUDPC-in[a]	rAUDPC-sv[b]	Bulbing	Bulb size	Bulb weight	Leaf color
Leaf-avg	1	-0.2763	-0.1968	-0.3355	-0.2939	0.6609	0.4015	-0.1239
		0.0765	0.2116	0.0298	0.0589	<.0001	0.0084	0.4345
Thrips-day	-0.2763	1	0.4211	0.2355	-0.0707	-0.4916	-0.3722	0.2505
	0.0765		0.0055	0.1333	0.6566	0.0009	0.0152	0.1096
rAUDPC-in[a]	-0.1968	0.4211	1	0.2289	-0.0178	-0.4637	-0.3483	0.0269
	0.2116	0.0055		0.1448	0.9109	0.0020	0.0238	0.8659
rAUDPC-sv[b]	-0.3355	0.2355	0.2289	1	-0.0028	-0.3881	-0.2584	-0.0677
	0.0298	0.1333	0.1448		0.9860	0.0111	0.0984	0.6703
Bulbing	-0.2939	-0.0707	-0.0178	-0.0028	1	-0.0706	-0.1169	-0.1992
	0.0589	0.6566	0.9109	0.9860		0.6568	0.4611	0.2059
Bulb size	0.6609	-0.4916	-0.4637	-0.3881	-0.0706	1	0.7560	-0.1751
	<.0001	0.0009	0.0020	0.0111	0.6568		<.0001	0.2674
Bulb weight	0.4015	-0.3722	-0.3483	-0.2584	-0.1169	0.7560	1	-0.0128
	0.0084	0.0152	0.0238	0.0984	0.4611	<.0001		0.9360
Leaf color	-0.1239	0.2505	0.0269	-0.0677	-0.1992	-0.1751	-0.0128	1
	0.4345	0.1096	0.8659	0.6703	0.2059	0.2674	0.9360	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[a]Relative area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV severity.

Appendix II.C.5. Pearson's correlation coefficients for *Iris yellow spot virus* (IYS) and onion thrips (*Thrips tabaci*) responses in transplanted onion germplasms evaluated for their resistance/tolerance to IYSV and/or onion thrips in northern Colorado, near Fort Collins, in 2011.

	Leaf-avg	Thrips-day	rAUDPC-in[a]	rAUDPC-sv[b]	Bulbing	Maturity	Bulb size	Bulb weight	S_B	Leaf color
Leaf-avg	1	0.8941	0.6581	0.1404	0.1413	0.5969	0.8155	0.7570	0.0891	0.1820
		<.0001	<.0001	0.2112	0.2054	<.0001	<.0001	<.0001	0.4259	0.1437
Thrips-day	0.8941	1	0.6642	0.2285	0.1378	0.5510	0.7953	0.7303	-0.0427	0.1103
	<.0001		<.0001	0.0402	0.2172	<.0001	<.0001	<.0001	0.7035	0.3781
rAUDPC-in[a]	0.6581	0.6642	1	0.3578	-0.0557	0.2920	0.5833	0.5599	-0.2228	0.2618
	<.0001	<.0001		0.0010	0.6211	0.0082	<.0001	<.0001	0.0456	0.0337
rAUDPC-sv[b]	0.1404	0.2285	0.3578	1	-0.1393	-0.1068	0.1429	0.1527	-0.2513	0.0744
	0.2112	0.0402	0.0010		0.2149	0.3425	0.2033	0.1736	0.0236	0.5526
Bulbing	0.1413	0.1378	-0.0557	-0.1393	1	0.4589	0.1419	0.1096	0.3899	-0.2795
	0.2054	0.2172	0.6211	0.2149		<.0001	0.2036	0.3268	0.0003	0.0230
Maturity	0.5969	0.5510	0.2920	-0.1068	0.4589	1	0.6586	0.5951	0.3161	-0.1730
	<.0001	<.0001	0.0082	0.3425	<.0001		<.0001	<.0001	0.0038	0.1647
Bulb size	0.8155	0.7953	0.5833	0.1429	0.1419	0.6586	1	0.9451	-0.1015	-0.0155
	<.0001	<.0001	<.0001	0.2033	0.2036	<.0001		<.0001	0.3642	0.9020
Bulb weight	0.7570	0.7303	0.5599	0.1527	0.1096	0.5951	0.9451	1	-0.2018	0.0351
	<.0001	<.0001	<.0001	0.1736	0.3268	<.0001	<.0001		0.0691	0.7799
S_B	0.0891	-0.0427	-0.2228	-0.2513	0.3899	0.3161	-0.1015	-0.2018	1	-0.1103
	0.4259	0.7035	0.0456	0.0236	0.0003	0.0038	0.3642	0.0691		0.3780
Leaf color	0.1820	0.1103	0.2618	0.0744	-0.2795	-0.1730	-0.0155	0.0351	-0.1103	1
	0.1437	0.3781	0.0337	0.5526	0.0230	0.1647	0.9020	0.7799	0.3780	

Pearson's correlation coefficients are given in the first row and the p-values of the correlations are given in the second row.

[a]Relative area under the disease progress curve for IYSV incidence.

[b]Relative area under the disease progress curve for IYSV severity.

APPENDIX II.D

A list of all the onion (*Allium cepa* L) germplasms evaluated for resistance/tolerance to *Iris yellow spot virus* (IYSV) and/or onion thrips (*Thrips tabaci*) in northern Colorado is given in this appendix. The seed companies, countries, onion breeders and other co-operators from whom the germplasms were obtained are indicated as well as bulb color information (where known). Also provided are the year(s) in which the specific germplasm was evaluated and whether it was transplanted or direct-seeded.

Germplasm	2009		2010		2011		Bulb Color	Source
	T	S	T	S	T	S*		
574	-	-	-	-	+	-	Yellow	M. Havey
575	-	-	-	-	+	-	Red	M. Havey
577	-	-	-	-	+	-	Red & White	M. Havey
578	-	-	-	-	+	-	Yellow	M. Havey
579	-	-	-	-	+	-	Red	M. Havey
580	-	-	-	-	+	-	Red	M. Havey
582	-	-	-	-	+	-	Yellow	M. Havey
583	-	-	-	-	+	-	Yellow	M. Havey
589	-	-	-	-	+	-	White	M. Havey
592	-	-	-	-	+	-	White	M. Havey
593	-	-	-	-	+	-	White & Yellow	M. Havey
594	-	-	-	-	+	-	Red & White	M. Havey
596	-	-	-	-	+	-	White	M. Havey
597	-	-	-	-	+	-	White	M. Havey
602	-	-	-	-	+	-	Yellow	M. Havey
607	-	-	-	-	+	-	Yellow	M. Havey
615	-	-	-	-	+	-	Yellow	M. Havey
618	-	-	-	-	+	-	Yellow	M. Havey
619	-	-	-	-	+	-	Yellow	M. Havey
620	-	-	-	-	+	-	White	M. Havey
621	-	-	-	-	+	-	White	M. Havey
622	-	-	-	-	+	-	White	M. Havey
624	-	-	-	-	+	-	White	M. Havey
628	-	-	-	-	+	-	White	M. Havey
629	-	-	-	-	+	-	White	M. Havey
632	-	-	-	-	+	-	Yellow	M. Havey
634	-	-	-	-	+	-	Yellow	M. Havey
643	-	-	-	-	+	-	Yellow	M. Havey
646	-	-	-	-	+	-	Yellow	M. Havey
648	-	-	-	-	+	-	Yellow	M. Havey
651	-	-	-	-	+	-	Yellow	M. Havey
654	-	-	-	-	+	-	Yellow	M. Havey
656	-	-	-	-	+	-	Yellow	M. Havey
658	-	-	-	-	+	-	Yellow	M. Havey
660	-	-	-	-	+	-	Yellow	M. Havey
696	-	-	-	-	+	-	Yellow	M. Havey
700	-	-	-	-	+	-	Yellow	M. Havey

702	-	-	-	-	+	-	Yellow	M. Havey
706	-	-	-	-	+	-	Yellow	M. Havey
708	-	-	-	-	+	-	Yellow	M. Havey
711	-	-	-	-	+	-	Yellow	M. Havey
712	-	-	-	-	+	-	Yellow	M. Havey
713	-	-	-	-	+	-	Yellow	M. Havey
718	-	-	-	-	+	-	Yellow	M. Havey
719	-	-	-	-	+	-	Yellow	M. Havey
753	-	-	-	-	+	-	White	M. Havey
759	-	-	-	-	+	-	White	M. Havey
765	-	-	-	-	+	-	Red	M. Havey
768	-	-	-	-	+	-	Yellow	M. Havey
769	-	-	-	-	+	-	Yellow	M. Havey
6001	-	-	-	+	-	-	Yellow	N.-Zwaan
6022	-	-	-	+	-	-	Yellow	N.-Zwaan
16535	-	-	-	+	-	-	Yellow	Seminis
18495	-	-	-	+	-	-	Yellow	Seminis
124525	+	-	+	-	-	-	Pink	India
142790	+	-	-	-	-	-	Pink	Iran
164361	+	-	-	-	-	-	Mix	USA
164807	+	-	+	-	-	-	Pink	India
165498	+	-	+	-	-	-	Mix	India
168962	+	-	+	-	-	-	Red	Turkey
168966	+	-	+	-	-	-	Yellow	Turkey
171475	+	-	+	-	-	-	Red	Turkey
171477	+	-	+	-	-	-	Pink	Turkey
172701	+	-	+	-	-	-	Mix	USA
172702	+	-	+	-	+	-	White	USA
172703	+	-	+	-	+	-	Pink	USA
172704	+	-	+	-	-	-	Pink	USA
174018	+	-	+	-	-	-	White	USA
174024	+	-	+	-	-	-	Yellow	USA
177242	+	-	+	-	-	-	Red	USA
179164	+	-	-	-	-	-	Pink	USA
179627	+	-	+	-	-	-	Red	USA
182138	+	-	+	-	-	-	Yellow	USA
183660	+	-	-	-	-	-	Yellow	Turkey
200874	+	-	+	-	-	-	Pink	Afghanistan
233186	+	-	+	-	-	-	Red	Russian Federation

239633	-	-	-	-	+	-	White	Iran
246140	+	-	-	-	-	-	Mix	Iran
248753	+	-	+	-	-	-	Mix	USA
248754	+	-	+	-	-	-	Red	USA
249899	+	-	+	-	-	-	Yellow	USA
251325	+	-	+	-	-	-	Yellow	USA
255557	+	-	+	-	-	-	Red	Slovenia
256048	+	-	-	-	-	-	Red	Afghanistan
256049	+	-	-	-	-	-	Red	Afghanistan
258956	+	-	+	-	+	-	Yellow	Chile
264320	+	-	+	-	+	-	Yellow	Spain
264321	+	-	-	-	-	-	White	Spain
264631	+	-	-	-	-	-	Yellow	Germany
264648	+	-	+	-	-	-	Yellow	Germany
269306	+	-	-	-	-	-	Yellow	Sweden
271039	+	-	+	-	-	-	Pink	India
273211	+	-	-	-	-	-	Yellow	Poland
274780	+	-	+	-	-	-	Pink	India
287540	+	-	-	-	-	-	Yellow	Israel
288073	+	-	+	-	-	-	Red	Netherlands
288270	+	-	+	-	-	-	Mix	India
288272	+	-	+	-	-	-	Pink	India
288902	+	-	+	-	-	-	Yellow	Hungary
288903	+	-	+	-	-	-	Yellow	Hungary
288908	+	-	+	-	-	-	Yellow	Hungary
288909	+	-	+	-	+	-	White	Hungary
289689	+	-	+	-	+	-	Yellow	Australia
289690	+	-	+	-	-	-	White	Australia
293756	+	-	-	-	-	-	White	USA
318886	+	-	-	-	-	-	Mix	USA
321385	+	-	-	-	-	-	Yellow	Romania
342943	+	-	-	-	-	-	White	Italy
343049	+	-	-	-	+	-	White	Spain
344392	+	-	+	-	-	-	Mix	Israel
391509	+	-	-	-	-	-	Red	Iran
430371	+	-	-	-	-	-	White	Israel
433330	+	-	+	-	-	-	Yellow	Chzech Republic
433332	+	-	+	-	-	-	Yellow	Chzech Republic
546096	+	-	+	-	-	-	Red	USA

546100	+	-	+	-	-	-	Yellow	USA
546101	+	-	+	-	-	-	Yellow	USA
546106	+	-	+	-	-	-	White	USA
546115	+	-	+	-	-	-	White	USA
546140	+	-	+	-	+	-	Yellow	USA
546162	+	-	+	-	-	-	Yellow	USA
546174	+	-	+	-	-	-	Yellow	USA
546188	+	-	+	-	+	-	Yellow	USA
546192	+	-	+	-	+	-	Yellow	USA
546201	+	-	-	-	-	-	Yellow	USA
639911	+	-	+	-	+	-	Yellow	Uzbekistan
639912	+	-	+	-	-	-	White	Uzbekistan
639913	+	-	+	-	-	-	Yellow	Uzbekistan
639914	+	-	-	-	-	-	Yellow	Uzbekistan
639915	+	-	+	-	-	-	Yellow	Uzbekistan
639916	+	-	+	-	-	-	Yellow	Uzbekistan
239633-1	+	-	-	-	-	-	White	C. Cramer
239633-2	+	-	-	-	-	-	White	C. Cramer
903-1	-	-	+	+	-	-	Yellow	M. Havey
904-1	-	-	+	+	-	-	Yellow	M. Havey
905-1	-	-	+	+	-	-	Yellow	M. Havey
Abilene	-	+	-	-	-	+	Yellow	Seminis
Advantage	-	-	-	+	-	-	Yellow	Crookham
Arcero	-	+	-	-	-	-	Yellow	Nunhems
Aruba	-	-	-	-	-	+		
Avalon	-	-	-	-	-	+	Yellow	Crookham
B2133C	-	-	-	-	+	-	Yellow	M. Havey
B5336C	-	-	-	-	+	-	Yellow	M. Havey
B5351C	-	-	-	-	+	-	Yellow	M. Havey
Bello Blanco	-	-	-	+	-	+	White	Sakata Seed
Belmar	-	-	-	+	-	+	Yellow	Crookham
Bradley	-	-	-	+	-	+	Yellow	Crookham
Brundage	-	-	-	+	-	-	white	Crookham
Calibra	-	+	-	+	-	-	Yellow	Seminis
Charismatic	-	+	-	-	-	-		
Colorado 6	+	+	+	+	+	-	Yellow	Crookham
Cometa	+	+	-	+	+	+	White	Nunhems
Crockett	-	+	-	+	-	+	Yellow	Bejo
Damascus	-	+	-	-	-	-	Yellow	Seminis

Delgado	-	+	-	-	-	+	Yellow	Bejo
Denali	-	+	-	-	-	-		
Desperado	-	+	-	-	-	-		Bejo
Elbrus	-	-	-	-	-	+	Yellow	Seminis
E203	-	-	-	-	+	-	Yellow	M. Havey
E205	-	-	-	-	+	-	Yellow	M. Havey
E206	-	-	-	+	+	-	Yellow	M. Havey
E207	-	-	-	-	+	-	Yellow	M. Havey
EX 14593	-	-	-	+	-	-	Red	Seminis
EX 16529	-	+	-	-	-	-	Yellow	Seminis
G32590	+	-	-	-	-	-	Red	Georgia
G32787	+	-	-	-	-	-	Red	Georgia
GCA-SYN	-	-	-	-	+	-	Yellow	M. Havey
Genesis	-	-	-	+	-	-	Yellow	Seminis
Granero	-	+	-	+	-	-	Yellow	Champion
Gunnison	-	+	-	+	-	-	Yellow	Crookham
Harmony	-	+	-	-	-	-		Crookham
Joaquin	-	+	-	+	-	-	Yellow	Nunhems
Legand	-	+	-	-	-	-	Yellow	Bejo
Marquette	-	+	-	-	-	+	Yellow	Seminis
Mesquite	-	+	-	+	+	-	Yellow	D. Palmer
Milestone	-	+	-	-	-	-	Yellow	Takii
Monarchos	-	+	-	-	-	-	Yellow	Seminis
Montero	-	+	-	-	-	-	Yellow	Nunhems
Morpheus	-	-	-	+	-	+	Yellow	Crookham
Mt. Blanc	+	-	-	-	-	-	White	
NUN7006ON	-	-	-	+	-	-	Yellow	Nunhems
NUN7007ON	-	-	-	+	-	-	Yellow	Nunhems
NUN7009ON	-	-	-	+	-	-	Yellow	Nunhems
NUN7606ON	-	+	-	+	+	-	Yellow	Nunhems
OLRH08-91	-	+	-	-	-	-	Red	Crookham
OLYSO5N5	+	-	+	-	-	-	Yellow	Crookham
OLYS03-207	-	+	-	-	+	-	Yellow	Crookham
OLYS03-209	-	+	-	-	+	-	Yellow	Crookham
OLYS06-25	-	-	-	+	-	-	Yellow	Crookham
OLYX00-23	-	+	-	-	-	-	Yellow	Crookham
OLYX06-25	-	+	-	-	+	-	Yellow	Crookham
Oracle	-	-	-	+	-	-	Yellow	Crookham
Oro Blanco	-	+	-	-	-	-		

Ovation	-	+	-	-	-	+	Yellow	Sakata Seed
Pulsar	-	+	-	-	-	+	Yellow	Nunhems
R 5978	-	-	-	+	-	-	Yellow	EnzaZaden
Ranchero	-	+	-	-	-	+	Yellow	Nunhems
Red Bull	-	+	-	-	-	-	Red	
Red Devil	-	-	-	+	-	-	Red	Crookham
Red Flare	-	+	-	-	-	-	Red	Log-Zen
Red Wing	-	+	-	-	-	-	Red	
Ruby Ring	-	+	-	-	-	-	Red	Takii
Rumba	-	-	-	-	+	-	Red	
Salsa Red	+	+	+	+	+	+	Red	
Sarape Café	-	+	-	-	-	-	Yellow	D. Palmer
SBO 5288	-	-	-	+	-	-	Yellow	Nunhems
SBO 5419	-	-	-	+	-	-	Yellow	Nunhems
SBO 5420	-	-	-	+	-	-	Yellow	Nunhems
SBO 5508	-	-	-	+	-	-	Yellow	Nunhems
SBO 5599	-	-	-	+	-	-	Yellow	Nunhems
Sedona	-	+	-	-	-	-		
SN 626	-	-	-	+	-	-	Yellow	Nunhems
Sp. Medallion	-	+	-	-	-	-	Yellow	Sakata Seed
Swale	-	+	-	+	-	-	Yellow	Seminis
T-433	-	+	-	-	+	-	Yellow	Takii
Talon	-	+	-	-	-	-	Yellow	Champion
Tamara	-	+	-	-	-	-	Yellow	Bejo
Tequila	-	+	-	+	-	-	Yellow	D. Palmer
The Rock	-	-	-	+	-	-	Yellow	Crookham
Tioga	-	+	-	-	-	-	Yellow	Seminis
Vantage	-	+	+	-	+	-	Yellow	
Valero	-	-	-	-	-	+		
Vaquero	-	+	-	-	-	+	Yellow	Nunhems
Vision	-	+	-	-	-	-		Log-Zen
White Cloud	-	+	-	+	-	-	White	Crookham
White Wing	-	+	-	-	-	-	White	Bejo

T indicates the entry was first raised in the greenhouse and then transplanted in the field.

S indicates the entry was directly seeded in the field.

Mix bulb color indicates entry had equal number of bulbs with white, yellow and red colors.

- indicates the entry was not included in the evaluation.

+ indicates the entry was included in the evaluation.

*No 2011 seeded entry reached maturity or could be evaluated.

APPENDIX II.E

During the 2011 evaluation, there was a cold spell 3-4 weeks after seedlings were transplanted. The frost and the sub-zero temperatures that followed killed several plants. Genotypes were categorized into Tolerant (a), Moderately Tolerant (b), Susceptible (c) and Very Susceptible (d) based on the percentage of plants killed by the frost.

Incidence of Xanthomonas leaf blight caused by *Xanthomonas axonopodis pv. allii* was unusually high in 2011 and genotypes were evaluated for their response to the infection. Genotypes were categorized into Resistant (w), Moderately Resistant (x), Susceptible (y) and Very Susceptible (z) based on the percentage of plants infected by the bacterial disease.

The following genotypes were most tolerant and most resistant to damage in 2011 by frost and Xanthomonas leaf blight: 628, 696, 708, PI 546140 and B5351C. Genotype 696 was also tolerant to IYSV and thrips damage in 2011; and PI 546140 was tolerant to IYSV and thrips damage in 2009 and 2010. In addition, PIs 264320, 289689 and 639911 were tolerant to frost damage in 2011, as well as tolerant to IYSV and thrips damage in 2009; PI 264320 was also tolerant to IYSV and thrips in 2010.

Genotype	Plants Killed by Frost (%)*	Xanthomonas Leaf Blight Infection (%)**
574[c,x]	55.0	50.0
575[b,x]	32. 5	28.0
577[c,x]	60.0	35.5
578[c,w]	60.0	0.0
579[b,w]	35.0	0.0
580[c,x]	62.5	37.5
582[d,w]	80.0	0.0
583[c,w]	67.5	12.5
589[c,x]	60.0	40.0
591[d]	100.0	N/A
592[c,y]	75.0	55.0
593[a,x]	25.0	31.0
594[d,w]	85.0	13.3
596[b,x]	35.0	32.4
597[d,x]	77.5	37.9
602[c,y]	75.0	62.8
607[c,y]	52.5	56.3
615[a,x]	12.5	30.4
618[c,x]	55.0	50.0
619[a,x]	5.0	38.8
620[b x]	30.0	27.3
621[b,x]	45.0	36.8
622[a,x]	7.5	36.3
624[c,w]	62.5	20.6
628[a,w]	2.5	3.0
629[b,x]	27.5	39.1
632[d,x]	97.5	50.0
634[c,x]	75.0	43.5
643[c,y]	67.5	54.8
646[c,x]	57.5	41.7
648[d,w]	77.5	22.5
651[c,y]	70.0	51.2
654[c,x]	55.0	46.8
656[c,x]	52.5	34.3
658[a,x]	0.0	42.3
660[c,x]	52.5	38.4
696[a,w]	20.0	0.0

700[a,y]	7.5	51.5
702[b,x]	47.5	29.3
706[b,w]	35.0	18.8
708[a,w]	7.5	8.5
711[b,x]	35.0	39.6
712[b,w]	35.0	5.4
713[b,w]	30.0	8.4
718[b,w]	27.5	8.4
719[c,w]	75.0	19.5
753[c,x]	57.5	31.7
759[c,x]	60.0	37.5
765[c,y]	75.0	55.5
768[c,y]	57.5	58.2
769[d,x]	80.0	45.0
172702[c,w]	55.0	14.3
172703[c,w]	75.0	20.9
239633[d,x]	90.0	41.8
258956[c x]	67.5	42.0
264320[a,x]	0.0	48.9
288909[b,w]	42.5	20.4
289689[a,x]	10.0	27.9
343049[b,x]	40.0	32.5
546140[a,w]	0.0	20.8
546188[c,y]	52.5	75.0
546192[a,y]	22.5	65.1
639911[a,x]	2.5	47.1
B2133C[b,x]	47.5	30.8
B5336C[d,z]	95.0	83.3
B5351C[a,w]	22.5	23.3
Colorado 6[c,y]	52.5	53.3
Cometa[a,x]	25.0	49.8
E203[b,w]	30.0	14.1
E204[d]	100.0	N/A
E205[c,x]	52.5	26.4
E206[a,y]	10.0	51.4
E207[a,x]	17.5	38.6
GCA-SYN[c,x]	57.5	31.3
Mesquite[b,x]	32.5	48.6
NUN7606ON[a,y]	10.0	50.5
OLYS03-207[a,y]	2.5	52.8

OLYS03-209[b,y]	32.5	62.1
OLYS05N5[b,y]	42.5	57.4
OLYX06-25[a,y]	25.0	64.5
Rumba[a,x]	0.0	32.3
Salsa Red[b,x]	30.0	35.1
T-433[a,y]	0.0	68.3
Vantage[b,x]	47.5	48.5

*Genotypes were categorized based on the percentage of plants killed by exposure to frost into:

[a]Tolerant (0-25 %).

[b]Moderately Tolerant (26-50 %).

[c]Susceptible (51-75 %).

[d]Very Susceptible (76-100 %).

**Genotypes were categorized based on the percentage of plants infected by Xanthomonas Leaf Blight into:

[w]Resistant (0-25 %).

[x]Moderately Resistant (26-50 %).

[y]Susceptible (51-75 %).

[z]Very Susceptible (76-100 %).

N/A indicates that all plants of the genotype died before inception of the disease.