

# The potato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae): life history, relationship to plant diseases, and management strategies

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## Summary

The potato/tomato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae) has been a major pest of solanaceous crops for decades. This pest can cause damage to crop plants by direct feeding and, as has been recently discovered, by transmitting the bacterial pathogen *Candidatus Liberibacter psyllaerous* (a.k.a. *Ca. L. solanacearum*). Many studies have been conducted to determine the relationship of this pest to plant injury and to develop management strategies to alleviate the damage caused by this pest in a wide variety of solanaceous plants. Studies in the past decade have documented substantial genetic variability in this invasive species, enhanced our rapidly-evolving understanding of the interactions between the insect and the pathogen it carries, and improved our appreciation of the invasive potential of the pest. This review seeks to provide a comprehensive update to *B. cockerelli* life history, relationship to plant diseases, and the current state of management strategies against *B. cockerelli*.

## Keywords

Potato psyllid; Psyllidae; 'zebra chip'; 'psyllid yellows'; management

## Introduction

When Karel Sulc first described *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae) in 1909 from individuals collected on peppers (*Capsicum* sp.) in Boulder, CO, USA, he inferred that due to the large number of nymphs observed on plants, this insect may become a destructive pest (Sulc, 1909). In 1915, *B. cockerelli* was recognized as a plant pest for the first time by damaging the ornamental False Jerusalem Cherry (*Solanum capsicastrum*) in San Francisco and Sacramento, CA, USA, to the point where control measures were necessary (Comper, 1915). In 1927, the full potential of how destructive *B. cockerelli* could be was realized when many state-wide outbreaks of 'psyllid yellows' (PY) occurred on potatoes (*Solanum tuberosum* L.) starting in Utah and then

spread to many other Rocky Mountain states (Richards et al., 1927; Richards, 1928). This new disease was ascribed to the feeding behavior of *B. cockerelli* (most scientists speculated that the psyllid was releasing a toxin) and caused the heaviest yield losses yet recorded for potatoes in the USA, often leading to the complete destruction of the crop in psyllid-infested areas (Linford, 1928). A more devastating outbreak of *B. cockerelli* and PY than the 1927 epidemic occurred in 1938 (Anonymous, 1929; Jensen, 1939; Morris, 1939). In the years after the 1938 outbreak, *B. cockerelli* was managed almost exclusively by insecticides (Pletsch, 1947; Wallis, 1955; Cranshaw, 1994).

In 1994, a new potato defect was discovered in Mexico and later named 'zebra chip' (ZC) (Munyanza et al., 2007a). This disease was later found to be transmitted by *B. cockerelli* (Munyanza et al., 2007a, 2007b) and caused by the bacterium *Candidatus Liberibacter psyllaeus* (a.k.a. *Ca. L. solanacearum*) (Hansen et al., 2008; Liefing et al., 2009). ZC became a serious problem for the potato industry as it was more insidious than PY; even late season infection with ZC renders tubers unmarketable and thus causes significant losses at harvest, often after the full costs of crop production. Thus, *B. cockerelli* regained prominence as a key, serious pest of solanaceous crops such as potato, tomato (*Solanum lycopersicum* L.), peppers, and eggplant (*Solanum melongena* L.) in North and Central America (Cranshaw, 1994; Crosslin et al., 2010). In recent years, *B. cockerelli* has also invaded New Zealand as pest of solanaceous greenhouse crops, and outdoor potatoes and tomatoes (Gill, 2006; Davidson et al., 2008). Currently *B. cockerelli* is causing substantial economic losses across a wide geographic range.

### **Taxonomy and distribution**

*Bactericera cockerelli* has two common names: the potato psyllid and the tomato psyllid (ESA, 2011). *Bactericera cockerelli* was originally described as *Trioza cockerelli* by Sulc (1909). In 1910, Crawford erected a new psyllid genus *Paratrioza*, and in 1911 *Trioza cockerelli* was assigned to *Paratrioza*. In 1997, when the genus *Paratrioza* was synonymized with the genus *Bactericera* as defined by combinations of adult, nymphal and egg characters, *B. cockerelli* also changed families from Psyllidae to Triozidae (Burckhardt and Lauterer 1997, Hodkinson 2009). Morphological descriptions of *B. cockerelli* can be found in Crawford (1911, 1914), Essig (1917), Ferris (1925), and Tuthill (1945). Tuthill (1945) and Burckhardt and Lauterer (1997) list the synonyms for *B. cockerelli* as well.

*Bactericera cockerelli* is endemic to North America with the distribution of this insect in the USA including Arizona, California, Colorado, Idaho, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, North and South Dakota, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming (Pletsch, 1947; Cranshaw, 1994; Munyanza et al., 2009, 2010). Additionally, *B. cockerelli* can be found in the Canadian Provinces of Alberta, British Columbia, Ontario, and Saskatchewan (Pletsch, 1947; Wallis, 1955; Ferguson et al., 2002), as well as Mexico, and in several countries in Central America at least as far south as Guatemala and Honduras (Tuthill, 1945;

Pletsch, 1947; Jackson et al., 2009; Crosslin et al., 2010). In the early-2000s, *B. cockerelli* invaded New Zealand and has spread throughout this country (Gill, 2006; Davidson et al., 2008; Teulon et al., 2009).

### Life history

*Bactericera cockerelli* is a polyphagous insect with a wide host range exceeding 20 plant families and is able to oviposit and complete development on more than 40 host species (Knowlton and Thomas, 1934; Wallis, 1951). The relative importance of host plants for *B. cockerelli* relates to the abundance, preference and proximity to agricultural areas (Wallis, 1955). In the North Platte Valley of Wyoming and Nebraska, an important non-economic host is matrimony-vine (*Lycium barbarum* L.) (Wallis, 1946, 1955). In a scientific note by Knowlton (1933), adult *B. cockerelli* were reported to be able to survive for a considerable length of time (i.e., 17–96 days) on various plant species in which nymphs were not able to successfully complete development. This host feeding may contribute to the successful survival of adult psyllids during the winter months. In general, *Bactericera cockerelli* can survive well on, and appears to prefer, plant species in the family Solanaceae (Wallis, 1955).

However, despite these observations by Knowlton (1933), most researchers hypothesize that adult migrations provide the primary mechanism by which *B. cockerelli* arrives in agricultural crops. Glick (1939) collected *B. cockerelli* by airplane in Mexico at altitudes up to 1200 m suggesting that this species can migrate via air currents. Evidence of this is also noted by Papp and Johnson (1979) as *B. cockerelli* have been found on the alpine snowfields in the Sierra Nevada Mountains in California.

Romney (1939) found spring breeding populations of *B. cockerelli* on *Lycium andersonii* Gray and *Lycium macrodon* Gray in southern Arizona, and on *Lycium* spp. in southern Texas. Breeding on these plants occurs from January to May with peak populations building in April and early May after several generations have been produced (Romney, 1939). By the middle of June, adults move out of these habitats, and are not seen again until a large influx of adults move back to these habitats in late October to early November (Romney, 1939). Observations by Romney (1939) and using information regarding the migration patterns of other insect species such as the beet leafhopper, *Circulifer tenellus* (Baker) and the psyllid *Heteropsylla mexicana* (Crawford) suggests that *B. cockerelli* from breeding populations in southern Arizona migrate north and west of the Continental Divide, while *B. cockerelli* populations in southern Texas migrate north and east of the Continental Divide. However, populations of *B. cockerelli* can occur much further south on the east coast area of Mexico (Pletsch, 1947). Thus, the possibility exists that primary overwintering sites may be in both the USA and Mexico. Wallis (1946) found that *B. cockerelli* does not overwinter in Wyoming and Nebraska, and the arrival of psyllids observed during the early potato crop in May and June provides circumstantial evidence of *B. cockerelli* migration. Recent genetic data based on inter simple sequence repeat (ISSR) markers by Liu et al. (2006) support that *B. cockerelli* populations were of two groups, one from western

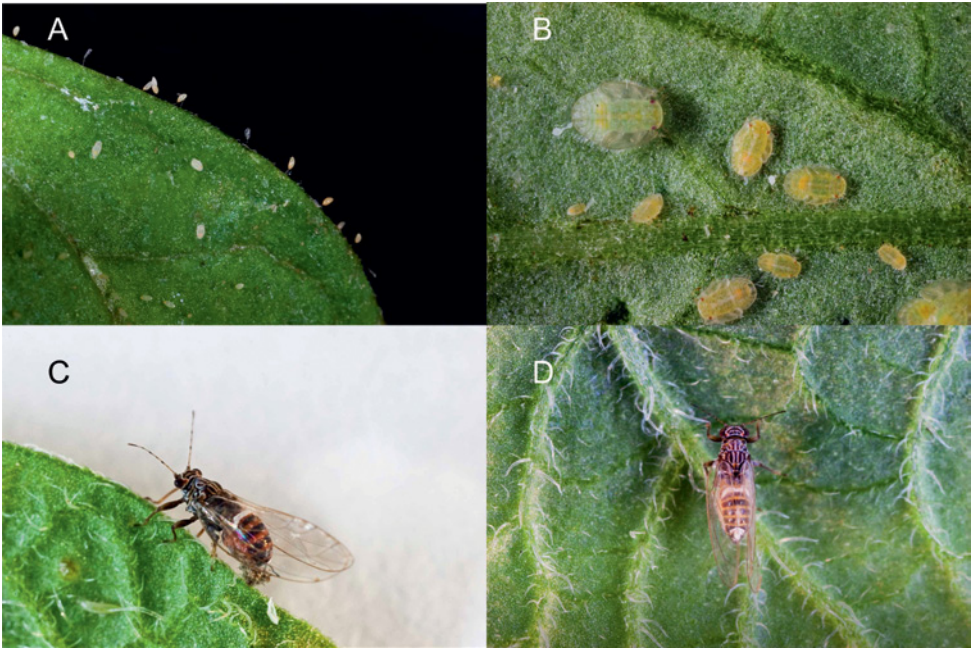
North America and the other from central USA and eastern Mexico. Liu et al. (2006) also found that there was genetic transfer between these populations. To date, the northernmost overwintering site known is in coastal Ventura County, California (Trumble, unpublished).

There is often great variation from year to year regarding the numbers of *B. cockerelli* found on economic and non-economic host plants (Wallis, 1946). *Bactericera cockerelli* is considered to be a 'temperature-zone' species (Knowlton, 1933; List, 1939), meaning this species life history characteristics are severely impacted by extremely hot or cold conditions. In the laboratory, the optimum range for *B. cockerelli* development is rather narrow (Wallis, 1946). Individuals reared at 26.7°C exhibit the best survival, development, and oviposition, with reductions in these life history characteristics at 32.2°C (List, 1939). Temperatures at 38.8°C for one or two hours are lethal to eggs and nymphs, and adult stop laying eggs (List, 1939); however, the data provided by List (1939) were not statistically analyzed. Romney (1939) believes the combination of high temperatures and/or the decline in the quality of host plants contribute to *B. cockerelli* leaving spring breeding sites. The temperature results agree with observation in agricultural fields (Wallis, 1946). Further research suggests that factors playing a role in *B. cockerelli* numbers in the field are related to temperature, size of the spring migration, and the size of crop plants. Larger plant canopies may shade *B. cockerelli* from the hot summer temperatures above 32.2°C as the temperature within the plant canopy is several degrees cooler, which can allow optimal development of populations (Wallis, 1946).

Essig (1917) described the life cycle of *B. cockerelli* in California. In California, *B. cockerelli* now appears to consistently overwinter (Liu et al., 2006). Essig (1917) found that winters were passed on evergreen host plants or sheltered places. Adults begin to lay eggs and could be found in southern California on wild host species in April (Essig, 1917; Jensen, 1954). Generations can vary from three or more in California with all life stages found from May until the end of November (Essig, 1917). Jensen (1954) provides further evidence of *B. cockerelli* populations increasing on wild host species in southern California and then moving northward in the spring, as well as the return of *B. cockerelli* to *Lycium* spp. host plants in November.

### *Description of life stages*

*Egg.* *Bactericera cockerelli* eggs are yellow, oblong in shape and attached to the leaves of the host plant with short stalks (Pletsch, 1947) (Figure 1A). The average length and width of a *B. cockerelli* egg is 0.3 mm and 0.1 mm, respectively, with the length of the stalk being 0.2 mm (Compere, 1916; Lehman, 1930; Pletsch, 1947). Eggs that are not fertilized do not hatch (Lehman, 1930). Eggs are deposited on the upper and lower surfaces of leaves, and most abundantly on the young apical leaves (Knowlton and Janes, 1930), but this varies with the host crop (Butler and Trumble, 2011a; Butler personal observation). Eggs can take from 3–15 days to hatch, and exhibit a 1:1 sex ratio of females to males (Pack, 1930; Knowlton and Janes, 1930).



**Figure 1.** Life stages of the potato psyllid. (A) eggs; ( B) nymphs; (C) red color morph of adult; (D) brown color morph. Picture credit: Michael Lewis.

*Nymph.* Development in the Hemiptera is of the hemimetabolous type, in which the adult stage is preceded by stages that are similar in appearance, but without wings. *Bactericera cockerelli* has five instars, and completion of development can vary from 12–44 days with an average of 15.4 days (Knowlton and Janes, 1930; Pack, 1930; Yang and Liu, 2009). The first four instars require an average of 2.4–2.8 days to complete development, but the fifth instar averages 4.9 days to complete (Knowlton and Janes, 1930). The range of the size of each instar can be found in Pletsch (1947). The nymphal stage is often where the greatest natural mortality occurs (Abdullah, 2008). Host plant and geographic origin can have an impact on nymphal growth and development of *B. cockerelli* (Liu and Trumble, 2007; Yang and Liu, 2009). First instar nymphs are pale yellow with an orange-colored head and abdomen, and as development occurs the color changes to a pale yellowish-green or can still remain yellowish-orange (Essig, 1917) (Figure 1B). Nymphs prefer the abaxial leaf surface and seldom move (Lehman, 1930).

*Adult.* After the last nymphal molt, adults are initially pale green or light amber, but soon become darker with considerable variation in the degree and intensity of colors (Essig, 1917; Lehman, 1930; Knowlton and Janes, 1930) (Figure 1C and D). The length of the adult body can vary from 1.3–1.9 mm (Essig, 1917; Lehman, 1930; Liu and Trumble, 2007). The adult life span can range from 16–97 days, however like all insects; developmental rates vary with temperature (Knowlton and Janes, 1930;

Lehman, 1930; Davis, 1937; List, 1939; Yang and Liu, 2009; Yang et al., 2010). The following conditions can also impact adult life history characteristics: 1) host plant, 2) geographic origin of populations, 3) sex and, 4) whether the measurement were conducted under field or laboratory conditions (Liu and Trumble, 2007; Yang and Liu, 2009; Yang et al., 2010).

Odorant sex attraction has been studied by Guedot et al. (2010) and they found that females and males of *B. cockerelli* emit odors that attract males; this was the first study to document male-male attraction within the Psylloidea. Adult females can lay eggs three days after emergence with a preoviposition period that can vary from 3-25 days (Knowlton and Janes, 1930; Abdullah, 2008). The oviposition period lasts an average of 21.5-27.8 days (Knowlton and Janes, 1930; Davis, 1937), and ovipositing females can usually deposit 5-50 eggs during 24 hours. After a single mating, which lasts on average 6 minutes, *B. cockerelli* females produce fertile eggs for up to 27.8 days (Knowlton and Janes, 1930). Adult females can lay on average up to 330 eggs over her lifetime (Knowlton and Janes, 1930).

Adult *B. cockerelli* feed primarily of the underside of leaves of host plants (Eyer and Crawford, 1933). However, some individuals have been observed to feed on the upper surface of leaves as well as stems and petioles (Knowlton and Janes, 1931; Eyer and Crawford, 1933; personal observation). Based on the histology of feeding punctures of *B. cockerelli*, this insect, like aphids, are phloem-feeders (Eyer and Crawford, 1933). When *B. cockerelli* probes a plant, penetration through the leaf epidermis and into the leaf is intercellular through the spongy mesophyll until the stylets reach the phloem parenchyma cells, which is the region of the leaf where the most extensive feeding occurs (Eyer and Crawford, 1933). Penetration of the xylem occurs only occasionally (Eyer and Crawford, 1933; Butler, 2011).

### *Endosymbionts*

Mutualistic associations between psyllids and intracellular bacteria or endosymbionts are common (Baumann, 2005). Endosymbionts are localized intracellularly in specialized host cells called bacteriocytes or mycetocytes that may constitute a larger structure called a bacteriome or mycetome (Buchner, 1965; Nachappa et al., 2011). The mycetome of *B. cockerelli* was described by Rowe and Knowlton (1935). Psyllid endosymbionts fall within two categories: primary (P) (obligatory and those that aid in psyllid nutrition) and secondary (S) (facultative and those with functions less clear than P endosymbionts, and those that vary among populations) (Hodkinson, 2009). Within the mycetomes of *B. cockerelli* can be found the P endosymbionts *Candidatus Carsonella ruddii* and two strains of *Wolbachia* (Liu et al., 2006; Nachappa et al., 2011); and the S endosymbiont *Candidatus Liberibacter psyllaerous* (Hansen et al., 2008) (to be discussed later).

### **Psyllid yellows**

In 1927, a destructive outbreak of a potato disease severely affected the potato crops in Colorado, Idaho, Montana, Utah and Wyoming with some fields exhibiting 100%

infection of plants (Richards et al., 1927; Richards, 1928). The early potato crop and home garden plots were described as ‘complete failures’ due to the affected plants producing few if any marketable tubers, and the late planted potato crops were not free from the disease either (Richards et al., 1927). Ensuing research found feeding by the nymphs of *B. cockerelli* associated with the diseased plants and suggested the name for this new disease as ‘psyllid yellows’ (PY) (Richards, 1928). Economic estimates in Utah alone in 1927 suggest that 25–30% of the total potato crop valued at ca. \$750,000 was lost due to PY. In the growing season after 1927, additional outbreaks of PY were noted in various section of the USA with varying degrees of severity (Richards, 1929; Richards et al., 1933). However, in 1938, one of the worst outbreaks of PY occurred in Colorado, Montana, Nebraska, and Wyoming as well as several reports of infection in California (Anonymous, 1929; Jensen, 1939; Morris, 1939). Even with insecticide applications, end of the year losses attributed to PY for potatoes ranged from 25–75% in the states affected (Anonymous, 1939). In western Nebraska alone, a 25% yield loss of potatoes equaled 27,200 metric tons (Hill, 1947). Other infestations that occurred after 1939 appeared to have been managed by new insecticides that were developed, including DDT, and the elimination of alternative breeding hosts such as matrimony-vine (Hill, 1947; Pletsch, 1947; Wallis, 1955; Cranshaw, 1994).

PY disease is systemic, and the entire plant becomes infected (Carter, 1939). Plant symptoms of PY include a reduction in growth, erectness of new foliage, chlorosis or reddening/purpling of leaves, basal cupping of leaves, shortened and thickened internodes, enlarged nodes, aerial tubers, premature senescence and plant death (Pletsch, 1947; Cranshaw, 1994). The marginal yellowing and upward rolling or cupping of younger leaves is a diagnostic character of PY (Richards et al., 1933). Histology of the diseased plants by Eyer and Crawford (1933) and Eyer and Miller (1938) found large deposits of starch granules in the cortex and pith of the stems and petioles as well as phloem necrosis in stems, stolons, and roots. Other reports found decreased nitrates/nitrogen, chlorophyll, and carotene contents, and decreased starch contents in tubers of PY diseased plants (Eyer, 1937; Schaal, 1938; Carter, 1973).

PY diseased potatoes and tomatoes exhibit significant decreases in yields. Tubers from potato plants infected with PY are tiny, misshapen, flabby, and have a rough skin (Lindford, 1928; Cranshaw, 1994). These tubers often have associated with them various defects such as early sprouting, weak sprouts, and significantly smaller plants (Metzger, 1936; Cranshaw, 1994). In tomatoes, foliar symptoms are similar to those of potatoes and fruit set, size, texture and yield can be significantly decreased due to PY (Cranshaw, 1994), with losses reaching 80% (Liu and Trumble, 2007).

In general, the nymphal stages of *B. cockerelli* are the life stage that produce the PY disease, and it appears they are inherently toxigenic (Cranshaw, 1994). Through repeated tests, Richards (1931) and Richards et al. (1933), found that densities as high as 1,000 *B. cockerelli* adults per potato plant, failed to produce PY symptoms. However, Daniels (1954) found that adults were able to produce disease symptoms on tomato seedlings. Richards (1931) found that fewer than 15 nymphs did not induce uniform disease symptoms in potatoes, but with higher infestations, symptoms appear in 4–6 days. Potato plants may resume a healthy, normal appearance if nymphs are removed 5–10 days after the appearance of first symptoms, but this does not always

happen (Richards, 1931; Arslan et al., 1985). For tomatoes, relationships regarding the number of nymphs per plant and the resulting damage threshold can vary among cultivars; however symptoms of PY will appear when at least 8 nymphs feed on 2 week old tomato plants (Liu and Trumble, 2006). Additional studies by Liu et al. (2006) found that the tested tomato cultivars also exhibit differing recovery potentials, and as a conservative measure recommend treating tomato cultivars when the number of psyllids approach 10 nymphs per plant for a period of 5 days.

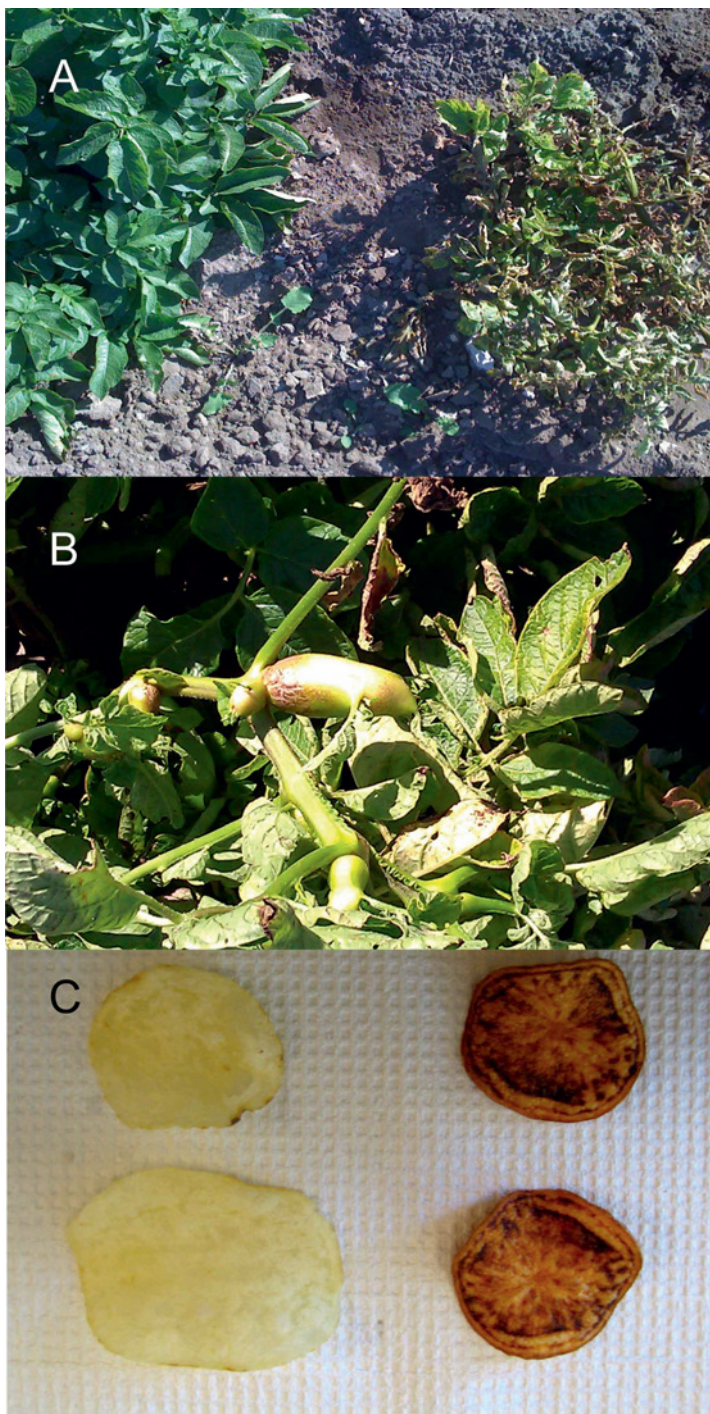
Through grafting experiments on potatoes, PY has proven capable of being transmitted to healthy plants; however, succeeding grafts result in a gradual recovery of plants (Daniels, 1954; Cranshaw, 1994), which suggest that a pathogenic microorganism is not involved with PY and supports the 'toxin' hypothesis. The identification of this 'toxin' still remains unknown (Abernathy, 1991).

### **Zebra chip disease**

'Zebra chip' (ZC) disease was first documented in potato fields near Saltillo, Mexico, in 1994 (Munyanzeza et al., 2007a). ZC-affected potatoes exhibit the following above-ground symptoms: stunting, chlorosis, swollen internodes of the upper growth, proliferation of axillary buds, aerial tubers, browning of the vascular system, leaf scorching, and early plant death (Munyanzeza et al., 2007b) (Figure 2 A-B). Symptoms of the infected tubers are shown through the entire tuber from the stem end to the bud end and include enlarged lenticels of the underground stem, collapsed stolons, brown lesions of the vascular ring, necrotic flecking of internal tissues, and occasionally streaking of the medullary ray tissues (Munyanzeza et al., 2007a). Chips that are processed from infected tubers exhibit severe dark brown streaking, thus the name 'zebra chip', which causes the rejection of fresh and processing potatoes for market (Munyanzeza et al., 2007a) (Figure 2C). The color changes are most evident following frying, but can often be detected in fresh tubers. Additionally, ZC-infected tubers sprout significantly less than ZC-free tubers or do not sprout at all; if they do sprout, hair sprouts or weak plants are produced that have significantly decreased survival (Henne et al., 2010; Munyanzeza et al., 2007a). Furthermore, the physiological effects of ZC infection on the potato tuber include significantly increased levels of tyrosine, phenolic compounds, salicylic acid and ion leakage as well as altered mineral content in ZC-affected tubers compared to ZC-free tubers (Navarre et al., 2009; Miles et al. 2009, 2010).

In the USA, ZC was first identified in commercial fields in Pearsall and the lower Rio Grande Valley in Texas in 2000 and since that time ZC has been recorded in Arizona, California, Colorado, Kansas, Nebraska, Nevada, and New Mexico (Secor and Rivera-Varas, 2004; Munyanzeza et al., 2007a). In the 2004–2006 potato growing seasons, economic losses due to ZC to both potato producers and processors in numerous locations in the USA and Mexico often led to the abandonment of fields resulting in losses exceeding millions of dollars (Munyanzeza et al., 2007a). In Texas alone, ZC has been responsible for a reduction in potato hectareage by > 20%, and is estimated to be responsible for a loss of \$25 million during the 2004–2006 outbreaks (CNAS, 2006;





**Figure 2.** Damage associated with *Candidatus Liberibacter psyllaeus* in potatoes. (A) a healthy plant (left) and an infected plant exhibiting stunting and leaf scorching; (B) aerial tuber; (C) potato chips from a healthy tuber (left) and from an infected tuber (right). Picture Credit: Gregory Kund.

Wen et al., 2009). ZC disease has also been documented in potato fields in Guatemala and Honduras with field incidences as high as 80% and total losses because of unmarketable tubers (Secor and Rivera-Varas, 2004; Crosslin et al., 2010).

Munyanze et al. (2007a) were the first to elucidate the association between *B. cockerelli* feeding and ZC expression on potato. In a greenhouse and a Washington field study by Munyanze et al. (2007a), potato plants not exposed to *B. cockerelli* did not exhibit ZC symptoms, but potato plants exposed to *B. cockerelli* exhibited symptoms three weeks after the initial *B. cockerelli* release. Furthermore, psyllid exposed plants exhibited initial plant symptoms which included upward rolling of the leaves and yellowish-reddish discolorations with later symptoms of plants and tubers that exhibited typical ZC symptoms (Munyanze et al., 2007a). Comparable results were documented by Munyanze et al. (2007b) in Texas too, whereby potato plants not exposed to *B. cockerelli* did not show ZC symptoms and plants exposed to psyllids showed ZC symptoms. In these field locations, the most predominant insect collected where ZC was prevalent was *B. cockerelli* (Munyanze et al., 2007a; Goolsby et al., 2007a). Later research found that *B. cockerelli* populations from different geographic localities varied in their ability to infect potato with ZC (Munyanze et al., 2008). Additionally, *B. cockerelli* reared upon the agricultural host plants of potato, tomato, bell pepper and eggplant can infect potato with ZC, although *B. cockerelli* reared on bell pepper and eggplant can cause relatively more severe ZC infections compared to psyllids reared on tomato and potato (Gao et al., 2009).

Hansen et al. (2008) were the first to identify a new bacterial species of *Candidatus* Liberibacter that was vectored by *B. cockerelli*. The bacterium was first sequenced 3 January 2008 at UCR's IIGB Bioinformatics Facility based on the 16S-ISR-partial 23S rRNA sequences found in *B. cockerelli* and infected plants (Hansen et al., 2008). These sequences were later deposited in GenBank 18 June 2008. The bacterium was named *Candidatus* Liberibacter psyllaourous and is an unculturable Gram-negative  $\alpha$ -proteobacterium that is associated with the phloem tissue of plants (Hansen et al., 2008; Lin et al., 2009). Results indicated that *Ca. L. psyllaourous* infection can occur throughout *B. cockerelli* life stages but can vary with eggs exhibiting a 15–47 percent infection frequency, which suggests transovarial transmission of *Ca. L. psyllaourous* (Hansen et al., 2008). For *B. cockerelli* reared on potato, *Ca. L. psyllaourous* infection from the first instar to adults appeared to be fixed at 100%, while *B. cockerelli* reared on tomato exhibited 100% infection of *Ca. L. psyllaourous* at the third instar (Hansen et al., 2008). This research also revealed transmission of *Ca. L. psyllaourous* by *B. cockerelli* after one week of exposure to a potato or tomato plant and subsequently displayed of symptoms, which were consistent with Munyanze et al. (2007a) description of ZC (Hansen et al., 2008). Later research by Munyanze (2010) has reported that as few as one *B. cockerelli* can transmit *Ca. L. psyllaourous* within two hours of colonizing the plant. The exact mechanism of transmission is unknown, but we suspect the bacteria are injected during salivation into the phloem.

In January 2008, related research was conducted in New Zealand regarding the etiology of a new disease of greenhouse grown tomatoes and peppers (Crosslin et al.,

2010). In April 2008, Liefting et al. (2009) discovered a bacterium-like organism in the phloem of symptomatic plants. In May 2008, various polymerase chain reaction (PCR) primers were used to amplify putative prokaryotic DNA extracted from healthy and symptomatic tomato and pepper; the result was the detection of what the authors named *Ca. L. solanacearum* (Liefting et al., 2008). Recent research has suggested haplotypes of *Ca. L. solanacearum* exist as described by single-nucleotide polymorphisms and *rplJ* and *rplL* ribosomal protein genes and the publication of the complete genome sequence of *Ca. L. solanacearum* is currently available (Nelson et al., 2010; Lin et al., 2010).

Since publication of the primers by Hansen et al. (2008) and Liefting et al. (2009), multiple laboratories in the USA, Mexico, and New Zealand have documented *Ca. L. psyllauros* and *Ca. L. solanacearum* infection in solanaceous agricultural crops and additional solanaceous hosts such as *L. barbarum*, tamarillo (*Solanum betaceum*), cape gooseberry (*Physalis peruviana*), silverleaf nightshade (*Solanum elaeagnifolium*), and black nightshade (*Solanum ptychanthum*) (Abad et al., 2009; Brown et al., 2010; Crosslin and Bester, 2009; French-Monar, 2010; Li et al., 2009; Liefting et al., 2008a,b; McKenzie and Shatters, 2009; Munyaneza et al., 2009a,b,c; Rehman et al., 2010; Wen et al., 2009). Sequence analysis of the 16S and 23S rRNA suggests that *Ca. L. psyllauros* and *Ca. L. solanacearum* are the same bacterium as a number of BLAST analyses of consensus sequences often show 99–100% identity of *Ca. L. solanacearum* with *Ca. L. psyllauros* (Crosslin and Bester, 2009; French-Monar, 2010; Munyaneza et al., 2009a,b,c; Secor et al., 2009; Wen et al., 2009; Crosslin et al., 2010). Both names are in current use, and the final ‘official’ naming of the bacterium will not occur until all of Koch’s postulates can be fulfilled when the bacterium can be cultured in the laboratory.

## Management strategies

### *Detection and monitoring*

Surveys for the purpose of population detection and monitoring of *B. cockerelli* have been conducted by various authors in cultivated and non-cultivated host plants (Pletsch, 1947; Wallis, 1955; Cranshaw, 1994; Al-Jabr, 1999, 2007; Goolsby et al., 2007a,b). These methods have involved suction traps, vacuum sampling of plants, sweep net sampling, examination of plant material, and colored sticky traps. Suction traps and vacuum samplers were found to be ineffective at detecting and sampling *B. cockerelli*, respectively (Cranshaw, 1994; Goolsby et al., 2007). The use of sweep nets to obtain a relative estimate of *B. cockerelli* has been used extensively (Pletsch, 1947 and reference therein). Pletsch (1947) used these data to calculate a “psyllid index” based on the number of *B. cockerelli* captured per 100 sweeps, and found the index correlated with the amount of PY observed in agricultural fields (Cranshaw, 1994). Information from the sweep net sampling of *B. cockerelli* have revealed patterns regarding the infestation and disease spread within agricultural fields. Within agricultural

fields, *B. cockerelli* were first detected on the edges and as the number of psyllids build in the field they progress toward the center (Jensen, 1939; Wallis, 1955; Cranshaw, 1994).

Examinations of leaf samples have often been described as ‘tedious and time consuming’ for *B. cockerelli*, but have provided detailed information regarding the population density of this pest (Pletsch, 1947; Goolsby et al., 2007). These data have also revealed that relative to other parts of potato plants, *B. cockerelli* prefer to inhabit leaves on the abaxial surface (Knowlton and Janes, 1931; List, 1939; Pletsch, 1947). Despite this information, a sampling plan for *B. cockerelli* has yet to be developed in agricultural fields. However, only recently has a statistically verifiable sampling plan been developed for an agricultural crop (Butler and Trumble, 2011a).

Sticky card traps have been used as monitoring tools in the greenhouse and the field (Al-Jabr, 1999; Goolsby et al., 2007). Al-Jabr (1999) was the first to study the effective detection and monitoring of *B. cockerelli* in greenhouse tomato. The results of his study indicated that *B. cockerelli* were most attracted to neon-green, neon-orange, and standard yellow sticky traps that were placed above the crop canopy and in the shade (Al-Jabr, 1999). Goolsby et al. (2007a,b) used yellow sticky cards to monitor adult *B. cockerelli* in potato fields in Texas, and suggested they could be an effective tool to detect *B. cockerelli* in cultivated and non-cultivated host plants at low densities. However, an evaluation of sticky traps compared to other sampling techniques has yet to be conducted. Also, there has been no publication that has reported a predictive relationship between the numbers of adults on traps and the numbers of nymphs in the foliage. Thus, this technique probably has the most utility for determining when adults are migrating into an area.

### *Insecticidal control*

Insecticidal control of *B. cockerelli* has been the subject of extensive research. Compounds used for *B. cockerelli* control included oils, nicotine, pyrethrum, zinc arsenite sprays and calcium cyanide dusts (Knowlton, 1931, 1933b; Pletsch, 1942, 1947). One of the first and most broadly used insecticides in the 1930’s and 1940’s for *B. cockerelli* control was lime-sulfur, which gave good control of this pest in tomatoes and potatoes with increases in yields for both of these crops (List, 1918, 1935, 1938; List and Daniels, 1934). Lime-sulfur was effective in killing the immature and adult stages of *B. cockerelli* as well as being repellent to the adults. However, lime-sulfur had the problem of being phytotoxic to crops (List, 1935; Pletsch, 1942). In the greenhouse, the residual toxicity of lime-sulfur lasted for up to five weeks (Tate and Hill, 1944). In 1945, DDT was used against *B. cockerelli* for the first time in Nebraska and was described as providing more effective control for a longer period of time compared to the other compounds available at the time (Hill, 1945; Pletsch, 1947).

In the 1960’s, organophosphates such as phorate, parathion, disulfoton, and demeton, and the carbamate aldicarb were used for control of *B. cockerelli* (Gerhardt and Turley, 1961; Harding, 1962; Gerhardt, 1966). In the 1980’s Cranshaw conducted extensive tests on insecticides for *B. cockerelli* management (Cranshaw, 1985a,b,c,

1989a,b,c, 1993). Foliar sprays of diazinon, endosulfan, permethrin, acephate and many pyrethroid insecticides were among the better compounds for *B. cockerelli* control; and the systemic soil applied applications of phorate and disulfoton still provided control of *B. cockerelli* early in the growing season (Cranshaw, 1985a,b,c, 1989a,b,c). The carbamates such as aldicarb, carbofuran, cloetiocarb, carbaryl, and the organochlorine methoxychlor were ineffective treatments at controlling *B. cockerelli* (Cranshaw, 1985a,c). Al-Jabr (1999) found for greenhouse tomatoes neem-derived compounds, spinosad and acetamiprid were effective in killing *B. cockerelli* 24 h post-application, and other compounds such as horticultural spray oil and pymetrozine were effective in killing *B. cockerelli* 5 days post-application.

Further research on tomatoes by Liu and Trumble (2004, 2005), found complex interactions between tomato cultivars and insecticides tested for the behaviors of *B. cockerelli* and life history characteristics measured. The compounds tested included imidacloprid, kaolin particle film, pymetrozine, pyriproxyfen, and spinosad. While *B. cockerelli* on insecticide-treated plants exhibited significant decreases in the duration of probing behavior and reduced egg-adult survivorship (Liu and Trumble, 2004, 2005), non-feeding behaviors (resting, cleaning, etc.) and other life history characteristics (antixenosis, oviposition) often exhibited unexpected interactions between the insecticide and tomato cultivar. Also, Liu and Trumble (2007) found resistance to imidacloprid and spinosad in populations of *B. cockerelli* in California compared to psyllids from the central USA. Subsequent experiments using the electrical penetration graph technique determined that imidacloprid interfered with penetration behaviors and could provide substantial reductions in *Ca. L. psyllaurae* transmission for at least 4 weeks after application (Butler, 2011; Butler et al., 2012).

Since the association was made between *B. cockerelli* feeding and ZC, management practices for potatoes in the USA have relied on insecticides to control *B. cockerelli* to lower ZC incidences and increase yields. In Texas, in-furrow applications of phorate followed by several in-season applications of foliar insecticides including imidacloprid + cyfluthrin, endosulfan, and methamidophos reduced ZC incidence in tubers to 12.9–20.4% (Goolsby et al., 2007a). Insecticides also were used as a management tool to further lower ZC incidence in tubers to 0.4–2.3% in a pest management plan that included an in-furrow application of imidacloprid, and weekly applications of dinotefuran and spiromesifen used in rotation applied at weekly intervals until the two week pre-harvest interval (Goolsby et al., 2007b).

In California, existing UC Pest Management Guidelines recommend treating potato plants with imidacloprid at planting, and additional treatments with abamectin, spiromesifen, or spinosad if monitoring indicates that psyllid populations are at one to two per leaf or ten per plant during the growing season (UC IPM Online, 2008). Further research by Gharalari et al. (2009) evaluated the knockdown effect for a variety of insecticides on *B. cockerelli* adults with thiamethoxam and abamectin being the most effective. The dosage and exposure time of abamectin can also significantly increase the mortality rates of *B. cockerelli* adults; however, after 24 h under field conditions the mortality rates on abamectin-treated potato plants are not significantly different from controls (Gharalari et al., 2009). Similar work has been conducted in Mexico and

New Zealand, which examined several compounds at the recommended fields and the subsequent impact on mortality of *B. cockerelli* nymphs (Vega-Gutierrez et al., 2008; Berry et al., 2009). In recent years, evaluations of selected biorational insecticides and kaolin particle film for the repellency of *B. cockerelli* have been examined in the laboratory and the field (Yang et al., 2010; Butler et al., 2011a; Peng et al., 2011). Results indicated reasonably good control (>50% for some psyllid stages) suggesting these materials are suitable for further investigation designed to incorporate them into integrated control programs.

### *Cultural control*

Cultural control refers to the purposeful manipulation of a cropping environment to reduce rates of pest increase and damage (Pedigo and Rice, 2006). For *B. cockerelli* management, this area of research has occasionally been investigated. These areas of research and observations have included the timing of crop planting, fertilization, trap crops, destruction of breeding sites, colored pesticide sprays, and mulches.

One of the first observations regarding timing of planting and damage by *B. cockerelli* was provided by Eyer and Enzie (1939). These authors observed that late-planted tomatoes and potatoes in New Mexico did not develop PY as severely as those planted earlier. Similar observations were noted by Starr (1939) and Hartman (1947) who noted that fields planted in Wyoming in early June appeared to be damaged less than fields planted before that time (Starr 1939, Hartman 1947). Wallis (1948) found that *B. cockerelli* populations were significantly higher in early plantings of potatoes in Wyoming and Nebraska compared to middle and late season plantings. Additional studies using current cultivars and modern production practices are clearly justified.

Eyer and Enzie (1939) also pointed out the possible value of fertilizers to correct the lack of chlorophyll and nitrates/nitrogen on *B. cockerelli* plant afflicted with PY, although no research studies regarding this have been formally conducted. In Colorado, pepper plants were recommended as an alternate trap crop for *B. cockerelli* to attract this pest from potatoes (Cranshaw, 1994). Starting in the 1930's, local practices recommended the removal of potential spring and early summer breeding places through the elimination of early potato plantings, non-economic solanaceous host plants such as *L. barbarum*, and volunteer potatoes in cull dumps to curtail *B. cockerelli* population buildups (Knowlton, 1934; Hill, 1947; Cranshaw, 1994). A single study regarding colored sprays has been investigated as a method to impact the number of *B. cockerelli* colonizing agricultural fields (Cranshaw and Liewehr, 1990). The study used the following compounds, which were sprayed on potatoes: yellow-colored maneb, white-colored chlorathalonil, and a white-colored inorganic insecticide sodium fluoaluminat; however results showed no significant differences in the captures of *B. cockerelli* in fields (Cranshaw and Liewehr, 1990). Colored mulches have offered promise as a cultural control method for *B. cockerelli* management in home garden tomato plants in Colorado as aluminum and white plastic mulches can be used to significantly decrease the population density of *B. cockerelli* on tomato (Demirel and Cranshaw, 2006).

### *Host plant resistance*

Similar to cultural control, studies regarding host plant resistance have seldom been investigated as a management technique for *B. cockerelli*. Host plant resistance refers to genetic resistance of plants to insects as categorized as antixenosis (inability of a plant to serve as a host for an arthropod), antibiosis (negative effects of a resistant plant that affect the biology an arthropod attempting to use that plant as a host) and tolerance (possessing the ability to withstand or recover from damage caused by arthropod populations equal to those on susceptible genotypes) (Smith, 2005). One of the first studies regarding host plant resistance involved examining potato varieties for tolerance to PY (Babb and Kraus, 1937). Results from the study by Babb and Kraus (1937) indicated that none of the thirty-nine varieties tested were immune to PY, and due to a lack of statistical analyses there was difficulty determining if the varieties were significantly more or less tolerant compared to each other. In field studies, Linford (1928) and Starr (1939) found that none of the commercial potato varieties tested exhibited enough resistance to *B. cockerelli* to provide a substantial benefit. Cranshaw (1989) found that for various varieties of potato, tomato, and pepper tested in Colorado fields that some varieties had increased numbers of *B. cockerelli*, but there was often an unclear relationship between the varieties preferred by *B. cockerelli* and the damage to the crop, suggesting that different varieties may need different thresholds.

The use of resistant varieties has been investigated as a management option against *B. cockerelli* in tomatoes (Liu and Trumble, 2004, 2005, 2006; Casteel et al., 2006, 2007). Some resistance by the *Mi-1.2* gene has been documented in tomatoes showing antixenosis (decreased host selection by *B. cockerelli* on plants with the resistant genotype) and antibiosis (significant decreases in survival of *B. cockerelli* reared on the resistant genotype) (Casteel et al., 2006). In addition, antixenosis (reported as decreased feeding and oviposition) and antibiosis (described as increased developmental time and decreases in survival) were observed for a wild-type accession tomato (PI 134417) when compared to the tomato varieties ‘7718 VFN’, ‘Yellow Pear’, ‘QualiT 21’, and ‘Shady Lady’ (Liu and Trumble, 2004, 2005, 2006). Butler et al. (2011b) documented changes in stylet penetration behaviors that reduced transmission in putatively resistant varieties from breeders in Texas and Idaho. However, reports of how effective these might be when incorporated into an IPM program are not yet available.

### *Biological control*

In North America, a number of natural enemies attack *B. cockerelli*. Generalist predators that attack *B. cockerelli* include chrysopid larvae (*Chrysoperla* spp.), various coccinellids (i.e., *Hippodamia convergens* Guerin-Meneville, *Hippodamia quinquesignata* (Kirby), *Hippodamia tredecimpunctata* (L.), and *Hippodamia americana* Crotch), syrphid fly larvae, and Hemiptera such as *Geocoris decoratus* Uhler, *Orius tristicolor* (White), *Anthocoris tomentosus* Pericart, *Deraeocoris brevis* (Uhler) and *Nabis ferus* (L.) (Knowlton 1933a,b, 1933c, 1934a,b; Knowlton and Allen, 1936; Romney, 1939; Pletsch, 1947). However, most of the observations of predators attacking *B. cockerelli* have been performed under artificial laboratory conditions, with the exception of

chrysopid larvae observed attacking *B. cockerelli* nymphs in Utah potato fields (Knowlton, 1933a) and the field observations by Butler (2011). Field observations by Romney (1939) indicated that coccinellids and chrysopids reduced the number of eggs and nymphs of *B. cockerelli* on *Lycium* spp. to varying degrees from year to year. Recent research by Butler (2011) found through two years of field studies (2009–2010) at four different sites and laboratory feeding tests, identified *O. tristicolor*, *Geocoris pallens* Stal (Hemiptera: Geocoridae), and *H. convergens* as key natural enemies of *B. cockerelli* in southern California potatoes, tomatoes, and bell peppers. The number of these natural enemies exhibited either significant positive or negative relationships with the number of *B. cockerelli* on these crop plants. Further tests to document the effects of natural enemies on *B. cockerelli* population dynamics using exclusion cage experiments in the potato crop and in American nightshade, *Solanum americanum* Miller, found the number of *B. cockerelli* surviving was significantly greater in the closed cage treatments (approximately 65% greater), thus confirming the impact natural enemies can have on *B. cockerelli*.

In the laboratory and in the field unknown species of *Chrysoperla* spp., *Chrysoperla carnea* (Stephens) and *Chrysoperla rufilabris* (Burmeister) have been further assessed as *B. cockerelli* predators (Pletsch, 1947; Al-Jabr, 1999). In laboratory experiments, *Chrysoperla* larvae can attack all life stages of *B. cockerelli* (Pletsch, 1947; Knowlton, 1933; Al-Jabr, 1999). Al-Jabr (1999) evaluated *C. carnea* and *C. rufilabris* as potential biological control agents of *B. cockerelli* and found they are capable of completing their entire life cycle on *B. cockerelli*. However, a field trial involving applications of *C. carnea* eggs to psyllid infested potatoes did not produce significant reductions in *B. cockerelli* numbers (Al-Jabr, 1999). Butler (2011) found numerous *Chrysoperla* spp. eggs in the field, but very few *Chrysoperla* spp. larvae; also the number of eggs or larvae of these predators did not correlate with the number of *B. cockerelli* that occurred on crop plants.

Natural enemies of *B. cockerelli* also include two primary parasitoids: *Metaphycus psyllidis* Compere (Hymenoptera: Encyrtidae), and *Tamarixia triozae* (Burks) (Hymenoptera: Eulophidae). Parasitism of *B. cockerelli* nymphs by *T. triozae* was noted for the first time by Romney (1939) on *Lycium* spp. in southern Arizona. *Metaphycus psyllidis* was described as a new *B. cockerelli* parasitoid species by Compere (1943). No follow-up work on *M. psyllidis* regarding its impact on *B. cockerelli* has been attempted since.

*Tamarixia triozae* has been found in the USA (Arizona, California, Colorado, Idaho, Kansas, Montana, New Mexico, and Washington) and recently in Mexico (Romney, 1939; Pletsch, 1947; Jensen, 1957; Lomeli-Flores and Bueno Partida, 2002). In a tomato field in Montana in 1939, 23% of the *B. cockerelli* nymphs were parasitized by *T. triozae*; although no parasitism was noted in the surrounding areas despite high *B. cockerelli* populations. Similar observations have been noted by Butler (2011) in which despite the presence of *T. triozae* in agricultural fields in southern California the percent parasitism was below 20%. Details regarding the life history of this parasitoid can be found in Pletsch (1947), and a list of additional psyllid species that *T. triozae* parasitizes can be found in Jensen (1957). In general, *T. triozae* attacks the fourth and fifth instars of *B. cockerelli* (Pletsch, 1947), and this parasitoid's dispersal can be rapid



at a distance limited to less than 1.5 m (Johnson, 1971). In the field, *T. triozae* is poorly synchronized with *B. cockerelli* populations and suffers high pupal mortality ranging from 38–100% (Johnson, 1971). In the laboratory, levels of parasitism were low averaging 13.2–26.5%, which is similar to parasitism rates found for other psyllid parasitoids (Jensen, 1957). Thus, Johnson (1971) finds control of *B. cockerelli* in agricultural settings with *T. triozae* unfeasible, but leaves the possibility of using this species as a biological control agent in the natural, overwintering areas of *B. cockerelli*. In addition, new records of *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae) and a single record tentatively identified as *Encarsia peltata* (Cockerell) (Hymenoptera: Aphelinidae) hyperparasitizing *T. triozae* have been documented on tomato and bell pepper plantings in southern California with proportions of parasitism between 5.3–6.9% (Butler and Trumble, 2011b). Despite this information, in New Zealand in 2006, *T. triozae* was imported from Mexico into quarantine for assessment as a potential biological control agent of *B. cockerelli* (Workman and Whiteman, 2009).

The entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin, *Isaria fumosorosea* (Wize), *Verticillium lecanii* (Zimmerman) and *Metarhizium anisopliae* (Metschnikoff) are known to attack *B. cockerelli* (Al-Jabr, 1999; Strand, 2006; Sanchez-Pena et al., 2007; Lacey et al., 2009, 2010). One of the first studies to document the effect of entomopathogenic fungi on *B. cockerelli* was conducted by Al-Jabr (1999). Under laboratory conditions, *B. bassiana* caused significant mortality (>82%) on *B. cockerelli* nymphs. Mixed results were obtained in the greenhouse with *B. bassiana*, *V. lecanii*, and *M. anisopliae* in terms of mortality on *B. cockerelli* nymphs on tomato (Al-Jabr, 1999). Studies by Sanchez-Pena (2007) testing *B. bassiana* and *M. anisopliae*, and Lacey et al. (2009) testing *B. bassiana*, *M. anisopliae*, and *I. fumosorosea* likewise demonstrated significant mortality on *B. cockerelli* in the laboratory compared to untreated controls. In field trials, Lacey et al. (2010) found fungal treatments of *M. anisopliae* and *I. fumosorosea* alone or in combination with insecticides caused significant reductions in *B. cockerelli* in southern Texas.

## Conclusions

Much research still needs to be conducted on the basic biology and control of this pest. While a number of symbionts have been identified, the role these may play in transmission of the ZC pathogen have not been elucidated. Similarly, research is needed to determine the possible impact of the *Ca. L. psyllaourous* on the fitness of the psyllid. The effects of the ZC pathogen on use and storage of potatoes destined for fresh market use versus frying/chipping is also largely unknown. Control strategies that are currently available tend to be relatively expensive and pesticide intensive, so economic evaluation of IPM programs that incorporate biological control agents, resistant varieties, and alternative suppression strategies are critically needed. We are aware that control strategies based on controlling the bacteria within the plant or production of transgenic plants with putative resistance are in progress, but no peer-reviewed studies were available at the time this was written. We still do not fully understand how these

pests are moving between countries and why the ZC pathogen is a huge problem in some locations but not in others. However, based on the intensive research efforts published in the past 10 years, and the remarkable interdisciplinary efforts of entomologists, plant pathologists, and epidemiologists, the overall outlook for management of this pest and its associated pathogen is promising.

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## References

- Abad, J. A., M. Bandla, R. D. French-Monar, L. W. Liefting and G. R. G. Clover. 2009. First report of the detection of '*Candidatus Liberibacter*' species in zebra chip disease-infected potato plants in the United States. *Plant Disease*. 93:108.
- Abdullah, N. M. M. 2008. Life history of the potato psyllid *Bactericera cockerelli* (Homoptera: Psyllidae) in controlled environment agriculture in Arizona. *African Journal of Agricultural Research* 3:60-67.
- Abernathy, R. L. 1991. Investigations into the nature of the potato psyllid toxin. Department of Entomology. M. S. Thesis, Colorado State University. Fort Collins, Colorado, USA. 54 pp.
- Al-Jabr, A. M. 1999. Integrated pest management of tomato/potato psyllid, *Paratrioza cockerelli* (Sulc) (Homoptera: Psyllidae) with emphasis on its importance in greenhouse grown tomatoes. Ph. D. Dissertation. Colorado State University. Fort Collins, Colorado, USA. 93 pp.
- Al-Jabr, A. M. and W. S. Cranshaw. 2007. Trapping tomato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Psyllidae), in greenhouses. *Southwestern Entomologist* 32:25-30.
- Anonymous. 1939. Psyllid yellows of potato in 1938. *Plant Disease Reporter* 23:2-4.
- Arslan, A., P. M. Bessey, K. Matsuda and N. F. Oebker. 1985. Physiological effects of psyllid (*Paratrioza cockerelli*) on potato. *American Potato Journal* 62:9-22.
- Babb, M. F. and J. E. Kraus. 1937. Tolerance of certain potato varieties to psyllid yellows. *Nebraska State Board of Agriculture Report* 1937:694-698.
- Baumann, P. 2005. Biology bacteriocyte-associated endosymbionts of plant sap-sucking insects. *Annual Review of Microbiology* 59:155-189.
- Berry, N. A., M. K. Walker and R. C. Butler. 2009. Laboratory studies to determine the efficacy of selected insecticides on tomato/potato psyllid. *New Zealand Plant Protection* 62:145-151.
- Brown, J. K., M. Rehman, D. Rogan, R. R. Martin and A. M. Idris. 2010. First report of "*Candidatus Liberibacter psyllaurosus*" (synonym "*Ca. L. solanacearum*") associated with 'tomato vein-greening' and 'tomato psyllid yellows' diseases in commercial greenhouses in Arizona. *Plant Disease* 94:376.
- Buchner, P. 1965. [Endosymbiosis of animals with plant microorganisms]. Interscience Publishers, New York, New York, USA. 909 pp.
- Burckhardt, D. and P. Lauterer. 1997. A taxonomic reassessment of the triozid genus *Bactericera* (Hemiptera: Psylloidea). *Journal of Natural History* 31:99-153.
- Butler, C. D. 2011. Management strategies for the potato psyllid in California. Ph. D. Dissertation. University of California, Riverside. Riverside, California, USA. 192 pp.
- Butler, C. D. and J. T. Trumble. 2011a. Spatial dispersion and binomial sequential sampling for the potato psyllid (Hemiptera: Triozidae) on potato. *Pest Management Science* 68:(in press).

- Butler, C. D. and J. T. Trumble. 2011b. New records of hyperparasitism of *Tamarixia triozae* (Burks) by *Encarsia* spp. in California. *The Pan-Pacific Entomologist* 87:130-133.
- Butler, C. D., F. J. Byrne, M. L. Keremane, R. F. Lee and J. T. Trumble. 2011a. Effects of insecticides on behavior of adult *Bactericera cockerelli* (Hemiptera: Trioziidae) and transmission of *Candidatus Liberibacter psyllae*. *Journal of Economic Entomology* 104:586-594.
- Butler, C. D., B. Gonzalez, K. L. Manjunath, R. F. Lee, R. G. Novy, J. C. Miller and J. T. Trumble. 2011b. Behavioral responses of adult potato psyllid, *Bactericera cockerelli* (Hemiptera: Trioziidae), to potato germplasm and transmission of *Candidatus Liberibacter psyllae*. *Crop Protection* 30:1233-1238.
- Butler, C. D., G.P. Walker and J. T. Trumble. 2012. Feeding disruption of potato psyllid, *Bactericera cockerelli*, by imidacloprid as measured by electrical penetration graphs. *Entomologia Experimentalis et Applicata* 142:247-257.
- Carter, W. 1939. Injuries to plants caused by insect toxins. *Botanical Review* 5:273-326.
- Carter, W. 1973. *Insects in relation to plant disease*, 2nd edition. John Wiley & Sons, New York, New York, USA. 759 pp.
- Casteel, C. L., L. L. Walling and T. D. Paine. 2006. Behavior and biology of the tomato psyllid, *Bactericera cockerelli*, in response to the *Mi-1.2* gene. *Entomologia Experimentalis et Applicata* 121:67-72.
- Casteel, C. L., L. L. Walling, and T. D. Paine. 2007. Effect of *Mi-1.2* gene in natal host plants on behavior and biology of the tomato psyllid *Bactericera cockerelli* (Sulc) (Hemiptera: Psyllidae). *Journal of Entomological Science* 42:155-162.
- Compere, H. 1915. *Paratrioza cockerelli* (Sulc). *Monthly Bulletin of the California State Commission of Horticulture* 4:12.
- Compere, H. 1916. Notes on the tomato psylla. *Monthly Bulletin of the California State Commission of Horticulture* 5:189-191.
- Compere, H. 1943. A new species of *Metaphycus* parasite on psyllids. *Pan-Pacific Entomologist* 19:71-73.
- (CNAS) Center for North American Studies. 2006. Economic impacts of zebra chip on the Texas potato industry. <http://cnas.tamu.edu/zebra%20chip%20impacts%20final.pdf> (Accessed on 11/2011).
- Cranshaw, W. S. 1985a. Control of potato psyllid and green peach aphid, Ft. Collins, Colorado, USA, 1984. *Insecticide and Acaricide Tests* 10:132.
- Cranshaw, W. S. 1985b. Control of potato insects with soap sprays, Greenley, Colorado, USA. 1984. *Insecticide and Acaricide Tests* 10:132.
- Cranshaw, W. S. 1989a. Potato insect control, 1986. *Insecticide and Acaricide Tests* 14:136.
- Cranshaw, W. S. 1989b. Potato insect control, 1987. *Insecticide and Acaricide Tests* 14:136.
- Cranshaw, W. S. 1989c. The potato/tomato psyllid as a vegetable insect pest., pp. 69-76. *In*, Proceedings of the 18<sup>th</sup> annual meeting of the Crop Protection Institute, Colorado State University, Fort Collins, Colorado, USA.
- Cranshaw, W. S. 1993. An annotated bibliography of potato/tomato psyllid, *Paratrioza cockerelli* (Sulc) (Homoptera; Psyllidae). Colorado Agricultural Experiment Station Bulletin TB93-5. 51 pp.
- Cranshaw, W. S. 1994. The potato (tomato) psyllid, *Paratrioza cockerelli* (Sulc), as a pest of potatoes, pp. 83-95. *In*, G. W. Zehnder, R. K. Powelson, R. K. Jansson and K. V. Raman (eds.), *Advances in potato biology and management*. APS Press, St. Paul, Minnesota, USA. 655 pp.
- Cranshaw, W. S. and D. J. Liewehr. 1990. Effects of colored sprays on aphid and psyllid colonization of potatoes. *Southwestern Entomologist* 15:205-209.
- Crawford, D. L. 1910. American Psyllidae I. (Trioziinae). *Pomona Journal of Entomology* 2:228-237.
- Crawford, D. L. 1911. American Psyllidae III. (Trioziinae). *Pomona Journal of Entomology* 3: 421-453.
- Crawford, D. L. 1914. A monograph on the jumping plant-lice of the new world. *United States National Museum Bulletin* 85. 186 pp.
- Crosslin, J. M. and G. Bester. 2009. First report of '*Candidatus Liberibacter psyllae*' in zebra chip symptomatic potatoes from California. *Plant Disease* 93:551.

- Crosslin, J. M., J. E. Munyaneza, J. K. Brown and L. W. Liefting. 2010. A history in the making: potato zebra chip disease associated with a new psyllid-borne bacterium—a tale of striped potatoes. <http://www.apsnet.org/publications/apsnetfeatures/Pages/PotatoZebraChip.aspx>. (Accessed on 1/2011).
- Daniels, L. B. 1954. The nature of the toxicogenic condition resulting from the feeding of the tomato psyllid *Paratrioza cockerelli* (Sulc). Ph.D. Dissertation. University of Minnesota, St. Paul, Minnesota, USA. 119 pp.
- Davis, A. C. 1937. Observations on the life history of *Paratrioza cockerelli* (Sulc) in southern California. *Journal of Economic Entomology* 30:377-378.
- Davidson, M. M., D. A. J. Teulon, I. A. W. Scott and P. Workman. 2008. A review of the potato psyllid (*Bactericera cockerelli*); a new pest of potato in New Zealand., p. 14, *Crop & Food Research Confidential Report No. 2231*.
- Demirel, N. and W. Cranshaw. 2006. Relative effect of color mulches to potato/tomato psyllid, *Paratrioza cockerelli* (Sulc) (Homoptera: Psyllidae), on garden tomato plants. *Journal of Economic Entomology* 3:189-193.
- (ESA) Entomological Society of America. 2011. Common names of insects database. Entomological Society of America at: <http://www.entsoc.org/common-names> (Accessed on 10/2011).
- Essig, E. O. 1917. The tomato and laurel psyllids. *Journal of Economic Entomology* 10:433-444.
- Eyer, J. R. 1937. Physiology of psyllid yellows of potatoes. *Journal of Economic Entomology* 30:891-898.
- Eyer, J. R. and J. V. Enzie. 1939. Dusting and spraying for the control of insect pests of the Irish potato. *New Mexico College of Agriculture and Mechanic Arts. Agricultural Experiment Station Bulletin* 266. 40 pp.
- Eyer, J. R. and M. Miller. 1937. A study of the pathological anatomy of psyllid yellows with special reference to similar changes in sugar beets affected with curly top. *Phytopathology*. 28:669.
- Eyer, J. R. and R. F. Crawford. 1933. Observations on the feeding habits of the potato psyllid (*Paratrioza cockerelli* Sulc) and the pathological history of the “psyllid yellows” which it produces. *Journal of Economic Entomology* 26:846-853.
- Ferguson, G., E. Banks and H. Fraser. 2002. Potato psyllid - a new pest in greenhouse tomatoes and peppers., Ontario Ministry of Food and Agriculture, Canada, Ontario, Canada. [http://www.omafra.gov.on.ca/english/crops/facts/potato\\_psyllid.htm](http://www.omafra.gov.on.ca/english/crops/facts/potato_psyllid.htm). (Accessed on 1/2011).
- Ferris, G. F. 1925. Observations on the Chermidae (Hemiptera; Homoptera). Part II. *Canadian Entomologist* 57:46-50.
- French-Monar, R. D., A. F. Patton III, J. M. Douglas, J. A. Abad, G. Schuster, R. W. Wallace and T. A. Wheeler. 2010. First report of “*Candidatus Liberibacter solanacearum*” on field tomatoes in the United States. *Plant Disease* 94:481.
- Gao, F., J. Jifon, X. Yang and T.-X. Liu. 2009. Zebra chip disease incidence on potato is influenced by timing of potato psyllid infestation, but not by the host plants on which they were reared. *Insect Science* 16:399-408.
- Gerhardt, P. D. 1966. Potato psyllid and green peach aphid control on Kennebec potatoes with Temik® and other insecticides. *Journal of Economic Entomology* 59:9-11.
- Gerhardt, P. D. and D. L. Turley. 1961. Control of certain potato insects in Arizona with soil applications of granulated phorate. *Journal of Economic Entomology* 54:1217-1221.
- Gharalari, A. H., C. Nansen, D. S. Lawson, J. Gilley, J. E. Munyaneza and K. Vaughn. 2009. Knockdown mortality, repellency, and residual effects of insecticides for control of adult *Bactericera cockerelli* (Hemiptera: Psyllidae). *Journal of Economic Entomology* 102:1032-1038.
- Gill, G. 2006. Tomato psyllid detected in New Zealand. *Biosecurity* 69:10-11.
- Glick, P. A. 1939. The distribution of insects, spiders, and mites in the air. *USDA Technical Bulletin* 673. 150 pp.
- Goolsby, J. A., B. Bextine, J. E. Munyaneza, M. Setamou, J. Adamczyk and G. Bester. 2007a. Seasonal abundance of sharpshooters, leafhoppers, and psyllids associated with potatoes affected by zebra chip disorder. *Subtropical Plant Science* 59:15-23.

- Goolsby, J. A., J. Adamczyk, B. Bextine, D. Lin, J. E. Munyaneza and G. Bester. 2007b. Development of an IPM program for management of the potato psyllid to reduce incidence of zebra chip disorder in potatoes. *Subtropical Plant Science* 59:85-94.
- Guedot, C., D. R. Horton and P. J. Landolt. 2010. Sex attraction in *Bactericera cockerelli* (Hemiptera: Psyllidae). *Environmental Entomology* 39:1302-1308.
- Hansen, A. K., J. T. Trumble, R. Stouthamer and T. D. Paine. 2008. A new Huanglongbing, “*Candidatus Liberibacter psyllauros*,” found to infect tomato and potato, is vectored by the psyllid *Bactericera cockerelli* (Sulc). *Applied and Environmental Microbiology* 74:5862-5865.
- Harding, J. A. 1962. Tests with systemic insecticides for control of insects and certain diseases on potato. *Journal of Economic Entomology* 55:62-65.
- Hartman, G. 1937. A study of psyllid yellows in Wyoming. Wyoming Agricultural Experiment Station Bulletin 220. 39 pp.
- Henne, D. C., F. Workneh, A. Wen, J. A. Price, J. S. Pasche, N. C. Gudmestad and C. M. Rush. 2010. Characterization and epidemiological significance of potato plants grown from seed tubers affected by zebra chip disease. *Plant Disease* 94:659-665.
- Hill, R. E. 1945. Effects of DDT and other insecticides on several species of potato insects. Nebraska Agricultural Station Research Bulletin 138. 14 pp.
- Hill, R. E. 1947. An unusual weather sequence accompanying the severe potato psyllid outbreak of 1938 in Nebraska. *Journal of the Kansas Entomological Society* 20:88-92.
- Hodkinson, I. D. 2009. Life cycle variation and adaptation in jumping plant lice (Insecta: Hemiptera: Psylloidea): a global synthesis. *Journal of Natural History* 43:65-179.
- Jackson, B. C., J. Goolsby, A. Wzyzkowski, N. Vitovksy and B. Bextine. 2009. Analysis of genetic relationships between potato psyllid (*Bactericera cockerelli*) populations in the United States, Mexico and Guatemala using ITS2 and inter simple sequence repeat (ISSR) data. *Subtropical Plant Science* 61:1-5.
- Jensen, D. D. 1954. Notes on the potato psyllid, *Paratrioza cockerelli* (Sulc). *Pan-Pacific Entomologist* 30:161-165.
- Jensen, D. D. 1957. Parasites of the Psyllidae. *Hilgardia*. 27:71-99.
- Jensen, J. H. 1939. Psyllid yellows in Nebraska – 1938. *Plant Disease Reports* 23:35-36.
- Johnson, T. E. 1971. The effectiveness of *Tetrastichus triozae* Burks (Hymenoptera: Eulophidae) as a biological control agent of *Paratrioza cockerelli* (Sulc) (Homoptera: Psyllidae) in north central Colorado. M. S. Thesis. Colorado State University. Fort Collins, Colorado, USA. 45 pp.
- Knowlton, G. F. 1931. Some economic insects of Utah-1931. *Proceedings of the Utah Academy of Sciences* 8:143-146.
- Knowlton, G. F. 1933a. Aphis lion predators of the potato psyllid. *Journal of Economic Entomology* 26:977.
- Knowlton, G. F. 1933b. Ladybird beetles as predators of the potato psyllid. *Canadian Entomologist* 65:241-243.
- Knowlton, G. F. 1933c. Length of adult life of *Paratrioza cockerelli* (Sulc). *Journal of Economic Entomology* 26:730.
- Knowlton, G. F. 1933d. Notes on injurious Utah insects: potato psyllid. *Proc. Utah Acad. Sci.* 10:153.
- Knowlton, G. F. 1934a. A big-eyed bug predator of the potato psyllid. *Florida Entomologist* 18:40-43.
- Knowlton, G. F. 1934b. Potato psyllid investigations. *Proceedings of the Utah Academy of Sciences* 11:261-265.
- Knowlton, G. F. and M. A. Allen. 1936. Three hemipterous predators of the potato psyllid. *Proceedings of the Utah Academy of Sciences* 13:293-294.
- Knowlton, G. F. and M. J. Janes. 1931. Studies on the biology of *Paratrioza cockerelli* (Sulc). *Ann. Entomol. Soc. Am.* 24: 283-291.
- Knowlton, G. F. and W. L. Thomas. 1934. Host plants of the potato psyllid. *Journal of Economic Entomology* 27:547.
- Lacey, L. A., F. de la Rosa and D. R. Horton. 2009. Insecticidal activity of entomopathogenic fungi (Hypocreales) for potato psyllid, *Bactericera cockerelli* (Hemiptera: Trioziidae): development of

- bioassay techniques, effect of fungal species and stage of the psyllid. *Biocontrol Science and Technology* 19:957-970.
- Lacey, L. A., T.-X. Liu, J. L. Buchman, J. E. Munyaneza, J. A. Goolsby and D. R. Horton. 2011. Entomopathogenic fungi (Hypocreales) for control of potato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Trioizidae) in an area endemic for zebra chip disease of potato. *Biological Control* 56:271-278.
- Lehman, R. S. 1930. Some observations on the life history of the tomato psyllid (*Paratrioza cockerelli* Sulc) (Homoptera). *Journal of the New York Entomological Society* 38:307-312.
- Li, W., J. A. Abad, R. D. French-Monar, J. Rascoe, A. Wen, N. C. Gudmestad, G. A. Secor, I.-M. Lee, Y. Duan and L. Levy. 2009. Multiplex real-time PCR for detection, identification and quantification of 'Candidatus Liberibacter solanacearum' in potato plants with zebra chip. *Journal of Microbiological Methods* 78:59-65.
- Liefting, L. W., L. I. Ward, J. B. Shiller and G. R. G. Clover. 2008a. A new 'Candidatus Liberibacter' species in *Solanum betaceum* (tamarillo) and *Physalis peruviana* (cape gooseberry) in New Zealand. *Plant Disease* 92:1588.
- Liefting, L. W., P. W. Sutherland, L. I. Ward, K. L. Paice, B. S. Weir and G. R. G. Clover. 2009. A new 'Candidatus Liberibacter' species associated with diseases of solanaceous crops. *Plant Disease* 93:208-214.
- Liefting, L. W., Z. C. Perez-Egusquiza, G. R. G. Clover and J. A. D. Anderson. 2008b. A new 'Candidatus Liberibacter' species in *Solanum tuberosum* in New Zealand. *Plant Disease* 92:1474.
- Lin, H., B. Lou, J. M. Glynn, H. Doddapneni, E. L. Civerolo, C. Chen, Y. Duan, L. Zhou and C. M. Vahling. 2011. The complete genome sequence of 'Candidatus Liberibacter solanacearum', the bacterium associated with potato zebra chip disease. *PLoS ONE*. 6:1-13.
- Lin, H., H. Doddapneni, J. E. Munyaneza, E. L. Civerolo, V. G. Sengoda, J. L. Buchman and D. C. Stenger. 2009. Molecular characterization and phylogenetic analysis of 16S rRNA from a new "Candidatus Liberibacter" strain associated with zebra chip disease of potato (*Solanum tuberosum* L.) and the potato psyllid (*Bactericera cockerelli* Sulc). *Journal of Plant Pathology* 1:215-219.
- Linford, M. B. 1928. Psyllid-yellows (cause undetermined). *Plant Disease Report Supplement* 59: 95-99.
- List, G. M. 1918. A test of lime sulphur and nicotine sulfate for the control of the tomato psyllid and effect of these materials upon plant growth. *Ninth Annual Report of the State Entomologist of Colorado*. 1917. 47: 16.
- List, G. M. 1935. Psyllid yellows of tomatoes and control of the psyllid, *Paratrioza cockerelli* Sulc, by use of sulphur. *Journal of Economic Entomology* 28:431-436.
- List, G. M. 1938. Tests of certain materials as controls for the tomato psyllid, *Paratrioza cockerelli* (Sulc), and psyllid yellows. *Journal of Economic Entomology* 31:491-497.
- List, G. M. 1939. The effect of temperature upon egg deposition, egg hatch and nymphal development of *Paratrioza cockerelli* (Sulc). *Journal of Economic Entomology* 32:30-36.
- List, G. M. and L. B. Daniels. 1934. A promising control for psyllid yellows of potatoes. *Science* 79:79.
- Liu, D. and J. T. Trumble. 2004. Tomato psyllid behavioral responses to tomato plant lines and interactions of plant lines with insecticides. *Journal of Economic Entomology* 97:1078-1085.
- Liu, D. and J. T. Trumble. 2005. Interactions of plant resistance and insecticides on the development and survival of *Bactericera cockerelli* [Sulc] (Homoptera: Psyllidae). *Crop Protection* 24:111-117.
- Liu, D. and J. T. Trumble. 2006. Ovipositional preferences, damage thresholds, and detection of the tomato-potato psyllid *Bactericera cockerelli* (Homoptera: Psyllidae) on selected tomato accessions. *Bulletin of Entomological Research* 96:197-204.
- Liu, D., and J. T. Trumble. 2007. Comparative fitness of invasive and native populations of the potato psyllid (*Bactericera cockerelli*). *Entomologia Experimentalis et Applicata* 123:35-42.
- Liu, D., J. T. Trumble and R. Stouthamer. 2006a. Genetic differentiation between eastern populations and recent introductions of potato psyllid (*Bactericera cockerelli*) into western North America. *Entomologia Experimentalis et Applicata* 118:177-183.

- Liu, D., L. Johnson and J. T. Trumble. 2006b. Differential responses to feeding by the tomato/potato psyllid between two tomato cultivars and their implications in establishment of injury levels and potential of damaged plant recovery. *Insect Science* 13:195-204.
- Lomeli-Flores, J. R. and R. Bueno Partida. 2002. New record of *Tamarixia triozae* (Burks), parasitoid of the tomato psyllid *Paratrioza cockerelli* (Sulc) (Homoptera: Psyllidae) in Mexico. *Folia Entomológica Mexicana* 41:375-376.
- McKenzie, C. L. and R. G. Shatters Jr. 2009. First report of “*Candidatus Liberibacter psyllaurosus*” associated with psyllid yellows of tomato in Colorado. *Plant Disease* 93:1074.
- Metzger, C. H. 1936. Some preliminary notes on the effect of psyllid yellows on seed stock from infected plants. *American Potato Journal* 13:277-285.
- Miles, G. P., J. L. Buchman and J. E. Munyaneza. 2009. Impact of zebra chip disease on the mineral content of potato tubers. *American Journal of Potato Research* 86:481-489.
- Miles, G. P., M. A. Samuel, J. Chen, E. L. Civerolo and J. E. Munyaneza. 2010. Evidence that cell death is associated with zebra chip disease in potato tubers. *American Journal of Potato Research* 87:337-349.
- Morris, H. E. 1939. Psyllid yellows in Montana in 1938. *Plant Disease Report* 23:18-19.
- Munyaneza, J. E. 2010. Psyllids as vectors of emerging bacterial diseases of annual crops. *Southwestern Entomologist* 35:471-477.
- Munyaneza, J. E., J. A. Goolsby, J. M. Crosslin and J. E. Upton. 2007a. Further evidence that zebra chip potato disease in the Lower Rio Grande Valley of Texas is associated with *Bactericera cockerelli*. *Subtropical Plant Science* 59:30-37.
- Munyaneza, J. E., J. L. Buchman, J. E. Upton, J. A. Goolsby, J. M. Crosslin, G. Bester, G. P. Miles and V. G. Sengoda. 2008. Impact of different potato psyllid populations on zebra chip disease incidence, severity, and potato yield. *Subtrop. Plant Science* 60:27-37.
- Munyaneza, J. E., J. M. Crosslin and J. E. Upton. 2007b. Association of *Bactericera cockerelli* (Homoptera: Psyllidae) with “zebra chip,” a new potato disease in southwestern United States and Mexico. *Journal of Economic Entomology* 100:656-663.
- Munyaneza, J. E., J. M. Crosslin, and J. L. Buchman. 2009a. Seasonal occurrence and abundance of the potato psyllid, *Bactericera cockerelli*, in south central Washington. *American Journal of Potato Research* 86: 513-518.
- Munyaneza, J. E., V. G. Sengoda, J. M. Crosslin, A. Garzon-Tiznado and O. G. Cardenas-Valenzuela. 2009b. First report of “*Candidatus Liberibacter solanacearum*” in pepper plants in Mexico. *Plant Disease* 93:1076.
- Munyaneza, J. E., V. G. Sengoda, J. M. Crosslin, A. Garzon-Tiznado and O. G. Cardenas-Valenzuela. 2009c. First report of “*Candidatus Liberibacter solanacearum*” in tomato plants in Mexico. *Plant Disease* 93:1076.
- Munyaneza, J. E., V. G. Sengoda, J. M. Crosslin, G. De la Rosa-Lozano and A. Sanchez. 2009d. First report of ‘*Candidatus Liberibacter psyllaurosus*’ in potato tubers with zebra chip disease in Mexico. *Plant Disease* 93:552.
- Nachappa, P., J. Levy, E. Pierson and C. Tamborindeguy. 2011. Diversity of endosymbionts in the potato psyllid, *Bactericera cockerelli* (Hemiptera: Triozidae), vector of zebra chip disease of potato. *Current Microbiology* 62:1510-1520.
- Navarre, D. A., R. Shakya, J. Holden and J. M. Crosslin. 2009. LC-MS analysis of phenolic compounds in tubers showing zebra chip symptoms. *American Journal of Potato Research* 86:88-95.
- Nelson, W. R., T. W. Fisher, and J. E. Munyaneza. 2011. Haplotypes of “*Candidatus Liberibacter solanacearum*” suggest long-standing separation. *European Journal of Plant Pathology* 130:5-12.
- Pack, H. J. 1930. Notes on miscellaneous insects of Utah. *Utah Agricultural Experiment Station Bulletin* 216. 32 pp.
- Papp, R. P. and J. B. Johnson. 1979. Origins of psyllid fallout in the Central Sierra Nevada of California (Homoptera). *Pan-Pacific Entomologist* 55:95-98.
- Pedigo, L. P., and M. E. Rice. 2006. *Entomology and Pest Management*. 5th Edition. Pearson Prentice Hall, Upper Saddle River, New Jersey, USA. 784 pp.

- Peng, L., J. T. Trumble, J. E. Munyaneza and T.-X. Liu. 2011. Repellency of a kaolin particle film to potato psyllid, *Bactericera cockerelli* (Hemiptera: Psyllidae), on tomato under laboratory and field conditions. *Pest Management Science* 67:815-824.
- Pletsch, D. J. 1942. The effect of some insecticides on the immature stages of the potato and tomato psyllid, *Paratrioza cockerelli* (Sulc). *Journal of Economic Entomology* 35:58-60.
- Pletsch, D. J. 1947. The potato psyllid *Paratrioza cockerelli* (Sulc), its biology and control. Montana Agricultural Experiment Station Bulletin 446. 95 pp.
- Rehman, M., J. Melgar, C. Rivera, N. Urbina, A. M. Idris and J. K. Brown. 2010. First report of “*Candidatus Liberibacter psyllaerous*” or “*Ca. Liberibacter solanacearum*” associated with severe foliar chlorosis, curling, and necrosis and tuber discoloration of potato plants in Honduras. *Plant Disease* 94:376.
- Richards, B. L. 1928. A new and destructive disease of the potato in Utah and its relation to the potato psylla. *Phytopathology* 18:140-141.
- Richards, B. L. 1929. Psyllid yellows (cause undetermined). *Plant Disease Report Supplement* 68:28-30.
- Richards, B. L. 1931. Further studies with psyllid yellows of the potato. *Phytopathology* 21:103.
- Richards, B. L. and H. L. Blood. 1933. Psyllid yellows of the potato. *Journal of Agricultural Research* 46:189-216.
- Richards, B. L., H. L. Blood and M. B. Linford. 1927. Destructive outbreak of unknown potato disease in Utah. *Plant Disease Report* 11:93-94.
- Romney, V. E. 1939. Breeding areas of the tomato psyllid, *Paratrioza cockerelli* (Sulc). *Journal of Economic Entomology* 32:150-151.
- Rowe, J. A. and G. F. Knowlton. 1935. Studies upon the morphology of *Paratrioza cockerelli* (Sulc). *Proceedings of the Utah Academy of Science* 12:233-239.
- Sanchez-Pena, S. R., E. Casas-De-Hoyo, R. Hernandez-Zul and K. M. Wall. 2007. A comparison of the activity of soil fungal isolates against three insect pests. *Journal of Agricultural and Urban Entomology* 24:43-47.
- Schaal, L. A. 1938. Some factors affecting the symptoms of the psyllid yellows disease of potatoes. *American Potato Journal* 15:193-206.
- Secor, G. A. and V. V. Rivera-Varas. 2004. Emerging diseases of cultivated potato and their impact on Latin America. *Revista Latinoamericana de la Papa (Supplement)* 1:1-18.
- Secor, G. A., V. V. Rivera, J. A. Abad, I.-M. Lee, G. R. G. Clover, L. W. Liefting, X. Li, and S. H. De Boer. 2009. Association of ‘*Candidatus Liberibacter solanacearum*’ with zebra chip disease of potato established by graft and psyllid transmission, electron microscopy, and PCR. *Plant Disease* 93:574-583.
- Smith, C. M. 2005. *Plant Resistance to Arthropods: Molecular and Conventional Approaches*. Springer. Dordrecht, The Netherlands. 423 pp.
- Starr, G. H. 1939. Psyllid yellows unusually severe in Wyoming. *Plant Disease Report* 23:2-3.
- Strand, L. L. 2006. *Integrated Pest Management for Potatoes in the Western United States*. University of California, Oakland, California, USA. 167 pp.
- Sulc, K. 1909. *Trioza cockerelli* n.sp., a novelty from North America, being also of economic importance. *Acta Societatis Entomologicae Bohemiae* 6:102-108.
- Tate, H. D. and R. E. Hill. 1944. Residual toxicity of sulfur to the potato psyllid in greenhouses. *Journal of Economic Entomology* 37:57-558.
- Teulon, D. A. J., P. J. Workman, K. L. Thomas and M.-C. Nielsen. 2009. *Bactericera cockerelli*: incursion, dispersal and current distribution on vegetable crops in New Zealand. *New Zealand Plant Protection* 62:136-144.
- Tuthill, L. D. 1945. Contributions to the knowledge of the Psyllidae of Mexico. *Kansas Entomological Society* 18:1-29.
- UC IPM Online. 2008. Potato psyllid. <http://www.ipm.ucdavis.edu/PMG/r607300811.html>. (Accessed 10/2011)
- Van Driesche, R., M. Hoddle and T. Center. 2008. *Control of Pests and Weeds by Natural Enemies: An Introduction to Biological Control*. Blackwell Publishing Ltd. Oxford, UK. 473 pp.



- Vega-Gutierrez, M. T., J. C. Rodriguez-Maciell, O. Diaz-Gomez, R. Bujanos-Muniz, D. Mota-Sanchez, J. L. Martinez-Carrillo, A. Lagunes-Tejeda and J. A. Garzon-Tiznado. 2008. Susceptibility to insecticides in two Mexican populations of tomato-potato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Trioziidae). *Agrociencia* 42:463-471.
- Wallis, R. L. 1946. Seasonal occurrence of the potato psyllid in the North Platte Valley. *Journal of Economic Entomology* 39:689-694.
- Wallis, R. L. 1948. Time of planting potatoes as a factor in prevention of potato psyllid attack. *Journal of Economic Entomology* 41:4-5.
- Wallis, R. L. 1951. Potato psyllid selection of host plants. *Journal of Economic Entomology* 44:815-817.
- Wallis, R. L. 1955. Ecological studies on the potato psyllid as a pest of potatoes. USDA Technical Bulletin 1107. 25 pp.
- Wen, A., I. Mallik, V. Y. Alvarado, J. S. Pasche, X. Wang, H. Lin, H. B. Scholthof, T. E. Mirkov, C. M. Rush and N. C. Gudmestad. 2009. Detection, distribution, and genetic variability of 'Candidatus Liberibacter' species associated with zebra complex disease of potato in North America. *Plant Disease* 93:1102-1115.
- Workman, P. J. and S. A. Whiteman. 2009. Importing *Tamarixia triozae* into containment in New Zealand. *New Zealand Plant Protection Society* 62:412.
- Yang, X.-B. and T.-X. Liu. 2009. Life history and life tables of *Bactericera cockerelli* (Homoptera: Psyllidae) on eggplant and bell pepper. *Environmental Entomology* 38:1661-1667.
- Yang, X.-B., Y.-M. Zhang, L. Hua and T.-X. Liu. 2010a. Life history and life tables of *Bactericera cockerelli* (Hemiptera: Psyllidae) on potato under laboratory and field conditions in the Lower Rio Grande Valley of Texas. *Journal of Economic Entomology* 103:1729-1734.
- Yang, X.-B., Y.-M. Zhang, L. Hua, L.-N. Peng, J. E. Munyaneza, J. T. Trumble and T.-X. Liu. 2010b. Repellency of selected biorational insecticides to potato psyllid, *Bactericera cockerelli* (Hemiptera: Psyllidae). *Crop Protection* 29:1320-1324.