Final report

Aphid monitoring in the South African Potato Industry

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2014
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EXECUTIVE SUMMARY

1. Establishment of a national aphid monitoring network. Aphid monitoring efforts from different seed potato-growing regions in South Africa were consolidated to establish a long-term national aphid monitoring network for seed potato growers in South Africa. The PSA network comprises nine standardized Rothamsted-type suction traps situated in major seed potato-production regions. The South African suction trap network is based on the UK network, whose extensive aphid monitoring programme has been running successfully for 50 years and has subsequently been adopted by other European countries and the U.S.A., for example (Irwin et al., 2007). The South African network and associated database are intended to serve as an early warning system to alert growers to the commencement of aphid flight and increased risk of PVY and PLRV transmission during aphid activity periods and thus to assist in making management decisions regarding location and timing of aphid control measures. The long-term goal is to provide an aphid forecasting system. Four further suction traps were added to expand the network for monitoring aphids in wheat. First data on longer-term trends (several years) in aphid flight and abundance (number of aphids) patterns are available. It is important to maintain the network and associated database as the information will be used to predict the risk of PVY/PLRV transmission as well as for studies on how climate and cropping systems affect aphid vector abundance, flight activity, etc.

2. Water-deficit stress and high temperature: potato-aphid and potato-aphid-parasitoid interactions. The effect of changes in climatic conditions such as drought (water-deficit stressed plants) and heat stress (high day-night temperature) was evaluated based on the interaction between potato (Solanum tuberosum, Solanaceae), the potato aphid, Macrosiphum euphorbiae (Hemiptera: Aphididae), and the parasitoid Aphidius ervi (Hymenoptera: Braconidae). The growth rate of M. euphorbiae was negatively affected by high day-night temperatures. High day-night temperatures and drought may reduce the effectiveness of the aphid parasitoid A. ervi in controlling M. euphorbiae because mortality of the parasitoid increased and reproduction decreased at high day-night temperatures and drought compared to ambient day-night temperatures.

3. Identification of potential crop border plants. Maize and wheat were evaluated as potential crop border plants in a laboratory study. The results suggest that maize could be used as a crop border plant in seed potato production regions where R. padi is abundant, due to high aphid landing in comparison to potato, and low reproduction rates in comparison to wheat. A suitable crop border plant should be a preferred host plant and cultivar of the dominant aphid vector species in a seed potato production region, reflect a higher percentage of light in the green-yellow wavelength region than the main crop, and the volatile profiles should preferably not contain compounds that are known to repel the aphid vector.

4. Transmission of PVYN\textsuperscript{NTN}. Macrosiphum euphorbiae transmitted the PVYN\textsuperscript{NTN-GP} isolate in contrast to R. padi and B. brassicae. The results have been incorporated in the overall mean relative efficiency factor value for PVY for these species. The mean value has been included in the calculation of the vector pressure indices for different seed-potato growing regions in South Africa. The calculation of the cumulative vector pressure for a season aids seed potato farmers in assessing the risk of viruses spreading to their potato fields.
1. BACKGROUND

Potato virus Y (PVY) and Potato leafroll virus (PLRV) lead to loss of yield and quality resulting from an increase in undersized potato tubers (PVY), while infection with PLRV induces net necrosis in tubers. Infection with these viruses leads to a downgrading of seed lots because of the low tolerances required by seed certification programmes for high quality seed (e.g. South African Seed Certification Scheme, 2010). The production of potatoes is dependent on the availability of virus-free seed potatoes.

Seed potatoes in South Africa are grown under a variety of conditions, ranging from the west coast of the Western Cape with its sandy soils and Mediterranean climate to KwaZulu-Natal on the east coast, which has a subtropical climate. The Western Cape is situated in the winter rainfall region and is characterized by hot dry summers and wet winters. It includes the Fynbos and Succulent Karoo as major vegetation types in seed potato producing regions. There is no frost, and seed potatoes are planted during the austral autumn in March (winter crop). In contrast, KwaZulu-Natal on the east coast is situated in the summer rainfall region, with wet summers and dry winters. The vegetation varies but is mainly characterized by grassland in the seed potato growing region. Because of frost during the winter seed potatoes are planted from August until November (summer crop).

To produce seed potatoes with low virus levels a balanced management approach is required to prevent virus transmission by aphids (Radcliffe & Ragsdale, 2002). Aphid monitoring using suction traps is a key component of management programmes to reduce PVY and PLRV transmission to seed potatoes. PVY and PLRV are usually transmitted to potato fields by immigrating winged aphids (Ragsdale et al., 2001). The relationship between aphid flights and virus spread has been well established (Basky, 2002). Virus incidence is related to, amongst others, aphid flight patterns, species and numbers (abundance), and virus transmission efficiency (Ragsdale et al., 2001). Reliable estimates of aphid numbers are a critical aspect of predicting the risk of virus transmission and essential for establishing an effective management programme. A major objective of this project is, therefore, to establish a national aphid vector monitoring network throughout seed potato producing areas in South Africa, making use of existing suction traps.

Aphids are thought to respond relatively fast to changes in climate conditions due to their biology and seem ideally suited to evaluate the relationships between climate change, aphid abundance and incidence of aphid-transmitted plant viruses. Climate is not the only factor affecting aphid abundance. Aphid population dynamics are also regulated, amongst others, by parasitic wasps (parasitoids). A further aspect of the project therefore involved examining the effect of changes in environmental conditions on plant-aphid-parasitoid interactions.

Generally, insecticides are used for managing aphid populations in potato fields. However, aphids are able to transmit PVY before becoming immobilized. Crop borders, consisting of virus non-host plants, have been identified as an alternative sustainable management option for reducing the incidence of PVY (Radcliffe & Ragsdale, 2002). Aphids tend to land in high numbers at the edge of a field. Planting a virus non-host plant as a border causes aphids to purge their mouthparts by feeding on plants in the crop border, creating a virus sink, before moving into potato fields (Radcliffe & Ragsdale, 2002; Hooks & Fereres, 2006). Thus, using a plant species/cultivar preferred by aphids would considerably strengthen the border effect. However, few studies have investigated the mechanisms underlying the feasibility of border crops. This study evaluated the role of vision and olfaction (smell) in host plant selection by the bird cherry – oat aphid, Rhopalosiphum padi. Three maize, potato, and wheat cultivars each were evaluated to identify a potential crop border plant species/cultivar to reduce the incidence of PVY in seed potato fields. Based on aphid abundance and species assemblages, maize and wheat were identified as potential crop border plants in regions where cereal aphids are abundant (project UP030205).

The project comprised three subprojects. Firstly, the aphid long-term monitoring initiative, secondly determining the effect of changes in climatic conditions on a potato - aphid - natural enemy interaction, and thirdly, the
identification of wheat and maize cultivars for crop borders. All aspects were concerned with managing *Potato virus Y* (PVY) and, where applicable, *Potato leafroll virus* (PLRV), and evaluating how changes in climatic conditions may affect aphid populations and thus PVY/PLRV virus incidence. This is a long-term project, and this report is on the first years of aphid monitoring.

**Project team**

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**Funding**

University of Pretoria, Potatoes South Africa, Western Cape Department of Agriculture, KwaZulu-Natal Department of Agriculture; Technology and Human Resources for Industry Programme (THRIP) of the Department of Trade and Industry (DTI) and the National Research Foundation (NRF), Agricultural Research Council (ARC).
Suction traps: Fritolay (Ceres & Malmesbury), GWK, KZN seed growers; Potatoes South Africa; Kwazulu-Natal Seed potato growers.

**Project Duration**

July 2009 to June 2013
2. OVERALL OBJECTIVES OF THE PROJECT

The overall objectives of the study were to:

1. Consolidate efforts of seed potato-growing regions and establish a national aphid monitoring network involving suction traps across South Africa and routine identification of aphid species received from suction trap samples
   - Required to establish a long-term aphid monitoring programme to serve as an early warning system for seed potato producers on the risk of virus transmission by aphids
   - Important for evaluating the possible impact of climate change on aphid abundance and virus (e.g. PVY) transmission

2. Determine the effect of water-deficit stress and high temperature on potato-aphid and potato-aphid-natural enemy interactions
   - Forms part of determining the effect of climate change on potato aphid populations

3. Identify maize and/or wheat cultivars that can be used as crop borders
   a) Determine the combined effects of visual and olfactory cues on host plant selection by *Rhopalosiphum padi*
   b) Determine the effect of visual cues on host plant selection by *R. padi*
   c) Determine the effect of olfactory cues on host plant selection by *R. padi*
      - Serves to identify suitable maize or wheat cultivars for crop borders to reduce PVY incidence in seed potato fields
3. NATIONAL APHID MONITORING NETWORK

Regional aphid monitoring efforts were consolidated and a long-term South African monitoring network for aphids was established. The national South African potato monitoring network with its nine standardized Rothamsted-type suction traps situated throughout major seed-potato growing regions in the country (Figs 1, 2) is of international standard.

The monitoring network and associated database provide an early warning system to alert growers to the commencement of aphid flight in a specific region and assist growers in making management decisions regarding planting times, killing of foliage, and location and timing of aphid control measures. The long-term goal is to determine the relationship between climate patterns, and aphid abundance and virus disease incidence to develop a forecasting system to alert growers to the risk of virus spread.

A centralized internet-based database was developed which allowed for regional processing of samples and input of aphid counts to provide instant feedback to growers. Aphid abundance data were captured daily or weekly and made immediately available on the aphid monitoring website (Fig. 3a). In cases where contributors did not have immediate access to upload recent aphid counts for a specific suction trap, weekly counts were sent to Janine Snyman at the University of Pretoria through email or SMS, who placed the information on the aphid monitoring website. To view long-term and short-term trends in aphid abundance, data were made available in the form of graphs and summary statistics for specific sites and time intervals (Fig. 3b). However, the volume of data generated reached such proportions that the retrieval of data became very slow. A new website and data storage system which allows for the expansion of the network and improved dissemination of data is being developed.

![Fig. 1. Position of suction traps for monitoring aphids in seed potatoes in South Africa. Four further suction traps were erected to complement existing units and expand the network to monitor aphid vectors of Barley yellow dwarf virus in wheat.](image)

Table 1. Number of aphid species identified to species / species group level from suction trap samples from different traps from June 2006 to June 2013.
### MANAGEMENT OF APHID SUCTION TRAPS

<table>
<thead>
<tr>
<th>Region</th>
<th>Trap</th>
<th>Start date</th>
<th>Number of aphids identified*</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Cape</td>
<td>Sand (Sandveld)</td>
<td>Jun. 2006</td>
<td>8138</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Joos (Sandveld)</td>
<td>Jan. 2007</td>
<td>4683</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skaapkraal (Sandveld)</td>
<td>Jan. 2007</td>
<td>8826</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vredelust (Ceres)</td>
<td>2012</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>Western Free State</td>
<td>Christiana</td>
<td>Nov. 2007</td>
<td>19336</td>
<td></td>
</tr>
<tr>
<td>KwaZulu-Natal</td>
<td>Cedara</td>
<td>Nov. 2005</td>
<td>4848</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kamberg</td>
<td>Nov. 2005</td>
<td>9898</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Underberg</td>
<td>Dec. 2009</td>
<td>734</td>
<td></td>
</tr>
<tr>
<td>Northern Cape</td>
<td>Douglas</td>
<td>Mar. 2007 to Jun. 2012</td>
<td>1616</td>
<td>Suction trap has been moved to new locality in 2013</td>
</tr>
</tbody>
</table>

Total 58289

*Identification at regional level and University of Pretoria

---

**Western Free State**

- **Christiana**
  - *Western Free State Seed Potato Growers*
  - Aphid sorting and counting
  - Weekly results added to database
  - Weekly samples sent to UP for aphid identification

**North West**

- **Brits**
  - *ARC-SGI/Winter Cereal Trust*
  - Trap emptied weekly
  - Samples to be sent to UP for aphid sorting and identification

**Limpopo**

- **Koedoeskop**
  - *ARC-SGI/Winter Cereal Trust*
  - Trap emptied weekly
  - Samples to be sent to UP for aphid sorting and identification

**KwaZulu-Natal**

- **Cedara**
  - *KZN Department of Agriculture*
  - Trap emptied weekly
  - Aphid samples sent to UP for identification

- **Kamberg**
  - *John Armstrong*
  - Trap emptied daily
  - Aphid sorting and counting
  - Aphid numbers sent via SMS to J. Snyman (UP)
  - Aphid and other insect samples sent to UP

**Western Cape**

- **Sandveld Lambert’s Bay**
  - Trap emptied weekly

- **Sandveld Redelinghuis**
  - Trap emptied weekly

- **Sandveld Malmesbury**
  - Trap emptied weekly

---

**Western Cape Dept. of Agriculture**

- *Aphid sorting and counting*
- *Weekly results added to database*
- *Weekly samples sent to UP for aphid identification*

**Ceres**

- *Western Cape Dept. of Agriculture*
- Suction trap emptied at irregular intervals

**Underberg Chris Owen**

- *KZN Department of Agriculture*
- Trap emptied daily
- Aphid samples sent to UP for identification

**Koedoeskop**

- *ARC-SGI/Winter Cereal Trust*
- Trap emptied weekly
- Samples to be sent to UP for aphid sorting and identification
Fig. 2. Flowchart of the aphid monitoring network for aphid sampling, sorting, identification and data capture. New traps are shown in grey.

Fig. 3. Examples of (a) an aphid trap data capture form and (b) graphical output of the database on the national aphid monitoring website.

Aphids were identified to species or genus level either regionally or at the University of Pretoria (Fig. 2). More than 58000 aphids from suction trap samples have been identified since the start of the aphid monitoring initiative in 2005 (Table 1). The data collated provide information on aphid flight patterns and vector species composition for specific regions. This information is used to determine peak aphid flight activity and thus increased risk of virus spread.

Sixty-five species or species groups were identified. The most important vector species or genera were the peach-potato aphid (*Myzus persicae*), the potato aphid (*Macrosiphum euphorbiae*), the bird cherry – oat aphid (*Rhopalosiphum padi*), the cotton aphid (*Aphis gossypii*) and other *Aphis* spp. Their contribution to the cumulative vector pressure varied with regions. For example, in some areas, such as the western Free State, where the dominant vegetation is grassland, *R. padi*, a vector of PVY which reproduces on Poaceaeae (e.g. grasses, maize and wheat), is the most important vector species. In contrast, *M. persicae*, a vector of PLRV and PVY, is an important vector species in the Sandveld in the Western Cape, where PLRV is considered a greater threat than PVY. In KwaZulu-Natal *M. persicae*, *M. euphorbiae* and *A. gossypii*, all vectors of PLRV and PVY, were considered to be the most important species during the study period.

Vector pressure indices have been calculated to aid growers in making decisions on the timing of aphid control measures. The index is based on suction trap data and provides information on the likelihood of immigrating aphids transmitting viruses (PVY, PLRV) to seed potato fields (Fig. 4). The vector pressure index is calculated by multiplying the number of individuals of a species caught in a trap with a factor estimating the virus transmission efficiency of that particular species and summing up the resulting value for all vector species. Thus, species may vary in their contribution to the overall vector pressure depending on virus transmission efficiency and numbers (abundance). For example, *M. persicae* contributed most to the cumulative vector pressure in a KwaZulu-Natal region (Fig. 4). The cumulative vector pressure is calculated by adding the latest value to the previous value. The cumulative vector pressure gives an indication of the virus risk associated with a region at a particular time of the year. However, it has to be kept in mind that the vector pressure index is a rather crude measure of vector pressure because a number of factors influence virus transmission. These include whether or not an individual aphid is infected with PVY/PLRV, the strain of PVY/PLRV involved, potato cultivar susceptibility, etc.

The collection of daily or weekly samples of migrating winged aphids allows for the initial analysis of longer-term trends in aphid flight patterns and vector numbers, and subsequently changes from year to year in the risk of PLRV.
and PVY transmission (Figs 5; 6). For example, based on suction trap data vector pressure for both PLRV and PVY decreased from July 2006 to June 2013 in KwaZulu-Natal (Fig. 5c).

In addition, daily or weekly samples provide information on the onset of aphid flight at the beginning of the growing season as well as on peak flight activity periods during the year. For example, in the 2006/2007 season aphids started to fly in mid-August and increased in numbers with a concomitant increase in vector pressure in mid-December in KwaZulu Natal (Fig. 5a, b). Whereas in the 2008/2009 and the 2009/2010 seasons aphid commenced flight and vector pressure increased already early in July due to an early increase of *M. persicae* (peach – potato aphid) (Fig. 4b). This pattern was observed for both traps operating in KwaZulu-Natal at the time, as well as for the 2009/2010 season for a third trap, which started operating in December 2008.
Fig. 4. Vector pressure based on suction trap catches in KwaZulu-Natal showing the differences between years and contribution of species towards the cumulative vector pressure index. (a) Vector pressure from 2006 to 2013 based on the three important vector species, and (b-d) the contribution of the individual species to the vector pressure. From July 2006 to June 2012 vector species identification concentrated on three species: *Myzus persicae*, *Macrosiphum euphorbiae* and *Aphis gossypii*. All three species are vectors of PLRV and PVY. From July 2012 all aphid species were identified. In the 2012/2013 season *Rhopalosiphum padi* (vector of PVY) contributed 74% to the cumulative vector pressure.
Fig. 5. Vector pressure based on suction trap catches in a seed potato region in KwaZulu-Natal. The cumulative vector pressure is based on three important virus vector species (*Myzus persicae*, *Macrosiphum euphorbiae* and *Aphis gossypii*) in the region. The graphs show the differences between years (a) for PVY and (b) PLRV; the arrows indicate differences in the onset of aphid flight and sudden increases in vector pressure for different years, and (c) the trend of vector pressure from the 2006/2007 to the 2012/2013 season for PVY ($R^2 = 0.704$, $P = 0.018$) and PLRV ($R^2 = 0.753$, $P = 0.011$).
Fig. 6. Vector pressure based on suction trap catches in the Western Free State showing the differences between years and contribution of species towards the cumulative vector pressure indices. (a, b) Vector pressure from 2008 to 2013, and (c-e) the contribution of the individual species to the vector pressure. The graphs show the differences between years (a) for PVY and (b) PLRV.
Suction trap data also provide a basis for determining the effects of changes in climate conditions on aphid populations and consequently virus transmission. An initial analysis was carried out to determine the relationship between vector pressure and temperature and rainfall patterns in a winter and summer rainfall region (Fig. 7). First results suggest that vector pressure is related to rainfall in the Sandveld region - vector pressure tended to increase with a decrease in rainfall in March, April and May. In contrast, vector pressure during the growing season in the KwaZulu-Natal region appeared to be related to temperature, which is considered the most important abiotic factor affecting population growth rates of insect herbivores (Bale et al., 2002). In KwaZulu-Natal, vector pressure was lower in the 2011/2012 season when the monthly mean temperatures from July to September were 1.9 to 4.9 °C below average, and also in the 2007/2008 and the 2010/2011 seasons when the monthly mean temperatures were 1.2 to 2.6 °C above the 2006 to 2012 average for July to September. However, for these and other regions longer data series are required to confirm trends and provide forecasts on aphid flight.

Fig. 7. Mean maximum and minimum temperature and rainfall for (a) the Sandveld (2007 to 2012) in the winter rainfall region and (b) KwaZulu-Natal (2006 to 2012) in the summer rainfall region of South Africa together with cumulative vector pressure for (c) PLRV in the Sandveld and (d) PLRV in KwaZulu-Natal.
4. EFFECT OF WATER-DEFICIT STRESS AND HIGH TEMPERATURE ON POTATO-APHID AND POTATO-APHID-NATURAL ENEMY INTERACTIONS

4.1 Effects of water-deficit stressed potato plants and high temperature on life-history traits of the potato aphid, *Macrosiphum euphorbiae*

To gain insight into the effects of changes in environmental conditions on aphid populations, the influence of high day/night temperature and water-deficit stress on insect growth parameters of the potato aphid *M. euphorbiae* (potato aphid) was determined. It has been proposed that prolonged water-deficit stress in plants leads amongst others to an increase in phloem nitrogen, which improves growth and reproduction of phloem-feeding insects and thus promotes population outbreaks (e.g. White, 1969). High temperature on the other hand is thought to have a negative effect on aphid growth parameters. The aims of this study were to determine the effect of water-deficit stress compared to no water stress, and high day/night temperatures (30/20°C) compared to ambient day/night temperatures (25/15°C), and their combined effect on plant nitrogen levels and population growth parameters (e.g. survival rate, intrinsic rate of increase) of *M. euphorbiae* on potato (cultivar ‘BP1’) under controlled laboratory conditions.

Four pilot studies were undertaken to determine the experimental design for temperature treatments and for inducing water-deficit stress. The method eventually adopted involves daily weighing of pots and adding the appropriate amount of water to keep plants stressed at 25 % pot capacity. Reproduction of *M. euphorbiae* was determined at two different constant temperature day/night regimes, 25/15 °C and 30/20 °C, two water treatments (water-deficit treatment (40–45 % relative humidity) and no deficit treatment at 80 to 100 % pot capacity (60–70 % relative humidity)), and 14L:10D photoperiod. Potato plants (cv. ‘BP1’) were preconditioned for 14 days before transferring a single wingless adult female per plant.

![Graphs showing age-specific survival rate (lx) and fecundity (mx) of *Macrosiphum euphorbiae* on (a) well-watered plants at 25/15 °C, (b) on water-stressed plants at 25/15 °C, (c) well-watered plants at 30/20 °C, and (d) on water-stressed plants at 30/20 °C.](image)

Fig. 8. Age-specific survival rate (lx) and fecundity (mx) of *Macrosiphum euphorbiae* on (a) well-watered plants at 25/15 °C, (b) on water-stressed plants at 25/15 °C, (c) well-watered plants at 30/20 °C, and (d) on water-stressed plants at 30/20 °C.
Water-deficit stressed plants had a smaller leaf area, and stomatal conductance (the speed at which water evaporates from pores in a plant) was lower in water-stressed than non-stressed plants. Plants exposed to water-deficit stress generally have a low stomatal conductance value compared to well-watered plants (Collatz et al., 1991). Nitrogen (crude protein) concentrations were slightly higher in water-deficit-stressed than non-stressed plants. Female aphids produced the highest number of progeny at ambient day/night temperatures and in the absence of water-deficit stress. Progeny production was lowest at high day/night temperatures and under water-deficit stress (Fig. 8). Survival was lowest and the mean generation time was shortest at high day/night temperatures combined with water-deficit stress. Overall population growth rates were higher at ambient than high temperature, as well as for non-stressed compared with water-stressed plants. The results indicate that water-deficit stress did not enhance the growth parameters of *M. euphorbiae*. In general, the growth rate of the potato aphid population used in the current study was negatively affected by high temperature.

### 4.2. Effects of water-deficit stressed potato plants and high day-night temperature on the biology of *Aphidius ervi* parasitizing *Macrosiphum euphorbiae*

The study was aimed at determining the influence of high temperature and water-deficit stress on the development of the aphid parasitoid (parasitic wasp) *Aphidius ervi* (Hymenoptera: Braconidae) using *M. euphorbiae* as a host and potato cv. BP1 as a host plant. A culture of *A. ervi* on the potato aphid *M. euphorbiae* on potato and wheat was established. *Aphidius ervi* is used commercially as a biological control agent in several countries (Boivin et al., 2012) and was recorded for the first time in South Africa during the present project (Muller et al., 2014).

#### Table 2. Development times and longevity of *Aphidius ervi* reared on the potato aphid *Macrosiphum euphorbiae* with potato as a host plant. Within rows means followed by the same lower case letters are not significantly different (Linear Mixed Model analysis, *P* > 0.05).

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<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg - Mummy</td>
<td>10.3 ± 0.2 a</td>
<td>10.3 ± 0.1 a</td>
<td>11.9 ± 0.2 b</td>
<td>12.1 ± 0.2 b</td>
</tr>
<tr>
<td>Mummy - Adult</td>
<td>5.6 ± 0.2 a</td>
<td>5.9 ± 0.1 a</td>
<td>4.9 ± 0.2 b</td>
<td>4.5 ± 0.2 b</td>
</tr>
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<td>Egg - Adult</td>
<td>15.9 ± 0.3 a</td>
<td>16.2 ± 0.1 ab</td>
<td>16.8 ± 0.2 b</td>
<td>16.7 ± 0.2 b</td>
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<td>Longevity</td>
<td>6.0 ± 0.5 a</td>
<td>7.6 ± 0.3 b</td>
<td>5.3 ± 0.4 a</td>
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Stomatal conductance, an indicator of water stress, was lower in water-stressed than non-stressed plants. Nitrogen (crude protein) concentrations were significantly higher at the 30/20°C temperature treatment compared to the 25/15°C temperature treatment. Egg-to-adult development was slightly faster on non-stressed plants at 25/15°C than on stressed and non-stressed plants at elevated day/night temperatures (30°C / 20°C) (Table 2). Water-deficit stress did not enhance parasitism, but parasitoid mortality was significantly higher and reproduction (percentage parasitism) was reduced at elevated day/night temperatures (30°C / 20°C) compared to ambient temperature (25/15°C) (Table 3).
Table 3. Percentage mummification, pupal survival, offspring per female and sex ratio of *Aphidius ervi* reared on the potato aphid *Macrosiphum euphorbiae* with potato as a host plant. Within rows means followed by the same lower case letters are not significantly different (ANOVA, *P* > 0.05).

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<td>Percentage parasitism</td>
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<td>35.3 ± 13.1</td>
<td>27.3 ± 8.4</td>
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<td>Percentage pupal survival</td>
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<td>88.2 ± 1.0 a</td>
<td>55.3 ± 6.1 b</td>
<td>48.9 ± 8.5 b</td>
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<td>1 : 1.1</td>
<td>1.1 : 1</td>
<td>2.1 : 1</td>
</tr>
</tbody>
</table>

The efficiency of *A. ervi* as a parasitoid of *M. euphorbiae* was measured as a functional response, i.e. the relationship between the number of parasitoids and number of available aphid hosts. Parasitism of *M. euphorbiae* was determined at host densities of 5, 10, 20, 30, 50, 80 and 100 aphids of preferable size (II, III to adult stage) by introducing one female parasitoid at each density (10 replicates). The study was done at ambient 25°C / 15°C day-night temperatures and 60-80% RH in growth chambers. Results show that the number of parasitized aphids increases with increasing host densities from 5 to 100 aphids (Fig. 9), confirming the high reproductive rate of *A. ervi* under ambient conditions.

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Fig. 9. Functional response of *Aphidius ervi* parasitizing *Macrosiphum euphorbiae* at different aphid host densities.

The study on the biology of *A. ervi* showed that this species is an efficient parasitoid of the potato aphid *M. euphorbiae* on potato. However, high temperature and drought may reduce the effectiveness of *A. ervi* in controlling *M. euphorbiae* because mortality of the aphid parasitoid increased and reproduction decreased at high temperature and drought compared to ambient temperature.
5. MANAGEMENT OF *POTATO VIRUS Y* (PVY) IN SEED POTATOES USING CROP BORDERS: POTENTIAL OF MAIZE AND/OR WHEAT CULTIVARS AS CROP BORDERS

Aphids use visual and olfactory (smell) signals emitted by plants to locate and choose a host plant. Understanding how aphids use these types of plant signals facilitates the development of crop protection strategies to reduce the incidence of aphid-transmitted diseases. The aim of the present study was to evaluate vision and olfaction of the bird cherry-oat aphid *R. padi* and the potato aphid *M. euphorbiae*, both important vectors of PVY, for maize (cultivars '6Q-121', '78-15B', CRN 3505), potato (cultivars 'BP1', 'Hertha', 'Mondial') and wheat (cultivars 'Duzi', 'Kariega', 'Krokodil') to identify a potential crop border plant species/cultivar to reduce the incidence of PVY in seed potato fields.

5.1. Aphid host-finding: combined effects of visual and olfactory cues

To determine aphid host plant preference based on visual and olfactory cues combined, alate (winged) adult aphids were released among plants arranged in a randomized block to evaluate landing, settling and reproduction using the three maize, wheat and potato cultivars. *Rhopalosiphum padi* preferred to land on the maize and wheat cultivars rather than the potato cultivars. Only one winged adult of *R. padi* landed on one of the potato cultivars but left the plant shortly thereafter. The species showed no significant landing preference among the three maize and wheat cultivars (Fig. 10a, c). Aphids cultured on maize settled more frequently on wheat cultivar 'Kariega' compared to wheat cultivar 'Duzi' and maize cultivars '6Q-121' and '78-15B' (Fig. 10b). However, aphids cultured on wheat settled more frequently on wheat 'Krokodil' than maize cultivar '78-15B' (Fig. 10d). For aphids cultured on maize, the number of offspring was similar on all cultivars (Fig. 11a), whereas the number of nymphs produced was highest on the wheat cultivars compared to the maize cultivars for aphids cultured on wheat (Fig. 11b). No nymphs were recorded on any of the three potato cultivars.

The leaf area of a subset of plants used was estimated by scanning the leaves and using an imaging analysis software program (ImageJ; 1.45s; Wayne Rasband, National Institutes of Health, U.S.A., http://imagej.nih.gov/ij). No differences were observed, suggesting that leaf area did not influence aphid choice. The nitrogen content of maize and wheat leaves was determined because nitrogen content influences growth and reproduction in aphids. No differences in nitrogen content were recorded. Trichomes can constitute a physical barrier to aphid settling on plant leaves. No trichomes occurred on maize. Higher trichome density in one of the wheat cultivars may have contributed to a lower settling rate.
Fig. 10. *Rhopalosiphum padi* (mean ± SE) landing (a, c) and settling (b, d) on three maize and three wheat cultivars. Aphids were reared on maize (a, b) or wheat (c, d). Letters above bars indicate significant differences between means (LSD test: P < 0.05).

Fig. 11. Increase in number of *Rhopalosiphum padi* (mean ± SE) after 14 days on three maize and three wheat cultivars. Aphids were reared on (a) maize or (b) wheat. Letters above bars indicate significant differences between means (LSD test: P < 0.05).
A crop border plant should be attractive to winged aphid vectors but at the same time be a poor plant for reproduction. Therefore, a study was done to determine the reproduction rate of \textit{R. padi} on the three wheat and three maize cultivars in a no-choice situation. Both winged and wingless aphids were used because they follow different reproductive strategies. The reproductive potential of winged aphids (dispersal stage) is lower than that of wingless aphids. In addition to different morphs, aphids reared on maize and aphids reared on wheat were used to determine if previous host plant experience would have an effect on reproduction. Results show that winged and wingless aphids reared on maize and wheat, respectively, produced the highest number of offspring on the three wheat cultivars (Fig. 12). This together with the results of the multiple choice trial suggests that maize would be a better crop border plant than wheat because aphid populations do not rapidly reach high levels.

The study suggests that maize may be a more suitable crop border plant than wheat because it is a poorer host plant for \textit{R. padi} for reproduction. However, this could be due to the aphid population used in this study being better adapted to wheat than maize.

In summary, \textit{R. padi} preferred to land on maize and wheat cultivars compared with potato, suggesting that both plant species could increase the edge effect because they are preferred to potato by \textit{R. padi}. Wheat ‘Kariega’ and ‘Krokiol’ may be more suitable as crop border plants than the three maize cultivars based on aphid settling rates. However, the three wheat cultivars may be less suitable than the maize cultivars because they supported higher aphid numbers. An accumulation of aphids on the border crop will result in high aphid populations, increasing the risk of virus transmission due to higher aphid numbers. Therefore, the maize cultivars may be more suitable as crop border plants in potato-producing regions where \textit{R. padi} is abundant.
5.2. Aphid host-finding: visual cues

Visual cues can play a critical role in the attraction of insects to host plants, irrespective of whether true colour vision or wavelength-specific behaviour is involved. Similar to other herbivorous insects, most studies found that aphids are attracted to yellow. However, *R. padi* is also attracted to green leaves of its primary host plant *Prunus padus* (Rosaceae) (Archetti & Leather 2005).

The current study sought to determine if winged adult *R. padi* are attracted to different shades of green and to relate any preference to the spectral reflectance of the three cultivars of the non-host, potato, as well as maize and wheat used previously. Choice experiments were carried out in a glasshouse to determine aphid landing preference using colour models comprising six different hues of green, as well as yellow, white, black, and grey as controls. The spectral reflectance of the colour models as well as the leaves of three maize, potato and wheat cultivars was measured with a spectrophotometer. Results of the colour choice experiment show that *R. padi* is significantly attracted to lime green and yellow (Fig. 13). When landing preference of *R. padi* was compared in an earlier experiment on the combined effect of visual and olfactory cues using three potato, maize and wheat cultivars, winged aphids preferred to land on the wheat and maize cultivars (see above). The peak percentage spectral reflectance of the wheat cultivars was higher compared to the maize and potato cultivars. The yellow colour model reflected the highest percentage (46 %) of light between 570 and 700 nm. The peak percentage (c. 20 %) of the spectral reflectance of lime green and green at 528 and 519 nm, respectively, was most similar to that of the crop species at c. 540 nm. The results of the landing trial with colour models show that *R. padi* preferred to land on the colour targets with the highest reflectance, suggesting that this species will land in higher numbers on wheat than maize or potato cultivars based on reflectance. In the previous study *R. padi* did not distinguish between maize and wheat cultivars when landing. However, this may have been due to using single plants, which did not reflect the plant density in the field. However, in a previous field trial, the mean number of *R. padi* landing in wheat (cultivar ‘Kariega’) plots was similar to that in the maize (cultivar ‘CRN 3505’) plots (Schröder & Krüger, 2014).

![Fig. 13. Mean number (± SE) of *Rhopalosiphum padi* alates landing on sticky colour card models used as visual targets (n = 11; 36 aphids released per replicate). Different letters indicate significant differences (P < 0.05).](image)

The study demonstrates that wavelength reflectance curves of plant species/cultivars may be an important selection criterion when identifying potentially suitable crop border plants.
5.3. Aphid host-finding: olfactory cues

To determine the response of winged adult *R. padi* and *M. euphorbiae* to plant volatiles of the three maize, wheat and potato cultivars each, no-choice bioassays were carried out using a four-arm olfactometer. *Rhopalosiphum padi* was significantly attracted to odours of the maize cultivar ‘6Q-121’ but was neither attracted nor repelled by any of the remaining plant cultivars (Fig. 14a). In contrast to *R. padi*, which colonizes plants of a single family (Poaceae), *M. euphorbiae*, which colonizes many different plant species belonging to different families, did not show a significant preference for any of the cultivars (Fig. 14b). The reason could be that polyphagous species (many host plant species) such as *M. euphorbiae* rely less on olfactory cues to find their host plants than oligophagous species (restricted host plant range) such as *R. padi*.

During a three-month study visit to the Swedish University of Agricultural Sciences (SLU), the headspace volatiles (volatiles in the airspace surrounding above-ground plant parts) from three maize and wheat cultivars were collected (collaboration with Dr R. Glinwood and Prof. R. Ignell). Plant volatiles were analysed and identified using coupled gas chromatography mass spectrometry (GC-MS) and identified by comparing peaks with library databases. To determine which of the compounds identified from the cultivars were detected by *R. padi* and *M. euphorbiae*, gas-chromatography coupled electro-antennography (GC-EAG) was used to examine the antennal response to particular volatiles. However, results obtained with the GC-EAG were inconclusive and additional bioassays using a four-arm olfactometer to determine the olfactory preference of winged *R. padi* for volatile chemical compounds identified from the three maize, potato and wheat cultivars at three different concentrations were carried out. Having identified the volatile compounds of each of the three cultivars of maize, wheat and potato, the plant compounds identified were tested individually to determine their influence on aphid behaviour. Twenty-three individual compounds, using three concentrations (1, 10 and 100 ng/μl), and at least 20 replicates for each compound and concentration were tested in olfactometer trials to determine whether they repel or attract winged *R. padi*. Quantitative and qualitative differences were found between the maize, potato and wheat cultivars. One compound, (Z)-3-hexenyl acetate 100ng/μl, which occurred in the highest concentration in maize cultivar ‘6Q-121’, attracted aphids whereas α-farnasene 100 ng/μl, (E)-2-hexenal 10 ng/μl, Indole 10 ng/μl and TMTT 1 ng/μl, which occurred in several of the plant cultivars, may have reduced the attractiveness of the cultivars to *R. padi*. The olfactory responses of *R. padi* indicated that maize ‘6Q-121’ may be a suitable crop border plant because it did not contain compounds known to repel this species, such as α-farnasene, (E)-2-hexenal, indole and TMTT.

The identification of plant volatiles and bioassays to determine the olfactory preference in the laboratory can serve as an initial step in selecting crop border plant cultivars. Crop border plants should not contain compounds repellent to aphids because these compounds may reduce landing and subsequent probing.
In conclusion, both visual and olfactory cues can aid in identifying potentially suitable crop border plants in laboratory studies before embarking upon field trials. Using a crop border plant around seed potato fields whose visual and olfactory cues are more attractive than the main crop may cause adults to direct their low level flight towards the attractive crop border plant. *Rhopalosiphum padi* preferred to land on the maize and wheat cultivars compared to the potato cultivars tested. In addition to selecting cultivars with a high landing rate, suitable crop border plants should have a high aphid settling rate but a low aphid reproduction rate, reflect a higher percentage of light in the green-yellow wavelength region than the main crop, and not emit volatile compounds known to repel the aphid vector. The cultivars with the highest potential will then have to be evaluated further in crop border trials in the field in the respective South African seed potato-growing regions. Maize cultivars ‘6Q-121’ and ‘78-15B’ are suitable cultivars for further testing based on landing, settling and reproduction of *R. padi*. 
6. ADDITIONAL ASPECTS

6.1. Effect of volatiles emitted from PVY-infected plants on the aphid vector \textit{Rhopalosiphum padi}

Plant viruses can alter the volatiles emitted by their host plant and thus the behaviour of their insect vector by being more attractive to the vector. This can potentially result in a higher number of infected insects transmitting the virus. No studies have been done on the effect of volatiles emitted from PVY-infected potato plants on the aphid vector \textit{R. padi} and how the attractiveness of PVY-infected plants compares with that of maize, which has been identified as a potential border crop for \textit{R. padi}. The behaviour of PVY-uninfected winged adult \textit{R. padi} towards volatiles emitted from PVY-infected, PVY-free potato plants and maize, respectively, was examined in olfactometer trials. For this study, \textit{R. padi} was reared on oats to avoid bias. Responses of winged \textit{R. padi} to odours of two maize cultivars and one potato cultivar confirmed results obtained in previous trials, i.e. that even when reared on host plant species other than maize and wheat, \textit{R. padi} was attracted to odours of one maize cultivar. No difference in preferences was observed to odours emitted from PVY-infected and PVY-free potato plants.

6.2. Transmission of PVY\textsubscript{NTN} by three aphid species

Transmission efficiency of PVY by aphids depends amongst others on the species involved, its clone, its developmental stage and whether it is in its winged (alate) or wingless (apterous) form. The dominant PVY strain in South Africa is currently PVY\textsubscript{NTN}, and the study accordingly concentrated on this strain. The transmission efficiency of PVY\textsubscript{NTN} was determined for three aphid species, the cabbage aphid (\textit{Brevicoryne brassicae}), the potato aphid (\textit{Macrosiphum euphorbiae}), and the bird-cherry oat aphid (\textit{Rhopalosiphum padi}). Aphid transmissions were performed between PVY\textsubscript{NTN-GP}-infected and non-infected potato plants followed by reverse-transcriptase polymerase chain reaction (RT-PCR) to test for the presence of viral RNA (Lorenzen \textit{et al}., 2009). The transmission efficiency of each aphid species was determined and expressed as a relative efficiency factor. The transmission efficiency of \textit{M. persicae} was 0.33, whereas \textit{R. padi} and \textit{B. brassicae} did not transmit the specific isolate of PVY\textsubscript{NTN} used in the study. A comparison of these results with those from Europe shows that the ability of \textit{R. padi} to transmit PVY\textsubscript{NTN} is isolate-dependent. The relative efficiency factor values have been included in the calculation of the vector pressure indices for different seed-potato growing regions in South Africa.
7. CONCLUDING REMARKS

Aphid monitoring. Initial information on longer-term trends (several years) in aphid flight and abundance (number of aphids) patterns is available. This report is on the first years of aphid monitoring with suction traps in South Africa. In order to develop reliable virus risk forecasting models, longer-term monitoring is required.
Potato-aphid-parasitoid interactions. High temperature and drought may reduce the effectiveness of the aphid parasitoid A. ervi in controlling M. euphorbiae, because mortality of the parasitoid increased and reproduction decreased at high temperature and drought compared to ambient temperature. The study was laboratory-based and findings need to be validated in the field, because life history parameters such as development time, reproductive capacity and thermal tolerance are subject to change and insects may adapt.
Crop border. Based on the relatively high aphid landing rate and low reproduction in regions where R. padi is an important PVY vector, one maize cultivar has been identified as the most promising candidate as a potential crop border plant in regions where this aphid species is an important vector.
Transmission of PVY. Future research should also focus on assessing the transmission efficiency of other aphid vector species using common PVY strains and isolates, as well as the susceptibility of different potato cultivars to infection with common PVY strains and isolates.
8. REFERENCES


9. OUTPUTS

Technology / Technology transfer
1. Long-term national long-term aphid monitoring network
2. Internet-based database for seed potato growers to provide instant feedback regarding aphid abundance and to serve as an early warning system.
3. Plant volatile entrainment system at the University of Pretoria
4. Training of growers in aphid monitoring using yellow bucket traps
5. Aphid identification course for suction and yellow bucket trap catches

Popular articles

Post-graduate qualifications
1. F. Venter, 2012, BSc(Hons), University of Pretoria (with distinction)  
   Title of research report: Transmission efficiency of Potato virus Y strain PVYNTN by four aphid species in South Africa.
2. T. France, 2013, BSc(Hons), University of Pretoria  
   Title of research report: Attraction of Rhopalosiphum padi (L.) (Hemiptera: Aphididae) to Potato virus Y -infected potato plants and maize, a potential crop border plant
   Title of the research report: Test of plant volatiles for the management of the bird cherry-oat aphid Rhopalosiphum padi L. (Hemiptera: Aphididae) on potatoes (Solanum tuberosum)
4. M. Schröder (2014) Host plant preference of Rhopalosiphum padi (Hemiptera: Aphididae) and its role in selecting crop border plants to reduce Potato virus Y (PVY) in seed potatoes. PhD (Entomology), University of Pretoria
5. L. Bethke (2015), Effects of elevated temperature and water-deficit stress on the potato aphid Macrosiphum euphorbiae (Thomas) (Hemiptera: Aphididae) and its parasitoid Aphidius ervi Haliday (Hymenoptera: Braconidae). MSc (Entomology), University of Pretoria

Presentations
National meetings
Oral


International meetings

Oral


Posters


Peer-reviewed publications


Conference Proceedings
## 10. FINANCIAL REPORTING

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