A survey of Sternorryncha on tomatoes and potatoes across South Africa with implications for disease vectoring

A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE
In
ENTOMOLOGY

At

RHODES UNIVERSITY

By

Ayandisa Zongo

(24Z3020)

December 2025

ABSTRACT

Pests significantly decrease both the yield and quality of many agricultural crops, ultimately leading to significant economic losses for farmers. Many hemipterans feed on plant sap and affect a wide range of economically important crops. Among these, the most significant phytophagous species are found within the suborder Sternorrhyncha which comprises aphids, psyllids, scales and whiteflies. This group of insects is effective at vectoring plant diseases that lead to production losses. This group of insects is problematic to some of the most important vegetable crops in South Africa, specifically potatoes and tomatoes. Aphids are some of the most important pests of potatoes which can cause damage and yield through direct feeding, but their main impact is due to their ability to transmit viruses such as Potato Leaf Roll Virus (PLRV) and Potato Virus Y (PVY). Whiteflies on the other hand not only suck plant sap but also transmit plant viruses such as Tomato Yellow Leaf Curl Virus (TYLCV), while psyllids spread bacteria such as *Candidatus* Liberibacter solanacearum. In order to reduce the negative impact of these insect pests, sound pest management strategies have to be implemented.

Insect monitoring is a crucial component of integrated pest management (IPM), intended to ensure that pest populations remain below the economic injury level (EIL). Pest surveillance is also essential for assessing the presence and economic impact of pests in agriculture and is carried out to establish the pest status in a given area, enhance the chances of early detection, and track pest prevalence. Therefore, this study aimed to map the prevalence of important aphid species in two different potato producing areas and the impact of environmental factors on aphid species diversity and populations. It also aimed to map the potential outbreaks using a continuous monitoring approach. The study further sought to conduct a survey for incursion by the invasive *Bactericera cockerelli* Šulc (Hemiptera: Triozidae) as well as the prevalence of other Sternorryncha on Solanaceae plants in South Africa, establishing whether *B. cockerelli* or other non-native psyllids are present in the surveyed regions. This surveillance is intended to inform future biosecurity measures and contribute to South Africa's preparedness against high-risk agricultural pests.

A continuous monitoring approach across multiple growing seasons was carried out in two potato growing regions of South Africa, Christiana, North-West and Douglas, Northern Cape to collect aphid populations using suction traps. A field national survey using sticky traps, bucket traps and physical sampling was also carried to monitor Sternorryncha of interest on solanaceae in South Africa over 2 years. Collected insects were preserved in alcohol and identified to species or genus level using dichotomous identification keys. Furthermore, DNA extractions and sequencing were done on the aphid specimens to confirm the morphological identifications.

For the continuous monitoring survey, 39 species were collected with, *Acyrthosiphon kondoi* Shinji (Hemiptera: Aphididae), *Aphis* spp Linnaeus (Hemiptera: Aphididae), *Metopolophium dirhodum* Walker (Hemiptera: Aphididae), *Pemphigu*s spp Hartig (Hemiptera: Aphidoidea, Eriosomatidae), *Rhopalosiphum maidis* Fitch (Hemiptera: Aphididae), *Rhopalosiphum padi* Linnaeus (Hemiptera: Aphididae) and *Therioaphis trifolii* Monell (Hemiptera: Aphididae) recorded as the most abundant species that potentially vector the important potato viruses, PVY and PLRV. *Rhopalosiphum padi* and *Rhopalosiphum maidis* were the most abundant potential PVY vectors while *Myzus persicae* Sulzer (Hemiptera: Aphididae) was the most abundant potential vector for PLRV. The aphid populations were mostly influenced by temperature (both monthly averages of daily maximum and minimum), windspeed and precipitation where an increase in temperature led to an increase in aphid populations. Temperature data were recorded daily and averaged over each month for the analysis. The diversity, evenness and abundance of aphid species collected was similar across the sampling locations.

For the national survey, with targeted surveillance for the invasive *B. cockerelli*, a total of 49 aphid species, 37 psyllid species and 1 whitefly species and other non-sternorryncha (Diptera, Hymenoptera, Thysanoptera, Nueroptera, Mantidae, Coleoptera, Lepidoptera and Hemiptera) were collected. Out of the three collection methods used to collect insects, sticky traps captured a lot more psyllid species while bucket traps captured more aphid species and outperformed the other methods used. The most abundant aphid species were, *R. maidis*, *Aphis* spp and *R. padi*; while the tipu psyllid, *Platycorypha nigrivirga* Burckhardt (Hemiptera: Psylloidea) was the most dominant psyllid species. The whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) was most abundant on the tomato crops compared to the other crops sampled. There were no psyllid species associated with solanaceous crops collected in the field and all the sampled plants did not host *B. cockerelli*, however, its congeneric species *Bactericera capensis* Hollis, 1984 was collected during sampling hosted by non-crop solanaceae. The diversity, evenness and abundance of the Sternorryncha insects collected was also similar across the sampling locations.

The findings indicate that there was a high diversity of Sternorryncha that feed on solanaceous crops, potentially spreading viruses with temperature influencing these populations.

Furthermore, agricultural crops may harbour insects not associated with them. Additionally, *B. cockerelli* was not encountered during the field work even though *B. capensis* was collected, indicating that South Africa is still safe from the invasive pest. Thus, constant monitoring should remain active in order to detect its incursion into the country. Further studies into the biology and distribution of *B. capensis* need to be conducted in order to compare it with *B. cockerelli*. This will help researchers understand whether these two species would have a synergistic effect to each other should there be an incursion into the country. Furthermore, it will be worthwhile to test *B. capensis* and its wild hosts for any Liberibacter that might potentially be spread by *B. cockerelli* should there be incursion.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS, UNITS AND SYMBOLS

Abbreviations:

ACF	Autocorrelation Factor
ACP	Asian Citrus Psyllid
ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
Bt	*Bacillus thuringiensis*
BYMV	Bean Yellow Mosaic Virus
CLs	*Candidatus* Liberibacter solanacearum
CMV	Cucumber Mosaic Virus
DAFF	Department of Agriculture, Forestry & Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural Development
DNA	Deoxyribonucleic Acid
EFSA	European Food Safety Authority
EIL	Economic Injury Level
EPG	Electrical Penetration Graph
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization
FAW	Fall armyworm
GLMMs	Generalized Linear Mixed Models
GLMs	Generalized Linear Models
GSOD	Global Surface Summary of the Day
HLB	Huanglongbing

icipe	International Center of Insect Physiology and Ecology
IPM	Integrated Pest Management
ISH	Integrated Surface Hourly
NAMC	National Agricultural Marketing Council
NAPPO	North American Plant Protection Organization
NCEI	National Center for Environmental Information
NDA	National Development Agency
NPPOs	National Plant Protection Organisations
PCA	Principal Component Analysis
PLRV	Potato Leafroll virus
PSA	Potatoes South Africa
PVY	Potato virus Y
TAU	Tel Aviv University
TBE	Tris-boric acid-EDTA
TPO	Tomato Producers Organisation
TPP	Tomato Potato Psyllid
TYLCV	Tomato Yellow Leaf Curl Virus
USA	United States of America
ZC	Zebra Chip

Units:

cm	Centimeters
ha	Hectares
km	Kilometers
m	Meters

mm	Millimeters
mmol/L	Millimoles per litre
U/μl	International units per microliter.
X^2	Chi-squared
μL	Microlitre

Symbols:

%	Percentage
~	Approximately
±	Plus or minus
°C	Degrees Celsius

ACKNOWLEDGEMENTS

Firstly, I would like to express my gratitude to the Almighty God for all the strength and grace to take and carry on this journey.

Secondly, I would like to extend my sincere thanks to the following individuals and organizations whose contributions have been invaluable towards the journey of completing this study:

My research supervisors, Prof M. Hill and Dr Z. Maseko for their consistent support, guidance, patience and constructive feedback. Thank you for your time and dedication towards this research; teaching me critical skills that I will always carry during this time. Your faith in me throughout the course of my work will always give me strength in my ability. May the good Almighty God always carry and pour his blessings upon you.

Agricultural Research Council Plant Health and Protection (ARC-PHP) for making it possible to carry out this research by providing funding.

Rhodes University, for providing guidance and support throughout the course of the study.

Noma Mkhize, you were an amazing and fantastic field buddy and friend. Thank you for always providing support, guidance, good laughs and a cup of coffee whenever I needed one.

Sinethemba Nkosi, thank you for being a part of my journey, the long venting sessions in the kitchen, your love, and words of encouragement really shaped me and played a huge role in my journey.

ARC-Biosystematics staff, thank you for always being kind and providing support during this time. Their willingness to give suggestions and enhancements contributed significantly to the quality of this study.

My family, for the love, support, prayers, patience and sacrifices to ensure that I pursue my dreams for a better future. Your endless support made everything possible, I will forever be grateful for everything.

My friends, your support and your faith in me, always pushing and encouraging me to do better and strive for excellence. Nobuhle; thank you so much for always pouring into my cup, listening to me, sharing ideas. I will always be grateful for your love and support.

To all the farmers of South Africa that granted me permission to collect data and conduct my field surveys on their premises.

CHAPTER 1: General Introduction

1. INTRODUCTION

1.1 Introduction to Integrated pest management

Integrated Pest Management (IPM) was developed as a strategy to promote sustainable agriculture and importantly, rationalize the use of pesticides (Orr, 2003). Its goals were to prevent, or delay, the resurgence of pest populations that had developed resistance to pesticides, and to safeguard beneficial insects. IPM is a comprehensive approach that emphasizes a systems perspective. This approach fosters synergies by incorporating preventive methods from a wide range of strategies. The approach relies on agronomic, mechanical, physical, and biological principles, using selective pesticides only when other tools are insufficient for effective management. There are various strategies for managing pests, including host resistance, chemical control, biological control, cultural practices, mechanical methods, and sanitation measures (Ehi-Eromosel et al., 2013). The European Union designed and implemented eight IPM principles (1-prevention and suppression, 2-monitoring, 3-decision-making, 4-non-chemical methods, 5- pesticide selection, 6- reduced pesticide use, 7- anti-resistance strategies, 8- evaluation) to encourage practitioners to embrace the complexity involved in developing sustainable crop protection strategies because relying on pesticides for crop protection has been linked to negative effects on the environment, human health, and the long-term effectiveness of these chemicals through the development of resistance (Barzman et al., 2015). The topic of this thesis was to investigate the pests associated with solanaceous crops in South Africa and develop integrated management plans for their control.

1.2 **Solanaceae crops**

The Solanaceae, (the nightshade family), is among the most significant families within the Angiosperms group of plants, with major implications for the world’s agriculture, economy, and pharmaceuticals. Solanaceae originated in South America, given its significant genetic diversity, and then spread across every continent, predominantly in tropical regions (Motti, 2021). The family includes a variety of plants such as herbs, shrubs, small trees, and some woody vines, with or without thorns (Svobodova et al., 2018). From a botanical perspective, there are many vegetables (fruits) from the Solanaceae including tomatoes (*Solanum lycopersicum* Mill.), peppers (Capsicum annuum L.), black nightshade (*Solanum nigrum* L.), pepino (*Solanum muricatum* Ait.), and ground cherry tomatillos (*Physalis philadelphica* Lam.). In contrast, the potato is a thickened, modified underground (tuber) and is often categorized as a starchy staple crop rather than a typical vegetable (Svobodova et al., 2018).

Economically important Solanaceae fruit include various *Physalis* and *Solanum* species, such as cape gooseberry (*Physalis peruviana* L.), wild gooseberry (*Physalis angulata* L.), goji berry (*Lycium barbarum* L. and *Lycium chinense* Mill.), cocona (*Solanum sessiliflorum* Dunal), naranjilla (*Solanum quitoense* Lam), pepino (*Solanum muricatum* Ait.), and tamarillo (*Solanum betaceum* Cav.) (Lim, 2012). The vegetable category features eggplant (*Solanum melongena* L.), chili and bell peppers (*Capsicum annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, *C. pubescens*), potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum* Mill), tomatillo (*Physalis philadelphica* Lam), turkey berry (*Solanum torvum* Sw.), and nipple fruit (*Solanum mammosum* L.). It also includes popular African indigenous vegetables from the *Solanum nigrum* complex (Linnaeus) (*Solanum americanum* (Mill) and *Solanum scabrum* (Mill), *Solanum villosum* Mill.), the eggplant relatives (*Solanum macrocarpon* (Linnaeus.) and *Solanum aethiopicum* (Linnaeus), and other lesser-known species (Van Rensburg, et al., 2007). The two targeted crops for this study are tomatoes and potatoes since they are part of the most important agricultural crops in South Africa.

1.2.1 Tomato (*Solanum* l*ycopersicon* L)

Tomato is a herbaceous perennial plant that is usually cultivated as an annual crop (Waheed et al. 2020). Tomato is a warm-season crop, intolerant of prolonged exposure to temperatures below 12°C and excessively wet conditions (Waheed et al., 2020). The ideal conditions for growth, yield, and fruit quality typically occur with an average daily temperature ranging from 20°C to 24°C (Department of Agriculture, Forestry & Fisheries (DAFF), 2010). According to DAFF (2010) excessive flower drop is induced by hot, dry winds, while continuous moist, rainy weather conditions contribute to the development and spread of foliar diseases. Tomato is one of the important economic and nutritional crops as it contains vitamins (Liu & Wang, 2020). Furthermore, it is a primary dietary source of the antioxidant lycopene, which has been linked to various health benefits, including a reduced risk of heart disease and cancer (Giovannucci et al., 2002).

1.2.2 Global production of Tomato

South America was initially recognized as a potential origin for tomatoes but is likely to have seen the first domestication in Mexico in the 1500s (Caruso et al., 2022). Tomato is a major economically important crop around the world and on a global scale, and its consumption exceeds that of all other vegetables except for potatoes (Food and Agriculture Organization (FAO), 2017). Tomato holds the 7th position in global production, following wheat, rice, maize, potatoes, soybeans, and cassava, with a worldwide production of about 189 million tonnes annually (FAO, 2022). According to Wakil et al. (2018), China leads the world in tomato production, contributing over 50% of the global tomato acreage. Following China, the United States and India together account for over one-third of the world's production. Turkey and Egypt also make significant contributions (Wakil et al., 2018).

1.2.3 Tomato production in South Africa

In South Africa, tomatoes are the second-most significant vegetable crop, accounting for approximately a quarter of all vegetable crop production, therefore, tomatoes play an extremely important role in agricultural vegetable production and vegetable trade (DALRRD), 2020). According to the Department of Agriculture, Land Reform and Rural Development (DALRRD), 2020), tomatoes contribute about 24% of the total vegetable production in South Africa. The Department of Agriculture, Land Reform and Rural Development (DALRRD), (2020) reported that all South African Provinces grow tomatoes, and the largest production area with 3 590 ha is in the warm-weather Province of Limpopo. The primary regions contributing to tomato production include the Mpumalanga Province covering 770 ha and KwaZulu Natal spanning 450 ha. Tomatoes are susceptible to heat stress and the ideal temperature range for optimal leaf development, as well as fruit formation and growth in tomatoes, is approximately 22 to 25°C (Tshiala & Olwoch, 2010). The geographical distribution of tomato crops is influenced by the climatic conditions of a specific area. The Limpopo Province, with its temperature ranges averaging around these optimal values, is thus associated with the high tomato production (Tshiala & Olwoch, 2010).

1.2.4 Economic importance of tomatoes in South Africa

While the bulk of tomato production in South Africa is found in Limpopo Province, the commodity is widely consumed across the entire country and is also exported internationally (Mandizvidza, 2017). According to DALLRD, (2020), South Africa's tomato exports currently account for 0.1% of global tomato exports, and its position has not changed since 2016 and still ranked number 40 in the world for tomato exports. Gauteng and Western Cape Provinces have commanded the greatest share of tomato exports for the past ten years. In 2019, tomatoes worth R63 430 720.00 were exported from the Province of Gauteng because it serves as the location for the majority of registered exporters and has exit points for tomato exports. The tomato industry in 2019, made up around 15.4% of the total gross value of vegetable production with at least 135 000 dependents, in an industry that employs around 22,500 workers (Tomato Producers Organisation (TPO), 2021), therefore, the tomato industry has a significant contribution to the national economy.

1.3 Potato (*Solanum tuberosum*)

Potato is a short-lived perennial species and the potato tuber, which is the plant's most commercially important component, serves as a location to store carbohydrates (Bradeen et al. 2011). Potatoes are highly nutritious with carbohydrates (22%), proteins (2%), fats (0.1%), water (74%) along with minerals and trace elements such as potassium, sodium, iodine and magnesium, folic acid, pyridoxine, vitamin C, ascorbic acid and iron (Al-Saadi et al., 2020). According to Campos & Ortiz (2020), potatoes are also a source of antioxidants. Chlorogenic acid and glycoalkaloids are present in all potatoes independent of the flesh color while deep, yellow-fleshed potatoes contain high amounts of lutein and zeaxanthin, and purple-fleshed potatoes contain high amounts of anthocyanins. Potatoes glycoalkaloids in high concentrations can be toxic to humans but in low concentrations can have beneficial effects such as inhibition of the growth of cancer cells (Campos & Ortiz, 2020).

1.3.1 Global production of potatoes

Potatoes are presently the fourth most important staple food crop in the world after maize, wheat, and rice with a production of 368 million tonnes annually (Chandrasekara & Kumar, 2016). According to Wang et al. (2023), China is the world's top producer of potatoes and has one of the quickest rates of growth in potato consumption. In China, potatoes have emerged as the fourth most important staple item and are essential for maintaining food security. The introduction of potatoes to Africa took place around the early 20th century, but widespread cultivation across the continent occurred notably after the 1950s (Muthoni et al., 2013).

1.3.2 Potato production in South Africa

According to Statista: Agriculture in South Africa (2023), the total production of potatoes in South Africa was just over 2.5 million metric tons in 2022, a slight drop from the previous year. Potatoes are the third most produced crop in the country. While the area under production in South Africa represents only 3.5% of the total area in Africa, the country contributes 11% to the overall potato production on the continent. Potatoes constitute approximately 45% of the gross value of vegetables in South Africa and make up 3% of the total value of all agricultural products (Statista, 2023). The country is home to approximately 650 active commercial potato growers and 1,000 emerging small-scale potato growers. Potato production in South Africa takes place in all Provinces namely, Limpopo, Northwest, Gauteng, Mpumalanga, Northern Cape, Free State, Kwazulu Natal, Western Cape and Eastern Cape (Van der Waals et al., 2004), each possessing the capacity and capability to provide a year-round supply of potatoes (PSA, 2021). The key coastal region for potato production in South Africa is the Sandveld, situated in the Western Cape Province, approximately 200 km north of Cape Town. In this area, farmers cultivate around 6600 ha of potatoes each year, benefiting from relatively uniform production conditions (Franke et al., 2011). Potato production in South Africa has been steadily increasing, with an average of 52 407 ha cultivated between 2010 and 2020. During this period, there was an estimated average total crop yield of 2.3 million tonnes (PSA, 2021).

1.3.3 Economic importance of potatoes

Potatoes, being the single most important vegetable crop in the country, contribute about R3.5 billion to the economy per year (National Agricultural Marketing Council (NAMC), 2017). According to PSA (2020/2021), the gross value of the agricultural industry is thought to have increased from 10% to 13% in 2020, and the production of potatoes generates at least R6.6 billion for the national economy. Potato production has also opened up employment opportunities in the industry reaching 810 000 jobs in the fourth quarter of 2020, a slight decrease of 8% from the same time in 2019. Owing to the scale of the potato industry, it, therefore, contributes significantly to the South African industry via employment creation, export earnings, economic opportunities for marginalized communities, and small-scale farmers amongst others (NAMC, 2017).

1.4 Pests associated with potato and tomato production in South Africa

Pests within the Sternorryncha are the least studied of the pests on solanaceous crops but are the topic of this thesis and what is known of their biology, impact and control are briefly described below, highlighting knowledge gaps (Table 1.1).

Table 1. 1: Non-Sternorryncha pests affecting tomatoes and potatoes production in South Africa.

Common Pests	Host plant	Reference
Potato tuber moth	Potato	Chandel et al., 2020, Mahmoud et al. 2020
Mole crickets	Tomato	Wakil et al., 2018
Flea beetles	Tomato	Wakil et al., 2018
Cutworms	Potato	Kroschel et al., 2020
Armyworms	Potato	Kroschel et al., 2020
Thrips	Potato	Kroschel et al., 2020
Tomato leaf miner	Tomato	Visser et al., 2017

1.4.1 Sternorryncha pests of tomatoes and potatoes

1.4.1.1 Aphidoidea

Aphids damage their host plants both directly and indirectly by feeding on them, spreading viruses, and promoting the development of saprophytic fungal infections like sooty mould (Hein et al., 1992). Aphids have biological characteristics that make them excellent virus vectors, including a brief life cycle and the capacity to create numerous generations during the summer because of parthenogenetic reproduction (Davis et al., 2006). Aphids belong to Order Hemiptera and they are classified as insects of agricultural importance in South Africa and they also account for 75% of the pest problems on cultivated crops (Moran, 1983). Aphids are phloem-feeders, and as such, they play a significant role in the spread of plant viruses since their unique feeding habits allow for the direct transfer of virus particles into the cytoplasm of cells in the new host's epidermis, mesophyll, vascular tissue, and/or phloem sap (Chesnais et al., 2022), and are among the most prevalent pests in agricultural production, and plant infestations can result in serious harm to plants. Current management techniques including chemical, biological, and cultural control have been used to address these pests; using natural predators such as ladybugs, lacewings, and parasitoid wasps to manage aphid populations is one way of biological management (Ali, 2023). Insecticides are used in chemical management approaches to lower the aphid population, although this approach may be detrimental to non-target species and the environment. Chemical management strategies employ insecticides to reduce the aphid population, however, there is a chance that this technique will harm non-target species and the ecosystem (Ali, 2023).

In South Africa, the primary aphid species affecting potatoes are *Macrosiphum euphorbiae* Thomas (Hemipter: Aphididae) and *Myzus persicae* (Daiber, 1963). According to Whittaker (2015), *M. euphorbiae* is native to North America but has long been established in Central and South America, Europe, Asia, and Africa and it has extended its presence to countries in eastern Asia and Oceania. The potato aphid is a medium-sized to large aphid with green eyes that can occasionally be pink or magenta in certain forms. It is a polyphagous species native to North America that feeds on up to 200 distinct plant species from 20 different families, including multiple species of *Solanum* (Giordanengo et al., 2013). The potato aphid is found all over the world, including populations in Europe, North America, Asia, Africa, and Oceania. They can be found in every major tomato-producing region in the United States, however, they are more prevalent in the southern states because of the longer, warmer seasons (Ali, 2023). *Macrosiphum euphorbiae* poses a significant threat to potatoes, tomatoes, and lettuce, impacting both field and greenhouse cultivation. Elevated populations of *M. euphorbiae* lead to direct feeding damage as aphids use their stylets to access a plant's phloem and occasionally the xylem. Extensive colonies of aphids can extract substantial nutrients from plants, resulting in distorted leaves and stems, leaf roll, necrotic spots, stunted plant growth, and a decrease in photosynthetic efficiency, leading to notable yield losses. The period 6 to 8 weeks before harvest is particularly vulnerable to high infestations because this is often the stage when fruits and tubers are ripening which makes them appealing to pests and more vulnerable to diseases. Additionally, aphids secrete abundant honeydew, fostering the growth of sooty molds on foliage and fruit. This aesthetic damage significantly diminishes the value of vegetables and fruit (Whittaker, 2022). *Macrosiphum euphorbiae* is recognized for colonizing potato plants and spreading viruses such as Potato leafroll virus (PLRV) and Potato virus Y (PVY) (Srinivasan & Alvarez 2007). According to Muller, (2016), The optimal temperature for the reproduction of *M. euphorbiae* was found to be 22 ºC and higher temperatures have an adverse impact on the survival and reproductive efficacy of nymphs belonging to the species *M. euphorbiae* (Muller, 2016). The temperature conditions in Limpopo Province averaged close to these optimal levels, which are conducive for the development of *M. euphorbiae*.

Myzus persicae is the other significant potato aphid globally, often referred to as the peach-potato aphid, which is thought to have originated in China. This aphid is very polymorphic, ranging in size from small to medium and having colors that range from green to red (Giordanengo et al., 2013). According to Capinera (2001), aphids on young plants can reach extremely high densities on green peach tissue, which can lead to water stress, wilting, and slow plant growth. Root and leaf crop yields can be significantly reduced by a persistent aphid infestation. The major damage caused by green peach aphid is through transmission of plant viruses with major viruses being Potato leaf roll (PLRV) virus and Potato virus Y (PVY) on potatoes and Tomato yellow leaf curl on tomatoes (TYLC) (Capinera, 2001). *Myzus persicae* is the most effective carrier of PLRV. PLRV is confined to the phloem and aphids pick up PLRV while feeding on phloem sap from infected plants, then transmit it to new plants as they secrete saliva into the phloem sieve elements (Alvarez et al., 2007). *Myzus persicae* can also vector Potato Virus Y (Srinivasan & Alvarez, 2007). *Myzus persicae* has demonstrated a greater preference for plants infected with PLRV over those infected with PVY. Additionally, aphids that consumed sap from PLRV-infected plants exhibited improved growth and reproductive capabilities compared to those that fed on PVY-infected plants (Srinivasan & Alvarez, 2007).

The green peach aphid can withstand high temperatures when exposed to fluctuating temperature conditions (Davis et al., 2006). When temperatures rise above the upper developmental thresholds, the rate of development slows down; with a developmental threshold of 37.3°C (Davis et al., 2006). Higher temperatures facilitate a more rapid increase in the green peach aphid population, leading to improved survivorship and higher fecundity. The ideal temperature for the growth of the green peach aphid population is between 6.5°C (lower threshold) and 26.7°C, with an upper developmental threshold of 37.3°C (Davis et al., 2006).

1.4.1.2 Psylloidea

These small insects are sometimes referred to as jumping plant lice or psyllids (Spodek et al., 2015). They are phytophagous, sap-sucking insects and the majority are highly host-specific and predominantly associated with perennial dicotyledonous angiosperms (Hodkinson, 2009).

A small number of psyllid species have been documented to inflict harm on potatoes; they include *Bactericerra cockerelli*, *Bactericerra nigricornis* Förster (Hemiptera: Triozidae), and *Russelliana solanicola* Tuthill (Hemiptera: Psylloidea). The potato psyllid has garnered the most attention because of its important roles in the spread of *Candidatus* Liberibacter solanacearum (Wenninger and Rashed, 2022).

The tomato-potato psyllid (*Bactericera cockerelli*)

The tomato-potato (TPP) psyllid is a native of western North America and is found in Mexico and the central to western United States. In the early 2000s, it was transported to New Zealand and has since spread to multiple potato production regions (Wenninger and Rashed, 2024). The pest was first observed in Clevedon, New Zealand on tomato plants in March 2006 (Tuelon et al., 2009) and has been observed in Mainland Australia, where it is currently reported to be restricted to Western Australia (Sarkar et al., 2023).

In the upper parts of potato and tomato plants, *B. cockerelli* can induce distinctive effects such as the upright positioning of new leaves, stunted growth, chlorosis, purpling, and basal cupping of emerging leaves. Additionally, symptoms may include the upward rolling of leaves, shortened and thicker terminal internodes, enlarged nodes, axillary branches, or the formation of aerial potato tubers (European Food Safety Authority (EFSA), 2019). Furthermore, the psyllid may influence fruit production, resulting in either the absence or the generation of numerous small, low-quality fruits. Below ground, the impact of the psyllid can manifest as an overabundance of very small and misshapen potato tubers or chain tubers, along with an early breaking of dormancy in tubers (EFSA, 2019). The tomato-potato psyllid is a significant agricultural pest, as it not only harms crops through feeding but also spreads the bacterium *Candidatus* Liberibacter solanacearum (CLs), responsible for causing zebra chip disease in potatoes (Nachappa & Tamborindeguy, 2012). According to Suwandharathne et al. (2023), the tomato-potato psyllid has recently spread to Australasia and is expected to broaden its geographical distribution, particularly in semi-arid, temperate, and continental climates. In Australia, besides its established presence in Western Australia, there's a likelihood that TPP will spread to South Australia, Victoria, New South Wales, and Queensland. This projected range aligns with current observations, indicating that New Zealand might have even more favorable climatic conditions for TPP. Europe doesn't currently have the tomato-potato psyllid (TPP), but it is predicted that the region's climate could be well-suited for its potential establishment. Certain temperate regions in Africa are forecasted to be conducive to the establishment of the tomato-potato psyllid (TPP). Specifically, a narrow strip in North Africa and parts of Southern Africa are projected to have optimal to moderate climatic conditions that could support TPP (Suwandharathne et al., 2023).

Bactericera nigricornis (Förster, 1848)

According to Moreno et al. (2021) *Bactericera nigricornis*, a polyphagous species, is capable of feeding and reproducing in various plant families, including Solanaceae and Apiaceae. It was first described as *Trioza nigricornis* in 1848 by Förster from Frankfurt, Germany (Halbert & Munyaneza, 2012). This particular species has been identified on crops such as carrot (*Daucus carota* L.) and potato in European regions and there is a potential for *Bactericera nigricornis* to transmit *Candidatus* Liberibacter solanacearum in carrots (Halbert & Munyaneza, 2012). Its geographical distribution extends from Europe across Central Asia, reaching southward to the Middle East and North Africa (Halbert & Munyaneza, 2012). *Bactericera nigricornis* has been documented as a significant contributor to substantial yield losses in potatoes in Iran. The affected tubers display distinct striped patterns of necrosis, resembling symptoms associated with Zebra Chip (ZC) diseases (Fathi, 2011). *Bactericera nigricornis* has the potential to transmit *Candidatus* Liberibacter solanacearum (Quintana et al., 2022).

1.4.1.3 Aleyrodoidea (Whitefly)

The whitefly is a serious pest of a wide range of economically important agricultural regions in the world (Borisade, 2015). The insect feeds on phloem sap of plants and is responsible for the transmission of tomato curl virus. Besides disease transmission, large amounts of honeydew excreted by the insect encourage the development of black sooty mould on leaves and fruits. A direct shading of leaves by the powdery coating has been reported to significantly reduce photosynthetic capabilities of crop plants, which results in economic loss (Borisade, 2015). Whiteflies are key constraints to vegetable crop production and are especially challenging for tomato growers as they are highly susceptible to whitefly infestation and whitefly-transmitted virus (Moodley et al., 2019).

Bemisia tabaci Gennadius (Hemiptera: Aleyrodidae)

Bemisia tabaci is a significant pest of a variety of economically important agricultural and ornamental crops. In tomatoes, the pest feed on the phloem sap of plants (Borisade, 2015) and transmits the Tomato yellow leaf curl virus (TYLCV) (Tang et al., 2017). TYLCV is the name given to a complex of virus species that poses a significant risk to tomato cultivation across temperate regions globally. The virus is more effectively transmitted by females than males because they consume more phloem, have larger concentrations of particular endosymbionts that protect the virus and have better virus acquisition capacities than males and nymphs are just as capable as adults at picking up the virus (Moriones & Navas-Castillo, 2000). A direct shading of leaves by the powdery coating reduces photosynthetic capabilities of crop plants, which results in economic loss (Tang et al., 2017). *Bemisia tabaci* was first reported and named *Aleyrodes tabaci* by Gennadius in 1889, as a pest of tobacco in Greece (Sani et al., 2020).

According to Oliveira et al. (2001), since its description more than a century ago, *B. tabaci* has grown to become one of the most significant pests in tropical and subtropical agriculture, as well as greenhouse production systems, globally. It is easily adapted to new host plants and geographical areas; reports of it have been made from every continent on Earth, apart from Antarctica. According to Liu & Wang, (2020), its growth and development are greatly impacted by high or low temperatures, particularly in terms of survival and reproduction, which can result in a stop of growth and development or even death. As a result, variations in temperature have an impact on both the behaviour and the growth and development of individual insects. It can withstand temperatures exceeding 40 °C in general, and nymphs and adults can survive at 5 °C. The establishment of *B. tabaci* is frequently significant when the conditions are right and the host is wealthy, particularly in high temperature and dry season. The ideal temperature range for *B. tabaci* development is 26–28 °C, with a distinct beginning temperature for each stage (Liu & Wang, 2020).

1.5 Monitoring and surveillance of pests

The rise in non-native species invading new regions calls for more effective monitoring surveillance techniques (Ascolese et al., 2022). Monitoring is a crucial component of integrated pest management (IPM), intended to ensure that pest populations remain below the economic injury level (EIL). Pest surveillance is essential for assessing the presence and economic impact of pests in agriculture. A well-structured surveillance system with a carefully designed protocol, combined with strong diagnostic skills and knowledge, is crucial to prevent pest outbreaks and avoid economic losses in crop production (Asia-Pacific Economic Cooperation, 2007). Plant pest surveillance is carried out to establish the pest status in a given area, enhance the chances of early detection, and track pest prevalence (Moir et al., 2021).

Various insect trapping methods for insect monitoring and surveillance are in use in different cropping systems. Sticky traps are a common tool used to monitor winged arthropod pests in greenhouses (Böckmann et al., 2015). Yellow sticky traps offer more than just pest detection; they also deliver quantitative data on the growth of pest populations, which can indicate the success or failure of plant protection strategies to some extent (Böckmann et al., 2015). Generally, sticky traps are placed at a density of about one trap per 200 m^2 vertically, just above the crop canopy (Sampson et al., 2021). In addition to sticky traps, Malaise traps, which are expansive tent-shaped structures constructed of netting, are designed to channel and capture insects. Malaise traps effectively sample various flying insects, including many species of flies (Diptera), as well as some wasps, flying ants, bees (Hymenoptera), bugs (Hemiptera), moths (Lepidoptera), and semi-aquatic taxa (Montgomery et al., 2021).

Light traps are prevalent and effective techniques for surveying nocturnal flying insects. Essentially, these traps comprise a light source to attract insects and a viewing surface, typically a bedsheet, and are utilized for surveying a broad spectrum of insect taxa. This method is suitable for capturing various insects, including flies (Diptera), true bugs (Hemiptera), beetles (Coleoptera), caddisflies (Trichoptera), parasitic wasps (Hymenoptera), moths (Lepidoptera), and other groups. Light trapping is particularly well-suited for capturing moths (Montgomery et al., 2021). Pan traps, which are trays filled with liquid, are set out to collect insects. These traps primarily rely on color as an attractant, taking advantage of insects mistaking them for food sources. Pan trapping is well-suited for monitoring flying insects and is notably efficient at sampling a diverse range of insect groups, such as aphids (Hemiptera), thrips (Thysanoptera), bees and parasitic wasps (Hymenoptera), flies (Diptera), specific beetles (Coleoptera), and even some grasshoppers (Orthoptera) (Montgomery et al., 2021).

This system serves to provide scientific and technical evidence for determining the status of pests. Moreover, it supports the early detection of pests, emergency response operations, and pest reporting. Surveillance activities are backed by the development of guidelines and protocols, the presence of plant health laboratories, the procurement of fieldwork equipment, and the allocation of institutional budgets. In South Africa, Crop Watch Africa (CWA) designs and implement surveillance programs to monitor the presence, spread and severity of pests and diseases. Their surveillance programs include Early warning surveys, Areawide survey, Delimiting surveys and Independent audits. However, surveillance efforts in Kenya suffer from inadequate funding, lack of coordination, and fragmentation among the relevant institutions responsible for this mandate. There is also a failure to fully leverage community and passive surveillance methods, as well as a deficiency in nationally agreed-upon standards and plans for collecting surveillance data.

In 2018, the International Center of Insect Physiology and Ecology (*icipe*), Kenya and Tel Aviv University (TAU), had a collaborative research project aimed at establishing a regional early warning and monitoring system in areas affected by fall armyworm, crucial for providing support in decision-making for pest management (Agritask, 2020). *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae), an invasive pest, inflicts substantial damage on various staple crops such as maize. Its initial sighting in Africa in 2016 marked the beginning of its rapid spread, amplifying the threat to food security. The project, Emergency Support to Manage Outbreaks and Infestation by *Spodoptera exempta* Walker (Lepidoptera: Noctuidae) in Eastern Africa, helps six countries in the region: Eritrea, Ethiopia, Kenya, Somalia, South Sudan, and Uganda. Through this project, there was the establishment of 2400 monitoring sites, with 400 sites in each country. After conducting surveillance on more than 1.12 million hectares, Kenya discovered that African Armyworm was present on around 296 thousand of those hectares. Through ground spraying, more than 173,000 hectares of land have been preserved thus far (FAO, 2023).

The North American Plant Protection Organization (NAPPO) (2012) provided guidelines for surveillance for the tomato leaf miner in North America (Canada, Mexico and United States) aimed for early detection and delimitation of *Phthorimaea absoluta* Meyrick (Lepidoptera: Gelechiidae) in the North American region (Mexico, USA, and Canada), should it become introduced. They used pheromone lures and traps such as Tomato leaf miner lure which should be changed every four to six weeks and examined every two weeks. Since *P. absoluta* tends to stay close to the ground and prefers young shoots, traps should be placed at a height of approximately 0.40 meters. Delta traps are set at a rate of two traps per hectare at specified distances of two to five kilometers. Every trap placement site should have one trap, except for those that are more than 5,000 square meters with a trap servicing frequency of two weeks (NAPPO, 2012).

A study conducted by Monzó et al. (2015) monitoring of the Asian Citrus Psyllid (ACP) in Central and Southwest Florida, United States used yellow sticky traps, suction traps, sweep net sampling and stem-tap samples were used as monitoring techniques. Using stem-tap sampling, samples were taken every two weeks by shaking a randomly chosen branch three times with a 40 cm long, 2 cm diameter PVC pipe. As the Asian Citrus Psyllid adults fell on a clipboard with a 22 cm by 28 cm laminated white sheet held horizontally beneath the branch, they were counted. Each tree underwent two stem-tap samples on the canopy. A sample is collected by swinging a net 180° from right to left (Monzo et al., 2015). Sweep net samples are taken in the morning, between 9 and 11 a.m. and samples can be taken on the sides of the tree canopy and on the space above the vegetation (Medlock et al., 2018). Sweep netting protocol can vary with regard to time spent sweep netting, number of aerial sweeps, number of collectors per transect and distance (Prado et al., 2017). Sweep samplings can be conducted while traversing a 1.5 km transect path, starting from the undergrowth (layers of shrubs and herbs) (Arun & Vijayan, 2004). One hundred sweeps can be regarded as one sample and one such sample taken from each site (Arun & Vijayan, 2004) whereas, 30 sweeps can be taken as one sample and two sweep samples are taken from a site (Spafford & Lortie, 2013). After sweeping remove all insects from the net using an aspirator (Medlock et al., 2018)

Suction traps in the form of hand-held re-purposed leaf blowers as well as stationary Rothamsted suction traps are useful sampling tools. For the handheld suction traps, samples are taken using a converted handheld suction device, 4.3 kg, powered by a 2-cycle engine. The suction trap is a blower that is converted to a suction device by switching the exhaust tube to the intake port. The intake tube is widened at the end to 25 cm diameter by attaching a bottomless plastic flowerpot with duct tape to increase suction area. A sheer nylon elastic stocking is fitted into the suction pipe each time a sample is taken to retain all insects captured.

In South Africa, there is an aphid monitoring initiative by Department of Agriculture, Potatoes South Africa and Agricultural Research Council designed to offer seed potato growers regional estimates of aphid abundance and diversity. This enables growers to evaluate the risk of virus transmission. Monitoring aphid populations aids growers in determining when and where to implement aphid control measures (DALRRD, 2018). The national aphid monitoring suction trap network comprises thirteen suction traps (Rothamsted-type suction traps), each standing at 12.2 m high. These traps are strategically located in the primary seed potato cultivation regions of South Africa. Each trap provides data representative of aphid populations within an 80 km radius of its location (Kruger et al., 2018). Data derived from the aphid monitoring program holds significant importance for the potato industry, particularly concerning the behavior of particular species which include bird cherry-oat aphid, rose-grain and other aphid species and their potential impact on potato cultivation in specific areas (DALRRD, 2018).

According to Prasad & Prabhakar, (2012), pest monitoring serves as the basis for issuing early warnings, developing and validating pest forecast models, and creating decision support systems. These elements are critical for the design and implementation of effective Integrated Pest Management (IPM) programmes. Using attractants and traps to monitor and control insect populations can increase the effectiveness of insecticide applications and, in some cases, reduce the reliance on broad-spectrum, more toxic chemicals (Weinzierl, 2005).

1.6 Problem Statement

Food availability and food security remains a challenge in South Africa, due to crop diseases and pests attacking a number of plants thus, reducing food quality and quantity and causing great agricultural losses. According to the Food and Agriculture Organization (FAO) (2022), world hunger has increased by 150 million since 2019 (pre-COVID-19 pandemic) to 828 million in 2021. Results indicate that out of 17.9 million households in South Africa in 2021, almost 80 % (14.2 million) reported that they had adequate access to food, while 15 % (2.6 million) stated that they had inadequate, and 6 percent (1.1 million) had severely inadequate access to food, respectively (Stats SA, 2023).

Members of the Sternorrhyncha (Order: Hemiptera) group attack tomatoes (*Lycopersicon esculentum* Miller–Solanaceae) and potatoes (*Solanum tuberosum* L); vectoring diseases that lead to production losses. Aphids are the most important pest of potato which can cause damage and yield impacts through direct feeding, but their main economic impact is due to their ability to transmit viruses such as potato leaf roll virus and potato virus Y. Aphids (Aphidoidea) and Whiteflies (Aleyrodoidea) are the most important tomato pests. Whiteflies on the other hand not only suck plant sap, but they also transmit plant viruses such as tomato yellow leaf curl virus (TYLCV).

1.7 Aims and Objectives

This study aims to map the prevalence of important Sternorryncha species in various potato and tomato producing areas across South Africa.

Specific objectives:

- To conduct a survey of Sternorrhyncha pests on tomato and potato farms in the country to ascertain current pest species occurrence.

- To survey for incursion by the invasive *Bactericera cockerelli* in South Africa.

Chapter 2: Determining the population dynamics, and species diversity of aphids on potato in Douglas, Northern Cape Province, and Christiana, North-West Province, South Africa

2.1 Introduction

Population dynamics is a branch of population ecology focused on the factors influencing changes in population densities (Karuppaiah & Sujayanad, 2012). This branch of ecology further describes and forecasts the size and age distribution of a group of individuals belonging to a specific species, as well as the ways in which the number and age distribution of a population fluctuate over time (Olson & Stenlid, 2022). Population dynamics is crucial in various strategies for preserving biodiversity, which have traditionally concentrated on a single-species approach (Hasting, 2013). Two broad components of population dynamics are; quantitative descriptions of the changes in population number and form of population growth or decline for a particular organism; and investigations of the forces and biological and physical processes causing those changes. The first of these components involves descriptive data useful for quantifying trends, and with appropriate statistical treatment, for forecasting future trends (Juliano, 2007). Four major variables must be taken into account in order to characterize population dynamics: individual births, deaths, immigrations, and emigrations. A population's changes can be tracked and predicted using these variables (Olson & Stenlid, 2022). Population dynamics and species diversity are closely connected (Connor et al., 2018). At the community level, ecosystems with high diversity tend to be more stable and resilient to environmental changes compared to those with lower diversity. However, at the population level, empirical data and modeling indicate that individual populations within diverse communities may experience greater instability than those in less diverse communities (Connor et al., 2018).

Several factors influence insect population dynamics, with climate being a major environmental predictor. Variations in temperature can alter developmental rates, voltinism, and survival, which in turn affect the size, density, and genetic composition of insect populations, as well as the extent of host plant exploitation (Karuppaiah & Sujayanad, 2012).

In agricultural ecosystems, environmental changes influence pest population dynamics either directly or indirectly by modifying host physiology (Karuppaiah & Sujayanad, 2012).

Krause-Sakate et al. (2020) stated that in agricultural ecosystems, insect behaviour and development can be influenced by multiple factors, including temperature, the presence of endosymbionts, host plants, associated viruses, and management practices. For example, in whiteflies, these factors significantly affect their predominance and establishment in an ecosystem. One of the most important factors influencing insect development is temperature, which affects the insect's performance, and in turn affects the insect's behaviour, colonization, and distribution (Krause-Sakate et al., 2020). The population dynamics of whiteflies are further influenced by crop senescence, natural predators, and the movement of adults from surrounding plants (Leite et al., 2005). The natural enemies of whiteflies and the ambient temperature are important variables in determining the dynamics of the whitefly population on a particular host plant. In addition to temperature, relative humidity has a significant impact on whitefly populations, as they thrive in warm, humid conditions (Riley & Ciomperlik, 1997). As temperatures rise, whitefly populations tend to increase (Khalid et al., 2024). In a 2022, study in Pakistan on cotton plants, a positive correlation was observed between whitefly populations and temperature (Khalid et al., 2024). The study found that whitefly numbers peaked during periods of high temperature and relative humidity, while populations were lower when both factors were reduced.

Some biotic influences can determine insect population abundance and patterns. For example, leaf senescence triggered by environmental stress can decrease photosynthesis, cause early cell death, and limit anabolite availability prior to flowering (Gregersen & Gregersen, 2009), resulting in reduced plant quality and a decline in insect pest populations (Leite et al., 2005). Plants of the same variety, but grown under different conditions, were found to either support or inhibit whitefly development, regardless of the extent of whitefly migration into the field. This highlights the crucial role of plant characteristics in controlling whitefly population growth because factors such as nutrient composition, leaf morphology, chemical defenses, and overall plant health can determine whether a plant supports or inhibits whitefly development. (Moawad & Gerling, 2000).

According to Fernandes et al. (2018), aphid population dynamics are influenced by seasonal weather changes, the physiological traits of host plants, farming methods, and management practices. Additionally, certain crops may repel, while others attract sap-sucking insects, with local variations in resource quality having a significant impact on overall population dynamics. Aphid populations exhibit periodic fluctuations, with various factors contributing to their dynamics. Aphid species can overwinter as either anholocyclic or holocyclic clones (Brabec et al., 2014). Aphid populations typically experience a sharp increase in size during the spring, followed by a significant decline in abundance during the summer, and occasionally another rise in the autumn. Throughout spring and summer, all generations are parthenogenetic and have short life spans of 1–4 weeks (Kindlmann & Dixon, 2010). In autumn, sexual forms are produced, which mate and lay overwintering eggs. These eggs give rise to fundatrices, the first parthenogenetic generation, which hatch the following spring (Kindlmann & Dixon, 2010).

Most aphid species are capable of both asexual and sexual reproduction, with multiple parthenogenetic generations occurring between periods of sexual reproduction. This process, known as cyclical parthenogenesis, involves sexual reproduction in autumn in temperate regions, resulting in the production of overwintering eggs that hatch in spring to begin another cycle. However, many aphids overwinter not as eggs but as nymphs or adults, while some can overwinter as both eggs and active stages (Kindlmann & Dixon, 2010). Parthenogenetic individuals have very short developmental times relative to their size, leading to high rates of population increase. As a result, aphid populations display complex and rapidly shifting dynamics throughout the year, with each clone passing through several generations during the vegetative season and spreading widely. The survival of overwintering eggs and/or aphids significantly influences the aphid population in the following spring season (Kindlmann & Dixon, 2010).

2.1.1 Species diversity

The study of biodiversity typically starts with species diversity, as it is the most familiar aspect of biodiversity. Species diversity is a core component of biodiversity, and its indices consider two key aspects of a community: species richness and evenness (Hamilton, 2005). Species richness is typically expressed in relation to an area and represents the number of species present in that area and can be defined by political boundaries, ecological regions, or by using an equal area grid that is placed without regard to political divisions (Kiester, 2013). To calculate species richness, it is necessary to define what constitutes a species and select a higher taxon for which a list of species is available (Kiester, 2013). Species evenness considers both the number of species and their relative abundance within a community (Moore, 2013). Species dominance refers to the extent to which one or a small number of species account for a large proportion of the total individuals or biomass within a community, thereby exerting a strong influence on community structure and communities with high dominance often have low species diversity, because the numerical prevalence of dominant species reduces evenness among all species (Avolio et al., 2019).

Species diversity results from a complex interplay of multiple factors, meaning that the impact of one factor can be influenced or overshadowed by others. Additionally, some determinants of species diversity such as predation, herbivory, disturbance, seasonality, and environmental predictability affect diversity in a non-linear manner. This means that fluctuations in these factors can lead to either an increase or a decrease in species diversity (Diamond, 1988). It is evident that host plant communities have largely influenced the diversity of insect species. For instance, approximately 40% of known aphid species live on trees, with the other 55% preferring to feed on herbaceous host plants and shrubs (the remaining 5% live on unknown hosts). Some aphids, about 10% of them, have a heteroecious life cycle. In this cycle, aphids migrate to secondary hosts consisting of flowering herbaceous hosts in the summer after spending all the seasons except summer on primary hosts (Yilmaz & Kok, 2023). Aphids are closely linked to their host plants, which serve as both their food source and habitat, exerting significant selective pressure on their evolution (Peccoud et al., 2010).

Singh & Singh, (2022) reported that in India, 51 plant species from the Solanaceae family are infested by 60 different species of aphids. Among these, *S. tuberosum* hosted the largest number of aphid species, with 21 species found on it. This is followed by *Nicotiana tabacum* (Linnaeus), which was colonized by 18 aphid species. *Solanum melongena* supported 14 aphid species, while *S. lycopersicum* was infested by 13 species. Both *Datura metel* (Linnaeus) (thornapple) and *Solanum nigrum* (black nightshade) harbored 11 aphid species each, and *Cestrum fasciculatum* (Schltdl.) Miers (early flowering jessamine) was a host to 10 aphid species. These findings emphasize the susceptibility of key crops like potatoes, tobacco, eggplant, and tomatoes to aphid infestations, underlining the importance of pest control strategies for these plants (Singh & Singh, 2022). Aphids are significant pests in agriculture, causing substantial damage through feeding and serving as vectors for viruses (Jaouannet et al., 2014). Aphids also cause great damage to cruciferous crops; broccoli, brussels sprouts, cabbage, cauliflower, kale, mustard, radishes, turnips, the cabbage aphid, *Brevicoryne brassicae* (Linnaeus, 1758), *Lipaphis pseudobrassicae* Kaltenbach (Hemiptera: Aphididae) and *Myzus persicae* (Essig, 1948). Wheat and sorghum plants are infested by important and common cereal crop pest aphid species, *Diuraphis noxia* Kurdjumov (Hemiptera: Aphididae) (very damaging on wheat in South Africa), *Metopolophium dirhodum, Rhopalosiphum maidis,* *Rhopalosiphum padi, Sitobion avenae* Fabricius, (Hemiptera: Aphididae) and *Schizaphis graminum* Rondani (Hemiptera: Aphididae) (Bandyan et al., 2021). Watermelon, sweet pepper, eggplant and broad bean plants are infested by known aphid pest species, *Aphis fabae* Scopoli (Hemiptera: Aphididae), *Aphis craccivora* Koch (Hemiptera: Aphididae) and *Myzus persicae*. *Aphidius matricariae* Haliday (Hymenoptera: Braconidae) feeds on three different host plants; wheat, sorghum and watermelon and *Lysiphlebus fabarum* Marshall (Hymenoptera: Braconidae) was also discovered to feed on three host plants (eggplant, sweet pepper and broad bean) (Bandyan et al., 2021). Many leguminous plants are attacked by the pea aphid *Acyrthosiphon pisum* Harris (Hemiptera: Aphididae)). *Brevicoryne brassicae* L. (Hemiptera: Aphididae)is a serious pest of major cabbage crops including cabbages, cauliflower, and brussels sprouts. *Toxoptera citricida* Kirkaldy (Hemiptera: Aphididae) is a pest of citrus and the main vector of citrus tristeza virus in the subtropics and tropics. *Aphis gossypii* Glover (Hemiptera: Aphididae) is an important aphid in citrus. *Myzus persicae* is an important aphid of potatoes and can also host tobacco, radish, Chinese cabbage and wild cabbage (Jiang et al. 2022). *Myzus nicotianae* Blackman (Hemiptera: Aphididae) occurs primarily on tobacco but is also found on *Brassica, Capsicum, Orobanche, Sesamum* and *Sisymbrium* (Semtner et al., 1998).

According to Perring et al. (2018), there are 18 aphid species that feed on tomatoes and these include *Aphis craccivora*, *Aphis fabae, Aphis gossypii*, *Aphis spiraecola* Patch (Hemiptera: Aphididae), *Aulacorthum solani* Kaltenbach (Hemiptera: Aphididae), *Macrosiphum euphorbiae*, *Myzus ornatus* Laing (Hemiptera: Aphididae*)*, *Mizus persicae*, *Rhopalosiphum rufiabdominale* Sasaki (Hemiptera: Aphididae) and *Smynthurodes betae* Westwood (Hemiptera: Aphididae: Eriosomatine: Fordini). While any of the species mentioned may be economic pests of tomatoes in the local context, such as *A. gossypii*, only two species are considered to be global pests; *Macrosiphum euphorbiae* and *Myzus persicae* and they are sympatric aphid species, which are serious pests of potato crops (Dugravot et al., 2007). *Myzus persicae*, *Macrosiphum euphorbiae*, *Aphis gossypii* and *Aulacorthum solani* are principal pests of protected pepper crops in southeastern Spain (Sanchez et al., 2011). Thus, the aim of this chapter was to investigate the population dynamics and species diversity of aphids on potatoes in Christiana and Douglas focusing on how environmental factors influence the patterns and the aphid populations.

2.2 Materials and Methods

2.2.1 Description of sampling sites

Douglas, Northern Cape is located in South Africa's dry continental area with an annual average rainfall of approximately 200 mm. Winters are cold with regular frost, while summers can be hot. Temperatures range from 20° to 33°C in the summer and from 5° to 20° C in the winter. The geographical coordinates of Douglas are -29.055and 23.77403 with an elevation of 992.124m elevation (Figure 2.1). The topography within 3.328km of Douglas contains only modest variations in elevation, with a maximum elevation change of 61.874m and an average elevation above sea level of 1.0027m. The area within 3.218km of Douglas is covered by shrubs (43%), cropland (30%), and artificial surfaces (27%), within 16 km by shrubs (73%) and cropland (15%), and within 80 km by shrubs (87%) and grassland (10%). Douglas's annual average temperature is 25.23°C and receives approximately 38.78 mm rainy days (Weatherspark, 2024). The gross value of potato production accounts for about 43 % of major vegetables, with eighteen producers that are currently producing potatoes for the country's fresh produce markets on 2 214 ha in the Northern Cape potato production region and approximately 60.74% of this region's potato production comprises seed potatoes (Prins & Verster, 2023). The diverse terrain includes softer sandy soils, rocky outcrops, rolling hills, and rich Savanna veldt vegetation (Weatherspark, 2024).

Christiana is a small farming community that is situated along the banks of the Vaal River in the Northwest Province, with several major potato growers. The sandy soil types of the region are good for producing potatoes of high quality. Temperatures range from 17°C to 31°C in the summer and from 3° to 21° C in the winter. Annual rainfall averages about 360 mm, with almost all of it falling during the summer months, between October and April. The geographical coordinates of Christiana are -27.914 and 25.161 and 1207m elevation (Figure 2.1). The topography within 3.32 km of Christiana contains only modest variations in elevation, with a maximum elevation change of 38.1m and an average elevation above sea level of 1207m. Within 80 km, Christiana exhibits only modest variations in elevation. The area within 3.21 km of Christiana is covered by shrubs (52%), grassland (25%), and artificial surfaces (21%), within 16 km by grassland (45%) and shrubs (39%), and within 80 km by grassland (40%) and shrubs (27%) (Weatherspark, 2024). Within the South African context, the gross value of potato production accounts for about 43 % of major vegetables, 15 % of horticultural products and 4 % of total agricultural production (Department of Agriculture

Land Reform and Rural Development, 2023) with Northwest accounting for 3 036 ha. in total production (Potatoes SA, 2024).

Figure 2. 1: South African map illustrating the two collection sites marked by two red stars, Christiana and Douglas.

2.2.2 Aphid sampling

Aphid population (samples taken each month over the 2 year period) data were collected from Christiana and Douglas on a weekly basis from two suction traps in Christiana and Douglas respectively from May 2023 to March 2025 (Figure 2.1). The aphids were collected from Rothamsted-type suction traps (Figure 2.2) in both locations. The 12.2m high suction traps continuously collect airborne insects on a regional scale at a standardized volume of 45 m^3 air/min from a radius ranging from 30 to 80 km^2 or more, depending on the topography of the region. The suction trap placements are in open spaces where airflow is not obstructed by trees or large structures. The trap consists of two main parts: a 9.2m plastic tube at the top and a 3m box that houses an electric fan along with filtering and storage systems to collect insect samples (Macaulay et al., 1988). The collected aphids were sorted, counted and identified to species level or to genus level using the Aphid Identification guide by Millar, (1990). The insects were collected on a weekly basis and stored in 99% alcohol. The morphologically identified aphids were randomly selected for Deoxyribonucleic acid (DNA) barcoding targeting the CO1 gene to confirm the identifications and this was to reduce selection bias and improve the validity and reliability of the results.

Figure 2. 2: A Rothamsted-type, 12.2m suction trap in an open field.

2.2.3 DNA extraction, sequencing and data analysis

DNA was extracted from 14 insects per site where each individual insect was counted as a sample. The Qiagen DNeasy Blood and Tissue kit (Qiagen Inc., Valencia, CA) was used to extract the DNA following the protocol prescribed by the manufacturer. The extracted DNA samples were stored in a freezer. Folmer fragment of the 5 ′ region of COI was amplified using polymerase chain reaction (PCR) by using forward primer LCO (5′- GGTCAACAAATCATAAAGATATTGG-3′) and reverse primer HCO (5′- TAAACTTCAGGGTGACCAAAAAATCA-3′) (Folmer et al. 1994). PCR reaction was performed in a total volume of 25 μL reaction mixture containing 1 μL template DNA (50–150 ng), 4.7 μL 10X1 PCR buffer (contains 25mM (magnesium chloride)), 1 μL of forward and reverse primer (10 μmol each), 2 μL dNTP mixture (0.2 mmol/L each of dATP, dCTP, dGTP, and dTTP), 0.3 μL Taq DNA polymerase (3U/μl), and final volume made with 16 μL distilled water. The PCR mixture was processed in a Thermal Cycler (eppendorf) with 35 cycles, each cycle consists of 3 min of pre-denaturation at 94 °C, followed by 30 cycles of amplification (40 sec of denaturation at 94 °C; 1 min of annealing at 47 °C for COI; 45 s of extension at 72 °C), and final extension at 72 °C for 10 min.

Gel electrophoresis on Agarose gels (1%) was used to visualize the PCR products. The gel electrophoresis was run at 90V in 0.5 x Tris-boric acid-EDTA (TBE) buffer for 30 minutes and thereafter stained with ethidium bromide. Bio-Rad ChemiDoc™ system (Bio-Rad, USA) was used to capture the images from the gel electrophoresis. The products of the PCR were packaged and sent to Inqaba Biotechnical Industries for sequencing. The resultant sequences were analysed in BioEdit (version 7.2.6). Prior to sequence alignments, "noise" (false and irregular peaks) in the sequences was removed. The cleaned-out sequences were aligned using the Clustal-W alignment method in BioEdit. The aligned sequences were migrated to MEGA-11 (Molecular Evolutionary Genetics Analysis) where they were re-aligned with the "Muscle" method, and thereafter, a phylogenetic tree was drawn in order to visualize the separation of species.

2.2.4 Weather data

Weather data were obtained from the Global Surface Summary of the Day (GSOD) data that are derived from the Integrated Surface Hourly (ISH) dataset hosted by the National Center for Environmental Information (NCEI). These data were directly downloaded into R (v 4.4.1) using the package GSODR where various functions were used to download the data. Initially, weather station IDs were obtained using the "*nearest_station()*" function, which located the nearest weather station to the sampling sites. Once the station ID was obtained, the "*get_GSOD()*" function was used to download data for the specified sampling period (May 2023 to March 2025). The weather data consists of temperature, precipitation, windspeed, relative humidity and vapour pressure.

2.2.5 Statistical analysis

The data collected from the suction traps combined with the weather data were analyzed in R (v 4.5.0) and R-Studio (v 2025.05.1+513). Data visualization was done on the monthly data to illustrate the total population dynamics from the two sampling stations. The weekly data collected from the suction traps was then pooled into monthly data for statistical analysis where the resultant data was used for tests of significance and for aphid species diversity at the two sites. Prior to analysis, the data were tested for normality using the Shapiro-Wilks test and it was shown that the data were not normally distributed. The data were further tested for auto-correlation owing to the repeated measures nature over 23 months, hence temporal auto-correlation had to be taken into account. The Autocorrelation Factor (ACF) was used to measure and visualize autocorrelation. Generalized linear mixed models (GLMMs) following the negative binomial distribution (link = "log") with zero inflation because the data was autocorrelated, while the Analysis of variance (ANOVA) was used to test the differences in aphid species diversity between the sites. The Analysis of Similarities (ANOSIM) was used to test significant differences in the diversity of species that were collected across the two sites, even though the ANOSIM test is similar to an ANOVA hypothesis test, but it uses a dissimilarity matrix as input instead of raw data. It was also used to further validate the results of the ANOVA. (Principal Component Analysis (PCA) was used to test for the most influential environmental variables. Rank abundance curves were used to visualize the relative abundances of aphids across the two sites. To test the species diversity, the diversity indices; Simpson's index, Shannon's index, species evenness and species richness were tested using the 'vegan' package in R (Oksanen et al., 2025). For the species evenness the Pielou's evenness index was used, Pielou's evenness index measures how evenly the number of individuals are distributed among the species (Herrmann et al., 2022). For these indices a Welch two sample t-test was computed, and boxplots were used to visualize the differences in the diversity of aphids between the two sites. The Chao richness estimator was used to estimate the species richness between the two sites. An R-package, Richness, performs the proposed richness estimates along with jackknife estimation and bootstrapped precision. A literature search was done to check the potential species vectoring Potato Virus Y (PVY) and Potato Leaf Roll Virus (PLRV).

2.3 Results

2.3.1 Genetic sequence data analysis

During the survey, a total of 39 aphid species were collected, identified morphologically and were randomly selected for DNA barcoding targeting the CO1 gene to confirm the identifications. The sequence data was compared with GenBank sequence data and a total of 8 species sequences from the collected insects were submitted to GenBank, where some of the species were sequence deficient on GenBank. The submitted species were; *Dysaphis aucupariae* Buckton (Hemiptera: Aphididae) (PX230070), *Neotoxoptera oliveri* Essig (Hemiptera: Aphididae) (PX230072), *Rhopalosiphoninus staphyleae* Koch (Hemiptera: Aphididae) (PX230073), *Sitobion avenae* Fabricius (Hemiptera: Aphididae) (PX230074), *Geioca lucifuga* Zehntner (Hemiptera: Aphididae) (PX230071), *Pemphigus populitransversus* Riley (Hemiptera: Aphididae) (PX239597), *Cinara pinivora* Wilson (Hemiptera: Aphididae) (PX219505), *Tetraneura intraabdominally* Sasaki (Hemiptera: Aphididae) (PX230075). *Aonidiells pini* Young (Hemiptera: Diaspididae), a scale insect, was used as the outgroup. The evolutionary history was concluded using the Maximum Likehood method. The bootstrap consensus tree of 1000 is taken to represent the evolutionary history of the taxa analyzed. Branches corresponding to partitions reproduced in less than 50% bootstrap replicates collapsed (Figure 2.3). The phylogenetic tree shows the evolutionary relationships among aphid species collected from agricultural crops in the study sites and sequenced but did not have information and data on Genbank (Figure 2.3).

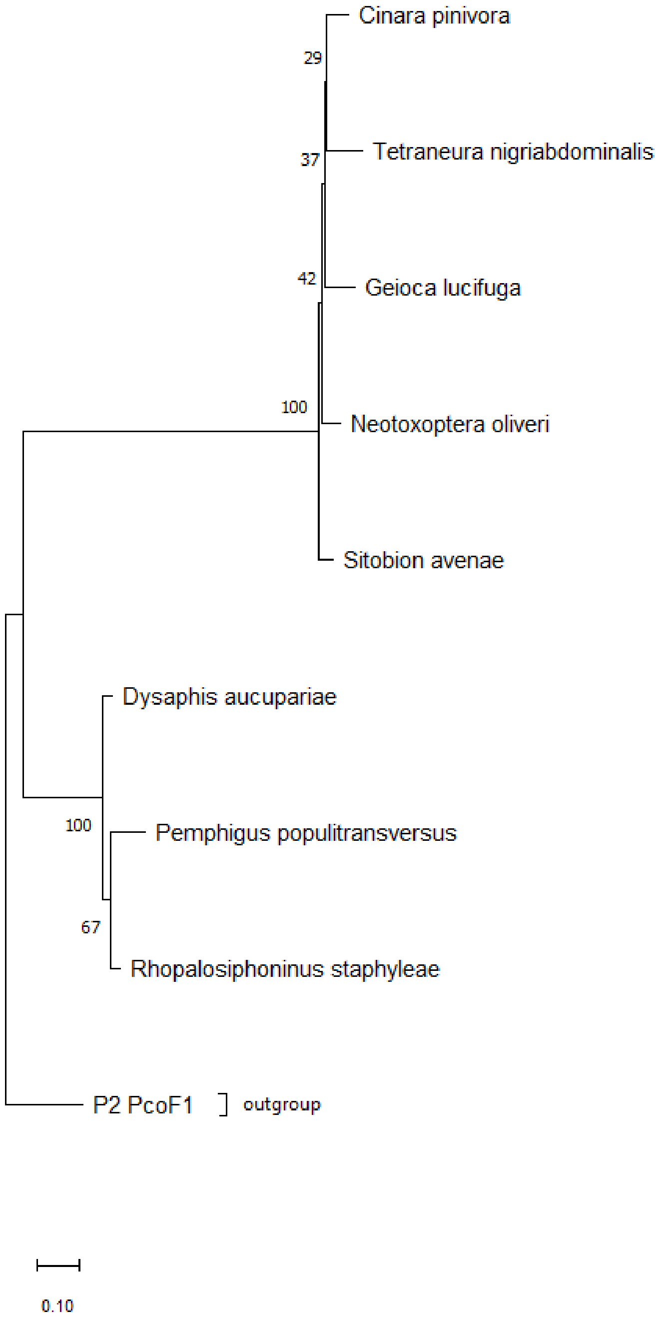

Figure 2. 3: Phylogenetic tree showing the aphid species sequenced for identification confirmation.

2.3.2 Population dynamics of aphids

Aphid populations were collected from May 2023 to March 2025 from Christiana and Douglas. Cumulatively, 39 species were collected from both sites (Table 2.1), with *Acyrthosiphon kondoi*, *Aphis* spp, *Motolophium dirhodium*, *Pemphigus* spp, *Rhopalosiphum maidis*, *Rhopalosiphum padi* and *Therioaphis trifolii* as the seven most abundant species in both Christiana and Douglas over the two years (Figure 2.5) while *Rhopalosiphum padi* as the most abundant species in both sites (Figure 2.4).

Table 2. 1: A summary of all the aphid species collected from the suction trap from May 2023 until March 2025 from Christiana and Douglas. N represents the total number of aphid specimens collected per site across the sampling months (May 2023 to March 2025), while n represents the abundance of each individual species per site. The percentage indicates the proportion of each species per site.

Species	**Christiana**, N = 292[1]	**Douglas**, N = 68[1]
Acyrthosiphon kondoi	15/N5.1%)	2/N2.9%)
Acyrthosiphon pisum	20/N6.8%)	4/N5.9%)
Aphis spp	34/N12%)	3/N4.4%)
Brevicoryne brassicae	4/N1.4%)	0/N0%)
Capitophorus hippophaes	4/N1.4%)	0/N0%)
Dysaphis spp	4/N1.4%)	1/N1.5%)
Geoica lucifuga	14/N4.8%)	1/N1.5%)
Hyadaphis coriandri	3/N1.0%)	1/N1.5%)
Hyalopterus pruni	19/N6.5%)	2/N2.9%)
Hyperomyzus lactucae	1/N0.3%)	0/N0%)
Hysteroneura setariae	8/N2.7%)	1/N1.5%)
Lipaphis pseudobrassicae	4/N1.4%)	0/N0%)
Macrosiphum euphorbiae	1/N0.3%)	0/N0%)
Melanaphis sacchari	1/N0.3%)	0/N0%)
Melanaphis spp	1/N0.3%)	0/N0%)
Metopolophium dirhodum	13/N4.5%)	5/N7.4%)

Myzus persicae	5/N1.7%)	0/N0%)
Paoliella spp	2/N0.7%)	0/N0%)
Pemphigus spp	14/N4.8%)	1/N1.5%)
Rhopalosiphum maidis	17/N5.8%)	4/N5.9%)
Rhopalosiphum nymphaeae	3/N1.0%)	1/N1.5%)
Rhopalosiphum padi	29/N9.9%)	15/N22%)
Rhopalosiphum rufiabdominalis	11/N3.8%)	3/N4.4%)
Saltusaphis scirpus	8/N2.7%)	1/N1.5%)
Schizaphis graminum	4/N1.4%)	1/N1.5%)
Sitobion spp	4/N1.4%)	0/N0%)
Smynthurodes betae	3/N1.0%)	0/N0%)
Tetraneura fusiformis	19/N6.5%)	6/N8.8%)
Therioaphis riehmi	1/N0.3%)	0/N0%)
Therioaphis trifolii	25/N8.6%)	15/N22%)
Uroleucon sonchi	0/N0%)	1/N1.5%)

[1] Mean (SD); n/N%)

The Rank abundance analysis was used to analyse the distribution of species abundance between Christiana and Douglas from May 2023 to March 2025. The results showed that *Rhopalosiphum padi* was the most abundant species in both sites. In Christiana, *Rhopalosiphum padi* (3512), *Rhopalosiphum maidis* (2936), *Pemphigus* spp (2231), *Metopolophium dirhodum* (771), *Aphis* spp (504), *Therioaphis trifolii* (480) and *Acyrthosiphon kondoi* (322) were the seven most abundant species. In Douglas *Rhopalosiphum padi* (2069), *Therioaphis trifolii* (794), *Pemphigus* spp (634), *Metopolophium dirhodum* (127), *Acyrthosiphon kondoi* (68), *Lipaphis pseudobrassicae* (47) and *Aphis* spp

(44) (Figure 2.4). Furthermore, the rank abundance analysis showed low species evenness in Christiana as illustrated by the steep curve where the seven most abundant species occupied the lower ranks (Figure 2.4).

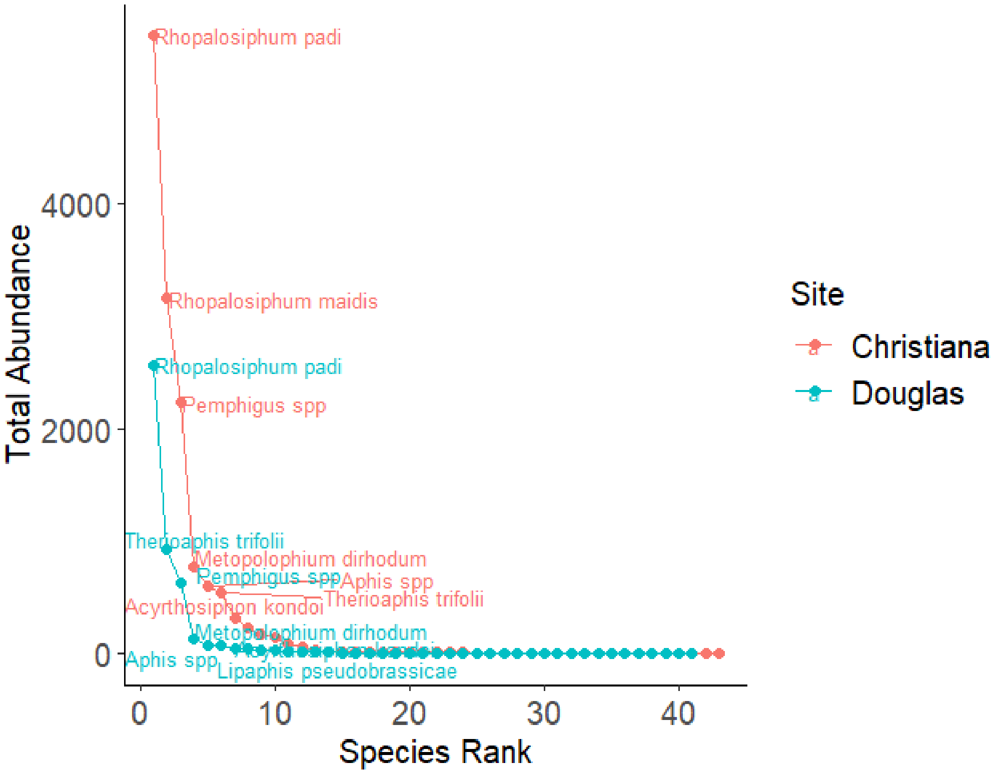

Figure 2. 4: Species rank abundance curves illustrating the seven most abundant aphid species at the two sites from May 2023 to March 2025. *Rhopalosiphum padi* was the most abundant in both sites.

When aphid collections started the aphid numbers fluctuated over time, with two distinct peaks observed. The first peak occurred around October to November 2023, where both sites experienced a sharp increase in aphid numbers, although Christiana recorded a higher mean than Douglas (Figure 2.5). The second peak occurred in March 2024, but this was only observed at Christiana, where the mean number of aphids rose dramatically to over 100 aphids/month, while Douglas remained relatively low (Figure 2.5). After this peak, aphid numbers dropped and remained low at both sites through the middle and latter half of 2024, with only minor fluctuations. From January 2025 onward, there was a gradual increase in aphid numbers, especially at Christiana. Throughout the entire study period, Christiana consistently showed higher aphid counts compared to Douglas (Figure 2.5).

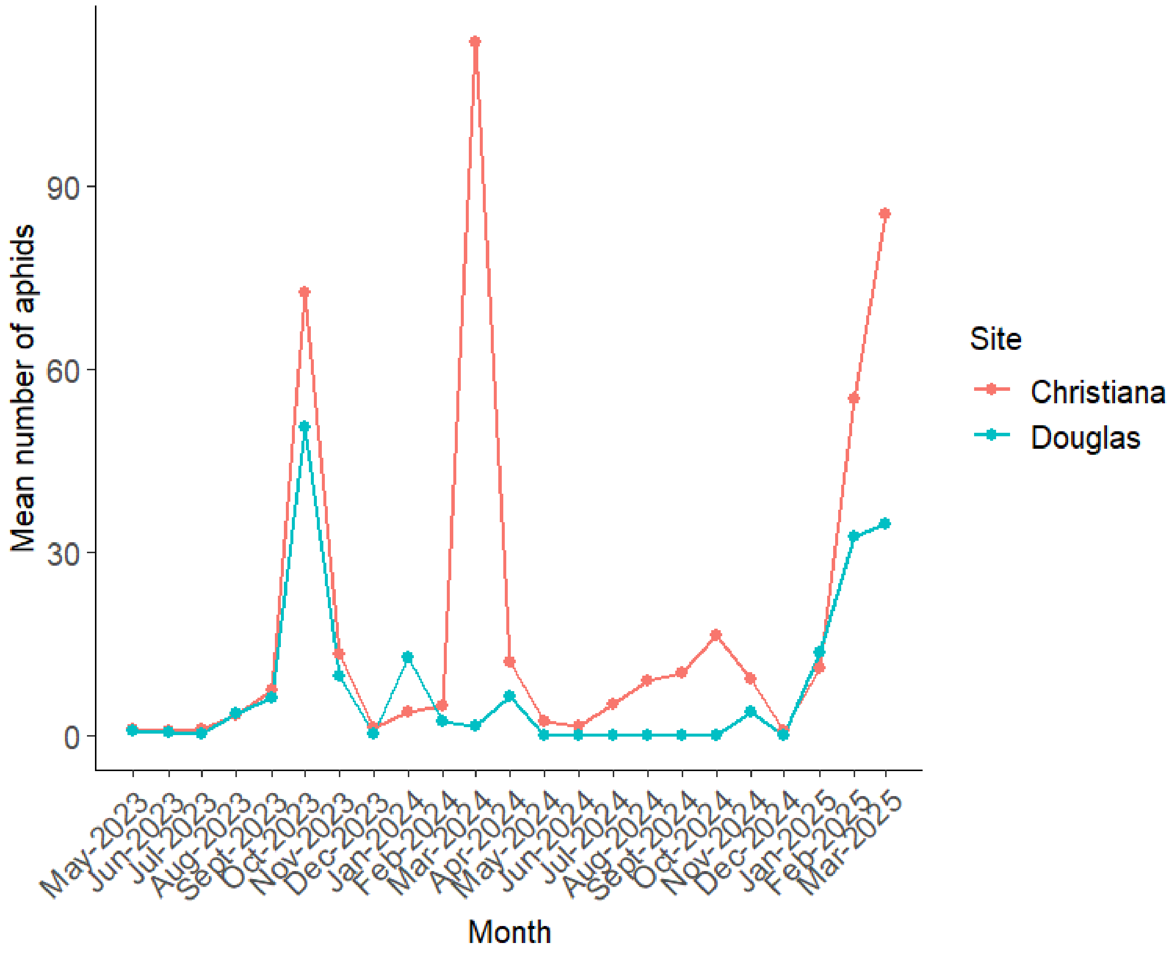

Figure 2. 5: Overall population dynamics of the average numbers of aphids at the two sites during the sampling period from May 2023 to March 2025. The dotted points represent the mean number of aphids per month.

At the beginning of the data collection, in both Christiana and Douglas, all the species occurred in relatively low numbers, until July 2023 when *Pemphigus* spp. started increasing and showed a high peak in October 2023 with 781 insects collected, with *Rhopalosiphum maidis* having a sum of 1,187 insects, together with *Metolophium dirhodum* with 605 insects (Figure 2.6). Thereafter, the aphid numbers declined and remained low until March 2024 when there was another peak with *Rhopalosiphum maidis* recording 2,851 insects collected, *R. padi* with a sum of 1,213 and *Aphis* spp. with 297 insects collected. The numbers declined in May 2024 and continued to fluctuate until the end of the collection period in March 2025 (Figure 2.6). In Douglas, the numbers were low when insect collection started until October 2023, with *Pemphigus* spp. increasing in number and peaked in October 2023 with insects below 500. *Rhopalosiphum padi* peaked in the same month with 1,500 aphids while *Metolophium* *dirhodum* recorded 663 insects. *Rhopalosiphum padi* recorded another slight peak in March 2024 with about 1,256 insects and all the species continued to fluctuate until March 2025 (Figure 2.6).

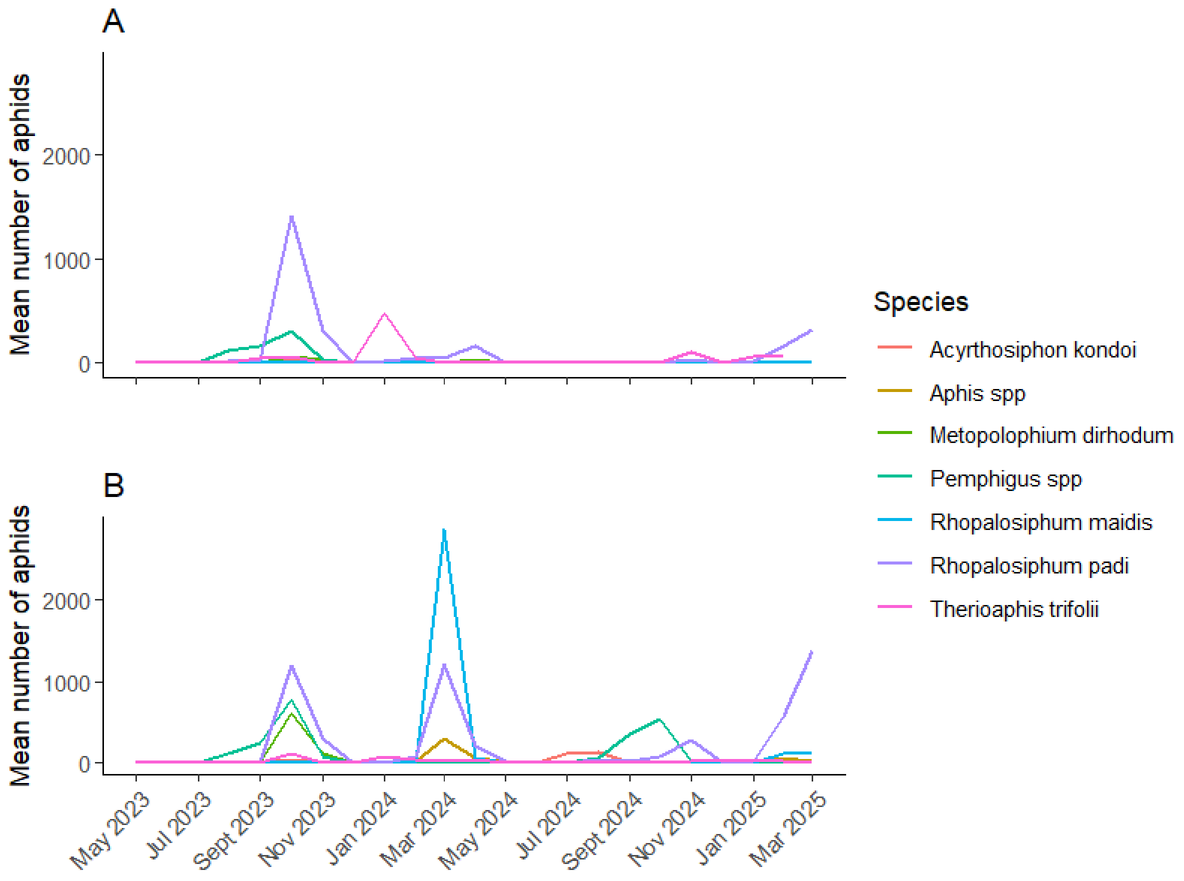

Figure 2. 6: Population dynamics of the seven most abundant aphid species in Douglas (A) and Christiana (B) from May 2023 until March 2025.

2.3.3 Influence of weather on aphid abundance in potato fields

Auto-correlation models were run on the data in order to explore the influence of weather on the populations of aphids over the two-year study period. The initial model revealed that the data were positively autocorrelated where the ACF plot was used to explore the autocorrelation between variables (Figure 2.7). Lag 2, 4 and 9 exhibited positive autocorrelation as these lags overlapped the 95% confidence intervals (blue dotted line) of the plot (Figure 2.7).

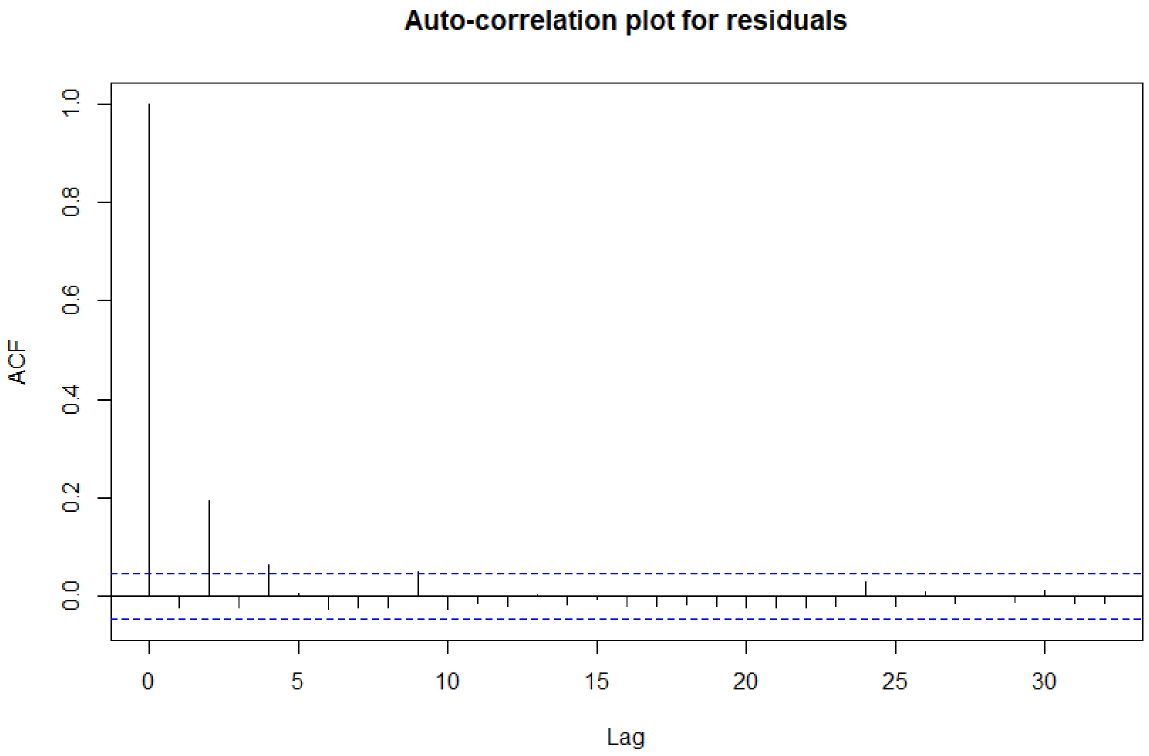

Figure 2. 7: ACF plot illustrating the temporal autocorrelation of the data. The blue dotted lines indicate the confidence interval, beyond which a lag may exhibit either positive or negative autocorrelation.

The changes in aphid populations influenced by weather and the time between the two sites across seasons were analyzed using GLMMs to account for the observed temporal autocorrelation in the data (Figure 2.7). There were no differences in aphid abundance at the two locations during spring and summer (Table 2.2), while abundances were significantly lower in winter (Table 2.2; Figure 2.5). The data showed that temperatures (minimum and maximum) significantly affected aphid abundance across all seasons except spring, where maximum temperatures were nearly significant (Table 2.2). An increase in minimum temperatures led to higher aphid populations during spring (Table 2.2; Figure 2.5), whereas winter minimum temperatures negatively impacted aphid populations (Table 2.2; Figure 2.10). Higher maximum temperatures had a positive effect on aphid abundance in all seasons except spring at both sites (Table 2.2). An increase in relative humidity significantly reduced aphid numbers during spring and summer (Table 2.2; Figure 2.11). Wind speed also significantly affected aphid counts, especially in summer when lower wind speeds had a negative impact on the number of aphids collected (Table 2.2). Rainfall did not have a significant effect on aphid abundance. These findings suggest that aphid populations are highly responsive to both spatial and seasonal environmental changes, with spring and summer being critical periods when climate conditions strongly influence their abundance. Notably, there was considerable variability between the two study sites, with higher aphid abundance recorded in Christiana compared to Douglas ($\sigma^2 = 0.9321$, $\sigma = 0.9654$) (Table 2.2). Populations were shown to be variable ($\sigma^2 = 0.2122$, $\sigma = 0.4606$) across different years between 2023 and 2025 (Table 2.2).

Table 2. 2: GLMM summary on the effect of season and weather variables on aphid abundances in Christiana and Douglas. The asterisk indicates the significant effects.

	Estimate	Std. error	z value	Pr(>|z|)	
(Intercept)	10.77481	4.72531	2.28	0.02259	*
Spring	-17.2472	11.349319	-1.52	0.12859	
Summer	-7.52031	7.101513	-1.059	0.28961	
Winter	-13.0527	6.129942	-2.129	0.03323	*
MAX	-0.5075	0.199275	-2.547	0.01087	*
MIN	0.811259	0.186985	4.339	1.43E-05	***
RH	-0.03385	0.014755	-2.294	0.02178	*
WDSP	-0.30843	0.137385	-2.245	0.02477	*
PRCP	-0.00718	0.015466	-0.464	0.6425	
Spring:MAX	0.926008	0.521801	1.775	0.07596	.
Summer:MAX	0.452918	0.226901	1.996	0.04592	*
Winter:MAX	0.714099	0.262738	2.718	0.00657	**
Spring:MIN	-0.86962	0.292239	-2.976	0.00292	**
Summer:MIN	-0.91469	0.304896	-3	0.0027	**
Winter:MIN	-0.89621	0.276711	-3.239	0.0012	**

Spring:RH	-0.0725	0.067404	-1.076	0.28214	
Summer:RH	0.040421	0.045596	0.887	0.37535	
Winter:RH	-0.01425	0.025444	-0.56	0.57541	
Spring:WDSP	0.212304	0.2317	0.916	0.35952	
Summer:WDSP	0.53289	0.167676	3.178	0.00148	**
Winter:WDSP	0.115127	0.210297	0.547	0.58407	
Spring:PRCP	-0.22763	0.359748	-0.633	0.5269	
Summer:PRCP	-0.00105	0.01466	-0.072	0.94297	
Winter:PRCP	0.388852	0.383668	1.014	0.31082	

AIC	BIC	logLik	-2*LOG(L)	df.resid
4907	5055.4	-2426.5	4853	1774

Conditional model:

Groups Name	Variance	Std.Dev.
Trap (Intercept)	0.9321	0.9654
Month (Intercept)	0.2122	0.4606

Number of obs: 1801, groups: Trap, 2; Month, 23

Dispersion parameter for nbinom2 family (): 0.0729

The influence of environmental factors on aphid populations was further explored using a Principal Components Analysis (PCAs). The PCA revealed an overlap in the species found between the two sites, meaning the two sites; Christiana and Douglas share a common group of species (Figure 2.8B). The most influential environmental variables to the aphid populations were temperature (both maximum and minimum), windspeed, precipitation, saturation vapour pressure (ES) (Fig 2.8A). The PCA explains 69.9% of variation observed in aphid populations at the two sites with dimension 1 representing 42.8% of the population greatly influencing the populations in Christiana while dimension 2 representing 27.1% of the aphid population and influencing the populations in Douglas (PCAs) (Figure 2.8B).

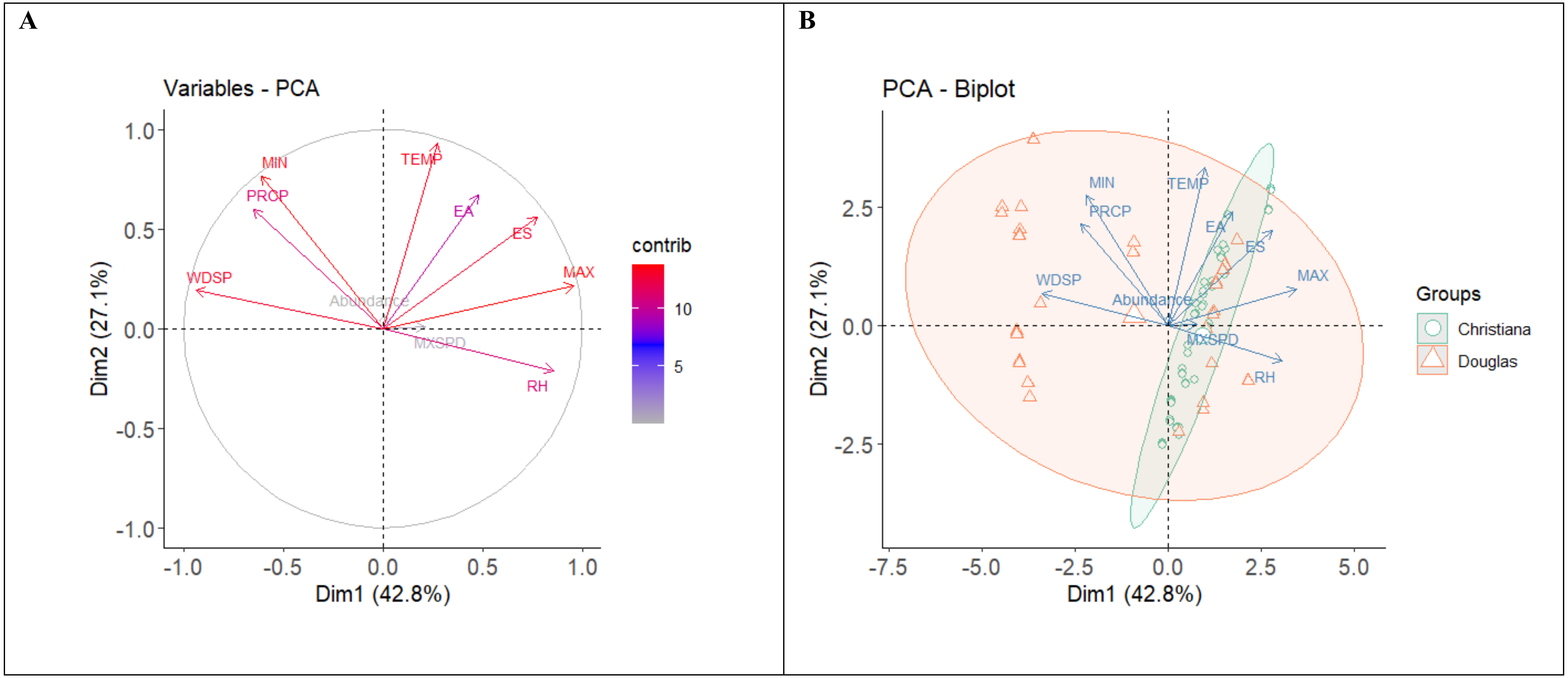

Figure 2. 8: PCA of aphid populations in Christiana and Douglas from May 2023 to December 2025. The PCA explains 69.9% of the variation observed in aphid populations at the two sites. Figure A shows weather parameters that had a significant impact on the aphid populations between Christian and Douglas while Figure B shows the relationship between the weather parameters and aphid populations in Christiana and Douglas.

A Kruskal-Wallis test was used to compare the environmental parameters between Christiana and Douglas during the sampling period (May 2023 to December 2024) to determine if there were differences in weather conditions between the two sites. The Kruskal-Wallis test revealed that Douglas had a significantly higher average temperature than Christiana, $X^2_{(19,20)} = 1493.8$, = 19, $P < 0.001$ (Figure 2.9), while relative humidity was significantly higher ($X^2_{(19,20)} = 662.21$, $P < 0.001$) in Christiana compared to Douglas (Figure 2.8). Significantly higher wind speeds were recorded in Christiana compared to Douglas $X_{2(19,20)} = 394.45$, $P < 0.001$. In Douglas minimum temperature $X_{2(19,\ 20)} = 394.45$, $P < 0.001$ and maximum temperature $X_{2(19,20)} = 899.42$, $P < 0.001$ were higher compared to Christiana (Figure 2.7). Therefore, the prevailing environmental factors significantly affected the aphid populations at the two sites, Christiana and Douglas.

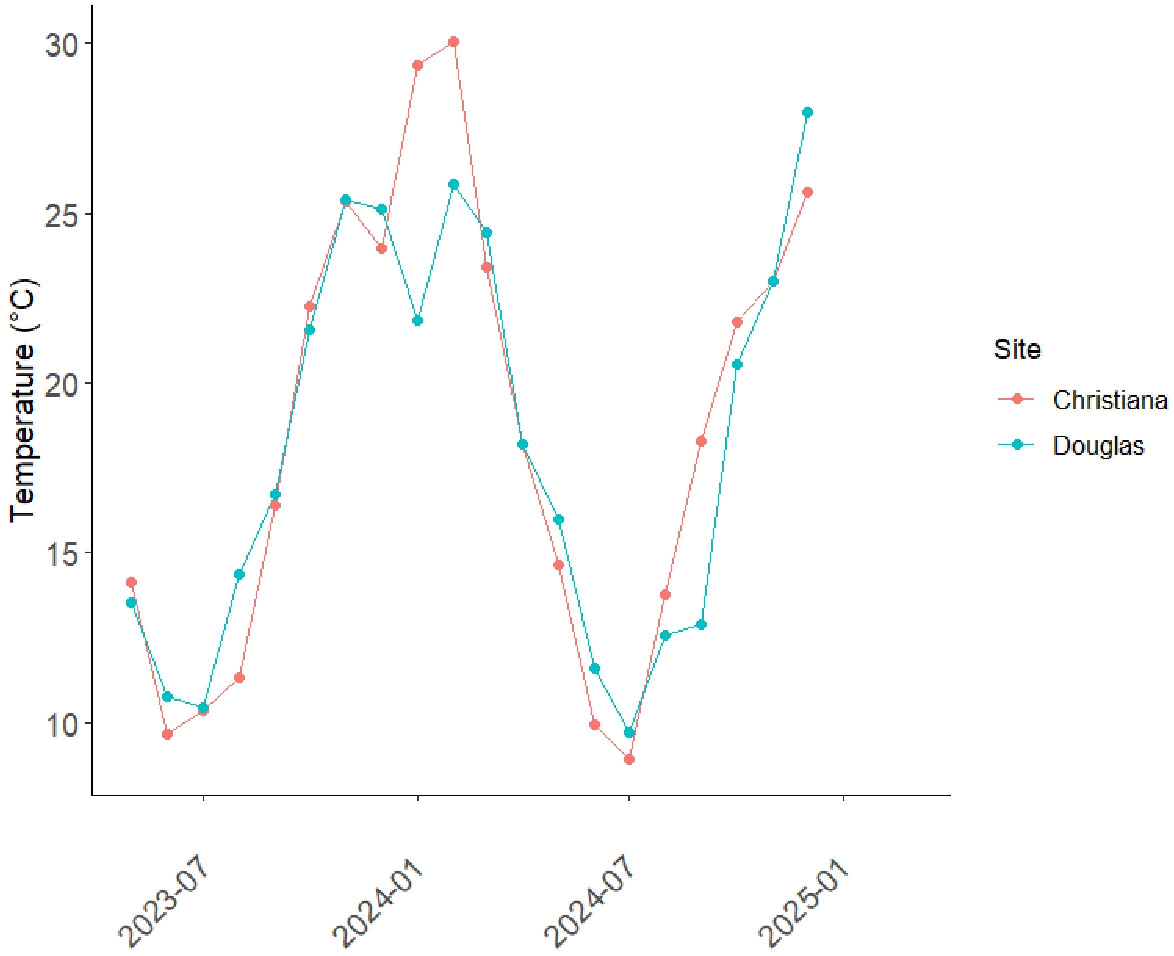

Figure 2. 9: Average temperatures recorded in Douglas and Christiana from 2023 to 2024 during aphid collections.

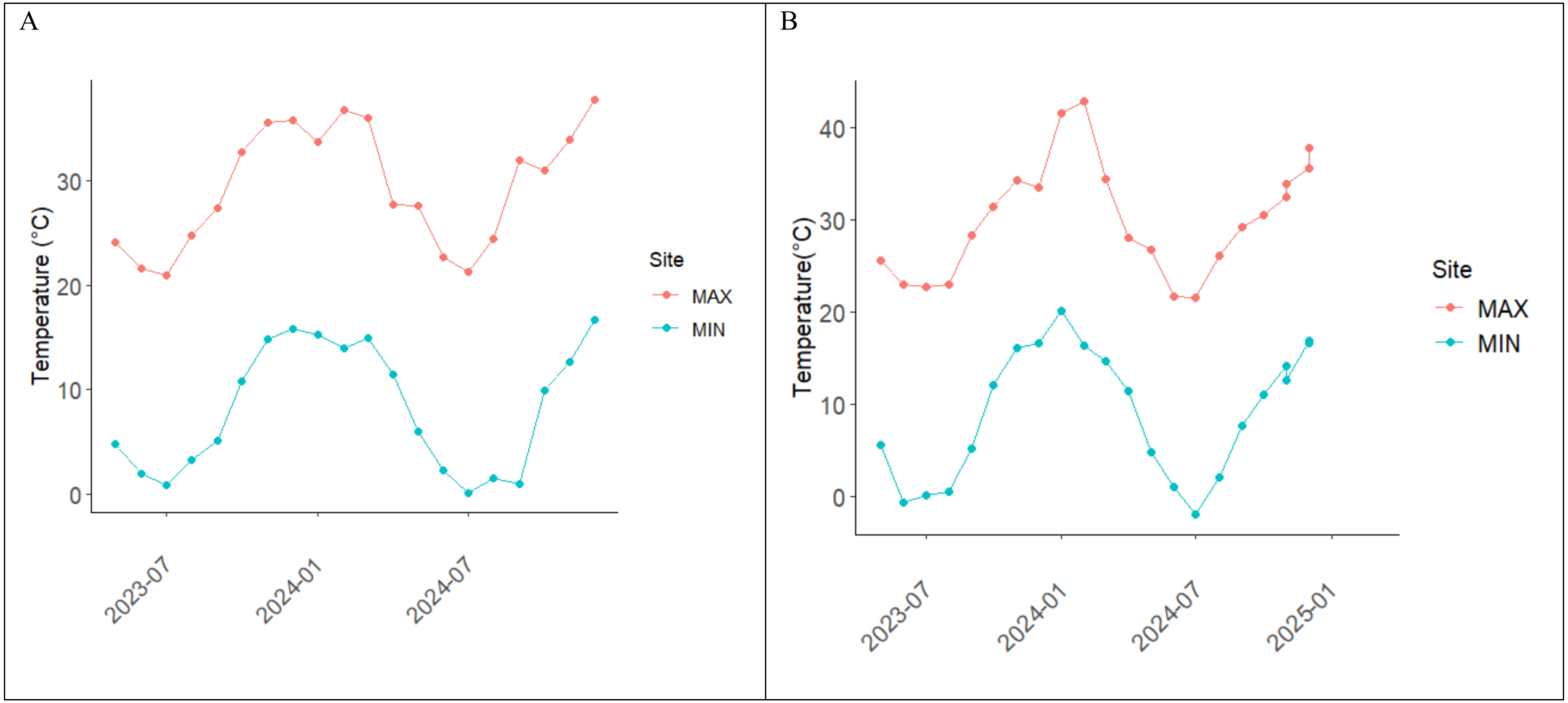

Figure 2. 10: Monthly temperatures recorded in Douglas and Christiana from 2023 to 2024. The blue lines represent the maximum temperature and red represent minimum temperatures. A represents the maximum and minimum temperature recorded in Douglas. B represents the maximum and minimum temperature recorded in Christiana between 2023 and 2024.

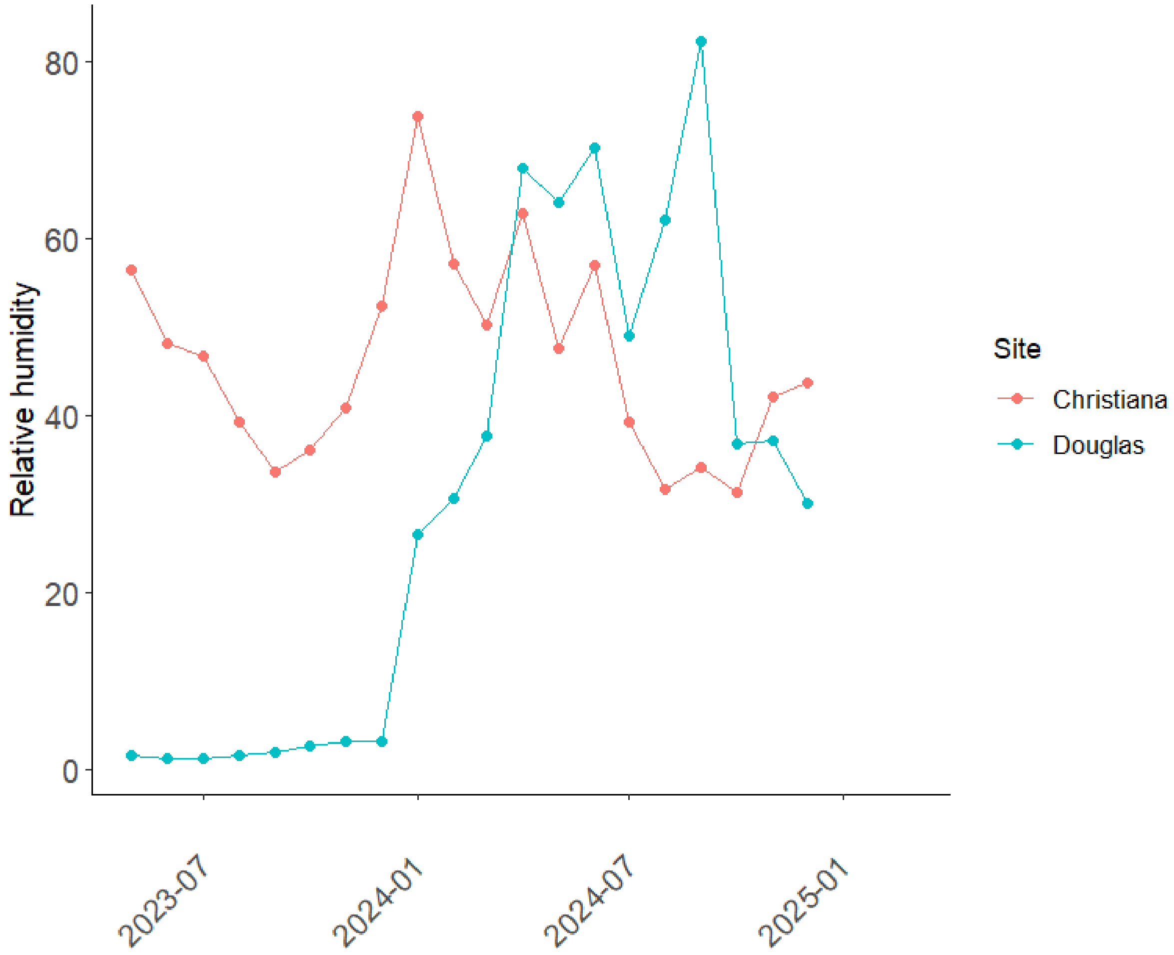

Figure 2. 11: Relative humidity recorded in Douglas and Christiana from 2023 to 2024 during aphid collections.

2.3.4 Species diversity analyses

An ANOVA was conducted to test for differences in species diversity, evenness and abundance between Christiana and Douglas between 2023 and 2024. The ANOVA showed a significant difference in species diversity between Christiana 2023 and Douglas 2024 ($F_{(1, 1016)} = 5.044$, and $P = 0.0309$), however, no differences were observed between the two sites within each year. Furthermore, there were no significant differences in species evenness and in species dominance between Christiana and Douglas between 2023 and 2024 (Figure 2.12). There was no difference in the species evenness between Christiana and Douglas in 2023 and 2024, meaning that aphid species were evenly distributed between Christiana and Douglas between the years 2023 and 2024 (Figure 2.12). There were no significant differences in the species dominance between 2023 and 2024 between Christiana and Douglas, meaning that no one species dominated the agroecosystems at the two sites for the duration of the study, but rather different species dominated the systems across different times across the sampling period.

Analysis of Similarities (ANOSIM) with 999 permutations was used to determine if there were similarities in species diversity, species evenness and species distribution between Christian and Douglas. The jacknife replicates was 48 (the number of sites and the total observations), while the bootstrap replicates was 999 (the permutations). The ANOSIM analysis revealed that there were significant differences in the diversity of species that were collected in Christiana and Douglas ($r = 0.9959$, $P = 0.027$), however, there was no difference in the species evenness ($r = 0.03671$, $P = 0.131$) and in the species dominance between the two sites in the distribution of the aphid species ($r = 0.038$, $P = 0.7122$).

For the species richness, the Chao richness estimator was used to estimate species richness between the two sites, and it estimated 42 species to be cumulatively present for the two sites, although there were 39 species observed during sampling. The chao estimation was 42.655 ± 4.623, a jackknife estimation of 44.650 ± 2.513 and a bootstrap estimation of 41.302 ± 1.634 in Christiana, while for Douglas, the chao estimation was 31.665 ± 4.623, a jackknife estimation of 33.650 ± 3.467 and a boot estimation of 30.180 ± 2.202. The species richness estimation ranges were estimated to be between 30 and 44 potential species of aphids in Christiana and Douglas.

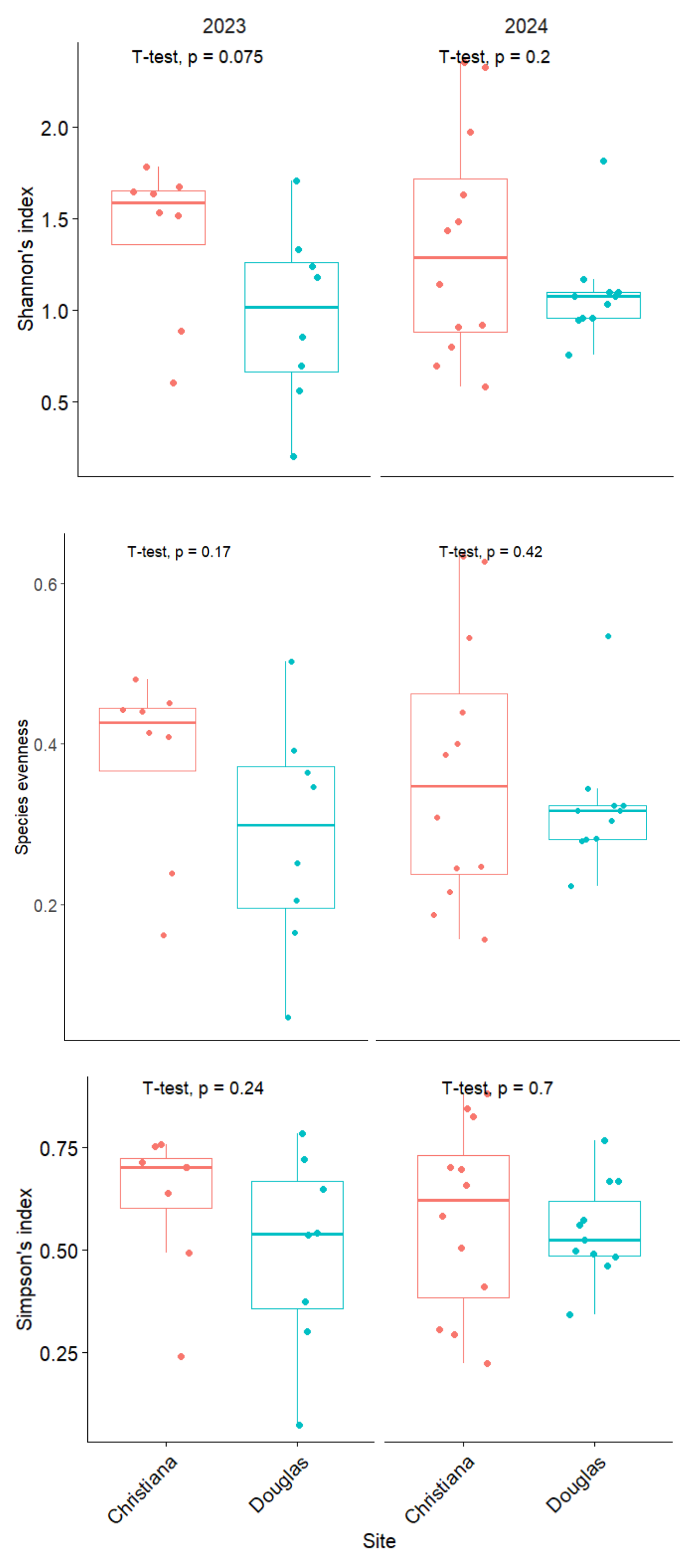
2023
2024
T-test, p = 0.075
T-test, p = 0.2
Shannon's index
2.0
1.5
1.0
0.5
T-test, p = 0.17
T-test, p = 0.42
Species evenness
0.6
0.4
0.2
T-test, p = 0.24
T-test, p = 0.7
Simpson's index
0.75
0.50
0.25
Christiana
Douglas
Christiana
Douglas
Site

Figure 2. 12: Boxplot visualizing the differences in species diversity, evenness and dominance between Christiana and Douglas between 2023 and 2024.

2.3.5 Vectors of PVY and PLVR abundances

The aphid potential vectors of Potato virus Y (PVY) and Potato Leaf Roll Virus (PLRV) were explored using existing literature and they were correlated against the collected aphid species. In both sites, the most abundant PVY potential vector was *R. padi* with 60% in Christiana and ~90% in Douglas, while the rest of the potential vector species were in low abundances (Fig. 2.13). *Aphis* sp. (~35%) and *T. trifolii* (30%) were the most abundant potential vectors of PLRV in Christiana, while *M. persicae* (30%) and *T. fusiformis* (20%) were the most abundant in Douglas (Fig. 2.13). A Kruskal-Wallis test revealed that abundances of potential vectors of both viruses were similar at the two sites, PLRV: ($H_{(1)}$= 1.486, $P = 0.2228$) and PVY: $H_{(1)}$= 1.224, $P = 0.2686$ (Fig. 2.13). Furthermore, the Wilcox test revealed that the abundances of potential vectors of PVY compared to PLRV in Christiana were similar ($V = 174$, $P = 0.2802$), while in Douglas the relative abundance of PLRV was significantly higher than PVY ($V = 99$, $P = 0.02845$) (Fig. 2.14).

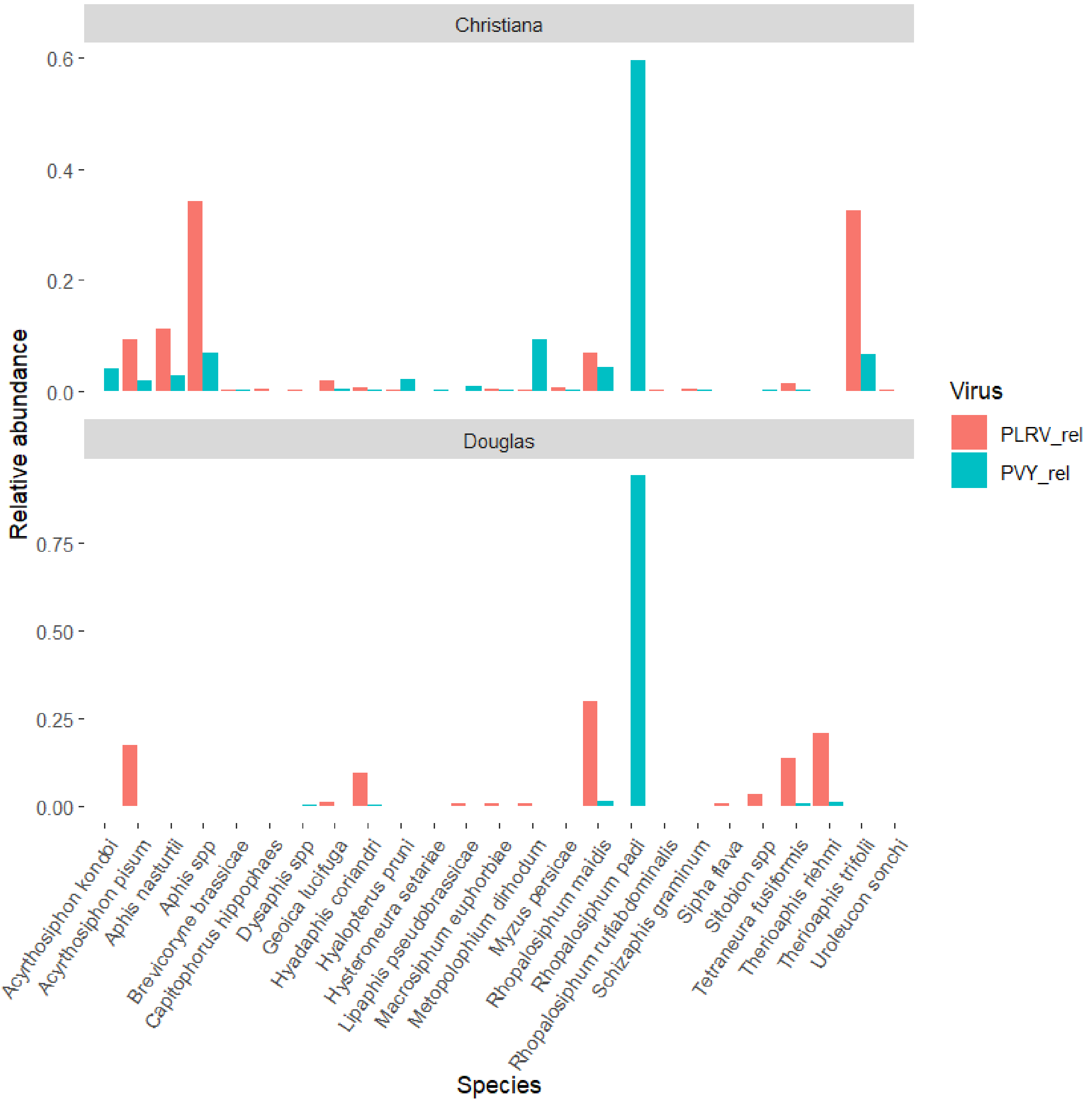

Figure 2. 13: Illustration of the relative abundances of vectors and non-vectors for the two potato viruses PVY and PLRV in Christiana and Douglas.

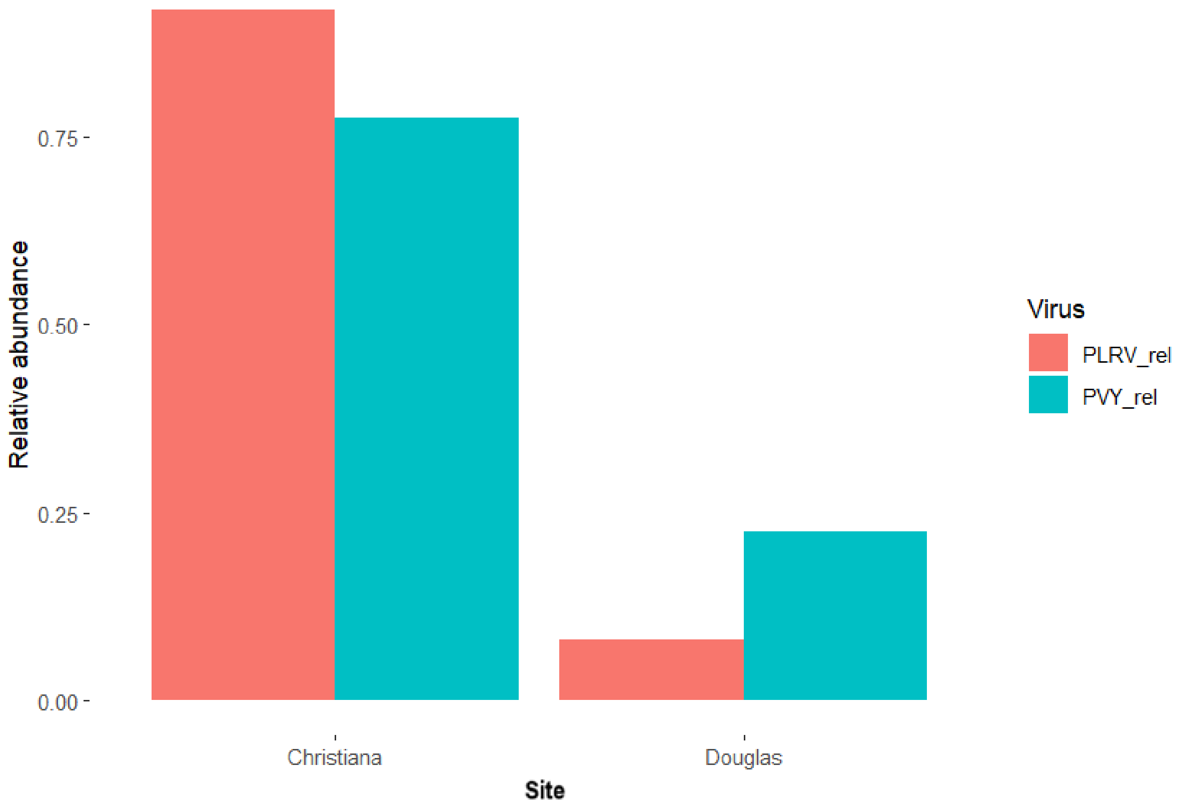

Figure 2. 14: Cumulative relative abundances of vectors of Potato Leaf Roll Virus (PLRV_rel) and Potato Virus Y (PVY_rel) in Christiana and Douglas.

2.4 DISCUSSION

Given the significant damage aphids and other pests inflict on agricultural crops, it is essential to develop sustainable management solutions as an effective alternative to synthetic insecticides (Kumar, 2019). Early detection of insect pests can contribute to pest management at the beginning of an infestation using low-cost solutions (De Oliveira et al., 2023). Moreover, monitoring helps in the understanding of insect pest dynamics, which is key to understanding and establishing predictive models (De Oliveira et al., 2023). The point at which action is required to prevent economic damage is determined using insect trapping data, which helps establish the relationship between pest populations and the level of harm they cause. Trapping provides crucial information for pest managers, enabling informed decision-making to safeguard crops, ecosystems, and public health while reducing environmental impact (Kammara et al., 2023). Acting as early-warning systems, these traps detect pest outbreaks and supply data for timely interventions. Their species-specific attraction highlights the precision of Integrated Pest Management (IPM), where identifying the pest is essential for selecting effective control methods. Additionally, trapping enhances understanding of pest behavior and life cycles, contributing to the development of more advanced and sustainable management strategies (Kammara et al., 2023). Therefore, monitoring insect pests is an essential step to improve our knowledge and ability to manage serious insect pests in agriculture and forestry (Robinson-Baker, 2024).

Of the 39 species collected results revealed that *Acyrthosiphon kondoi, Aphis* spp*, Lipaphis psuedobrassicae*, *Metolophium dirhodum*, *Pemphigus* spp, *Rhopalosiphum padi* and *Therioaphis trifolli* were the most prevalent aphid species at the two study sites. The patterns observed at the two sites could be due to similar environmental conditions as the weather conditions do not vary significantly across the locations. A study by Mondal et al. (2016) recorded a closely related number of 46 different species, with the most abundant aphids being *R. padi*, *M. dirhodum*, *S. avenae*, *D. noxia*, and *S. graminum*. Their study explored potato production areas located in close proximity to cereal fields in Idaho, United States. In the current study, *M. dirhodum* was found to be a highly contributing species in both studies. For instance, there is a possibility that field populations of species such as *M. dirhodum* are resistant to the neonicotinoid and pyrethroid insecticides most frequently used to control this aphid species (Gong et al., 2021). A study conducted by Wosula et al. (2012), reported 27 aphid species collected on sweet potato, where the most common species were: *A. gossypii*, *M. persicae*, *R. padi*, and *T. trifolii*.

In the current study, *T. trifolii*, *R. padi* and *Aphis* sp were present in high abundances, similar to the study by Wosula et al. (2012), and all these species have been reported to potentially vector Potato Virus Y (PVY), while *T. trifolii* further vectors Cucumber mosaic virus (CMV), and Bean yellow mosaic virus (BYMV). The aphid community observed in the current study was dominated by *R. padi*, *R. maidis*, followed by *Pemphigus* spp., *M. dirhodum*, *Aphis* spp., *T. trifolii*, and *A. kondoi*. Amongst these, *R. padi*, *R. maidis*, *M. dirhodum*, *A. kondoi* and *Aphis* spp. are known potential vectors of important potato viruses, including Potato leafroll virus (PLRV) and Potato virus Y (PVY). PLRV is of great economic importance because it is widespread globally, where in plants propagated from infected tubers (secondary infection) yields may be reduced by 33–50% (Loebenstein, 2008). PVY is one of the most important aphid-transmitted viral pathogens of potato worldwide. It negatively impacts the production of certified potato seed and also crops grown for processing or the fresh market (Mahmoud et al., 2020). Furthermore, it causes severe losses in several economically important crops, especially potato, tobacco, tomato and pepper (Abdalla et al., 2018). PVY yield losses range between

30%–64% and the largest losses are when a crop is grown from infected seed tubers (Torrance and Talianksy, 2020).

The present study found that *R. padi,* which is a potential vector of PVY transmission was the dominant species at both sites, accounting for about 60% in Christiana and almost 90% in Douglas. In contrast, PLRV transmission was not dominated by any single potential vectoring species, but rather shared among several potential vectors. In Christiana, *Aphis spp.* (35%) and *T. trifolii* (30%) were most important, while in Douglas, *M. persicae* (30%) and *T. fusiformis* (20%) were the leading contributors. However, the presence of the vector does not always translate to the presence of the virus but rather can be used as a proxy for a potential virus outbreak in the production area (Davis et al., 2006). Potato leafroll virus (PLRV) causes upward leaflet rolling in primary infections and shoot stunting with leaflet rolling in secondary infections (Loebenstein, 2001). Yield losses are highest when infected tubers are planted or when young plants are infected early by viruliferous aphids. PLRV can also cause internal net necrosis in some cultivars, making tubers unsuitable for seed, sale, or processing (Krijger & Waals, 2020). PVY infection has been detected, causing tuber necrotic ringspot symptoms in susceptible cultivars and negatively impacting both potato quality and yield with yield reductions estimated at 0.13 tonnes per ha. in the United States of America (USA) (Amin et al., 2023). Therefore, potato crops are highly vulnerable during peak migrations of these species. Migratory alates represent the primary pathway of virus introduction into potato fields, as they often arrive carrying viruses acquired from surrounding crops or alternative hosts. Even at low numbers, these migrants can initiate infection events, particularly for non-persistently transmitted viruses such as PVY, which are efficiently spread through brief probing. Once viruses are introduced, high local abundances of colonizing aphids accelerate within field spread, especially for persistently transmitted viruses like PLRV that require sustained feeding. One distinguished feature between persistent and non-persistent viruses is that the persistent virus is retained through a molt but non-persistent have a non-circulative interaction with their vectors (Gray & Banerjee, 1999).

A study conducted by Boukhris-Bouhachem et al. (2007) on potatoes, reported very high diversity with 103 aphid species collected. The most abundant species were: *A. gossypii, A. fabae*, and *M. persicae* which are known potential vectors of PVY and PLRV. Even though aphid population abundance and changes in species composition depend on season, year, and location, these fluctuations could also be attributed to biotic or abiotic factors. Biotic factors such as aphid reproduction cycle; hostplant quality and availability; predators, parasitoids, and entomophagous fungi; or abiotic factors such as rainfall, temperature, wind, and light intensity (Wosula et al., 2012). Another reason could be; their study was conducted in four regions of potato seeds production using two different trapping methods over a period of three years. In the present study, the aphid diversity was 39 species collected and the most abundant were; *Acyrthosiphon kondoi, Aphis* spp*, Metolophium dirhodum*, *Pemphigus* spp, *Rhopalosiphum padi* and *Therioaphis trifolli.* Higher aphid diversity increases the variety of potential vectors. Even if most species are inefficient, a single efficient species present at low abundance can still drive transmission, because aphids can form facultative (non-essential) relationships with a range of bacterial endosymbionts that confer a diverse range of traits to the aphid. Facultative endosymbionts can also modulate the probing and feeding behaviour of cereal aphids with potential consequences for virus acquisition and transmission (Leybourne et al., 2024). *Rhopalosiphum padi* was the most dominant species and previous research using the electrical penetration graph (EPG) technique to monitor aphid probing and feeding behaviour has shown that the presence of a facultative endosymbiont, *Hamiltonella defensa*, in *R. padi* can alter aphid feeding behaviour. This included altering behavioural traits that are involved in virus transmission, such as phloem contact. These behaviours could increase the vectoring capacity of endosymbiont-infected aphids by making them more efficient at acquiring and transmitting the virus (Leybourne et al., 2024).

High temperatures that cause aphid populations to suddenly crash can be considered lethal temperatures. However, in the field, other factors play a major role in rapidly reducing the population of aphids: (1) predators and parasites can cause the rapid emigration of aphids from the plant and high temperatures increase mortality of aphids off the plant; (2) high densities of aphids are conducive to the multiplication of their natural enemies, which leads to a subsequent crash in populations of aphids; (3) high densities of aphids can suddenly cause the plant to become an unsuitable host; and (4) as the plants mature in summer, host plants become physiologically less suitable as food for aphids and high populations of aphids rapidly decline. With all of these reductive factors, high temperatures accentuate the population decline (Tamaki et al., 1980). Maximum and minimum temperatures were found to significantly influence the development of aphid populations in the present study, with an increase in temperature leading to an increase in aphid populations. A study by Sampaio et al. (2017), reported that an increase in temperature favors an increase in aphid populations, similar to the results that were reported in the current study. Conversely, a study conducted by Das et al. (2019) in India, reported that as the maximum and minimum temperatures decreased, the aphid population increased, and this could be because increased temperature beyond the optimum range may also affect different crop growth stages negatively because when potatoes are stressed (e.g., by drought, nutrient deficiency, or virus infection itself), they may alter their physiology in ways that actually make them more attractive or accessible to aphids. The study reported weekly temperatures ranging from 13.5 °C to 31°C (Das et al., 2019). A different study conducted by Ahmad et al. (2016) on wheat in Pakistan reported monthly temperatures ranging from 14.9 °C to 30.1°C. They further reported that high maximum temperatures caused a decline in aphid populations and negatively affected the wheat yield, which was also contrary to the results of the present study. In comparison, the present study recorded more extreme temperatures, with a monthly maximum of 42°C and a minimum of 1°C and optimal temperatures for the most contributing species ranging from 20 °C to 30 °C (*R. padi: 2*4°C to 28.5°C (Cao et al., 2018), *R. maidis:* 24°C to 30°C (Chen, 2019), *Pemphigus* spp, 20 °C to 25 °C (Pretorious et al., 2016), *M. dirhodum*, 24.5°C to 27°C (Asin & Pons, 2001), *Aphis* spp, 20°C to 25°C (Satar et al., 2005), *T. trifolii* 25°C to 29°C (Jovičić et al., 2022) and *A. kondoi* 20°C to 25°C (Villena et al., 2024)). This shows that aphid occurrence at the current sites took place under both higher and lower temperature extremes than those reported in the two studies, indicating greater variability in environmental conditions. Interestingly, potatoes have higher susceptibility to aphid infestation under high temperatures and heat stress, due to increased quality of plant sap, which favors aphid reproduction (Beetge and Krüger, 2019). Under low temperatures the potato susceptibility to aphid infestation is reduced as aphid development, reproduction and dispersal are constrained (De Souza et al., 2019). Aphid populations reached their peak in March 2024 which had relatively lower average temperatures than February 2024 in Christiana. This suggests that optimal developmental temperatures for aphids occurred in March, for example *R. pad*i which was most abundant, realized a peak during this month compared to January and February which were hot.

High relative humidity supports the survival of immature stages, extends adult lifespan, enhances fecundity, and promotes population growth (Dixon, 2003). The present study observed that high relative humidity led to a decrease in aphid populations. Contrary phenomena have been reported for mirid species in a study conducted by Lu & Wu (2011), where high relative humidity was beneficial for immature survival, adult longevity and fecundity, and population growth of *Apolygus lucorum* Meyer-Dür *(*Hemiptera: Miridae). The study further observed that *A. lucorum* population drastically increased after heavy or continuous rainfall because heavy rainfall will directly result in an increase of environmental humidity. After heavy rainfall, plants usually grow more rapidly and produce fresh shoots which most insects, including aphids and mirids prefer, as tender plants have high-nitrogen plant tissues. A study by Neupane & Subedi (2019) reported that aphid populations decreased with increasing relative humidity and rainfall in Chitwan, Nepal on lentil aphids. Prasad et al. (2008) also reported that; aphid population had a negative association with relative humidity and rainfall.

Wind could have direct and indirect effects on herbivorous insects (Follman et al., 2019), as insect abundance decreases drastically with increasing wind (Møller, 2013). Wind is generally known to facilitate the migration of alate aphids from surrounding hosts to late-planted crops (Shonga & Getu, 2021). In their study, overall aphid abundance was negatively but not significantly associated with wind speed. However, in the present study, results showed that wind speed alone was not significant, however, in summer wind had a negative impact on aphid abundance, similar to the study by Shonga & Getu (2021). These results were contrary to a study by Abbasi et al. (2019) on the different wheat varieties from Larkana district in Pakistan which showed a positive correlation between aphid population and wind speed. The wind speed played a positive role in fluctuating aphid density meaning as wind speed increased, aphid numbers also tend to increase in certain areas.

2.5 Conclusion

This chapter investigated the diversity and abundance of aphid species associated with potato production in Christiana and Douglas. A total of 39 species were recorded, with *R. padi* overwhelmingly dominating the population. *Rhopalosiphum padi* and other species have the potential to contribute to the spread of PVY & PLRV, and these are of great economic importance greatly affecting the production of potatoes. These results suggest that aphid diversity and community composition are critical determinants of virus vectoring potential. Dominance by highly efficient vectors such as *R. padi* can increase transmission risk through elevated plant–vector contact rates. At the same time, the presence of transient species and higher species turnover can enhance virus spread by increasing brief probing events, which are important for non-persistent viruses like PVY.

Understanding these patterns is important for predicting periods of elevated virus risk in potato crops. Monitoring both dominant and transient vectors can provide early warning of high-risk periods, enabling timely management interventions.

Chapter 3: Survey for the tomato psyllid *Bactericera cockerelli* and other Sternorryncha on Solanaceous plants

3.1 Introduction

Invasive alien species can cause diverse economic losses, including expenses for management, crop losses, and damage to infrastructure (Haubrock et al., 2022). They are also a major driver of species decline and ecological disruption, with serious consequences for socio-economic development worldwide. Invasive alien species are distributed across diverse ecosystems around the globe. In South Africa, 466 established alien terrestrial invertebrates have been documented, but this is considered an underestimate. Insects make up most of these species, with Hemiptera being the most species-rich group of invasive invertebrates, followed by Coleoptera (Janion-Scheepers & Griffiths, 2020).

Fall armyworm (FAW), *Spodoptera frugiperda* is one of the most damaging invasive alien invertebrate species. It is a lepidopteran pest that attacks the leaves, stems, and reproductive structures of over 350 plant species (Togola et al., 2025). This pest causes significant damage to key cereal crops such as maize, rice, sorghum, sugarcane, and wheat, as well as to various vegetables and cotton, however, maize is its most preferred host (Rwomushana et al., 2018; Rwomushana, 2019). In Europe, the pest has frequently been intercepted on fresh produce from Latin America especially *Capsicum* and *Solanum* species and since 2017, on infested exports from Africa including roses (EFSA Panel et al., 2018). In the United States, annual losses were estimated at around US$300 million, rising to over US$500 million during severe outbreaks. Assessing management costs in the Americas is difficult, since genetically modified *Bacillus thuringiensis* (Bt) crops and insecticides are widely used to limit FAW damage. In Brazil alone, control efforts in 2009 cost an estimated US$600 million, or roughly US$40 per hectare. In its invasive range, farmer surveys reported maize yield losses of US$284 million in Ghana and US$198 million in Zambia, with projected losses of US$2.5–6.3 billion across 12 African countries in 2017. FAW is further estimated to cause annual losses of up to US$13 billion in maize, rice, sorghum, and sugarcane across sub-Saharan Africa (EFSA Panel et al., 2018).

The Asian citrus psyllid, *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), is another example of invasive pests. This species is a major citrus pest because it spreads phloem-restricted bacteria (*Candidatus Liberibacter* species) that cause citrus greening disease (Huanglongbing, HLB), which is regarded by many as the most severe disease affecting citrus worldwide (Hall, 2008). Asian citrus psyllid invaded many countries in Central and North America starting in the 1990s, and HLB subsequently has been detected in the USA, eastern and western Mexico, Belize, Puerto Rico, and Cuba (Hall et al., 2013). In Africa, the Asian citrus psyllid has been reported in Belin, Ethiopia, Ghana, Kenya, Mauritius, Nigeria, Reunion and Tanzania (EPPO, 20025). According to Leong et al. (2022), HLB wiped out about 1,143 hectares of orchards in Sarawak, Malaysia in 1991. The affected crops included 'limau langkat' (*Citrus aurantium*, also known as Tanaka's *C. suhuiensis*), mandarin orange, sour/bitter orange, and leech lime. The outbreak caused an estimated economic loss of 6.5 million Malaysian ringgit (about 1.6 million US dollars) (Leong et al., 2022).

The tomato potato psyllid (TPP), *Bactericera cockerelli*, poses a significant biosecurity risk to solanaceous crop sectors in various countries. TPP is regarded as one of the most damaging pest species from the Western Hemisphere, responsible for significant losses in potato production globally (Suwandharathne et al., 2023). TPP feeds on a wide range of plant species across more than 20 families, primarily targeting small to medium-sized soft-wooded shrubs. Among these, are members of the Solanaceae family which are the preferred hosts, including potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), capsicum (*Capsicum annuum*), tamarillo (*Solanum betaceum*), and tobacco (*Nicotiana tabacum*). In addition, various non-crop plants can serve as alternative hosts for TPP during winter or crop-free periods, such as Chinese boxthorn (*Lycium barbarum*), African boxthorn (*Lycium ferocissimum*), apple of Peru (*Nicandra physalodes*), poroporo (*Solanum aviculare*), Jerusalem cherry (*Solanum pseudocapsicum*), and bittersweet nightshade (*Solanum dulcamara*) (Vereijssen 2020; Suwandharathne et al., 2023).

Originally from North and Central America, *B. cockerelli* was unintentionally introduced into New Zealand in the mid-2000s (Figure 3.1). This psyllid transmits a phloem-restricted alpha-proteobacterium, *Candidatus* Liberibacter solanacearum (also known as *Ca. L. psyllaurous*), which is linked to psyllid yellows disease affecting tomatoes, potatoes, capsicums, eggplants, and tamarillos, as well as zebra chip disease in potatoes. The presence of both the vector and pathogen has caused severe damage to these crop industries, leading to multimillion-dollar losses annually due to increased pest management and monitoring costs, lower crop yields, and disruptions in export markets (Walker et al., 2015). In Texas, USA, the pest has been linked to economic losses of approximately US$2 million annually due to zebra chip disease, with an estimated 35–40% of potato crops in affected regions considered susceptible to infection (Suwandharathne et al., 2023).

Numerous integrated pest management strategies are required to control *B. cockerelli* and reduce the occurrence of zebra chip disease in potato crops. At present, most farmers employ a combination of cultural, biological, and chemical control methods as part of integrated pest management (IPM) programmes. Cultural practices that contribute to effective management include the use of clean, certified pathogen-free seed, planting and harvesting before *B. cockerelli* populations peak, and selecting fields free from infested or diseased non-crop plants as part of a proper crop rotation plan (Vereijssen, 2020). In New Zealand, management of the tomato potato psyllid (TPP) largely depends on frequent applications of broad-spectrum insecticides. However, this approach is expensive, poses risks to the environment and non-target organisms, and may accelerate the development of insecticide resistance within pest populations (Vereijssen et al., 2013). Certain conventional and biorational pesticides such as plant-based oils, mineral oils, and kaolin have demonstrated significant deterrent and repellent effects on potato psyllid feeding and oviposition in both laboratory and field studies. These products could serve as valuable components of integrated pest management (IPM) programs aimed at controlling *B. cockerelli* and reducing the incidence of zebra chip disease (Vereijssen, 2020).

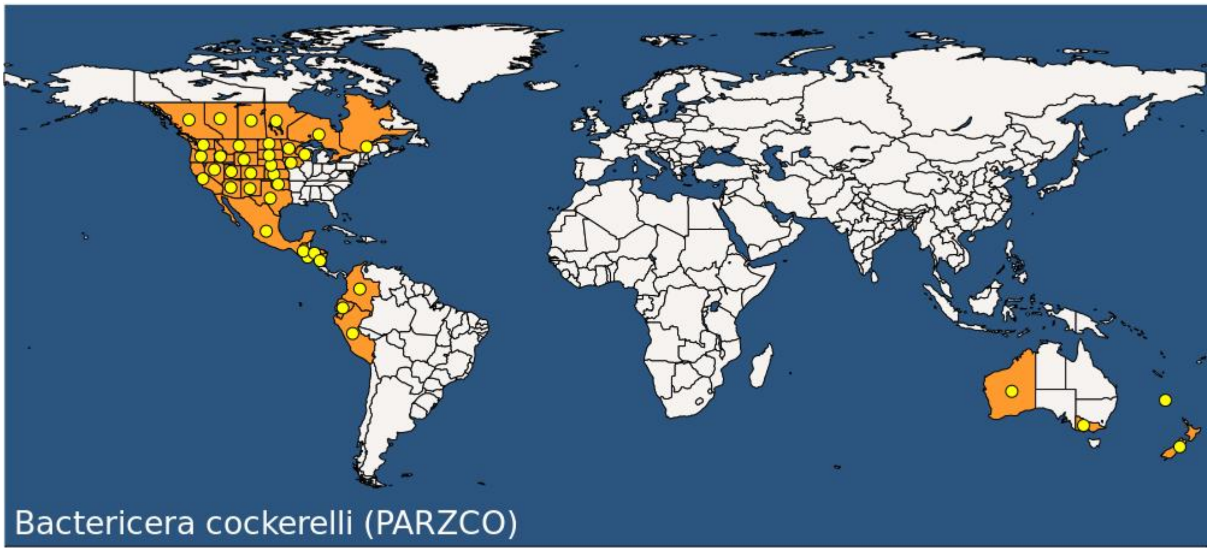

Figure 3. 1: Current world's distribution map of *Bactericera cockerelli* from EPPO (2025) as of 23 September 2025. Yellow dots indicate the presence of *B. cockerelli*.

The emergence of new pests in agriculture necessitates baseline studies to gain insights into their ecology and distribution before suitable management strategies can be developed and implemented (Mugala et al., 2022). The purpose of early detection is to discover and identify pathogens and pests before they become established, preventing widespread damage and economic losses in agriculture, landscaping, and environmental areas (Bowers et al., 2022). Growers, researchers, and regulatory officials frequently require effective methods to detect psyllids and track their populations. Visual inspections conducted by individuals trained to identify the various life stages of psyllids can often provide the quickest means of detecting an infestation (Hall, 2008). South Africa does not currently have *B. cockerelli*, but the country's climate and farming methods could support the pest's establishment and spread. Since solanaceous crops like potatoes and tomatoes are economically important in the region, the pest's arrival could cause serious problems. With the rise in global trade of goods and agricultural products, it is crucial to implement early detection and monitoring systems to prevent accidental introductions and reduce potential damage. Furthermore, threats from other psyllid species, such as *D. citri*, highlight the need for comprehensive surveillance targeting the Sternorrhyncha group (Hall, 2008). For effective biosecurity, it is crucial that countries and regions collaborate in developing and implementing surveillance programmes targeting invasive pests that are not yet present but are highly likely to be introduced. This need is especially pressing for South Africa, given the establishment of invasive pests in neighbouring countries and their rapid spread across the African continent. Key barriers to adequate surveillance include limited time and resources for updating pest lists, the lack of horizon scanning to anticipate potential invasions, and insufficient routine monitoring of high-priority pests (Tshikhudo et al., 2025).

In this chapter a targeted surveillance of Sternorrhyncha insects was undertaken, with a primary focus on detecting the potentially invasive *Bactericera cockerelli* in solanaceous crop systems as well as potential wild hosts in the nightshade family. By monitoring aphid and psyllid populations associated with potato and tomato crops, the study sought to provide baseline data on species composition and abundance, while establishing whether *B. cockerelli* or other non-native psyllids are present in the surveyed regions. This surveillance is intended to inform future biosecurity measures and contribute to South Africa's preparedness against high-risk agricultural pests.

3.2 Materials and Methods

3.2.1 Insect sampling locations

National surveys were conducted over two consecutive years with 39 sites sampled from 2024 to 2025 in various production zones in all nine South African Provinces (Figure 3.2). Sampling was conducted using three different sampling methods: physical sampling, sticky traps and bucket traps. The survey targeted various crops in the Solanaceae family as well as their wild relatives. At sites where there was marginal natural vegetation, physical sampling was applied, targeting mostly *Lycium* species because they belong to the family, Solanaceae and therefore potential hosts for pests of Solanaceae (Suwandharathne et al., 2023).

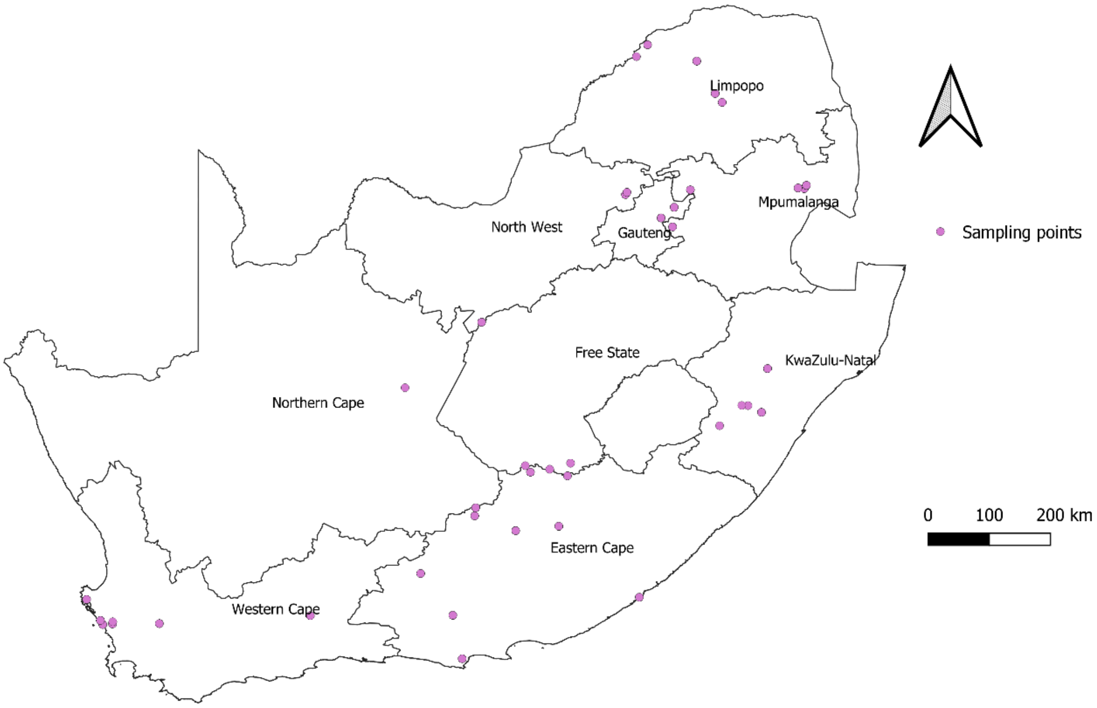

Figure 3. 2: Sampling locations for the national survey targeting mainly potato and tomato production zones around South Africa.

3.2.2 Physical sampling

The tomato and potato canopies were sampled for insects using telescopic folding sweep nets. Each sample consisted of three consecutive sweeps along a 2 m² surface at ten different points, covering a total distance of 100 m, to obtain three samples per site and date, following the method by Antolínez et al., (2019). Different species of *Lycium* were sampled in various areas, especially in the Eastern and Western Cape Provinces, where these plant species are most abundant. This plant group has been reported to be a non-crop host of *Bactericera cockerelli* (London et al., 2022) and the native congeneric species, *B. capensis* (Hollis, 1984). Each sample was placed in glass vials with 70% (for morphological studies) and 99% (for molecular studies) ethanol and taken to the laboratory for storage until taxonomic identifications.

3.2.3 Yellow sticky traps

Asian Citrus Psyllid (A.C.P) Trap (Insect Science®, The Science of Entomology) were used as another trapping method (Figure 3.3). These traps were sticky on both sides, 25 cm high and 10 cm wide, and were placed above the crop canopy to trap adult insects on the tomato and potato patches and the plant canopy of the marginal vegetation. Sampling for adults began when the plants emerged and continued until the senescence of the canopy. A total of 10 sticky traps in each site were deployed and collected after 28 days in the field. Traps retrieved from the sampling sites were wrapped in cling wrap and placed in cooler boxes for transportation to the laboratory. The samples were then stored in the fridge during the sample processing. The sticky traps were observed under a microscope where insects (aphids, psyllids and whiteflies) trapped were identified and counted.

Figure 3. 3: The A.C.P sticky trap retrieved from the field during sampling period.

3.2.4 Bucket trap

The daily insect activity was monitored using bucket traps at various locations, no baits or chemical attractants were used. The bucket traps were located in potato fields selected for sampling. The bucket traps were deployed and left out in the field for three months, they were serviced at weekly intervals at the various sites between April and December 2024. The trap contents were removed at weekly intervals for the duration of the sampling period and the insects preserved in 99% ethanol until taxonomic identification.

3.2.5 Insect identifications

Aphid identification: The collected aphids were sorted, counted and identified to species level or to genus level using the Aphid Identification guide by Millar (1990) and consultation with an external service provider, AphidSolutions. The insects were collected and transported to the laboratory on a weekly basis and stored in 99% alcohol.

Psyllid identifications: Adults psyllids were sorted, counted and were identified to species level or to genus level based on morphological characteristics following the taxonomic keys of (Burckhard, 2022; Hollis, 2004; Hollis, 1984; Capener, 1970; Capener, 1973).

3.2.6 Statistical analysis

The data collected during the national survey were analyzed in R (v 4.5.0) and R-Studio (v 2025.05.1+513). Prior to analysis, data were inspected for normality using the Shapiro–Wilk test which revealed that the data were not normally distributed. Because the data violated normality assumptions, differences in insect abundance among and between Provinces were analysed using generalized linear models (GLMs) with a negative binomial error distribution. To calculate the species diversity, the diversity indices; Simpson's index, Shannon's index, species evenness and species richness were calculated using the 'vegan' package in R. For the species evenness the Pielou's evenness index was used, Pielou's evenness index measures how evenly the number of individuals were distributed among the species (Herrmann et al., 2022). For these indices Kruskal–Wallis tests were computed, and bar plots were used to visualize the differences in the diversity of insect between the sampling sites. All data visualizations were computed using R Studio.

3.3 Results

3.3.1 Overview of insect sampling

A total of 27,591 insects were collected during the national survey using a combination of sticky traps, bucket traps, and physical sampling (sweep netting). Across all methods, sampling was conducted in Provinces/sites, representing the major tomato and potato production regions of the country and the marginal vegetation was also sampled (Figure 3.4). Sticky traps contributed 40.2% and Bucket traps accounted for 40.9% of total captures, yielding the Sternorrhyncha group insects (aphids, psyllids and whiteflies). Physical sampling produced 18.9% of records, and detected a broader range of insects, including additional taxa besides the Sternorrhyncha group recorded at the order level (e.g., Diptera, Hymenoptera, Thysanoptera, Nueroptera, Mantidae, Coleoptera, Lepidoptera, Hemiptera), providing host-specific and immature-stage information.

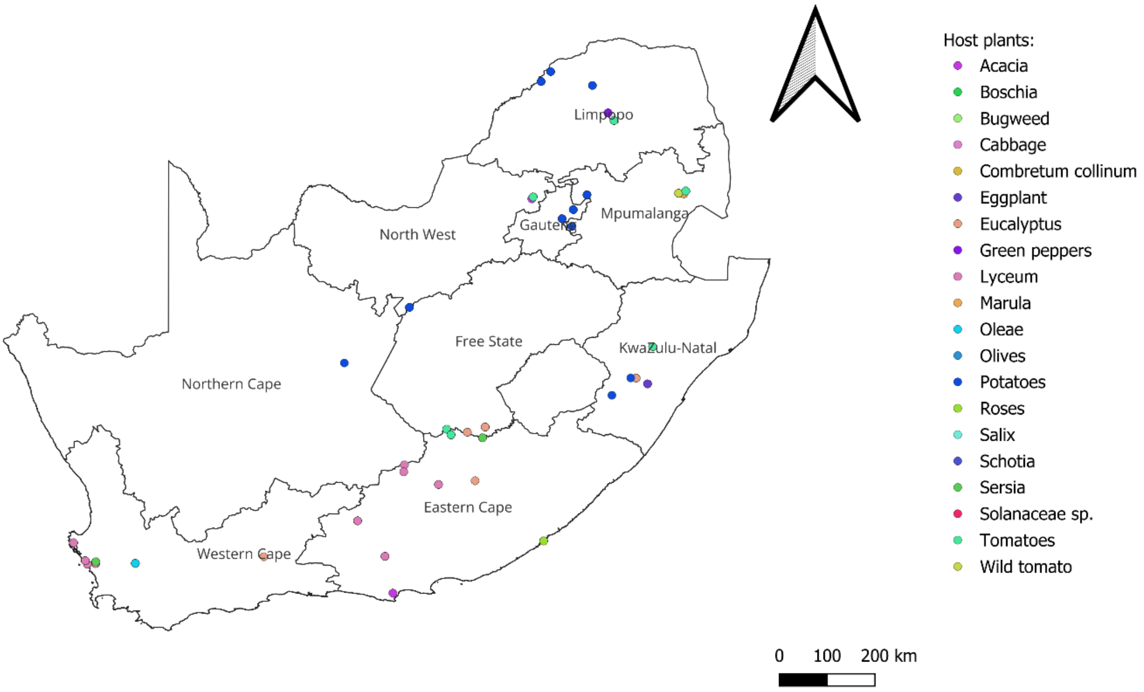

Figure 3. 4: The plant species sampled in the different potato and tomato production areas during the national survey.

The Rank abundance analysis was used to analyse the distribution of species abundance of the aphid and psyllid species collected during the survey. Among aphids, *Rhopalosiphum maidis* (6412), *Aphis* spp (1619), *Rhopalosiphum padi* (520), *Myzus persicae* (479), *Capitophoruus hippophaes* Walker (Hemiptera: Aphididae) (399), *Lipaphis erysimi* Kaltenbach (Hemiptera: Aphididae) (398) and *Lipaphis pseudobrassicae* (278) were the seven most abundant species (Figure 3.5). For Psyllids, *Platycorypha nigrivirga* (253), *Retroacizzia mopanei* Petteyi (Hemiptera: Psyllidae) (148), *Acizzia* spp (130), *Psyllidae* spp (Hemiptera: Psyllidae) (105), *Agonoscena crotolariae* Petteyi (Hemiptera: Psyllidae) (67), *Ciriacremum capensis* Enderlein (Hemiptera: Psyllidae) (62) and *Diaphorina solani* Capener (Hemiptera: Psyllidae) (43) were the seven most abundant species (Figure 3.6).

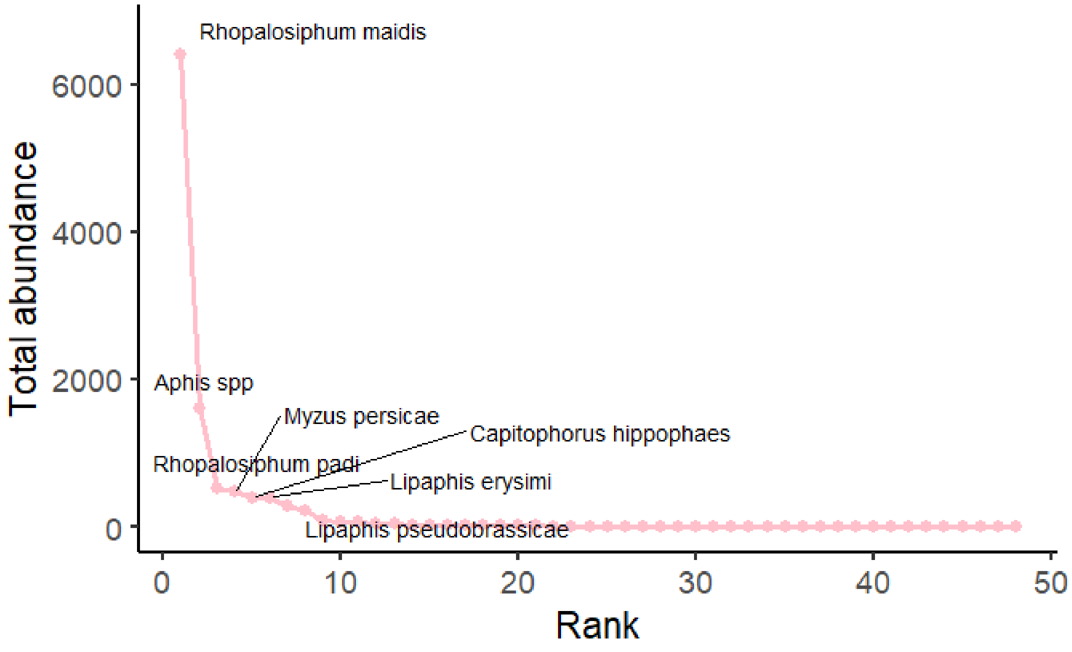

Figure 3. 5: Species rank abundance curves illustrating the seven most abundant aphid species collected during the national survey. *Rhopalosiphum maidis* was the most abundant species.

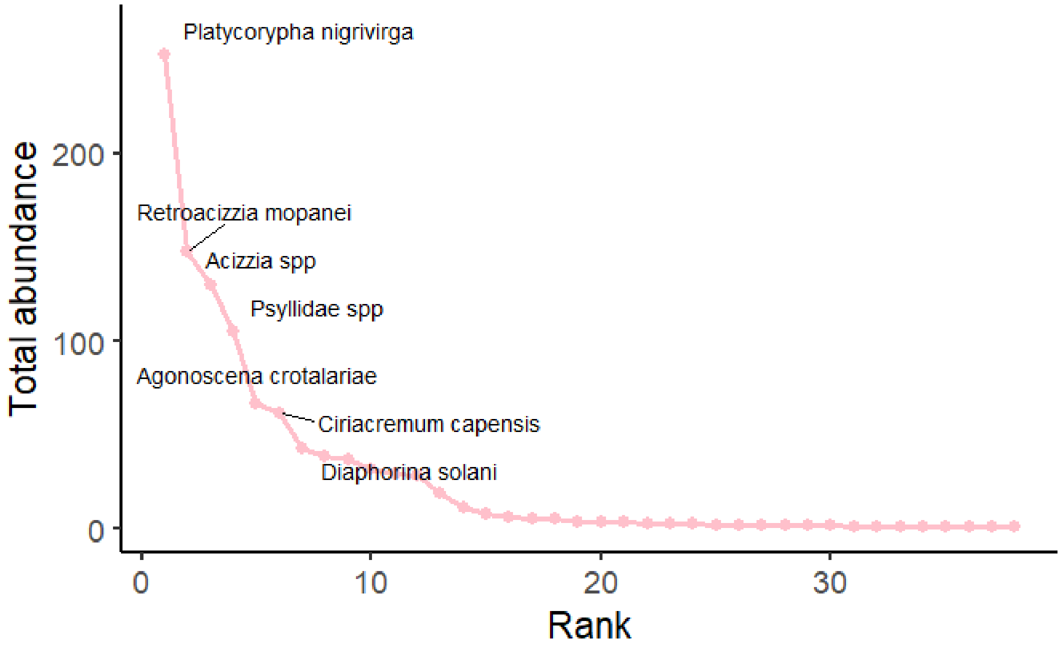

Figure 3. 6: Species rank abundance curve illustrating the seven most abundant psyllid species collected during the national survey. *Platycorypha nigrivirga* was the most abundant species.

3.3.2 Physical sampling

Physical sampling yielded a total of 5,216 insects: both targeted pest species and a range of non-target insect groups and the total abundance of insect groups collected across all sampling sites showed considerable variation. The targeted taxa were identified to species and genus levels. The contributions to the populations by the target groups were aphids: 24.5%, psyllids: 6.9%, and whiteflies: 54.7%. In addition, non-targeted insect groups (Diptera, Coleoptera, Thysanoptera, Lepidoptera and non-Sternorryncha hemipterans) were recorded at order level and they contributed 13.9%, providing insight into the broader arthropod community associated with the cropping systems (Figure 3.7).

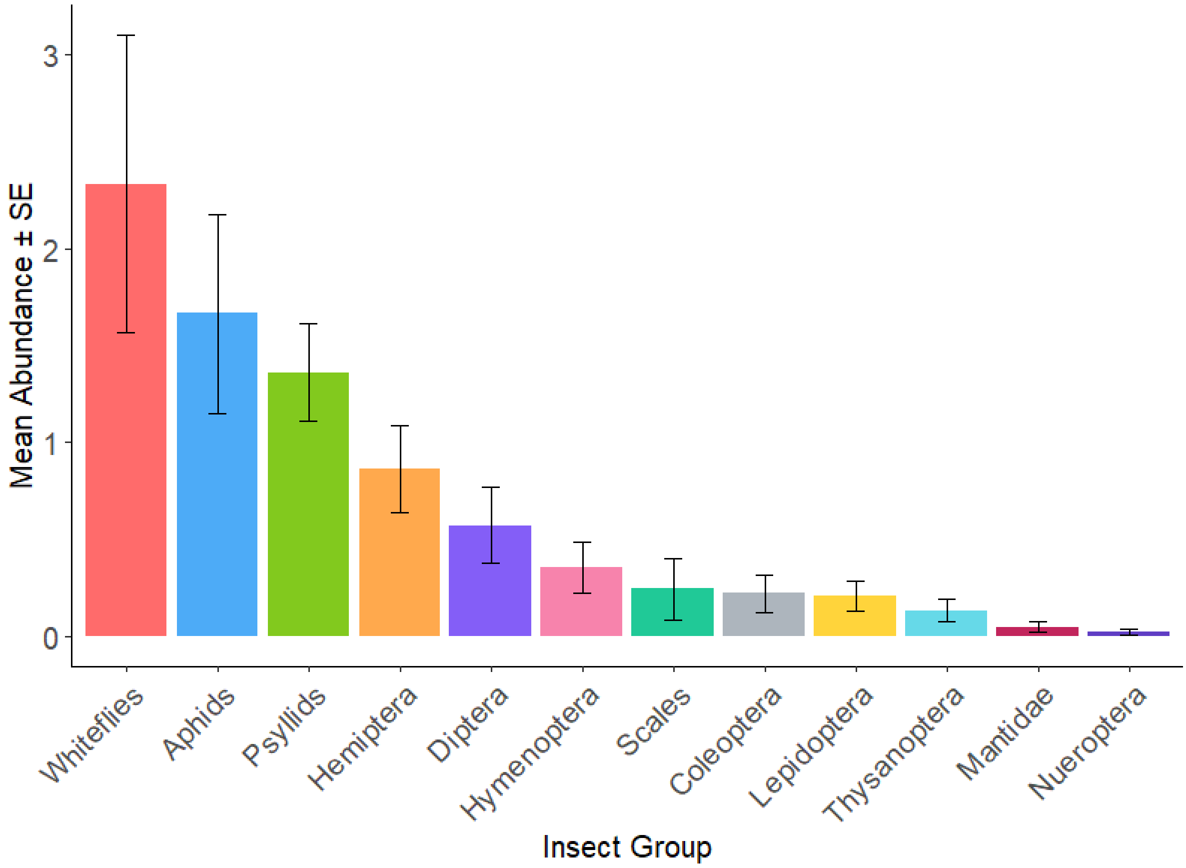

Figure 3. 7: Mean total abundance of the insect groups collected across all sampling sites during physical sampling across the locations. Error bars represent standard errors of the mean.

A total of 1068 psyllids assigned to 37 species were collected across all sampling sites. The most abundant species were *Platycorypha nigrivirga* (23.7%), *Acizzia* spp (13.9%), and *Retroacizzia mopanei* (9.7%), which together accounted for most individuals recorded. A congeneric species of *Bactericera cockerelli* (the target pest for this current study), *Bactericera* *capensis* (Figure 3.9), was found during the sampling, with a total of 9 insects collected from *Lycium cinereum* and these specimens were collected from only one site in Elandsburg, Eastern Cape (-31.28231659, 25.05525634). The similarities between *B. cockerelli* and *B. capensis* are only apparent on the abdomen where they both have a white transverse band on the first abdominal segment and another, inverted 'V' shaped band on the last abdominal segment (Figure 3.8). The two are easily distinguishable by the apparent lack of yellow markings on the head and thorax of *B. capensis,* which are prominent on the invasive *B. cockerelli* (Figure 3.8).

Figure 3. 8: **A**. *Bactericera cockerelli* adult (agrobaseapp.com.), the targeted invasive psyllid species in the national survey; **B**. *Bactericera capensis* ((South African National Collection of Insects) (SANC)) adult, found during the survey in Eastern Cape.

3.3.3 Sticky traps

A total of 11,087 insects were captured using sticky traps across all survey sites. Sticky traps captured three targeted Sternorrhyncha groups: whiteflies, aphids, and psyllids. The highest overall counts were recorded for whiteflies (92.5%), which dominated the collections across most Provinces; psyllids were moderately abundant (5.9%), and aphids (1.6%) were the least abundant as some sampling sites did not capture aphids and psyllids (Figure 3.5). Whiteflies were captured from all the sampling sites however, Marlo Farm (55.5%) had the highest contribution of whiteflies to the populations, LA Fresh Produce (27.3%) also had quite a large number of whiteflies collected. Reasetla Farm (0.19%) in Limpopo and Timeless Tomatoes (0.47%) in Free State had the lowest numbers of whiteflies captured on the sticky traps. In the Eastern Cape the sticky traps captured whiteflies only in Red Baron tomatoes (7.8%). Reasetla, Marlo Farmand LA Fresh Produce in Limpopo were the only farms that captured psyllids during the survey, with LA Fresh Produce (76.7%) having high numbers of psyllids with

Platycorypha nigrivirga as the most abundant species collected, Marlo Farm (21.3%) had a moderate number collected and Reasetla (2%) had the lowest numbers of psyllids collected (Figure 3.9).

The differences in insect abundance for the insect groups captured from the sticky traps between the sampling sites were analyzed using GLMs. The GLM revealed significant effects of both site and insect group on overall insect abundance (Table 3.1). Insect abundance was significantly higher at Marlo Farms and LA Fresh Prod Farm compared to Reasetla Farm, while no significant differences were observed for Red Baron Tomatoes or Timeless Tomatoes. Among the insect groups, Whiteflies were significantly more abundant than aphids followed by psyllids, which also showed a significantly higher abundance relative to aphids (Figure 3.9; Table 3.1).

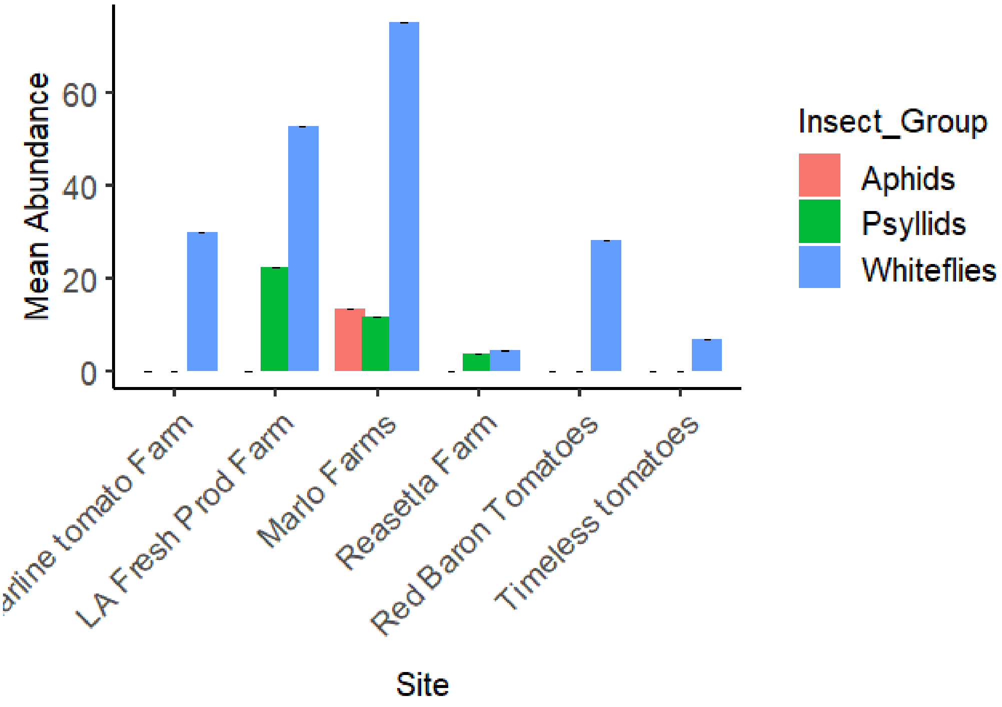

Figure 3. 9: Mean abundance of aphids, psyllids, and whiteflies captured using sticky traps across six tomato producing farms sampled by sticky traps.

Table 3. 1: Summary of differences between the sticky traps sampling sites (Farms & Provinces). The asterix indicates significant differences.

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-0.1177	0.4855	-0.243	0.80835	
LA Fresh Prod Farm	2.8348	0.5752	4.928	8.3e-07	***
Marlo Farms	0.6618	0.4734	1.398	0.16212	
Reasetla Farm	0.2711	0.8194	0.331	0.74074	
Red Baron Tomatoes	-0.1000	0.6443	-0.155	0.87664	
Timeless tomatoes	-2.4031	0.7596	-3.164	0.00156	**
Psyllids	0.2051	0.2858	0.718	0.47304	
Whiteflies	4.0233	0.2762	14.564	< 2e-16	***
Dispersion	1				
Null deviance	78.37				
Residual deviance	294.69				
AIC	1838.6				

3.3.4 Bucket traps

Bucket traps captured a total of 11,288 individuals that belong to the three target insect groups in the potato production zones; whiteflies, aphids, and psyllids. The highest overall counts on the bucket traps were recorded for aphids (96.8%), which dominated the agroecosystems, psyllids (2.92%) were moderately abundant, and whiteflies (0.27%) are the least abundant (Figure 3.10). For the overall bucket trap data, all sampling sites captured aphids, however; a very high number of the aphids was recorded in Mpumalanga, Delmas (71.6%) and the lowest were captured in Gauteng, Bronkhornspruit (0.09%). For psyllids, the bucket traps did not capture any insects in Sandveld, Free State, Mooi River in Kwazulu-Natal and Skaapkraal in Gauteng even though Verena, Bronkhornspruit and Bapfontein captured some psyllids with

Bronkhornspruit (34.8%) contributing largely to the psyllid populations and Verena (2.7%) having the lowest insect contribution to the populations. Bronkhornspruit (6.5%), Bapsfontein (6.5%) and Verena (87%) in Gauteng were the only three sites that captured whiteflies on the bucket traps during the survey and all the other sampling sites did not capture any whiteflies. Overall, for the bucket traps, aphids were the most captured insect than the two other groups, and their highest counts were from Delmas, Mpumalanga (Figure 3.10).

A generalized linear model tested the differences in insect abundance from the bucket traps. Insect abundance was significantly higher at Verena, Bronkhorstspruit, and Swartwater and no significant differences were observed among the other sites (Figure 3.10). Psyllids and whiteflies had lower abundances compared to aphids, highlighting clear differences in population patterns among insect groups. Overall, these results demonstrate pronounced spatial and taxonomic variation in insect abundance, with Verena and Bronkhornspruit showing extreme differences among locations and distinct abundance patterns across insect groups (Figure 3.10; Table 3.2).

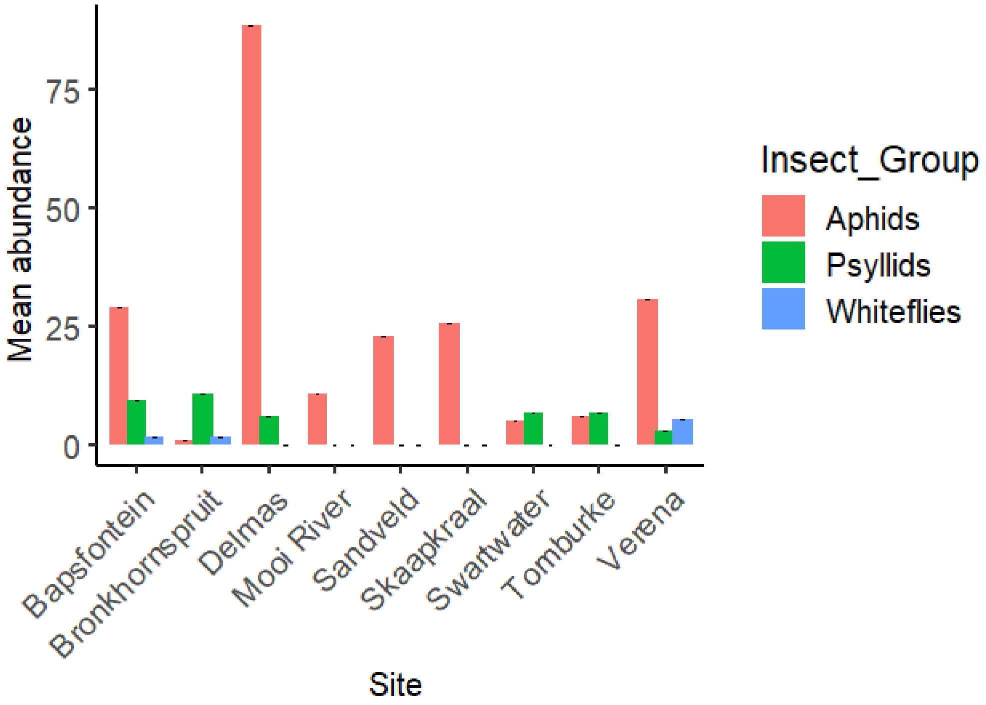

Figure 3. 10: Comparison of insects means abundances between the sites sampled by bucket traps. Error bars represent standard error.

Table 3. 2: Summary of differences between the bucket traps sampling sites (Farms & Provinces). The asterix indicates significant differences.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	7.222	1.665	4.337	1.44e-05 ***
Bronkhornspruit	35.822	2.118	16.916	< 2e-16 ***
Delmas	1.178	2.122	0.555	0.578619
Mooi River	-2.996	2.256	-1.328	0.184257
Sandveld	-1.520	2.167	-0.702	0.482926
Skaapkraal	-1.313	2.159	-0.608	0.543117
Swartwater	7.569	2.118	3.574	0.000351 ***
Tomburke	-1.968	2.217	-0.887	0.374910
Verena	43.878	2.118	20.721	< 2e-16 ***
Psyllids	-2.504	1.213	-2.064	0.039035 *
Whiteflies	-7.191	1.287	-5.587	2.31e-08 ***
Dispersion	1			
Null deviance	34.780			
Residual deviance	88.047			
AIC	341.35			

3.4 Species diversity

3.4.1 Species diversity of psyllids across locations

A Kruskal-Wallis tests was conducted to test for differences in species diversity, evenness and abundance across sampling locations. The Kruskal-Wallis showed that there was no significant difference in the diversity of species found in the different sites; Shannon diversity (X^2 (26, N=27) = 33.699, $P = 0.1428$ and there was also no significant difference in the abundance of species collected; Simpson diversity (X^2 (26, N=27) = 35.795, $P = 0.09551$ indicating that overall species diversity and dominance were relatively consistent. In contrast, Evenness differed significantly among locations; X^2 (15, N=15) = 32.002, $P = 0.006343$, suggesting that while the number of species was similar, the distribution of individuals across species varied (Figure 3.11). This implies that certain locations were more dominated by specific species, whereas others had a more equitable distribution, potentially reflecting local ecological conditions such as host availability, habitat structure, or microclimatic differences, for instance in Dalmada and Marlo Farm the dominant species was *Platycorypha nigrivirga* and Swartwater was dominated by *Retroacizzia mopanei*.

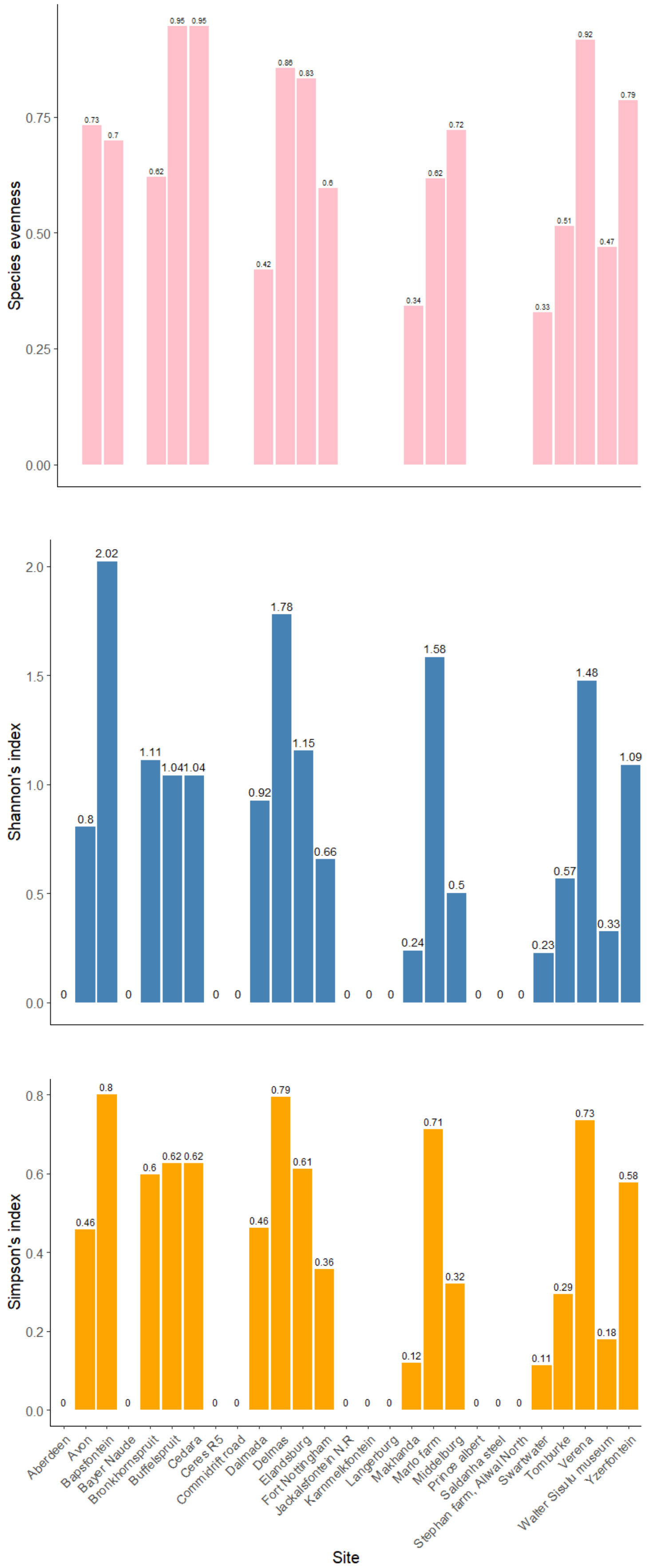
Species evenness
0.00
0.25
0.50
0.75
0.73
0.7
0.62
0.95
0.95
0.42
0.86
0.83
0.6
0.34
0.62
0.72
0.33
0.51
0.92
0.47
0.79
Shannon's index
0.0
0.5
1.0
1.5
2.0
0
0.8
2.02
0
1.11
1.04
1.04
0
0
0.92
1.78
1.15
0.66
0
0
0
0.24
1.58
0.5
0
0
0
0.23
0.57
1.48
0.33
1.09
Simpson's index
0.0
0.2
0.4
0.6
0.8
0
0.46
0.8
0
0.6
0.62
0.62
0
0
0.46
0.79
0.61
0.36
0
0
0
0.12
0.71
0.32
0
0
0
0.11
0.29
0.73
0.18
0.58
Aberdeen
Avon
Bapsfontein
Bayer Naude
Bronkhorstspruit
Buffelspruit
Cedara
Ceres R5
Commidrift road
Dalmada
Delmas
Elandsburg
Fort Nottingham
Jackalsfontein N.R
Karnmelkfontein
Langerburg
Makhanda
Marlo farm
Middelburg
Prince albert
Saldanha steel
Stephan farm, Alwal North
Swartwater
Tomburke
Verena
Walter Sisulu museum
Yzerfontein
Site

Figure 3. 11: Bar plots visualizing the differences in species diversity, evenness and dominance of psyllid species between the sampling sites. The numbers indicate diversity scores.

3.4.2 Species diversity of aphids across locations

The diversity of aphid species across sites was assessed using Shannon, Simpson, and Evenness indices. Kruskal-Wallis tests indicated that there were no statistically significant differences in Shannon diversity: X^2 (12, N=13) = 16.486, $P = 0.17$, Simpson diversity: (X^2(16, N=23) = 17.468, $P = 0.1328$ and species evenness across sampling locations. While the evenness index: X^2 (12, N=13) = 32.002, $P = 0.06813$) showed a trend toward higher variation among sites, it did not reach statistical significance, suggesting that overall aphid diversity and distribution were relatively consistent across the sampled locations indicating that overall species diversity and the relative distribution of individuals among species were similar across sites. In other words, no site consistently had higher or lower diversity or more uneven species distributions than the others, suggesting a relatively uniform aphid community structure across the sampled locations (Figure 3.12).

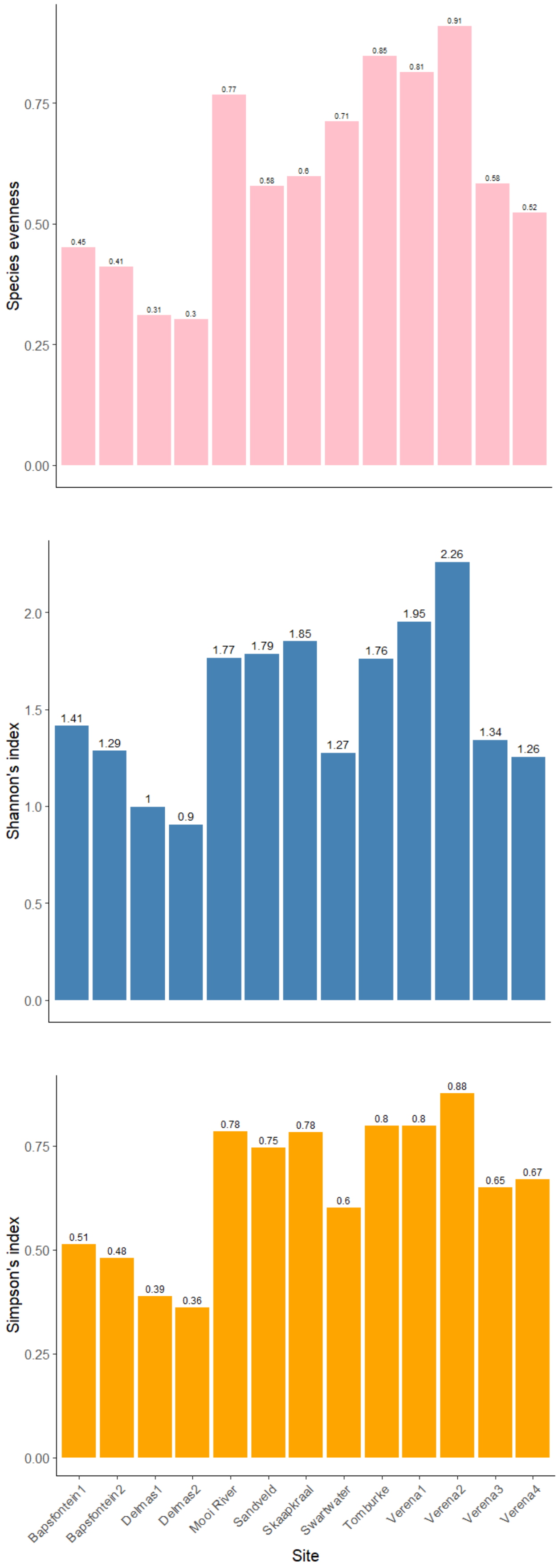
Species evenness
0.75
0.50
0.25
0.00
0.45
0.41
0.31
0.3
0.77
0.58
0.6
0.71
0.85
0.81
0.91
0.58
0.52
Shannon's index
2.0
1.5
1.0
0.5
0.0
1.41
1.29
1
0.9
1.77
1.79
1.85
1.27
1.76
1.95
2.26
1.34
1.26
Simpson's index
0.75
0.50
0.25
0.00
0.51
0.48
0.39
0.36
0.78
0.75
0.78
0.6
0.8
0.8
0.88
0.65
0.67
Bapsfontein1
Bapsfontein2
Delmas1
Delmas2
Mooi River
Sandveld
Skaapkraal
Swartwater
Tomburke
Verena1
Verena2
Verena3
Verena4
Site

Figure 3. 12: Bar plots visualizing the differences in species diversity, evenness and dominance of aphid species between the sampling sites. The numbers indicate diversity scores.

3.4.3 Overall species diversity of Sternorrhyncha on Solanaceae

The diversity of all psyllid and aphid species across sites was assessed using Shannon, Simpson, and Evenness indices. Kruskal-Wallis tests indicated that there were no statistically significant differences in Shannon diversity: X^2 (38, N=39) = 38, p=0.4695, Simpson diversity: X^2 (38, N=39) = 38, p = 0.4695 and species evenness: X^2 (26, N=27) = 26, p=0.4631 across sampling locations. In other words, no site consistently had higher or lower diversity or more uneven species distributions than the others, suggesting a relatively uniform aphid community structure across the sampled locations (Figure 3.13).

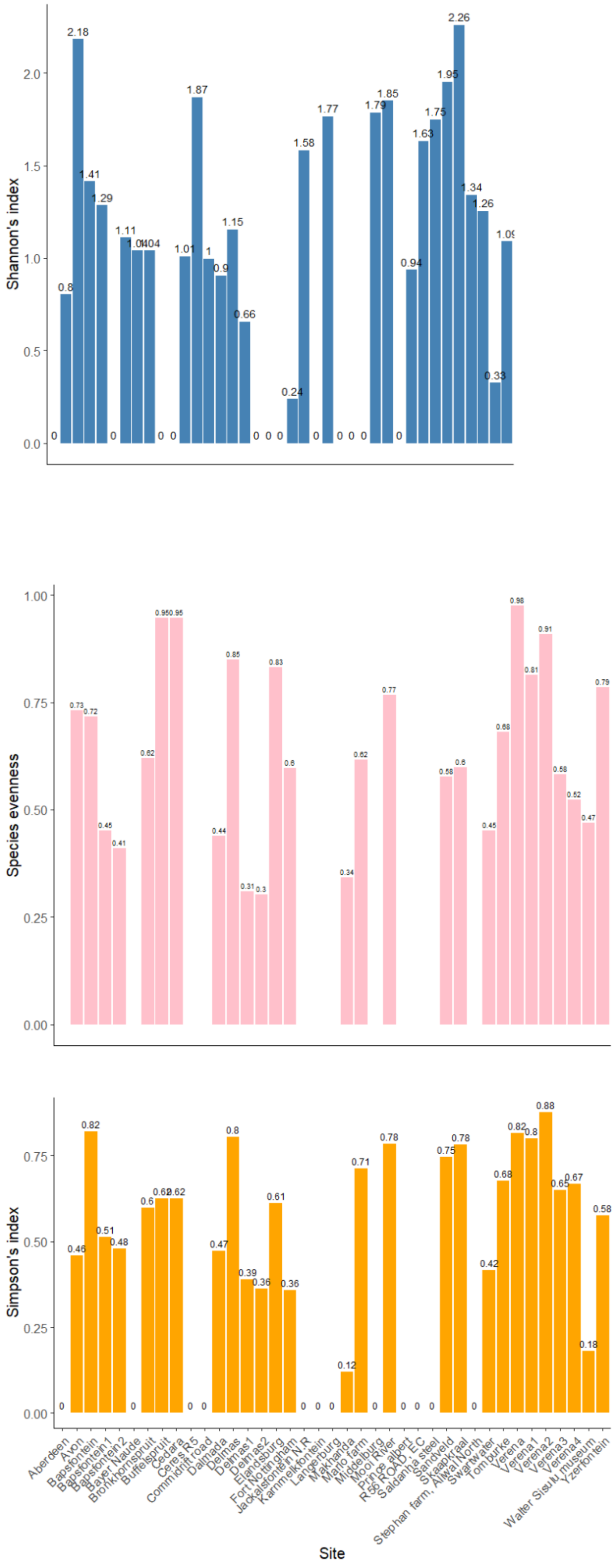
Shannon's index
0.0
0.5
1.0
1.5
2.0
0
0.8
2.18
1.41
1.29
0
1.11
1.04
1.04
0
0
1.01
1.87
1
0.9
1.15
0.66
0
0
0
0.24
1.58
0
1.77
0
0
0
1.79
1.85
0
0.94
1.63
1.75
1.95
2.26
1.34
1.26
0.33
1.09
Species evenness
0.00
0.25
0.50
0.75
1.00
0.73
0.72
0.45
0.41
0.62
0.95
0.95
0.44
0.85
0.31
0.3
0.83
0.6
0.34
0.62
0.77
0.58
0.6
0.45
0.68
0.98
0.81
0.91
0.58
0.52
0.47
0.79
Simpson's index
0.00
0.25
0.50
0.75
0
0.46
0.82
0.51
0.48
0
0.6
0.62
0.62
0
0
0.47
0.8
0.39
0.36
0.61
0.36
0
0
0
0.12
0.71
0
0.78
0
0
0
0.75
0.78
0
0.42
0.68
0.82
0.8
0.88
0.65
0.67
0.18
0.58
Aberdeen
Avon
Bapsfontein
Bapsfontein1
Bapsfontein2
Bayer Naude
Bronkhornspruit
Buffelspruit
Cedara
Ceres R5
Commidrift road
Dalmada
Delmas
Delmas1
Delmas2
Elandsburg
Fort Nottingham
Jackalsfontein N.R
Karnmelkfontein
Langerburg
Makhanda
Mario farm
Middelburg
Mooi River
Prince albert
R56 ROAD, EC
Saldanha steel
Sandveld
Skaapkraal
Stephan farm, Aliwal North
Swartwater
Tomburke
Verena
Verena1
Verena2
Verena3
Verena4
Walter Sisulu museum
Yzerfontein
Site

Figure 3. 13: Bar plots visualizing the differences in species diversity, evenness and dominance of all the Sternorrhyncha on Solanaceae species between the sampling sites. The numbers indicate diversity scores.

3.5 DISCUSSION

Yellow sticky traps are commonly used to monitor *B. cockerelli* populations both within fields and across regions (Rubio-Aragón et al., 2023; Roberts et al., 2025). However, to effectively monitor arthropod species, it is important to use a range of sampling methods (Wynne et al., 2019). In this study three sampling methods (sticky traps, bucket traps and sweep netting) were used and sticky traps captured a lot more psyllid species and outperformed the other methods used. This was similar to a study by Yen et al. (2013) where they evaluated the effectiveness of five sampling methods for detection of the tomato potato psyllid in North Island, New Zealand. In their study sticky traps and water traps outperformed all other methods which included sweep netting. The results of their study suggested that in the event of a suspected incursion by *B. cockerelli* in Australia, a programme of surveillance using yellow sticky or water traps would be easy and time-effective to implement and maintain and would provide a high probability of detection if the psyllid was present.

Miranda et al. (2018) showed that, in citrus orchards, sticky cards were the most effective method for detecting and quantifying *Diaphorina citri* populations. Their study compared sticky cards of different colours (yellow, light green, green, and dark green) with sweep netting, two suction device models, visual inspection, and stem-tap sampling. In their study, the short- and long-term experiments demonstrated that sticky cards were the most effective method for detecting and quantifying *D. citri* populations, especially in areas where chemical control was frequently applied. The sampling methods that involve a direct collection or observation of psyllids on the citrus trees, such as stem tap and visual inspection have the advantage of being faster and less expensive than the yellow sticky card (Miranda et al., 2018).

During the current study, no psyllid species associated with cultivated solanaceae (potato, tomato, eggplant) were collected. All the collected and described species are hosted by wild solanaceae plants and other plant families, an indicator that the cultivated crops are not in any immediate threat from the invasive psyllid (Antolínez et al., 2022). During the surveillance for *B. cockerelli*, all sampled potatoes, tomatoes and other agricultural solanaceae (green pepper, eggplant) did not host the targeted *B. cockerelli*. Furthermore, wild solanaceae plants (*Lycium* spp.) were also sampled to check if they hosted *B. cockerelli* and this was because they are potential alternative non-crop hosts for *B. cockerelli* primarily belonging to the solanaceae family and these non-crop hosts can sustain life stages of *B. cockerelli* year round in the New Zealand, even after frost and snow events (Verreijssen, 2020). The non-crop host plants include; Chinese boxthorn *(Lycium barbarum* L.), African boxthorn (*L. ferocissimum* Miers), apple of Peru (*Nicandra physalodes* (L.) Gaertner), Poroporo (*Solanum aviculare* G. Forster), Jerusalem cherry (*Solanum pseudocapsicum* L.), Common Thornapple, also known as Jimsonweed, (*D. stramonium* L.) and field bindweed (*Convolvulus arvensis* L.) (Convolvulaceae) (London et al., 2022; Verreijssen, 2020; Barnes et al., 2015). However, during sampling, on the wild solanaceae, a con-generic species of *B. cockerelli* was collected on *Lycium cinereum* from Eastern Cape, Elandsburg. *Bactericera capensis* and *B. cockerelli* are both members of the same genus, which all develop on solanaceous hosts (Hollis, 1984). *Bactericera capensis* was first collected in Aliwal North, Eastern Cape, South Africa in 1922 on *Lycium salinicola* and *Lycium tetrandrum* (Solanaceae).

There is no documented relationship between *B. capensis* and potato or any agricultural solanaceae species, however since it belongs to the same genus as *B. cockerelli* a serious pest of potatoes and tomatoes (Castillo Carrillo et al., 2019), this insect species has a potential of causing problems for agricultural solanaceae crops. The native *B. capensis* was collected over 200km from the closest potato farm in Aliwal North. According to Antolínez et al. (2023), maximum long-distance dispersal in the absence of wind for *B. cockerelli* can go up to 980 m, but since wind can facilitate psyllid movement under field conditions, their actual dispersal distances may be greater and a study conducted by Cameron et al. (2013), suggested that, mean dispersal distances for *B. cockerelli* is 100 and 330 m per 3-day period, respectively, for linear and radial assumptions. Therefore, it will be important to carry out studies on the flight potential for *B. capensis* and compare to what has been observed with *B. cockerelli* in an effort to predict potential spread patterns of the pest should it make an incursion into South Africa.

The most dominant psyllid species was the *Platycorypha nigrivirga, a neotropical* invasive species strictly associated with the tipu tree, *Tipuana tipu* (Benth.) Kuntze (Fabaceae: Papilionoideae) (Del Pino et al., 2023), *Acizzia* spp. (associated with host plants in the *Acacia* and *Albizia* genera), and *Retroacizzia mopanei* (associated with the mopane tree *Colophospermum mopane*). Psyllids are host specific and closely related psyllid species typically occur on closely related host plants (Van Klinken, 2000). *Platycorypha nigrivirga* was collected on tomatoes in very high numbers on tomatoes and potatoes from different sites with no original host, the tipu tree in sight. This could be caused by a lot of factors including flight dispersal since *P. nigrivirga* seems to be a monophagous insect that feeds on the tipu tree only (Rung et al., 2009). Tomatoes, potatoes and the tipu tree share the green leaf volatiles which are emitted by green plants (Sarang et al., 2021), and plant leaf volatiles can act as olfactory cues that attract insects and affect their preferences during host selection (Liu et al., 2024), and some psyllids depend on olfactory cues to identify and select their host plants (Makunde et al., 2023). However, the appropriate/inappropriate landing theory suggests that when insects search for host plants, they tend to land indiscriminately on any green objects, including both host (appropriate landing) and non-host plant leaves (inappropriate landing), while generally avoiding brown surfaces such as soil (Finch & Collier, 2000). Furthermore, the incidence of serious storms particularly during the 2024 sampling season could have contributed to the captures of this species in high numbers on the tomatoes particularly in Limpopo where most of the tipu psyllid was collected.

The most dominant aphid species were *Rhopalosiphum maidis*, *Aphis* spp and *Rhopalosiphum padi*, with *R. maidis* as the most abundant species, (which are aphids that can infest potatoes and act as vectors for diseases). These aphid species are the same insects that were observed as some of the most abundant in Chapter 2. However, there was a shift because during the continuous monitoring period (Chapter 2) the three most dominant species were *Rhopalosiphum padi*, *Rhopalosiphum maidis* and *Pemphigus* spp however, *Aphis* spp was more prominent during the national surveys, replacing *Pemphigus* spp. Furthermore, in the national survey, *R. maidis* was more abundant that *R. padi*, compared to what was recorded in Chapter 2. These results were similar to a study conducted by Were et al. (2015), in Kenya on potatoes where they found that the most abundant aphid species caught in all potato growing areas was *R. maidis*. All the collected species are known potential vectors of important potato viruses, including Potato leafroll virus (PLRV) and Potato virus Y (PVY). PVY infection has been reported, to cause tuber necrotic ringspot symptoms in susceptible cultivars and negatively impacting both potato quality and yield with yield reductions estimated at 0.13 tonnes per ha in the USA (Amin et al., 2023). Therefore, potato crops are highly vulnerable during peak migrations of these species. PLRV can also cause internal net necrosis in some cultivars, making tubers unsuitable for seed, sale, or processing (Krijger & Waals, 2020).

The whitefly species collected during the survey was *Bemisia tabaci,* one of the most important pests worldwide in subtropical and tropical agriculture as well as in greenhouse production systems and during the survey. This pest was collected in very high numbers from different sites and this has serious implications on the production of greenhouse crops like tomatoes and green pepper because the insect does not only feed and excrete honeydew onto the host plants, it also transmits the Tomato Yellow leaf curl virus (TYLCV) which hinders the host plant's ability to grow and develop (Cao et al., 2024). High numbers of this insect in the field can result to great yield losses and disease outbreaks and this could also mean the pest is/has developed resistance on the current control methods because even though there's a few control methods a lot of farmers prefer and rely on the chemical control measures to which the insect has evolved high levels of resistance (Li et al., 2025). A study conducted by Inak et al. (2025), in Türkiye, reported, over 750 instances of *B. tabaci* populations developing resistance to more than 65 pesticides have been documented. The high whitefly numbers encountered on the field could have been influenced by a lot of factors including temperature, host plant type, endosymbiont presence, associated viruses, and management practices and in whiteflies, these factors play a major role in determining their establishment and dominance and temperature is a key factor influencing insect development, as it affects their physiological performance and, consequently, their colonization, behaviour, and distribution (Krause-Sakate et al., 2020). However, the high magnitudes of pesticides spraying by the farmers could have exacerbated the whitefly populations because the whitefly *Bemisia tabaci* tends to rapidly develop strong resistance to insecticides (Saleem et al., 2022).

Whiteflies, aphids and psyllids are polygphagous phloem feeders that excrete honeydew to their host plants and transmit viruses causing production losses. According to Quiroga-Murcia et al. (2025), *Myzus persicae* like to inhabit in more nutrient rich, younger foliage while *B. cockerelli* may have less stringent requirements for nutrient composition or may prefer a different leaf developmental stage and this could cause serious damage on the host if they occur at the same time even though the two species are not competing for the same plant tissues and nutrients, while *Bemisia tabaci* deposits eggs on the underside surface of the tender and upper leaves of the young plants (Li et al., 2021). *Bemisia tabaci* and *Myzus persicae* can exist simultaneously on the same plant (Xue et al., 2010), however, plant mediated interactions or competition between the two species may occur (Tan et al., 2014). A study by Xue et al. (2010), revealed that, feeding by *B. tabaci* on tobacco triggers stronger plant defense responses, which can also provide protection against *M. persicae* and the growth rates of *M. persicae* were higher on leaves that either had whiteflies or had previously hosted whiteflies than on leaves that had never been infested. In the current study, these interactions were not studied as there were few instances where aphids and whiteflies were found to be infesting the same crop, with mostly whiteflies being predominant.

3.6 Conclusion

The rate of insect invasions is increasing due to multiple contributing factors, leading to ongoing reductions in agricultural productivity. Therefore, managing invasive insect species has become an urgent priority to minimize their negative effects amid the overlapping global challenges (Abram et al., 2024). It is therefore important to set up systems such as Targeted Detection Surveys, which concentrate on locations with a higher risk of new pest introductions. Such systems rely on phytosanitary information including emergency action alerts and records of pest interception (Kalaris et al., 2013). In this study we utilized the target national survey to conduct the surveillance for the invasive *Bactericera cockerelli* in the country. Regardless of all the psyllid species collected the results confirmed that *B. cockerelli* is currently absent in the country even though *Bactericera capensis* was encountered during the survey. Continuation of regular monitoring through crop surveys and surveillance is essential for the detection of *B. cockerelli* in the country and implementation of pest management strategies. Furthermore, awareness campaigns need to be intensified in order to alert the growers and other stakeholders to the potential invasion by this deleterious pest.

Chapter 4: GENERAL DISCUSSION

4.1 Introduction

Food availability and food security remains a challenge in South Africa, due to crop diseases and pests attacking crops thus, reducing food quality and quantity and causing economic losses. Insect pests pose a significant challenge to agriculture and are among the primary biotic agents responsible for crop losses. They harm plants not only through direct feeding but also by transmitting bacterial, viral, and fungal diseases (Amrani et al., 2023). Insect pests are responsible for reducing global agricultural yields by approximately 20–32%, both before and after harvest (Oberemok et al., 2023; Douglas, 2018). Insects belonging to the order Hemiptera feed on plant sap and the majority are phytophagous and affect a wide range of economically important crops. Among these, the most significant phytophagous species are found within the suborder Sternorrhyncha (Chougule & Bonning, 2012). Some species in the suborder Sternorrhyncha are serious agricultural pests worldwide as they act as vectors for numerous viral and bacterial plant diseases, leading to the weakening of host plants. They also produce honeydew, a sugary substance that promotes the growth of fungal infections (Oberemok et al., 2023).

Members of the Sternorrhyncha (Order: Hemiptera) group attack tomatoes *(Lycopersicon esculentum* Miller–Solanaceae) and potatoes (*Solanum tuberosum* L); vectoring diseases that lead to production losses. In this group, aphids are the most important pest of potatoes which pose negative impacts on yield through direct feeding, but their main economic impact is due to their ability to transmit viruses such as potato leaf roll virus (PLRV) and potato virus Y (PVY). Both aphids (Aphidoidea) and whiteflies (Aleyrodoidea) are important tomato pests, where whiteflies also transmit plant viruses such as tomato yellow leaf curl virus (TYLCV). Therefore, this thesis sought to map the prevalence of important Sternorryncha species with implications on disease vectoring in various potato and tomato producing areas across South Africa. To also determine the population dynamics and species diversity of aphids on potatoes in Christiana and Douglas and the potential outbreaks using a continuous monitoring approach (Chapter 2); and to conduct a survey for incursion by the invasive *Bactericera cockerelli* and prevalence of other Sternorryncha on Solanaceae plants in South Africa (Chapter 3).

4.2 Insect identification and molecular techniques

Morphological taxonomy faces several challenges that hinder accurate species identification and classification. High intraspecific variation often makes distinguishing species difficult (Sharma & Gupta, 2025), therefore integrating molecular techniques with morphological analysis improves the accuracy of taxonomic studies (Wang et al., 2016). In the current study, DNA extractions and sequencing were done on the specimens to confirm the morphological identifications, which confirmed that there were no cryptic species amongst the samples collected. In the current study a total of 8 species had no data on GenBank, therefore sequence submissions for these species were done, and these sequences will help researchers working on these species, they can also be used for reference and to eliminate duplications. Accurate identification of insect pests is the fundamental principle of pest management since they are a major factor in yield losses (Amarathunga et al., 2022). To predict and prevent pest outbreaks effectively, it is crucial to correctly and precisely identify the insect species involved (Mahalakshmi et al., 2024). This is important because different pests often require specific control strategies; for example, an insecticide effective against one species might be useless or even detrimental when used on another. Additionally, incorrect identification can result in the application of unsuitable control methods, potentially worsening the problem instead of resolving it as well as trade implications (Mahalakshmi et al., 2024). For this study, accurate identifications of the collected insects were essential to understand the diversity of insect species on solanaceae plants, and potential viruses they vector for better integrated pest management strategies; as well as possible implications the insect pests might have on the crop production and also for growers to know what occurs on their farms and apply proper and accurate control measures.

A study by Kim et al. (2022) in Korea was conducted to correct the misidentification of the yam borer. The species was first identified as *Digitivalva hemiglypha* (Diakonoff & Arita, 1976.) (Lepidoptera: Glyphipterigidae) but morphological and molecular analyses confirmed that *Digitivalva hemiglypha* were two different species; *Digitivalva hemiglypha* I and II that exhibit intraspecific genetic divergences within the same range similar to congerenic species. Their study confirmed that *Digitivalva hemiglypha* I is a correct species of *Digitivalva hemiglypha* and they listed *Digitivalva hemiglypha* II to be re-examined if it was a distinct species of *Digitivalva* or a different genus. A different study conducted by Normark et al. (2025) in South America sought to identify scale insect species that had been previously misidentified as *Diaspidiotus ancylus* Putnam (Hemiptera: Diaspididae). Their study used both molecular and morphological evidence and confirmed the insect as a different species, *Clavaspis patagonensis* Clasps & Wolff (Hemiptera: Diaspididae). Their study further explained that they thought and believed that the insect was an invasive population of a North American species while it is a native South American species and all this had implications on plant quarantine because even though C. *patagonensis* is not a major pest of any of its hosts plants, it does occur on the fruits subject to international trade while *D. ancylus* has not been considered a problem for plant quarantine. Therefore, correct species identification determines the appropriate management and phytosanitary responses to be applied on specific insects as this may have trade implications with export markets of agricultural produce.

4.3 Population dynamics of insect and vectors of PLRV and PVY abundances

In the current study, the species diversity between the two continuous monitoring sites showed a significant difference over the sampling period; however, no differences were observed between the two sites across each year indicating that the total number or variety of species changed between years, while species evenness and dominance were similar. Similar observations were made on the national survey where there were no differences in the species diversity, species evenness and species dominance. These findings concur with those of Vucetic et al. (2013), who discovered that different localities had similar diversity of aphid species and number of individuals. Their study was conducted on potatoes at twenty sites for four years thus further ascertaining their findings of similar diversities across the sites they studied. In contrast, a study by Rehman et al. (2019) that was conducted in North Kashmir on hoppers, discovered that species diversity, species evenness and species richness were different for the surveyed locations. Their study was conducted on seven different crops at various locations and that potentially influenced their results. Species diversity of insect communities is affected by a combination of geographical and environmental factors including vegetation, topography, altitude, climate, habitat and human influence. Since North Kashmir experiences temperate climate, which was variable across all studied locations potentially attributing the difference in species diversity to microclimate, even though spraying by farmers and different altitudes could have also influenced the populations (Rehman et al., 2019). Another factor could be, since the study was on different crops and some insect species were found on more than one crop that means there was more diversity of food materials and nutrient availability (Rehman et al., 2019).

However, in the current study, South Africa is semi-arid and experiences hot summers and cool, dry winters with different potato production locations experiencing different daily temperature. Despite this, the daily average temperatures are quite closer to each other and that could potentially influence the aphids to behave in a similar manner across different agricultural regions and since insects populations are also impacted by nutrient variables. For instance, they may become more herbivorous, consume more food, alter their diet, change their host, or be forced to migrate to a new flora (Khaliq et al., 2014), that could have influenced the species diversity since there was only one host which means somehow there was a limitation on food availability and nutrients availability.

During both the continuous monitoring and national survey, *Rhopalosiphum padi* and *Rhopalosiphum maidis* featured as the most abundant species in the areas sampled. This was similar to findings by Johansen et al., (2025) where *R. padi* was the most abundant species out of the ten most dominating species collected in their study in potato production areas in Norway. A different study conducted by Were et al., (2015), in Kenya on potatoes reported that the most abundant aphid species caught in the sampled potato growing areas was *R. maidis*, thus the current study reflects similar findings. However, an earlier study by Muthomi et al. (2009), also in Kenya on potatoes, found that the most abundant species were *Macrosiphum euphorbiae* and *Myzus persicae* in the potato fields in contrast to the results in the current study and those by Were et al. (2015). The study by Muthomi et al. (2009), was conducted in two growing regions while Were et al. (2015), was conducted in five different regions therefore, differences in aphid populations between the potato-growing regions may result from variations in surrounding vegetation and the types of other crops cultivated near the potato fields. Interestingly, a different study conducted by Sridhar et al., (2022), in India, revealed that *Myzus persicae* and *Aphis gossypii* were the most abundant species in the potato fields, supporting the findings by Muthomi et al. (2009). The differences between studies may therefore be a function of variable climatic or even geographic variation across the study sites as well as season. Environmental factors like temperature, precipitation, and host plant availability tend to influence aphid populations leading to seasonal peaks and declines which could explain the variation in the abundant species between these studies. Comparison of previous studies with the current study shows that the most abundant species reported across these studies are potential vectors of the two major potato viruses, PVY and PLRV. In the current study *R. padi* and *R. maidis* were the most abundant PVY vectors and these results were different from the study conducted by Sridhar et al. (2022), that revealed that the most dominant aphid vector was *M. persicae* for both PVY and PLRV. In the current study *M. persicae* was only the most abundant vector for PLRV which was similar to a study by

Machado-Assefh et al. (2023) that found *Myzus persicae*, *Macrosiphum euphorbiae* and *Aphis gossypii* as the most abundant vectors of PLRV, and this could be because *Myzus persicae* is the main carrier of PLRV (Eigenbrode et al., 2002).

While the continuous monitoring study (Chapter 2) focused on aphid species only, the national survey covered a broader spectrum with its focus on the entire Sternorryncha group and also considering the non-Sternorryncha by catches encountered in the field. During the national surveillance for *Bactericera cockerelli,* the pest was not detected but several other psyllid species that are not pests of solanaceae were collected. A project conducted by Wilson (2018), in Eastern States and South Australia on the surveillance of TPP had similar results where they did not encounter TPP but other psyllids that are not pests of solanaceae and anticipated that the absence of *B. cockerelli* in their survey may be attributed to both unfavourable climatic conditions and the implementation of effective phytosanitary measures that have limited its introduction. However, the first detection of *B. cockerelli* in Australia was reported in 2017 in Western Australia, the pest had been previously reported in Norfolk Island in 2024. In 2024, *B. cockerelli* was reported in Victoria near Portarlington, on the Bellarine Peninsula (EPPO, 2025). However, a larger region of South America together with most western and southern countries in South America are predicted to be climatically suitable for establishing TPP, mainly ranging from optimum to high climatic suitability (Suwandharathne et al., 2023). This result has positive implications for the potato and tomato industries in South Africa as they are currently safe from the new pest. This is especially significant because these two industries are currently suffering from serious pest infestations by *Phthorimaea absoluta* and the *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae).

None of the collected psyllid species in the current study are known to feed on solanaceous crops, however, it was confounding to find *Platycorypha nigrivirga* in high abundance on potatoes and tomatoes in three different study sites. This species is not a pest of solanaceae and is associated with the tipu tree. However, in the current study, the tipu trees were not found in the vicinity of the sampling sites in Limpopo while further ground truthing is needed in Gauteng where there are established stands of the tipu tree. Some species of *Diaphorina* were also collected during the survey, with *Diaphorina solani* associated with *Solanum incanum*, found in high numbers on several boxthorn (*Lycium* spp) species in the Cape Provinces and there was also a record of *D. solani* on potatoes in Gauteng. *Diaphorina petteyi* Capener (Hemiptera: Liviidae) was also collected on *Lycium* spp. in the Eastern Cape. The incidence of *D. solani* in low numbers from bucket traps needs further ground truthing done in to ascertain if the insect is potentially associated with crops in the Solanaceae family and not only the wild relatives. However, there is no known relationship between *P. nigrivirga* and *D. solani*, or associations with solanaceous crops and their ability to transmit Lso. These species were likely attracted to the yellow colour of the traps from surrounding vegetation and also possibly blown in by wind during the extreme weather events experienced in the sampling areas.

A study by Suwandharathne et al. (2023) listed southern Africa as a region suitable for TPP with optimum and moderate climate suitability categories. However, during the national survey only the con-generic species of the TPP, the *B. capensis* was collected on *Lycium cinereum* and there is no information about this species and any association with the solanaceae crops and its potential to become an important agricultural pest since *B. capensis* and *B. cockerelli* are in the same genera. A study conducted by Cooper et al. (2023) in Texas found another congeneric species of *B. cockerelli*, the *Bactericera dorsalis* Crawford (Hemiptera: Triozidae) from *Lycium carolinianum* and *Lycium berlandieri*. Their study also confirmed *B. dorsalis* to transmit Lso on *Lycium carolinianum*, however, in the current study the congeneric species was not tested for Lso. The two American congeneric species of TPP do not have any records of being pests of solanaceous crops, however; given that *B. cockerelli* is a major pest of tomatoes and potatoes these species may pose similar threats to solanaceous crops. Since *B. cockerelli* and *B. dorsalis* are vectors of Lso, any establishment of other *Bactericera* species in the South Africa could potentially result to an increase rate of the bacterial spread because there is evidence that any *Bactericera* species could potentially transmit Lso (Asenio-S.-Manzanera et al., 2022), and these pose a threat to potato and tomato production.

Whitefly species and non-Sternorryncha insects were also collected. The whitefly species *Bemisia tabaci*, is a very important pest of solanaceous crops, particularly tomatoes, causing serious economic losses. Although the whitefly was encountered in high numbers in the field, most of the farmers declared them to be of least concern due to chemical control. However, it was concerning to observe the high pesticidal applications which might influence whitefly pesticidal resistance. The whitefly abundances in the current study were similar to a study by Karaman et al. (2017), where they collected *B. tabaci* at Sohag region, Egypt on tomato, pepper and eggplant, crops similar to those sampled in the current study. In contrast, a study conducted by Kepngop et al. (2024), in Cameroon found three whitefly species on cassava and vegetables (tomatoes, pepper, and okra) were *B. tabaci*, *B. afer*, and *T. vaporariorum*. Although *B. afer* is not currently considered to be a significant threat to cassava production in

Africa, it has been shown to be an economically important viral vector in other crops, transmitting the sweet potato chlorotic stunt virus in sweet potatoes in Peru (Kepngop et al., 2024). In South Africa, Tomato chlorosis crinivirus (ToCV) transmitted by *B. tabaci* is the predominant whitefly virus affecting tomato crops and solanaceous weeds (Moodley et al., 2019).

4.4 Influence of environmental factors on insect populations

Abiotic factors are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal. Among the climatic factors, temperature is an important variable (Karuppaiah & Sujayanad, 2012). In the current study temperature and wind speed were the two weather parameters that had evident influence on the aphid populations. Temperature is a key factor influencing aphid population dynamics, as environmental conditions affect every aspect of aphid biology. The effects of temperature on aphid fitness are evident in their reproduction, development, survival, and overall population growth rate (Taylor et al., 2023). A study by Sampaio et al. (2017), reported that an increase in temperature favours an increase in aphid populations, similar to the results in the current study; higher temperatures had a positive effect on aphid abundance. A different study by Meinser et al. (2014), observed the same patterns of where higher temperature increased aphid developmental rates. In contrast, a study by Ma et al. (2013), revealed that high temperatures significantly reduced survival of aphids, which decreased generally as the temperature increased. Wind also plays a significant role in aphid population dynamics by aiding the migration of alate aphids from surrounding alternate hosts and infested crop fields to later-planted crops (Shonga & Getu, 2021). In the current study, low wind speeds led to lower aphid populations and a study by El Fakhouri et al. (2021), showed similar results of aphid populations significantly negatively correlated with wind speed. In contrast, a study conducted by Saxena et al. (2012), reported that wind speed did not affect the aphid population. These results were contrary to a study by Abbasi et al. (2019), where they observed a positive correlation between aphid populations and wind speed. They further reported that, wind speed played a positive role in fluctuating aphid density in their study. The environmental factors influenced the aphid populations quite differently, temperature increased the populations and the wind speeds decreased aphid populations that could potentially decrease the spread of virus in these crops. However, because of climate change the way these environmental factors affect insect populations can change and that could also influence the spread of viruses on the crops and lead to plant mortality and decreased production.

4.5 Conclusion

Insect pests cause serious damage on agricultural crops leading to decreased yields. Furthermore, a number of abiotic factors influence their behaviours with temperature being the most important factor. A comprehensive understanding of insect population dynamics in relation to both abiotic and biotic factors can enhance the development of effective pest management strategies. Monitoring insect populations is essential for effective management and control strategies (Wu et al., 2022). A number of approaches can be employed for these purposes, including physical surveys, insect trapping, molecular techniques, aerial observations, and remote sensing (Brockerhoff et al., 2023). The current study monitored Sternorryncha insects on solanaceous plants by means of a survey and using several trapping methods. The population dynamics of the insects was influenced by abiotic factors and the most important factor was temperature. During the survey several insect species belong to the sternorryncha group were collected, however the targeted invasive psyllids, *Bactericera cockerelli* was not encountered and this means that South Africa is currently free from the devastating invasive insect. The South African Department of Agriculture should continue protecting the agricultural industry by maintaining the phytosanitary regulations to prevent entry of TPP into the country. *Bactericera capensis* was collected and this was not a first report of this species, however there is no documented relationship of this insect with the agricultural solanaceous crops (even though it was hosted by a non-crop solanaceae, *Lycium cinereum*) and its ability of becoming a threat to the tomato and potato production. Therefore, these results suggest a need for future studies related to the biology of *Bactericera capensis* and investigate whether the insect can transmit Lso on *Lycium cinereum*, *L. salinicola*, *L. tetrandrum* and solanaceae crops. Furthermore, more continuous surveillance for *B. cockerelli* should be conducted to identify any incursions of *B. cockerelli* in the country for the convenience of implementing rapid control and management strategies.

REFERENCES

Abbasi, Z., Sultana, R., Wagan, M.S. and Soomro, F., 2019. Population, fluctuation of aphid on the different wheat varieties from Larkana District. *Sindh University Research Journal* Science Series, 411–418, doi:10.26692/sujo/2019.03.66, 1813-1743, 51, (3).

Abdalla, O.A., Eraky, A.I., Mohamed, S.A. and Fahmy, F.G., 2018. Management of Potato virus Y (PVY–NTN) causing potato tuber necrotic ringspot disease (PTNRD) in potato by prior treatment with a mild PVY strain. *Journal of Plant Protection Research*, *58*(2).

Abram, P.K., Franklin, M.T., Brodeur, J., Cory, J.S., McConkey, A., Wyckhuys, K.A. and Heimpel, G.E., 2024. Weighing consequences of action and inaction in invasive insect management. *One Earth*, 7(5), pp.782-793.

Agritask, 2020. Monitoring invasive pest species in Kenya on a regional scale.

Ahmad, T., Muhammad, W.H., Jamil, M. and Iqbal, J., 2016. Population dynamics of aphids (Hemiptera: Aphididae) on wheat varieties (*Triticum aestivum* L.) as affected by abiotic conditions in Bahawalpur, Pakistan. *Pakistan Journal of Zoology*, 48(4).

Ali, J., 2023. The peach potato aphid (*Myzus persicae*): ecology and management. CRC Press. https://doi.org/10.1201/9781003400974.

Al-Saadi, S.A.M., Al-wheeb, A.N. and Al-Taie, S.S.K., 2020. Phylogenetic relationship among some species of Solanaceae in Iraq. EurAsian *Journal of BioSciences*, 14(1), pp.2391-2394.

Alvarez, A.E., Garzo, E., Verbeek, M., Vosman, B., Dicke, M. and Tjallingii, W.F., 2007. Infection of potato plants with potato leafroll virus changes attraction and feeding behaviour of *Myzus persicae*. *Entomologia Experimentalis et Applicata*, 125(2), pp.135-144.

Amarathunga, D.C., Ratnayake, M.N., Grundy, J. and Dorin, A., 2022. Fine-grained image classification of microscopic insect pest species: Western Flower thrips and Plague thrips. *Computers and Electronics in Agriculture*, 203, p.107462.

Amin, H.A., El Kammar, H.F., Saied, S.M. and Soliman, A.M., 2023. Effect of Bacillus subtilis on potato virus Y (PVY) disease resistance and growth promotion in potato plants. *European Journal of Plant Pathology*, *167*(4), pp.743-758.

Amrani, A., Sohel, F., Diepeveen, D., Murray, D. and Jones, M.G., 2023. Deep learning-based detection of aphid colonies on plants from a reconstructed Brassica image dataset. *Computers and electronics in agriculture*, *205*, p.107587.

Antolínez, C.A., Martini, X., Stelinski, L.L. and Rivera, M.J., 2022. Wind speed and direction drive assisted dispersal of Asian citrus psyllid. *Environmental Entomology*, 51(2), pp.305-312.

Antolínez, C.A., Moreno, A., Ontiveros, I., Pla, S., Plaza, M., Sanjuan, S., Palomo, J.L., Sjölund, M.J., Sumner-Kalkun, J.C., Arnsdorf, Y.M. and Jeffries, C.J., 2019. Seasonal abundance of psyllid species on carrots and potato crops in Spain. Insects, 10(9), p.287.

Antolínez, C.A., Youngblood, R., Kenney, J.R., Gebiola, M., Mauck, K.E. and Rivera, M.J., 2023. Flight performance of the potato psyllid (Bactericera cockerelli) is negatively affected by 'Candidatus Liberibacter solanacearum'infection. *Journal of Insect Behavior*, 36(1), pp.59-67.

Arun, P.R. and Vijayan, V.S., 2004. Patterns in abundance and seasonality of insects in the Siruvani forest of western Ghats, Nilgiri Biosphere Reserve, southern India. *The Scientific World Journal*, 4, pp.381-392.

Ascolese, R., Gargiulo, S., Pace, R., Nappa, P., Griffo, R., Nugnes, F. and Bernardo, U., 2022. E-traps: A valuable monitoring tool to be improved. EPPO Bulletin, 52(1), pp.175-184.

Asensio-S.-Manzanera, M.C., Santiago-Calvo, Y., Palomo-Gómez, J.L., Marquínez-Ramírez, R., Bastin, S., García-Méndez, E.M., Hernández-Suárez, E. and Siverio-de-la-Rosa, F., 2022. Survey of Candidatus Liberibacter solanacearum and its associated vectors in potato crop in Spain. *Insects*, 13(10), p.964.

Asin, L. and Pons, X., 2001. Effect of high temperature on the growth and reproduction of corn aphids (Homoptera: Aphididae) and implications for their population dynamics on the northeastern Iberian peninsula. *Environmental Entomology*, *30*(6), pp.1127-1134.

Avolio, M.L., Forrestel, E.J., Chang, C.C., La Pierre, K.J., Burghardt, K.T. and Smith, M.D., 2019. Demystifying dominant species. *New Phytologist*, *223*(3), pp.1106-1126.

Bandyan, S.K., Peters, R.S., Kadir, N.B., Ferrer-Suay, M. and Kirchner, W.H., 2021. A survey of aphid parasitoids and hyperparasitoids (Hymenoptera) on six crops in the Kurdistan Region of Iraq. *Journal of Hymenoptera Research*, *81*, pp.9-21.

Barnes, A.M., Taylor, N.M. and Vereijssen, J., 2015. Non-crop host plants: prime real estate for the tomato potato psyllid in New Zealand. *New Zealand Plant Protection*, 68, p.441.

Barzman, M., Bàrberi, P., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Hommel, B., Jensen, J.E., Kiss, J., Kudsk, P. and Lamichhane, J.R., 2015. Eight principles of integrated pest management. *Agronomy for sustainable development*, *35*, pp.1199-1215.

Beetge, L. and Krüger, K., 2019. Drought and heat waves associated with climate change affect performance of the potato aphid Macrosiphum euphorbiae. *Scientific reports*, *9*(1), p.3645.

Böckmann, E., Hommes, M. and Meyhöfer, R., 2015. Yellow traps reloaded: what is the benefit for decision making in practice. *Journal of pest science*, 88, pp.439-449.

Borisade, O.A., 2015. Rearing tomato whitefly and field evaluation of modified and unmodified conidia of Beauveria bassiana, Isaria farinosa, Metarhizium anisopliae and low rates of chlorpyrifos under tropical conditions. *African Crop Science Journal*, 23(2), pp.177-195.

Boukhris-Bouhachem, S., Souissi, R., Turpeau, E., Rouzé-Jouan, J., Fahem, M., Brahim, N.B. and Hulle, M., 2007, January. Aphid (Hemiptera: Aphidoidea) diversity in Tunisia in relation to seed potato production. In *Annales de la Société Entomologique de France*. Vol. 43, No. 3, pp. 311-318.

Bowers, J.H., Malayer, J.R., Martínez-López, B., LaForest, J., Bargeron, C.T., Neeley, A.D., Coop, L.B., Barker, B.S., Mastin, A.J., Parnell, S.R. and Cossé, A.A., 2022. Surveillance for early detection of high consequence pests and pathogens. In *Tactical sciences for biosecurity in animal and plant systems*. pp. 120-177.

Brabec, M., Honěk, A., Pekár, S. and Martinková, Z., 2014. Population dynamics of aphids on cereals: digging in the time-series data to reveal population regulation caused by temperature. *PloS one*, *9*(9), p.e106228.

Bradeen, J.M., Haynes, K.G. and Kole, C., 2011. Introduction to potato. Genetics, genomics and breeding of potato, pp.1-19.

Brockerhoff, E.G., Corley, J.C., Jactel, H., Miller, D.R., Rabaglia, R.J., Sweeney, J., Allison, J.D., Paine, T.D., Slippers, B. and Wingfield, M.J., 2023. Monitoring and surveillance of forest insects. *Forest entomology and pathology*, 1, pp.669-705.

Burckhardt, D. (2022) Identification key to genera of Psylloidea (Insecta, Hemiptera) from the Afrotropical region. *Unpublished key*.

Cameron, P.J., Wigley, P.J., Charuchinda, B., Walker, G.P. and Wallace, A.R., 2013. Farm-scale dispersal of *Bactericera cockerelli* in potato crops measured using Bt mark-capture techniques. *Entomologia Experimentalis et Applicata*, 148(2), pp.161-171.

Campos, H. and Ortiz, O., 2020. The potato crop: its agricultural, nutritional and social contribution to humankind. *Springer Nature*. p. 518.

Cao, J.Y., Xing, K., Liu, H.P. and Zhao, F., 2018. Effects of developmental acclimation on fitness costs differ between two aphid species. *Journal of Thermal Biology*, *78*, pp.58-64.

Cao, X., Huang, M., Wang, S., Li, T. and Huang, Y., 2024. Tomato yellow leaf curl virus: Characteristics, influence, and regulation mechanism. *Plant Physiology and Biochemistry*, 213, p.108812.

Capener, A.L. (1973) Southern African Psyllidae (Homoptera)-3: A new genus and new species of South African Psyllidae. *Journal of the Entomological Society of Southern Africa*, 36, 37–61.

Capener, A.L., 1970. Southern African Psyllidae (Homoptera)-I: A check list of species recorded from South Africa, with notes on the Pettey collection. *Journal of the Entomological Society of Southern Africa*, *33*(2), pp.195-200.

Capinera, J.L., 2001. Green peach aphid, *Myzus persicae* (Sulzer) (Insecta: Hemiptera: Aphididae). Panama City, FL, USA: University of Florida Cooperative Extension Service, *Institute of Food and Agricultural Sciences*, EDIS.

Caruso, A.G., Bertacca, S., Parrella, G., Rizzo, R., Davino, S. and Panno, S., 2022. Tomato brown rugose fruit virus: A pathogen that is changing the tomato production worldwide. *Annals of Applied Biology*, 181(3), pp.258-274.

Castillo Carrillo, C., Fu, Z. and Burckhardt, D., 2019. First record of the tomato potato psyllid *Bactericera cockerelli* from South America. *Bulletin of Insectology*, 72(1).

Chandel, R.S., Vashisth, S., Soni, S., Kumar, R. and Kumar, V., 2020. The potato tuber moth, *Phthorimaea operculella* (Zeller), in India: biology, ecology, and control. *Potato research*, 63, pp.15-39.

Chandrasekara, A. and Kumar, J. T., 2016. Roots and tuber crops as functional foods: a review on phytochemical constituents and their potential health benefits. *International journal of food science*.

Chen, Y., 2019. *Phenotypic plasticity of corn leaf aphid Rhopalosiphum maidis under elevated temperature and CO2*. Universite de Liege (Belgium).

Chesnais, Q., Golyaev, V., Velt, A., Rustenholz, C., Verdier, M., Brault, V., Pooggin, M.M. and Drucker, M., 2022. Transcriptome responses of the aphid vector *Myzus persicae* are shaped by identities of the host plant and the virus. *Peer Community Journal*, 2.

Chougule, N.P. and Bonning, B.C., 2012. Toxins for transgenic resistance to hemipteran pests. *Toxins*, *4*(6), pp.405-429.

Connor, S.E., Colombaroli, D., Confortini, F., Gobet, E., Ilyashuk, B.P., Ilyashuk, E.A., van Leeuwen, J.F., Lamentowicz, M., van der Knaap, W.O., Malysheva, E. and Marchetto, A., 2018. Long-term population dynamics: Theory and reality in a peatland ecosystem. *Journal of Ecology*, 106(1), pp.333-346.

Cooper, W.R., Esparza-Diaz, G., Wildung, M.R., Horton, D.R., Badillo-Vargas, I.E. and Halbert, S.E., 2023. Association of two Bactericera species (Hemiptera: Triozidae) with native Lycium spp. (Solanales: Solanaceae) in the potato growing regions of the Rio Grande Valley of Texas. *Environmental Entomology*, *52*(1), pp.98-107.

Cooperation AP. APEC, 2007. Agricultural Technical Cooperation Working Group.

Das, S., Tejani, D.N., Patel, J.C., Desai, A.G., Desai, A.I. and Gangwar, G.P., 2019. Effect of weather parameters on population dynamics of mustard aphid. *International Journal of Current Microbiology and Applied Science*, *8*(04), pp.1648-1653.

Davis, J.A., Radcliffe, E.B. and Ragsdale, D.W., 2006. Effects of high and fluctuating temperatures on *Myzus persicae* (Hemiptera: Aphididae). *Environmental Entomology*, 35(6), pp.1461-1468.

De Oliveira, S.J., Silva, J.R., Franchini, G., Yasmin, E.I., & Fernandes, A. (2023). Monitoring of insect pests in integrated pest management. *Agricultural Entomology*.

De Souza, M.A., Armstrong, J.S., Hoback, W.W., Mulder, P.G., Paudyal, S., Foster, J.E., Payton, M.E. and Akosa, J., 2019. Temperature dependent development of sugarcane aphids

Melanaphis Sacchari,(Hemiptera: Aphididae) on three different host plants with estimates of the lower and upper threshold for fecundity.

Del Pino, M., Rodríguez, M.D.C., Boyero, J.R. and Vela, J.M., 2023. Predatory arthropods associated with the invasive Tipu psyllid, *Platycorypha nigrivirga*, in southern Spain. *Neotropical Entomology*, 52(4), pp.750-759.

Department of Agriculture, Forestry & Fisheries (DAFF), 2010. Fruit vegetables.

Department of Agriculture, Land Reform and Rural Development (DALRRD), 2018. Aphid monitoring on Cedara.

Department of Agriculture, Land Reform and Rural Development (DALRRD) (2020). A profile of the South African tomato market value chain.

Diamond, J., 1988. Factors controlling species diversity: overview and synthesis. *Annals of the Missouri botanical Garden*, pp.117-129.

Dixon, Anthony. (2003). Aphid Ecology: Life Cycles, Polymorphism, and Population Regulation. *Annual Review of Ecology and Systematics*. 8. 329-353. 10.1146/annurev.es.08.110177.001553.

Douglas, A.E., 2018. Strategies for enhanced crop resistance to insect pests. *Annual review of plant biology*, *69*, pp.637-660.

Dugravot, S., Brunissen, L., Létocart, E., Tjallingii, W.F., Vincent, C., Giordanengo, P. and Cherqui, A., 2007. Local and systemic responses induced by aphids in Solanum tuberosum plants. *Entomologia Experimentalis et Applicata*, *123*(3), pp.271-277.

EFSA Panel on Plant Health (EFSA PLH Panel), Jeger, M., Bragard, C., Caffier, D., Candresse, T., Chatzivassiliou, E., Dehnen‐Schmutz, K., Gilioli, G., Grégoire, J.C., Jaques Miret, J.A. and Navarro, M.N., 2018. Pest risk assessment of *Spodoptera frugiperda* for the European Union. *EFSA Journal*, 16(8), p.e05351.

Ehi-Eromosele, C.O., Nwinyi, O.C. and Ajani, O.O., 2013. Integrated pest management. In Weed and pest control-conventional and new challenges. *IntechOpen*.

Eigenbrode, S.D., Ding, H., Shiel, P. and Berger, P.H., 2002. Volatiles from potato plants infected with potato leafroll virus attract and arrest the virus vector, *Myzus persicae* (Homoptera: Aphididae). Proceedings of the Royal Society of London. Series B: *Biological Sciences*, 269(1490), pp.455-460.

El Fakhouri, K., Sabraoui, A., Kehel, Z. and El Bouhssini, M., 2021. Population dynamics and yield loss assessment for pea aphid, Acyrthosiphon pisum (Harris) (Homoptera: Aphididae), on lentil in Morocco. *Insects*, *12*(12), p.1080.

European and Mediterranean Plant Protection Organization (EPPO), 2025. EPPO Global Database. Available online: https://gd.eppo.int.

European Food Safety Authority (EFSA), Loiseau, M., Schrader, G., Camilleri, M., Diakaki, M. and Vos, S., 2019. Pest survey card on *Candidatus* Liberibacter solanacearum. *EFSA Supporting Publications*, 16 (6), p.1632E.

Fathi, S.A.A., 2011. Population density and life-history parameters of the psyllid *Bactericera nigricornis* (Forster) on four commercial cultivars of potato. *Crop Protection*, 30(7), pp.844-848.

Fernandes, F.S., Godoy, W.A.C., Ramalho, F.S., Garcia, A.G., Malaquias, J.B. and Santos, B.D., 2018. Population dynamics of Aphis gossypii Glover and Aphis craccivora Koch (Hemiptera: Heteroptera: Aphididae) in sole and intercropping systems of cotton and cowpea. *Anais da Academia Brasileira de Ciências*, *90*(1), pp.311-323.

Finch, S. and Collier, R. h. (2000) "Host-plant selection by insects – a theory based on 'appropriate/inappropriate landings' by pest insects of cruciferous plants," *Entomologia Experimentalis et Applicata*, 96(2), pp. 91–102. Available at: https://doi.org/10.1046/j.1570-7458.2000.00684.x.

Follman, T.J., Valls, A., Kral-O'Brien, K.C. and Harmon, J.P., 2019. Mechanical stimulation from plant contact and wind negatively impact pea aphids (Hemiptera: Aphididae) indirectly through host plants. *The Canadian Entomologist*, *151*(6), pp.768-776.

Folmer O., Black M., Hoeh W. DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. Mol. Marine Biol. Biotechnol. 1994;3:294–299.

Food and Agriculture Organization (FAO), 2017. Crop yield response to water. FAO irrigation and drainage paper.

Food and Agriculture Organization (FAO), 2023. FAO launches project to curb spread of African armyworm in eastern Africa.

Food and Agriculture Organization (FAO). 2022. The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO. https://doi.org/10.4060/cc0639en.

Franke, A.C., Steyn, J.M., Ranger, K.S. and Haverkort, A.J., 2011. Developing environmental principles, criteria, indicators and norms for potato production in South Africa through field surveys and modelling. *Agricultural systems*, 104(4), pp.297-306.

Giordanengo, P., Vincent, C. and Alyokhin, A., 2013. Insect pests of potato. *Glob. Perspect. Biol. Manag. Elsevier Inc Wyman Str. Walth. USA*.

Giovannucci, E., Rimm, E.B., Liu, Y., Stampfer, M.J. and Willett, W.C., 2002. A prospective study of tomato products, lycopene, and prostate cancer risk. *Journal-National Cancer Institute*, 94(5), pp.391-398.

Gong, P., Li, X., Wang, C., Zhu, S., Li, Q., Zhang, Y., Li, X., Li, G., Liu, E., Gao, H. and Yang, X., 2021. The sensitivity of field populations of *Metopolophium dirhodum* (Walker) (Hemiptera: Aphididae) to seven insecticides in Northern China. *Agronomy*, *11*(8), p.1556.

Gray, S.M. and Banerjee, N., 1999. Mechanisms of arthropod transmission of plant and animal viruses. *Microbiology and molecular biology reviews*, *63*(1), pp.128-148.

Gregersen, F. and Gregersen, H., 2009. Ongoing population decline and range contraction in Norwegian forest grouse. *Ornis Norvegica*, 32, pp.179-189.

Halbert, S.E. and Munyaneza, J.E., 2012. Potato psyllids and associated pathogens: a diagnostic aid. Florida State Collection of Arthropods.

Hall, D.G., 2008, May. Biology, history and world status of *Diaphorina citri*. In Proceedings of the International Workshop on Huanglongbing and Asian Citrus Psyllid (Vol. 8, pp. 1-11).

Hall, D.G., Richardson, M.L., Ammar, E.D. and Halbert, S.E., 2013. Asian citrus psyllid, D iaphorina citri, vector of citrus huanglongbing disease. *Entomologia Experimentalis et Applicata*, *146*(2), pp.207-223.

Hamilton, A.J., 2005. Species diversity or biodiversity. *Journal of Environmental Management,* 75(1), pp.89-92.

Hastings, A. (2013) Population Biology: Concepts and Models. *Springer Science & Business Media.*

Haubrock, P.J., Cuthbert, R.N., Hudgins, E.J., Crystal-Ornelas, R., Kourantidou, M., Moodley, D., Liu, C., Turbelin, A.J., Leroy, B. and Courchamp, F., 2022. Geographic and taxonomic trends of rising biological invasion costs. *Science of the Total Environment*, 817, p.152948.

Hein, G.L., 1992. Influence of plant growth stage on Russian wheat aphid, *Diuraphis noxia* (Homoptera: Aphididae), reproduction and damage symptom expression. *Journal of the Kansas Entomological Society*, pp.369-376.

Herrmann, B., Cerbule, K., Brčić, J., Grimaldo, E., Geoffroy, M., Daase, M. and Berge, J., 2022. Accounting for uncertainties in biodiversity estimations: A new methodology and its application to the mesopelagic sound scattering layer of the high Arctic. *Frontiers in ecology and evolution*, *10*, p.775759.

Hodkinson, I.D., 2009. Life cycle variation and adaptation in jumping plant lice (Insecta: Hemiptera: Psylloidea): a global synthesis. *Journal of Natural History*, 43(1-2), pp.65-179.

Hollis D. 1984 - Afrotropical jumping plant lice of the family Triozidae. *Bulletin of the British Museum (Natural History) Entomology* 49: 1-102 [55].

Hollis, D., 2004. Australian psylloidea: Jumping plantlice and lerp insects. Australian Government, Department of Environment and Heritage, Canberra.

Inak, A., Demirci, B., Erdem, E., Randa-Zelyüt, F., Karanfil, A., Idan, A.Y., Toprak, U., Inak, E. and Van Leeuwen, T., 2025. Insecticide resistance status and vector potential of *Bemisia tabaci* populations on vegetable crops in Türkiye. *Crop Protection*, 190, p.107097.

Janion-Scheepers, C. and Griffiths, C.L., 2020. Alien terrestrial invertebrates in South Africa. *Biological Invasions in South Africa*, 14, pp.185-205.

Jaouannet, M., Rodriguez, P.A., Thorpe, P., Lenoir, C.J., MacLeod, R., Escudero-Martinez, C. and Bos, J.I., 2014. Plant immunity in plant–aphid interactions. *Frontiers in plant science*, *5*, p.663.

Jiang, W., Cheng, Q., Lu, C., Chen, W., Zhao, D. and He, Y., 2022. Different host plants distinctly influence the adaptability of *Myzus persicae* (Hemiptera: Aphididae). *Agriculture*, *12*(12), p.2162.

Johansen, N.S., Eiken, H.G., Rossmann, S.L., Brurberg, M.B., Skogen, M., Fajardo, M.B., Glorvigen, B., Eklo, T.S., Haugen, F.A., Hagen, S. and Lysøe, E., 2025. Aphid populations and virus vector potential in potato fields across seasons and regions in Norway. *Scientific Reports*, *15*(1), p.36675.

Jovičić, I.S., Vujadinović, M.P., Vuković, A.J., Radonjić, A. and Petrović-Obradović, O.T., 2022. Effects of temperature on *Acyrthosiphon pisum* and *Therioaphis trifolii* (Hemiptera: Aphididae) abundance in alfalfa crops: A case study in northern Serbia. *Journal of Agricultural Sciences (Belgrade)*, *67*(3), pp.269-283.

Juliano, S.A., 2007. Population dynamics. *Journal of the American Mosquito Control Association*, 23 sp 2: 265-275.

Kalaris, T., Fieselmann, D., Magarey, R., Colunga-Garcia, M., Roda, A., Hardie, D., Cogger, N., Hammond, N., Martin, P.T. and Whittle, P., 2013. The role of surveillance methods and technologies in plant biosecurity. In The handbook of plant biosecurity: Principles and practices for the identification, containment and control of organisms that threaten agriculture and the environment globally. Dordrecht: *Springer Netherlands.* pp. 309-337.

Kammara, M., Japa Sowjanya, A.K., Mishra, R. and Mohan, M., 2023. Insect Traps: A Useful Tool in Integrated Pest Management. *Emerging Trends in Entomology*, p.167.

Karaman, G.A., Hamouda, S.H., Salem Hoda, A. and Mosalam, A., 2017. Survey of certain arthropods associated with some solanaceous vegetable crops at Sohag region. *Minia J. Agric. Res. & Develop*, *37*(1), pp.25-34.

Karuppaiah, V. and Sujayanad, G.K., 2012. Impact of climate change on population dynamics of insect pests. *World Journal of Agricultural Sciences*, 8(3), pp.240-246.

Kepngop, L.R., Wosula, E.N., Amour, M., Ghomsi, P.G., Wakam, L.N., Kansci, G. and Legg, J.P., 2024. Genetic diversity of whiteflies colonizing crops and their associated endosymbionts in three agroecological zones of Cameroon. *Insects*, *15*(9), p.657.

Khalid, L., Aslam, A., Aslam, M., Ateel, S.A. and Hanif, M.B., Comparative efficacy of Botanical extracts against Whitefly (*Bemisia tabbaci*) on Cotton crop under climate change scenario. *Global Scientific And Academic Research of Multidisplinery Studies*. 3(9), pp38-42.

Khaliq, A.M., Javed, M., Sohail, M. and Sagheer, M., 2014. Environmental effects on insects and their population dynamics. *Journal of Entomology and Zoology studies*, 2(2), pp.1-7.

Kiester, A. R. (2013). Species Diversity, Overview. *Encyclopedia of Biodiversity*, 706–714. doi:10.1016/b978-0-12-384719-5.00133-7.

Kim, S., Yagi, S., Park, D., Xinyu, Z., Hirowatari, T. and Lee, S., 2022. Integrated data lead to correct identification: the case of yam insect pest, *Digitivalva hemiglypha* (Lepidoptera: Glyphipterigidae: Acrolepiinae). *Journal of Asia-Pacific Biodiversity*, 15(4), pp.587-597.

Kindlmann, P. and Dixon, A.F., 2010. Modelling population dynamics of aphids and their natural enemies. *Aphid biodiversity under environmental change: patterns and processes*, pp.1-20.

Krause-Sakate, R., Watanabe, L.F.M., Gorayeb, E.S., da Silva, F.B., Alvarez, D.D.L., Bello, V.H., Nogueira, A.M., de Marchi, B.R., Vicentin, E., Ribeiro-Junior, M.R. and Marubayashi, J.M., 2020. Population dynamics of whiteflies and associated viruses in South America: Research progress and perspectives. *Insects*, *11*(12), p.847.

Krijger, K. and Waals, J.E., 2020. Potato virus Y and Potato leafroll virus management under climate change in sub-Saharan Africa. *South African Journal of Science*, *116*(11-12), pp.1-7.

Kroschel, J., Mujica, N., Okonya, J. and Alyokhin, A., 2020. Insect pests affecting potatoes in tropical, subtropical, and temperate regions. The potato crop: Its agricultural, nutritional and social contribution to humankind, pp.251-306.

Kruger, K., Laubscher, M.L., Miller, I. Miller, I. Prinsloo, G., and Synman, J., 2018. Aphid monitoring in seed potato production regions (July 2014-Jun 2017).

Kumar, S., 2019. Aphid-plant interactions: implications for pest management. In *Plant Communities and Their Environment*. IntechOpen. Available at: http;//dx.doi.org/10.5772/intechopen.84302.

Leite, G.L.D., Picanço, M., Jham, G.N. and Moreira, M.D., 2005. Whitefly population dynamics in okra plantations. *Pesquisa Agropecuária Brasileira*, *40*, pp.19-25.

Leong, S.S., Leong, S.C. and Beattie, G.A., 2022. Integrated pest management strategies for Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) and huanglongbing in citrus for Sarawak, East Malaysia, Borneo. *Insects*, 13(10), p.960.

Leybourne, D.J., Whitehead, M.A. and Will, T., 2024. Genetic diversity in vector populations influences the transmission efficiency of an important plant virus. *Biology letters*, *20*(5), p.20240095.

Li, Q., Ji, Y., Du, H., Ma, S., Zhu, J., Zhu, D., Belyakova, N.A., Zhang, Y. and Yang, X., 2025. Insecticide Resistance and Plant Virus Status of *Bemisia tabaci* on Soybean in Suzhou. *Agriculture*, 15(10), p.1071.

Li, Y., Mbata, G.N., Punnuri, S., Simmons, A.M. and Shapiro-Ilan, D.I., 2021. *Bemisia tabaci* on vegetables in the Southern United States: incidence, impact, and management. *Insects*, 12(3), p.198.

Lim, T.K., 2012. Edible medicinal and non-medicinal plants (Vol. 1, pp. 285-292). Dordrecht, The Netherlands: *Springer*.

Liu, J. and Wang, X., 2020. Tomato diseases and pests detection based on improved Yolo V3 convolutional neural network. *Frontiers in plant science*, 11, p.521544.

Liu, J., Tallat, M., Wang, G., Li, G., Zhang, H., Wu, X., Qiao, H., Zhao, X. and Feng, H., 2024. The utility of visual and olfactory maize leaf cues in host finding by adult *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Plants*, 13(23), p.3300.

Loebenstein, G. 2008. Plant Virus Diseases: Economic Aspects, *Encyclopedia of Virology* (Third Edition).

Loebenstein, G., 2001. Potato leafroll virus (PLRV; Genus Polerovirus; Family Luteoviridae). In *Virus and virus-like diseases of potatoes and production of seed-potatoes* (pp. 69-75). Dordrecht: Springer Netherlands.

London, H., Saville, D.J., Davidson, M.M., Olaniyan, O. and Wratten, S.D., 2022. The ecological fitness of the tomato potato psyllid after transferring from non-crop host plants to tomato and potato. *Plos one*, *17*(4), p.e0266274.

Lu, Y. and Wu, K., 2011. Effect of relative humidity on population growth of Apolygus lucorum (Heteroptera: Miridae). *Applied Entomology and Zoology*, *46*(3), pp.421-427.

MA, C.S., Hau, B. and Poehling, H.M., 2013. The effect of heat stress on the survival of the rose grain aphid, *Metopolophium dirhodum* (Hemiptera: Aphididae). *EJE*, *101*(2), pp.327-331.

Macaulay, E.D.M., Tatchell, G.M. and Taylor, L.R., 1988. The Rothamsted Insect Survey '12-metre'suction trap. *Bulletin of Entomological Research*, *78*(1), pp.121-128.

Machado-Assefh, C.R., Said-Adamo, M.D.M., Cortéz, S.D., Gialdi, A.I.L., Isasmendi, G.L., Ortego, J. and Alvarez, A.E., 2023. Newly recorded plant-aphid associations: Implications for PLRV and PVY control in potato crops. *Crop protection*, *167*, p.106202.

Mahalakshmi, K., Charumathi, M., Prasath, A.G., Rukmani, N. and Venkatesh, T., 2024. Insect Pests: Identification, Behaviour and Management. Elite Publishing House. First Edition 2024 ISBN: 978-93-58991-55-0.

Mahmoud, M.E., Mohammed, E.S., Mohamed, S.A., Khamis, F.M. and Ekesi, S., 2020. Development and implementation of a sustainable IPM and surveillance program for the invasive tomato leafminer, *Tuta Absoluta* (Meyrick) in Sudan. *Athens Journal of Sciences*, 7(3), pp.159-174.

Makunde, P.T., Joubert, J.C., Slippers, B., Hurley, B.P. and Hammerbacher, A., 2023. Leaf surface traits may influence host specificity in psyllids of Eucalyptus, *Spondyliaspis cf. plicatuloides* (Froggatt) and *Glycaspis brimblecombei* Moore (Hemiptera: Aphalaridae). *Chemoecology*, 33(3), pp.83-98.

Mandizvidza, K., 2017. Analyzing marketing margins and the direction of price flow in the tomato value chain of Limpopo Province, South Africa. *International Journal of Environmental & Agriculture Research* (IJOEAR), 3(3), pp.72-82.

Medlock, J., Balenghien, T., Alten, B., Versteirt, V. and Schaffner, F., 2018. Field sampling methods for mosquitoes, sandflies, biting midges and ticks: VectorNet project 2014-2018. *EFSA Supporting Publications,* 15(6), p.1435E.

Meisner, M.H., Harmon, J.P. and Ives, A.R., 2014. Temperature effects on long-term population dynamics in a parasitoid–host system. *Ecological Monographs*, *84*(3), pp.457-476.

Millar, I.M. (1990). The aphids (Homoptera: Aphidoidea) of South Africa : an identification guide / I.

Miranda, M.P., Dos Santos, F.L., Bassanezi, R.B., Montesino, L.H., Barbosa, J.C. and Sétamou, M., 2018. Monitoring methods for *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) on citrus groves with different insecticide application programmes. *Journal of Applied Entomology*, 142(1-2), pp.89-96.

Moawad, G.M. and Gerling, D., 2000. Dynamics of whiteflies and their enemies in cotton fields: Implications for pest management. In *Proceedings of the World Cotton Conference*, (Vol. 2, pp. 6-12).

Moir, M., Croeser, L., Telfer, D., Fenner, C. and McCauley, R., 2021. Optimizing efficiencies in biosecurity surveillance and monitoring: testing colour and multi-lure traps on tomato potato psyllid, other plant-lice (Psylloidea) and stinkbugs (Pentatomoidea). *Research Square*. Available at: https://doi.org/10.21203/rs.3.rs-853713/v1.

Møller, A.P. (2013) Long-term trends in wind speed, insect abundance and ecology of an insectivorous bird, *Ecosphere*, 4(1), p. art6. Available at: https://doi.org/10.1890/ES12-00310.1.

Mondal, S., Wenninger, E.J., Hutchinson, P.J., Weibe, M.A., Eigenbrode, S.D. and Bosque-Pérez, N.A., 2016. Contribution of noncolonizing aphids to Potato virus Y prevalence in potato in Idaho. *Environmental Entomology*, *45*(6), pp.1445-1462.

Montgomery, G.A., Belitz, M.W., Guralnick, R.P. and Tingley, M.W., 2021. Standards and best practices for monitoring and benchmarking insects. *Frontiers in Ecology and Evolution*, 8, p.513.

Monzó, C., Arevalo, H.A., Jones, M.M., Vanaclocha, P., Croxton, S.D., Qureshi, J.A. and Stansly, P.A., 2015. Sampling methods for detection and monitoring of the Asian citrus psyllid (Hemiptera: Psyllidae). *Environmental Entomology*, 44(3), pp.780-788.

Moodley, V., Gubba, A. and Mafongoya, P.L., 2019. A survey of whitefly-transmitted viruses on tomato crops in South Africa. *Crop protection*, 123, pp.21-29.

Moore, J.C., 2013. Diversity, Taxonomic versus Functional. Colorado State University, Fort Collins, CO, USA. 10.1016/B978-0-12-384719-5.00036-8.

Moran, V.C., 1983. The phytophagous insects and mites of cultivated plants in South Africa: patterns and pest status. *Journal of Applied Ecology*, pp.439-450.

Moreno, A., Miranda, M.P. and Fereres, A., 2021. Psyllids as major vectors of plant pathogens. *Entomologia Generalis*, 41(5).

Moriones, E. and Navas-Castillo, J., 2000. Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. *Virus research*, *71*(1-2), pp.123-134.

Motti, R., 2021. The Solanaceae family: Botanical features and diversity. *The wild solanums genomes*, pp.1-9.

Mugala, T., Visser, D., Malan, A.P. and Addison, P., 2022. Review of *Liriomyza huidobrensis* (Blanchard, 1926) (Diptera: Agromyzidae) on potatoes in South Africa, with special reference to biological control using entomopathogens and parasitoids. *African Entomology*, *30*, pp.1-10.

Muller, L., 2016. 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). University of Pretoria (South Africa).

Muthomi, J.W., Nyaga, J.N., Olubayo, F.M., Nderitu, J.H., Kabira, J.N., Kiretai, S.M., Aura, J.A. and Wakahiu, M., 2009. Incidence of aphid-transmitted viruses in farmer-based seed potato production in Kenya. *Asian Journal of Plant Sciences*, (166–171), doi:10.3923/ajps.2009.166.171, 1812-5697 1682-3974, 8, (2).

Muthoni, J., Shimelis, H. and Melis, R., 2013. Potato production in Kenya: Farming systems and production constraints. *Journal of Agricultural Science*, 5(5), p.182.

Nachappa, P., Levy, J. and Tamborindeguy, C., 2012. Transcriptome analyses of *Bactericera cockerelli* adults in response to "*Candidatus* Liberibacter solanacearum" infection. Molecular genetics and genomics, 287, pp.803-817.

National Agricultural Marketing Council (NAMC), 2017. A Competiveness analysis of the Potato Industry in South Africa.

Neupane, S. and Subedi, S., 2019. Climatic factors affecting the population dynamics of lentil aphid in inner Terai region of Nepal. *SAARC Journal of Agriculture*, *17*(2), pp.155-164.

Normark, B.B., Normark, R.D., García Morales, M., Claps, L.E. and Amouroux, P., 2025. Identity of the native South American armored scale insect species (Hemiptera: Coccomorpha: Diaspididae) widely misidentified as the North American species *Diaspidiotus ancylus* Putnam. *Annals of the Entomological Society of America*, 118(4), pp.358-370.

Oberemok, V.V., Gal'chinsky, N.V., Useinov, R.Z., Novikov, I.A., Puzanova, Y.V., Filatov, R.I., Kouakou, N.J., Kouame, K.F., Kra, K.D. and Laikova, K.V., 2023. Four most pathogenic superfamilies of insect pests of suborder sternorrhyncha: invisible superplunderers of plant vitality. *Insects*, *14*(5), p.462.

Oksanen, J., Simpson, G. L., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Borman, T., Carvalho, G., Chirico, M., De Caceres, M., Weedon, J. (2025). *vegan: Community Ecology Package* (R package version 2.7-1).

Oliveira, M.R.V., Henneberry, T.E. and Anderson, P., 2001. History, current status, and collaborative research projects for *Bemisia tabaci*. *Crop protection*, 20(9), pp.709-723.

Olson, Å. and Stenlid, J., 2022. Population dynamics of forest tree pathogens. In *Forest Microbiology* (pp. 131-143). Academic Press.

Orr, A., 2003. Integrated pest management for resource-poor African farmers: Is the emperor naked. *World Development*, *31*(5), pp.831-845.

Peccoud, J., Simon, J.C., von Dohlen, C., Coeur d'acier, A., Plantegenest, M., Vanlerberghe-Masutti, F. and Jousselin, E., 2010. Evolutionary history of aphid-plant associations and their role in aphid diversification. *Comptes Rendus Biologies*, *333*(6-7), pp.474-487.

Perring, T.M., Battaglia, D., Walling, L.L., Toma, I. and Fanti, P., 2018. Aphids: biology, ecology, and management. In *Sustainable management of arthropod pests of tomato* pp. 15-48. Academic Press.

Potato South Africa (2020/2021). Annual report.

Potatoes South Africa (2025). Annual report.

Potatoes South Africa, 2021. SOPIA REPORT. State of the potato industry address. https://www.potatoes.co.za/wp-content/uploads/2021/06/State-of-the-potato-industry-address-sopia-report-2021-2.pdf.

Prado, S.G., Ngo, H.T., Florez, J.A. and Collazo, J.A., 2017. Sampling bees in tropical forests and agroecosystems: a review. *Journal of Insect Conservation*, 21, pp.753-770.

Prasad, N.V.V.S.D., Rao, N.H.P. and Mahalakshmi, M.S., 2008. Population dynamics of major sucking pests infesting cotton and their relation to weather parameters. *Journal of Cotton Research and Development*, (85–90).

Prasad, Y. and Prabhakar, M., 2012. Pest monitoring and forecasting. Integrated pest management: principles and practice. Oxfordshire, UK: *Cabi*, pp.41-57.

Pretorius, R.J., Hein, G.L. and Bradshaw, J.D., 2016. Ecology and management of Pemphigus betae (Hemiptera: Aphididae) in sugar beet. *Journal of Integrated Pest Management*, *7*(1), p.10.

Prins, A., GWK, and Verster, E., Northern Cape cultivar trial under irrigation at Douglas in 2023. Potatoes SA.

Quintana, M., De-León, L., Cubero, J. and Siverio, F., 2022. Assessment of Psyllid Handling and DNA Extraction Methods in the Detection of '*Candidatus* Liberibacter Solanacearum'by qPCR. *Microorganisms*, 10(6), p.1104.

Quiroga-Murcia, D.E., Lozoya-Saldaña, H., Zenner, I., Vargas-Hernández, M., Pineda-Pineda, J., Lagunes-Tejeda, Á., Sanabria-Velázquez, A.D. and Enciso-Maldonado, G.A., 2025. Impact of Nitrogen Fertilization on *Myzus Persicae* (Hemiptera: Aphidae) and *Bactericera Cockerelli* (Hemiptera: Triozidae) Populations in Potato. *American Journal of Potato Research*, 102(1), pp.84-92.

Rehman, S.A., Ahad, I., Bano, P., Kumar, R., Farook, U.B. and Arifie, U., 2019. Diversity and abundance of hoppers on different vegetable crops in North Kashmir. *Journal of Entomology and Zoology Studies*, *7*(3), pp.667-676.

Riley, D.E. and Ciomperlik, M.A., 1997. Regional population dynamics of whitefly (Homoptera: Aleyrodidae) and associated parasitoids (Hymenoptera: Aphelinidae). *Environmental Entomology*, *26*(5), pp.1049-1055.

Roberts, N.S., Ndayiragije, J.C., Özek, T., Butt, T.M., Karaca, İ., Shah, F. and Allen, W.L., 2025. Visual modelling can optimise sticky trap design for simultaneous monitoring of multiple species of insect pests. *Scientific Reports*, 15(1), p.17280.

Robinson-Baker, A.M., 2024. Development of Detection, Monitoring, and Management Strategies for the Pine Bark Beetles (Coleoptera: Scolytidae) Under the Changing Climate Patterns in Florida Master's thesis, Florida Agricultural and Mechanical University.

Rubio-Aragón, W.A., López-Orona, C.A., Edeza-Urías, J.A., Castro-Diego, J.A., Gómez-González, G. and Retes-Manjarrez, J.E., 2023. Catch of the potato psyllid *Bactericera cockerelli* (Hemiptera: Triozidae) with yellow sticky traps covered with mesh of different color and size. *American Journal of Potato Research*, 100(6), pp.433-440.

Rung, A., Arakelian, G., Gill, R. and Nisson, N., 2009. 0097. *Platycorypha nigrivirga* Burckhardt (Hemiptera: Sternorrhyncha: Psylloidea), tipu psyllid, new to North America. *Insecta Mundi*, pp.1-5.

Rwomushana, I., 2019 *Spodoptera frugiperda* (fall armyworm). *CABI Compendium.*

Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda. W., Phiri, N., Pratt, C., Tambo, J. (2018). Fall armyworm: impacts and implications for Africa: *Centre for Agricultural Bioscience International.*

Saleem, M., Hussain, D., ul Hasan, M., Sagheer, M., Ghouse, G., Zubair, M., Brown, J.K. and Cheema, S.A., 2022. Differential insecticide resistance in *Bemisia tabaci* (Hemiptera: Aleyrodidae) field populations in the Punjab Province of Pakistan. *Heliyon*, 8(12).

Sampaio, M.V., Korndörfer, A.P., Pujade-Villar, J., Hubaide, J.E.A., Ferreira, S.E., Arantes, S.O., Bortoletto, D.M., Guimarães, C.M., Sánchez-Espigares, J.A. and Caballero-López, B., 2017. Brassica aphid (Hemiptera: Aphididae) populations are conditioned by climatic variables and parasitism level: a study case of Triângulo Mineiro, Brazil. *Bulletin of Entomological Research*, *107*(3), pp.410-418.

Sampson, C., Turner, R. and Ali, A., 2021. Monitoring and trapping with sticky traps, what's new? International Pest control, 63(3), p.166.

Sanchez, J.A., La-Spina, M., Michelena, J.M., Lacasa, A. and Hermoso de Mendoza, A., 2011. Ecology of the aphid pests of protected pepper crops and their parasitoids. *Biocontrol Science and Technology*, *21*(2), pp.171-188.

Sani, I., Ismail, S.I., Abdullah, S., Jalinas, J., Jamian, S. and Saad, N., 2020. A review of the biology and control of whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae), with special reference to biological control using entomopathogenic fungi. *Insects*, 11(9), p.619.

Sarang, K., Rudziński, K.J. and Szmigielski, R., 2021. Green leaf volatiles in the atmosphere—Properties, transformation, and significance. *Atmosphere*, 12(12), p.1655.

Sarkar, S.C., Hatt, S., Philips, A., Akter, M., Milroy, S.P. and Xu, W., 2023. Tomato potato psyllid *Bactericera cockerelli* (Hemiptera: Triozidae) in Australia: incursion, potential impact and opportunities for biological control. *Insects*, 14(3), p.263.

Satar, S., Kersting, U. and Uygun, N., 2005. Effect of temperature on development and fecundity of Aphis gossypii Glover (Homoptera: Aphididae) on cucumber. *Journal of Pest Science*, *78*(3), pp.133-137.

Saxena, S., Murty, N.S. and Singh, C.P., 2012. Effect of weather parameters on population dynamics of mustard aphid (Lipaphiserysimi Kalt) in Tarai region of Uttarakhand. *Journal of Agrometeorology*, *14*(2), pp.176-177.

Semtner, P.J., Tilson, W.M. and Dara, S.K., 1998. Performance of the tobacco aphid (Homoptera: Aphididae) on various host plants. *Journal of Entomological Science*, *33*(2), pp.180-195.

Sharma, K. and Gupta, R., 2025. Integrating Molecular Approaches in Taxonomic Study of Family Rhyparochromid (Hemiptera: Heteroptera): A Review. Uttar Pradesh J*ournal of Zoology*, 46(12), pp.262-273.

Shonga, E. and Getu, E., 2021. Efficacy of plant derived and synthetic insecticides against cabbage aphid, *Brevicoryne brassicae* (L.) (Homoptera: Aphididae) and their effect on coccinellid predators. *SINET: Ethiopian Journal of Science*, *44*(1), pp.27-37.

Singh, R. and Singh, G., 2022. Diversity of aphids (Homoptera: Aphididae) infesting solanaceous plants (Angiospermae: Solanales: Solanaceae) in India. *International Journal of Biological Innovations*, *4*(1), pp.189-204.

Spafford, R.D. and Lortie, C.J., 2013. Sweeping beauty: is grassland arthropod community composition effectively estimated by sweep netting. *Ecology and Evolution*, 3(10), pp.3347-3358.

Spodek, M., Burckhardt, D., Protasov, A. and Mendel, Z., 2015. First record of two invasive eucalypt psyllids (Hemiptera: Psylloidea) in Israel. *Phytoparasitica*, 43, pp.401-406.

Sridhar, J., Venkateswarlu, V., Shah, M.A., Kumari, N., Bhatnagar, A., Raigond, B. and Chakrabarti, S.K., 2022. Incidence of the cabbage aphid, *Brevicoryne brassicae* L. in potato crops in India and its efficiency for transmission of potato virus Yo. *International Journal of Tropical Insect Science*, *42*(1), pp.285-291.

Srinivasan, R. and Alvarez, J.M., 2007. Effect of mixed viral infections (Potato virus Y–Potato leafroll virus) on biology and preference of vectors *Myzus persicae* and *Macrosiphum euphorbiae* (Hemiptera: Aphididae). *Journal of Economic Entomology*, 100(3), pp.646-655.

Statista: Agriculture in South Africa (2023). Production of potatoes in South Africa from 2000 to 2022. https://www.statista.com/aboutus/our-research-commitment.

Stats SA, 2023. Focus on food inadequacy and hunger in South Africa in 2021. https://www.statssa.gov.zap16235

Suwandharathne, N.I., Holwell, G.I. and Avila, G.A., 2023. Current and future potential geographical distribution of *Bactericera cockerelli*: an invasive pest of increasing global importance. *Austral Entomology*, 62(4), pp.488-502.

Svobodová, B. and Kuban, V., 2018. Solanaceae: A family well-known and still surprising. *Phytochemicals in Vegetables*, pp.296-372.

Tamaki, G., Weiss, M.A. and Long, G.E., 1980. Impact of high temperatures on the population dynamics of the green peach aphid in field cages. *Environmental Entomology*, *9*(3), pp.331-337.

Tan, X.L., Wang, S., Ridsdill-Smith, J. and Liu, T.X., 2014. Direct and indirect impacts of infestation of tomato plant by *Myzus persicae* (Hemiptera: Aphididae) on *Bemisia tabaci* (Hemiptera: Aleyrodidae). *Plos one*, 9(4), p.e94310.

Tang, X., Shi, X., Zhang, D., Li, F., Yan, F., Zhang, Y., Liu, Y. and Zhou, X., 2017. Detection and epidemic dynamic of ToCV and CCYV with *Bemisia tabaci* and weed in Hainan of China. *Virology Journal*, 14(1), p.169.

Taylor, M., Hayashida, R., Hoback, W.W. and Armstrong, J.S., 2023. Effects of temperature and host plant on hedgehog grain aphid, Sipha maydis demographics. *Insects*, *14*(11), p.862.

Teulon, D.A.J., Workman, P.J., Thomas, K.L. and Nielsen, M.C., 2009. Bactericera cockerelli incursion dispersal and current distribution on vegetable crops in New Zealand. *New Zealand Plant Protection*, *62*, pp.136-144.

The North American Plant Protection Organization (NAPPO) (2012). Surveillance Protocol for the Tomato Leaf Miner, *Tuta absoluta*, for NAPPO Member Countries.

Togola, A., Beyene, Y., Bocco, R., Tepa-Yotto, G., Gowda, M., Too, A. and Boddupalli, P., 2025. Fall armyworm (Spodoptera frugiperda) in Africa: Insights into biology, ecology and impact on staple crops, food systems and management approaches. *Frontiers in Agronomy*, *7*, p.1538198.

Tomato Producers Organisation (TPO), 2021. Next generation technologies, i.e. microchips and 3D printing for real time tomato fruit quality monitoring.

Torrance, L. and Talianksy, M.E., 2020. Potato Virus Y emergence and evolution from the Andes of South America to become a major destructive pathogen of potato and other solanaceous crops worldwide. *Viruses*, *12*(12), p.1430.

Tshiala, M.F. and Olwoch, J.M., 2010. Impact of climate variability on tomato production in Limpopo Province, South Africa. *African Journal of Agricultural Research,* Vol. 5(21), pp. 2945-2951

Tshikhudo, P.P., Simandla, A., Nnzeru, L.R., Gebeyehu, S., Mokwele, J., Rambauli, M., Makhado, R.A., Nelufule, T. and Munyai, T.C., 2025. Horizon scanning for invasive insects with potential threats to crop production in South Africa. *Discover Sustainability*, 6(1), pp.1-13.

Van der Waals, J.E., Korsten, L. and Slippers, B., 2004. Genetic diversity among *Alternaria solani* isolates from potatoes in South Africa. *Plant Disease*, 88(9), pp.959-964.

Van Klinken, R.D. 2000. Host-specificity constrains evolutionary host change in the psyllid *Prosopidopsylla flava*. *Ecological Entomology*, 25(4), pp. 413–422. Available at: https://doi.org/10.1046/j.1365-2311.2000.00274.x.

Van Rensburg, W.J., Van Averbeke, W., Slabbert, R., Faber, M., Van Jaarsveld, P., Van Heerden, I., Wenhold, F. and Oelofse, A., 2007. African leafy vegetables in South Africa. *Water SA*, *33*(3), pp.317-326.

Vereijssen, J., 2020. Ecology and management of *Bactericera cockerelli* and *Candidatus* Liberibacter solanacearum in New Zealand. *Journal of Integrative Agriculture*, 19(2), pp.333-337.

Vereijssen, J., 2020. Ecology and management of *Bactericera cockerelli* and *Candidatus* Liberibacter solanacearum in New Zealand. *Journal of Integrative Agriculture*, 19(2), pp.333-337.

Vereijssen, J., Jorgensen, N., Taylor, N.M., Barnes, A.M., Butler, R.C., Berry, N. and Scott, I.A., 2013. Movement of *Bactericera cockerelli* in the New Zealand environment. 2013 Zebra Chip Reporting Session, 24.

Villena, O.C., Arab, A., Armbruster, P.A., Markovich, E., Zhang, K., Tonnang, H.E., Sokame, B.M., Kreuze, J., Carhuapoma, P., Gamarra, H. and Johnson, L.R., 2024. Thermal biology of aphids and implications for agriculture and food security. *bioRxiv*, pp.2024-10.

Visser, D., Uys, V.M., Nieuwenhuis, R.J. and Pieterse, W., 2017. First records of the tomato leaf miner *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) in South Africa. *BioInvasions Records*, 6(4), pp.301-305.

Vučetić, A., Vukov, T., Jovičić, I. and Petrović-Obradović, O., 2013. Monitoring of aphid flight activities in seed potato crops in Serbia. *Zookeys*, (319), p.333.

Waheed, K., Nawaz, H., Hanif, M.A. and Rehman, R., 2020. Tomato. In Medicinal Plants of South Asia. *Elsevier,* pp. 631-644.

Wakil, W., Brust, G.E. and Perring, T.M., 2018. Tomato and management of associated arthropod pests: past, present, and future. Sustainable management of arthropod pests of tomato, pp.3-12.

Walker, P.W., Allen, G.R., Tegg, R.S., White, L.R. and Wilson, C.R., 2015. The tomato potato psyllid, *Bactericera cockerelli* (Šulc, 1909) (Hemiptera: Triozidae): a review of the threat of the psyllid to Australian solanaceous crop industries and surveillance for incursions in potato crops. *Austral Entomology*, *54*(3), pp.339-349.

Wang, Y., Nansen, C. and Zhang, Y., 2016. Integrative insect taxonomy based on morphology, mitochondrial DNA, and hyperspectral reflectance profiling. *Zoological Journal of the Linnean Society*, *177*(2), pp.378-394.

Wang, Z.J., Liu, H., Zeng, F.K., Yang, Y.C., Xu, D., Zhao, Y.C., Liu, X.F., Kaur, L., Liu, G. and Singh, J., 2023. Potato processing industry in China: Current scenario, future trends and global impact. *Potato research*, 66(2), pp.543-562.

Weatherpark, 2024. https://weatherspark.com/

Weinzierl, R., Henn, T., Koehler, P.G. and Tucker, C.L., 2005. Insect attractants and traps. ENY277, Avalaible: http://ufdcimages. uflib. ufl. edu/IR/00/00/27/94/00001/IN08000.

Wenninger, E.J. and Rashed, A., 2022. Psyllids. In *Insect Pests of Potato* pp. 69-101. Academic Press.

Wenninger, E.J. and Rashed, A., 2024. Biology, Ecology, and Management of the Potato Psyllid, *Bactericera cockerelli* (Hemiptera: Triozidae), and Zebra Chip Disease in Potato. *Annual Review of Entomology*, 69, pp.139-157.

Were, H.K., Olubayo, F.M., Kabira, J., Aura, J. and Torrance, L., 2015. Aphids infesting potato in Kenya. In *Potato and sweetpotato in Africa: transforming the value chains for food and nutrition security* pp. 396-404. Wallingford UK: CABI.

Whittaker, A., 2015. *Macrosiphum euphorbiae* (potato aphid). *Crop Protection Compendium*, (32154).

Whittaker, A., 2022. Macrosiphum euphorbiae (potato aphid). *CABI Compendium*.

Wilson, C., 2018. Surveillance of Tomato Potato Psyllid in the Eastern States and South Australia. University of Tasmania, Tasmanian Institute of Agriculture (TIA).

Wosula, E.N., Clark, C.A. and Davis, J.A., 2012. Effect of host plant, aphid species, and virus infection status on transmission of Sweetpotato feathery mottle virus. *Plant disease*, *96*(9), pp.1331-1336.

Wu, Q., Zeng, J. and Wu, K. (2022) “Research and application of crop pest monitoring and early warning technology in china,” *Frontiers of Agricultural Science and Engineering*, 9(1), pp. 19–36. Available at: https://doi.org/10.15302/J-FASE-2021411.

Wynne, J.J., Howarth, F.G. and Sommer, S., 2019. Fifty years of cave arthropod sampling: techniques and best practices. *KIP Articles.* 2042.

Xue, M., Wang, C.X., Bi, M.J., Li, Q.L. and Liu, T.X., 2010. Induced defense by *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae) in tobacco against *Myzus persicae* (Hemiptera: Aphididae). *Environmental Entomology*, 39(3), pp.883-891.

Yen, A.L., Madge, D.G., Berry, N.A. and Yen, J.D., 2013. Evaluating the effectiveness of five sampling methods for detection of the tomato potato psyllid, *Bactericera cockerelli* (Šulc) (Hemiptera: Psylloidea: Triozidae). *Australian Journal of Entomology*, 52(2), pp.168-174.

Yılmaz, B. and Kök, Ş., 2023. The diversity and host interactions of aphids (Hemiptera: Aphididae) on different plant communities in an urban ecosystem. *Turkish Journal of Entomology*, *47*(4), pp.457-468.