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# THE VALUE OF PEST MONITORING FOR THE ECONOMIC SUSTAINABILITY OF SOUTH AFRICAN APPLES FOR THE EXPORT MARKET

by
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# Declaration

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# Summary

There is a risk of market closure for South African Fuji apples due to phytosanitary pest interception. Pests that are proving problematic in our local climate include codling moth (*Cydia pomonella*), mealybug species (*Planococcus citri*, *Pseudococcus longispinus* and *Pseudococcus viburni*), mites (*Panonychus ulmi* and *Bryobia*) and woolly apple aphid (*Eriosoma lanigerum*). This is problematic due to this market paying a large premium for these fruits, not realised elsewhere and otherwise making this widely planted variety significantly less profitable to produce. While applying more pesticides to reduce pest presence is effective, it reduces environmental and economic sustainability.

A 25-tree per two-hectare monitoring program was applied to address this issue, alongside codling moth trap counts, a preharvest assessment and packhouse fruit sampling. This was applied to 264 Fuji orchards across the Elgin, Grabouw, Vyeboom and Villiersdorp (EGVV) area. Data was collected biweekly and analysed using various methods appropriate to the data type.

The findings of this study showed that both using this monitoring program effectively or using an aggressive spray program significantly reduced the occurrence of mealybug while woolly apple aphid was best managed using regular monitoring. Mite and codling moth presence were unaffected. Mites were shown to be managed efficiently through the use of natural predatory mites. Woolly apple aphid, while having high levels of parasitism by *A. mali*, was still a hindrance to export due to mummies left on fruit. The preharvest assessment showed to be significantly more effective at reducing risk when allocating orchards to a particular market, when compared to the use of a packhouse sample. Various orchard environmental factors were identified as being influential on each of the phytosanitary pests' presence. Financial data used in partial budget modelling revealed that the use of monitoring to reduce risk of phytosanitary pests could result in a 62% increase on return on investment of annual costs per hectare.

These findings show that implementing holistic monitoring systems can aid in reducing the risk of market closure while simultaneously improving growers' financial standings and better serving the environment. Further research should be aimed at studying seasonal differences in phytosanitary pest pressures and what impacts this may have as well as place focus on industry leaders to make trade more sustainable and less volatile to closure.

# Opsomming

Die Suid-Afrikaanse Fuji appels beloop die risiko vir n Spesiale marksluiting weens fitosanitêre plaagonderskepping. Die plae wat hulself problematies bewys in ons plaaslike klimaat, sluit in: kodlingmot (*Cydia pomonella*), witluis (*Pseudococcus*), myte (*Panonychus ulmi* en *Bryobia*) en bloedluis (*Eriosoma lanigerum*). Dit is problematies omdat hierdie mark 'n groot premie vir hierdie vrugte betaal, wat nie elders gerealiseer word nie en hierdie wyd aangeplante variëteit andersins aansienlik minder winsgewend maak om te produseer. Alhoewel die toediening van meer plaagdoders om hierdie risiko te verminder doeltreffend is, verminder dit omgewings- en ekonomiese volhoubaarheid.

'n 25-boom per twee hektaar moniteringsprogram is toegepas om hierdie probleem aan te spreek, tesame met verpligte kodlingmot lokvaltellings, 'n voor-oes assessering en pakhuis vrugte monsterneming. Dit is toegepas op 264 Fuji-boorde regoor die Elgin, Grabouw, Vyeboom en Villiersdorp (EGVV) area. Data is twee-weekliks ingesamel en ontleed met behulp van verskeie metodes wat van toepassing is vir die data tipe.

Die bevindinge van hierdie studie het getoon dat beide die doeltreffende gebruik van hierdie moniteringsprogram of die gebruik van 'n aggressiewe spuitprogram, die voorkoms van witluis verminder het. Appelbloedluis was beter gebeheer met net moniteering maar het nie die teenwoordigheid van myt- of kodlingmot beïnvloed nie. Daar is getoon dat myte doeltreffend bestuur word deur die gebruik van natuurlike roofmyte. Alhoewel daar hoë vlakke van parasitisme deur A. mali op die bloedluis gevind is, blyk dit steeds ‘n hindernis vir die Spesiale markuitvoer te wees as gevolg van die mummies wat op vrugte agter gelaat is. In vergelyking met die gebruik van 'n pakhuismonster het die voor-oes assessering getoon dat dit die risiko aansienlik meer doeltreffend verminder wanneer boorde aan 'n spesifieke mark toegewys word. Daar is verskeie boordomgewingsfaktore geïdentifiseer wat die teenwoordigheid van elk van die fitosanitêre plae beïnvloed het. Finansiële data wat in die gedeeltelike begrotingsmodellering gebruik is, het gewys dat die gebruik van monitering om die risiko van fitosanitêre plae te verminder op vrugte, bestem vir die Spesiale mark, 'n 62% verhoging op opbrengs tot gevolg kan hê op die belegging van die jaarlikse koste per hektaar.

Hierdie bevindinge toon dat die implementering van holistiese moniteringstelsels kan help om die risiko van marksluiting in Spesiale markte te verminder, terwyl dit terselfdertyd produsente se finansiële stand verbeter en die omgewing beter dien. Verdere navorsing moet daarop gemik wees om seisoenale verskille in fitosanitêre plaagdruk te bestudeer en watter impak dit kan hê, asook om fokus op bedryfsleiers te plaas om Spesiale markte meer volhoubaar en minder wisselvallig vir sluiting te maak.

This thesis is dedicated to those who believed I could. I did.

Special thanks to Ricardo Du Plessis for your on-going support and keeping me motivated. Thank you to my dad, Peter and Ella Joyce Buckley for always being understanding and trying your best to create an environment for me to work on my studies. Lastly, thank you to my extended family for always being there to jump in with a warm plate of food and a place to sleep to help to reduce my number of trips over Sir Lowry's Pass.

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- Neil Hopkins at Viking for assisting with valuable information on industry standards in the EGVV production area.

# Preface

This thesis is presented as a compilation of 5 chapters.

# Table of Contents

# 1. Introduction

## 1.1 Background

The apple industry in South Africa resulted in a R12.19 billion turnover in 2021. The majority of this, 46% of the total tonnage, was from the export market. At an average price of R12 145 per ton, this equates to R6.8 billion. In contrast, local market fruit prices averaged R6 379 per ton (R1.25 billion) and processing fruit, R1 597 per ton (R650 million). Due to the price per ton differences, the focus for farmers is to prioritise producing high quantities of export quality fruit to remain as profitable as possible (Hortgro 2021).

Price differences naturally occur between different export markets. When considering Fuji apples specifically for the Taiwanese market, an additional R4000 per ton is realized compared to alternative export markets. This results in Fuji apples being not as economical to produce should they be sold elsewhere, and why the South African pome fruit industry pushes for a larger part of the export market share going to Asia (Steenkamp 2020).

The Taiwanese market is considered a “special” market based on National Plant Protection Organization (NPPO) to NPPO negotiations between the importing and exporting countries to secure and maintain the market. Major cost increases in inputs such as labour, chemicals, fertilizers, and diesel result in greater pressure on farmers to maintain profitability and sustainability of their farms and livelihoods. In order to realise the best possible prices for their fruit, focus needs to be placed on, not only quantity, but quality and compliance with the most lucrative markets’ regulations as well. The fear of loss of the Taiwanese market due to phytosanitary pest presence and the pome fruit industry’s economic sustainability, is currently of major concern.

The Taiwanese market has already experienced temporary closures due to interception of phytosanitary pests on South African apples on arrival of consignments in Taiwan. During the 2017/18 season the market was closed for a period of eight months due to a single codling moth (*Cydia pomonella*) larval interception. Reopening of this market is tedious with extended negotiations and more stringent protocols being put in place to prevent future interceptions. The 2020 season saw South African pome fruit exporters concerns for market closure heightened upon receiving photographic evidence of woolly apple aphid, mealybug and mite eggs from Taiwanese inspectors (Moelich, pers comm. 2022). This has further driven the need for improved risk mitigation strategies.

According to the MRL (Maximum Residue Limits) list published by Hortgro (2022), pesticides without MRLs specified for the Taiwanese market are not tested for detection by the Taiwanese. This creates a danger to environmental sustainability and human health as there is essentially no standard requirement to prevent farmers from spraying their crops excessively to ensure phytosanitary pest free fruit. Although the push to increase the footprint in the Taiwanese market is of a high priority according to personal communication with stakeholders, environmentally sustainable practices still need to be kept at the forefront. This is not only to protect environmental sustainability and human health, but also to meet alternative market regulations should fruit not be acceptable for the Taiwan market due to phytosanitary pest presence at harvest, colour requirements, etc.

A potential solution lies in the practice of pest monitoring. It forms part of the already widely practiced concept of integrated pest management where pests and diseases are managed using a combination of cultural, physical, biological and chemical methods. Monitoring is typically used to create constant awareness of pest presence, and at what pressure levels various pests and diseases are present in a crop. Producers can then apply the most appropriate management practices at the correct times based on these observations and developed thresholds. Although monitoring is a well-known practice with proven benefits, it is not always implemented correctly. Monitoring can be used as a tool, not only during the growing season to aid in pest and disease management decisions, but also to quantify risk just prior to harvest through preharvest assessments (Brown and Pringle 2006). This helps to ensure that phytosanitary pests do not make their way to markets not receptive of their presence. Mudavanhu et al. (2011) claimed that the lack of monitoring for mealybug resulted in exponentially increased pressure of this phytosanitary pest in Western Cape apple orchards. This could be the case for other pests as well, since management practices are affected by a lack of knowledge of pest pressures and life stages in orchards, and consequently the effectiveness of pest management.

## 1.2 Problem statement and research question

Different export markets have different requirements for apples in terms of chemical usage and phytosanitary pests. While producers should prioritise ensuring no phytosanitary pest presence on fruit and securing the best prices, integrated pest management and chemical usage still needs to be strongly considered to ensure environmental sustainability and allow for fruit that may need to be redirected, to still meet chemical usage requirements in alternative major markets such as Europe, the UK and Africa. Due to the Asian market preferences of a sweet red apple, the research will be focused on Fuji apples, a widely planted variety that fits this description and has high demand in the mentioned market.

How effectively can a pest monitoring program serve as a method to mitigate risk and secure special market access for export Fuji apples in the Elgin, Grabouw, Villiersdorp, Vyeboom (EGVV) production region as the largest contributing pome-fruit producing area in South Africa?

### 1.3.1 Rationale

The purpose of this study is to investigate the use of pest monitoring as a tool to mitigate the risk of phytosanitary pest presence on special market destined Fuji apples, to ultimately ensure that these markets remain open and pome fruit farmers remain economically sustainable while simultaneously minimising the impact on environmental sustainability.

### 1.3.2 Aim and objectives

The aim of this project is to evaluate how monitoring can be used as a risk mitigation tool to ensure market access for export Fuji apples in the EGVV production area.

The objectives are as follows.

1. To develop a system for training monitors to effectively conduct pest monitoring in orchards and capture meaningful data prior to the start of phytosanitary pest activity in the orchards.
2. To link monitoring observations and their effect on integrated pest management practices over the 2022 season.
3. To determine if predatory insects contribute significantly to phytosanitary pest management in the EGVV area.
4. To determine the financial considerations of conducting effective monitoring practices on export apples under current economic conditions, and
5. Ascertain an effective method to designate orchards to a particular market prior to harvest to improve logistical efficiency and mitigate risk.

## 1.4 Proposed method

For the purpose of this study, an orchard will be considered an experimental unit. With replicates within farms and across farms in the Elgin, Grabouw, Vyeboom and Hemel en Aarde Valley areas (EGVV). This makes up 264 total experimental units or orchards. Treatments vary in accordance with the measurements being considered per analyses. When investigating the effect of monitoring on management practices, the treatments will be split between those orchards that were regularly monitored versus those irregularly monitored versus those which were not, and control practices that were implemented will be compared. In the case of investigating the effect of predators on pest presence, treatments will be split by orchards with predator presence and those without predator presence, as treatment and control groups.

Monitoring will be done in accordance with the standard monitoring system of 25-tree per two-hectare block as developed by Brown & Pringle (2006) on a biweekly basis from the beginning of December until two weeks before harvest, when a preharvest assessment of the fruit will be performed for each experimental unit. Trees will be monitored for the following pests: codling moth (*Cydia pomonella*), mealybug (*Planococcus citri*, *Pseudococcus longispinus* and *Pseudococcus viburni*), mites (*Panonychus ulmi* and *Bryobia*) and woolly apple aphid (*Eriosoma lanigerum*), as well as predatory insects. Fruit fly (*Ceratitis*) is also a key phytosanitary pest but will not be included in this study as monitoring and management is undertaken by a third party.

During the preharvest fruit assessment, the above-mentioned pests and their damage will be inspected for, on five fruit clusters per monitoring tree. One fruit from each cluster will be cut to check for mealybug internally. Codling moth pheromone traps will be monitored on a weekly basis, in addition to tree monitoring. This data will be collected by designated orchard monitors on standard monitoring templates compiled according to best practice guidelines. After harvest, a 600-fruit sample will be taken on arrival at the packhouse for each orchard and inspected both externally and internally for pests and damage. Monitors will be trained by Lesley Brown (entomologist and monitor training service provider) and myself on their respective farms. This will encompass identifying the types of pests at various life stages and their associated damage, how to apply the 25-tree per two-hectare monitoring method and how to perform a preharvest fruit damage assessment.

Quantitative monitoring data will be gathered. This data will be analysed by comparing monitored, partially monitored and unmonitored orchards preharvest assessment results using the non-parametric Kruskal-Wallis test. This test is used as the data is not normally distributed. Both pest monitoring and financial data will be analysed in excel. Financial data will be gathered by online sources from sellers of products as well as industry specialists such as chemical representatives. A simple financial budget model will be constructed to illustrate the effects of costs of monitoring and the resultant market access. Partial budgets and enterprise budgets that focus on margin above specified cost serve as a simple method that also allow for the ability to accommodate many variables. A partial budget model will be used to compare the cost-benefit of monitoring by comparing the alternative additional costs and income returns should the suggested monitoring program be implemented. This method is also producer friendly as producers understand budgeting and can easily relate to the processes followed.

## 1.4 Study outline

Chapter 2 will comprise of a literature review. This will delve into an overview of the South African apple industry outlining the main production areas, the split of the market in terms of local, processing and export fruit and what share each of the export markets receive of our fruit. A history of South African apple market access will be discussed. This will outline how price trends and the share of different markets have evolved over time. The threats to market access, identified at the farm level will be discussed under the broad categories of chemical usage and phytosanitary pest presence. Current risk mitigation strategies for market access will be discussed relating to the aforementioned, in terms of monitoring and integrated pest management.

Chapter 3 will be a study of the effect that monitoring has on pest management practices and ultimately, the fruits' compliance at harvest in terms of phytosanitary pest presence with Taiwan's importation regulations. This will elaborate firstly on how the monitoring method was compiled and distributed through training. The results of this for farms which used this system, either fully compliantly or partially, versus farms on which it was opted not to be used and practiced control uninformed by pest presence, will be compared. The significance of predatory mites and the parasitic wasp, *Aphelinus mali*, as a contributor to phytophagous mite and woolly apple aphid management as an ecosystem service will be determined. Lastly, improvements in risk mitigation measures for phytosanitary pests will be considered.

Chapter 4 will illustrate an analysis of cost and additional income of implementing a concise monitoring program in an attempt to have more fruit available for the Taiwanese market. This will be achieved through the use of a partial budget model. The partial budget model will compare farming systems in which monitoring was used optimally versus not used but rather aggressive spray programs were relied upon for control. All additional costs, saved costs, additional income and reduced income will be considered. The results of this will then be discussed factoring in their impact on income and management practices such as chemical usage.

The final chapter, chapter 5, will be an overall conclusion of the study as well as recommendations based on the findings of this study. This chapter will also discuss difficulties encountered in the study and areas for future research.

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# 2. Literature Review

## 2.1 Introduction to the apple industry

Apple (*Malus domestica*) trees originate from the mountainous areas of central Asia and today are cultivated commercially on every continent bar Antarctica. Apples have been grown commercially in South Africa since the 1880's and were exported for the first time to the United Kingdom in the 1890's (Brodie, n.d.). Apples are keyed as the most popular fruit to consumers. Globally, China is the biggest producer and exporter of apples. China produces over 44 million metric tons per annum, of which 971 000 tons are exported, mostly to other Far East countries (Shahbandeh, 2022).

South Africa is the sixth largest apple exporter globally, equating to roughly 560 000 tons according to Hortgro's Key Deciduous Fruit Statistics publication (Hortgro 2021). This accounted for over half of South Africa's apple production in the 2021 season, with an increasing push to improve the percentage of exported apples due to significantly better prices abroad compared to the local and processing markets. The pome fruit industry of South Africa resulted in a turnover of R12.19 billion in 2021. There has been an 11% per annum average increase in total value of production over the past decade (Hortgro 2019).

The majority of South African apples are grown in the Western Cape (see Figure1), a large portion of which is situated in the Elgin, Grabouw, Vyeboom and Villiersdorp (EGVV) area with a total production area of 18 941 hectares. The remainder of Western Cape apple orchards make up 1 111 hectares. Other production areas include the Langkloof in the Eastern Cape with 4147 hectares, the Free State at 527 hectares, Mpumalanga at 205 hectares and the Northern Provinces with 186 hectares (Hortgro, 2021).

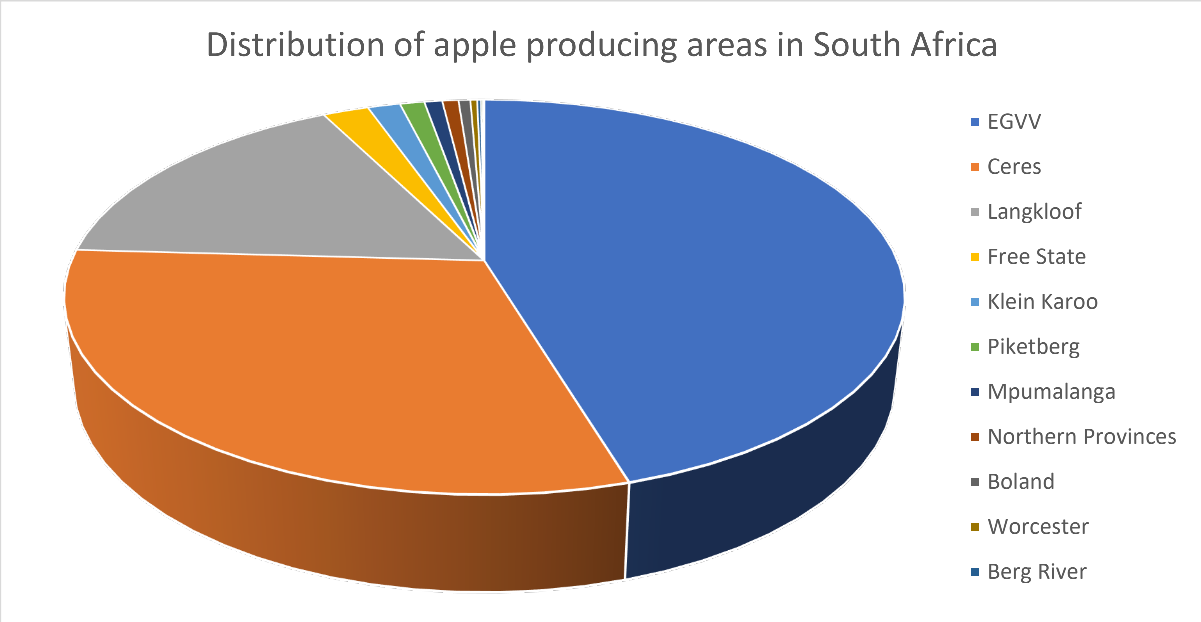


**Figure 1.1** A depiction of the size of the hectarage of the various apple producing regions of South Africa. (Hortgro, 2021)

Currently, the most common varieties produced nationally are, in order of decreasing area of hectares planted, Golden Delicious (20%), Gala (17%), Pinks (13%), Granny Smith (13%), Fuji (9%), Top Red (9%), Cripps Red (7%), Big Bucks (4%), Braeburn (2%), African Carmine (1%), Kanzi (1%), Oregon Spur (1%), and a small collection of various others (3%) (Hortgro, 2021). This distribution, however, is dynamic due to changing consumer preferences, changing market distributions and the development of new varieties. Figure 2 shows the change in percentage of total apple plantings, per variety, from 2009 to 2021. Trends in gradual increases in the variety share of Royal Gala, Fuji, Cripps Red and Cripps Pink, can be observed. The older varieties, Golden delicious, Granny Smith, Top Red and Braeburn are on the decline.

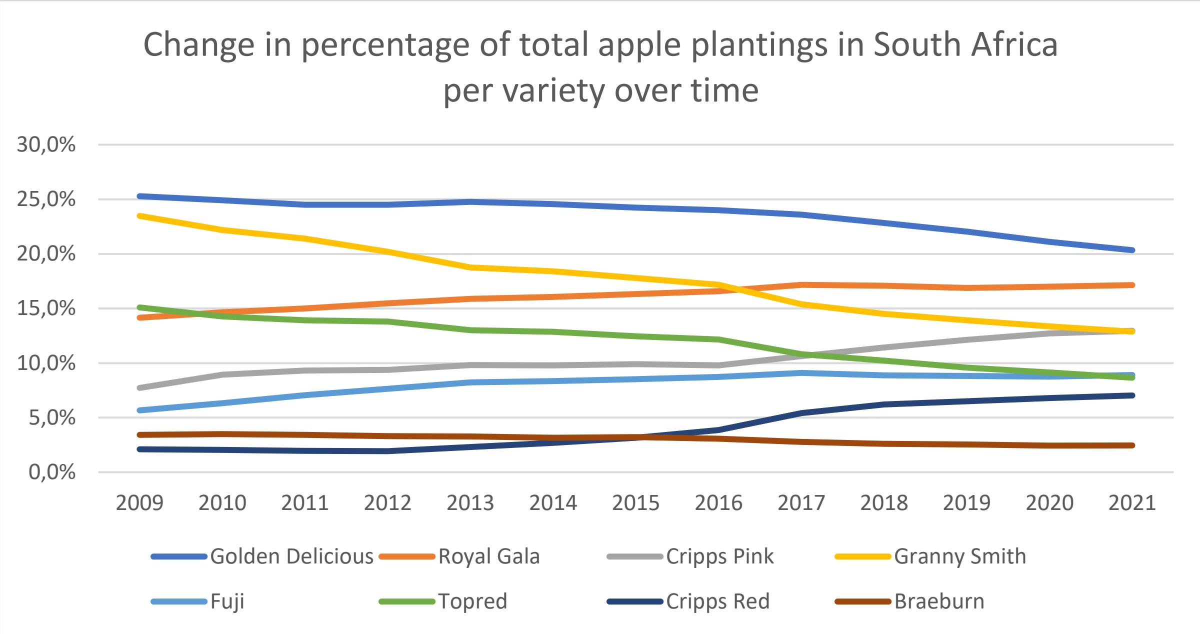


**Figure 1.2** A graph depicting the change in percentage coverage per variety of the total apple plantings in South Africa over the last 12 years. Only the most common varieties were represented due to insufficient data. (Hortgro, 2014-2021)

South Africa produced 1.16 million tons of apples in 2021. Of this, 46% was exported, 22% went to the local market and 32% was processed, mainly for juice. The ratio of export to local market fruit has been gradually increasing over the last decade with an average change of 2% per annum increased difference between export and local market quantities. This is coupled with a general price increase trend for export fruit from R6 656 per ton in 2012 to R12 145 per ton in 2021. Local market prices are experiencing the same trend, however at a slower rate with a price increase from R4 548 in 2012 to R6 379 in 2021. This equates to a 40.26% increase in local market prices over the last decade versus an 82.47% increase in export market prices. There is also a trend of the amount of processing fruit increasing annually (Hortgro, 2021).

The aim of this literature review is to provide a background of the South African apple industry and its economic sustainability with a focus on exports. An overview of factors affecting exports on the farm level is presented, as well as the current and potential risk mitigation strategies to maintain market access.

## 2.2 History of market access for South African apples

The export market was made more of a reality for the South African pome fruit sector in 1934 with the construction of controlled atmosphere storage rooms. This allowed for apples and pears to be stored and marketed for further extended periods, opening new markets and prolonging the time in which fruit could be sold and consumed. South Africa was in fact the second country internationally to apply this technology after the United Kingdom (Steenkamp, 2021). More recently, from 2014 until 2021, see Figure 3 for the change in market share of the top importing countries over time.

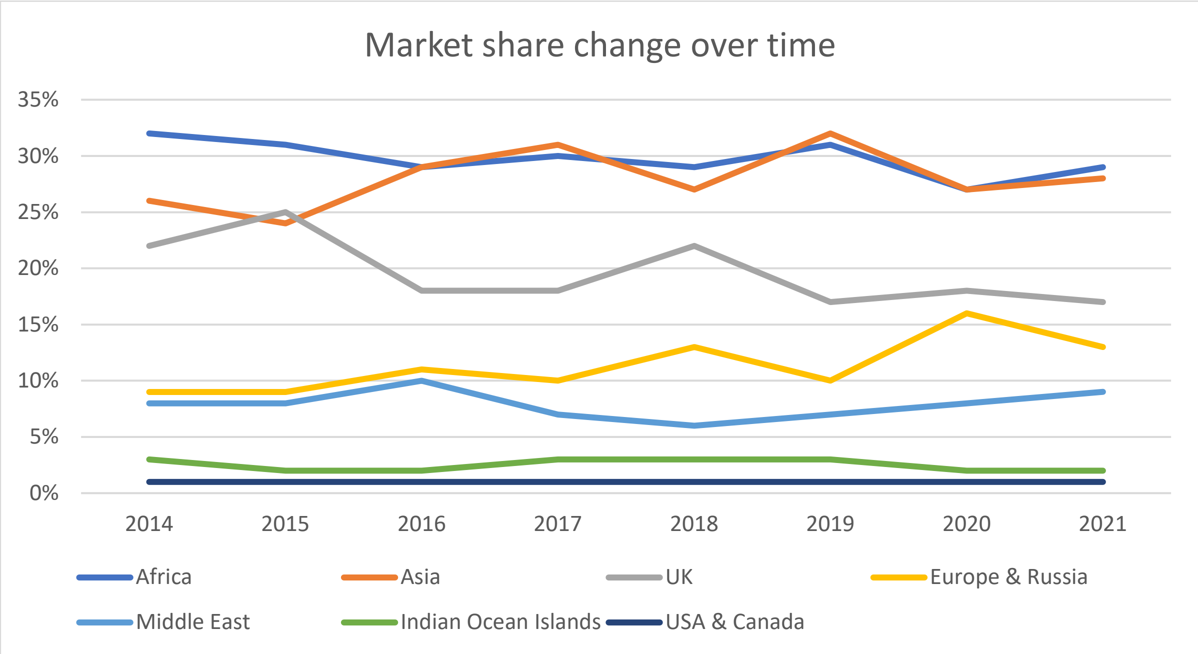


**Figure 1.3** The change in market share percentages for South African pome fruit over the past seven years (Own Adaptation).

According to Steenkamp (2020) the South African pome fruit industry has been making gradual progress to shift volumes to the Far East, including China and Taiwan as major consumers. This is expected to continue on a gradual trajectory for the foreseeable future, despite major interruptions in marketing as seen with Covid-19 in 2020. The key to achieving this will be by improving the sustainability of market access through effective phytosanitary pest interception risk mitigation strategies.

## 2.3 Threats to market access – farm level

The two biggest threats to market access related to management practices on the farm are, chemicals used in terms of their particular acceptance of use in certain markets and allowed chemicals resultant maximum residue levels on fruit, and the presence of living phytosanitary pests on fruit on arrival at their destination. Although these are navigated and addressed by the farmer, circumstances beyond the farmers' control do come into play ultimately affecting these factors. The levels of acceptance of these factors and details surrounding them are dependent on the importing country and in some cases, the specific market within said country.

### 2.3.1 Chemical usage and Maximum Residue Levels

Maximum residue levels (MRLs) indicate the maximum concentration of a particular chemical permissible on the fruit for a specific market. The MRL list differs from country to country. Where a specific market does not display a list of specific values, the codex values are used. The codex refers to a list of maximum allowable residue limits for all chemicals relating to food safety complied by the World Health Organization in conjunction with all food safety standards role players. MRLs were implemented to ensure consumer and environmental safety (Ferreira, pers comm., 2022).

The consequences of having chemical concentrations above the indicated MRLs result in major financial implications as many retailers will not accept the fruit. This puts both the farm itself and the associated exporter at risk in terms of client relations. Non-compliance can also result in sanctions from specific major retailers. Should the MRLs be discovered to be too high while the fruit is in transit the consignment could be returned or destroyed at the exporters cost (Ferreira, pers comm., 2023).

### 2.3.2 Phytosanitary pests

With the push towards the Taiwanese market for export South African pome fruit, the phytosanitary pests for this market are of great concern. The phytosanitary pests of concern for the Taiwanese market are codling moth (*Cydia pomonella*), fruit flies (*Ceratitis capitata* and *Ceratitis rosa*), woolly apple aphid (*Eriosoma lanigerum*), mealybugs (*Pseudococcus* species) and phytophagous mites (*Panonychus ulmi* and *Bryobia rubrioculus*). All of which are present and at times problematic in our main pome fruit production areas in South Africa (Moelich, pers comm., 2022).

While in earlier years the market was more aimed towards Europe, and emphasis was placed on environmental and social sustainability with phytosanitary pests being more secondary. Now however, sustainability in these areas needs to be maintained while ensuring zero presence of phytosanitary pests. This is challenging as it goes against the ideology of being in harmony with nature as previously pursued. The presence of these pests on fruit on arrival in restricted markets can result in the consignment being returned or destroyed at cost to the exporter. With repeated offence, the market can close entirely. The duration of which this closer will be maintained is undefined.

## 2.4 Current risk mitigation strategies

Various major role-players assist in pome fruit export regulations within South Africa. The Department of Agriculture, Land Reform and Rural Development (DALRRD) is a governmental department of South Africa responsible for supporting and developing the agricultural sector of the country. Hortgro is a private company which supports the deciduous fruit industry of South Africa with research and development and export. The Perishable Produce Export Certification Agency (PPECB) assists the pome fruit industry of South Africa by performing quality inspections, food safety certification, cold chain management services and laboratory analyses to ensure fruit quality for the export market. The Fresh Produce Exporters Forum (FPEF) is a non-profit organization that provides services to assist both local growers and international buyers of South African fresh produce through market access and value chain information.

Hortgro provides best practice guidelines to mitigate the risk of phytosanitary pest presence on South African pome fruit. These guidelines detail codling moth management steps from farm to export, as well as identification information. On the farm level these include the use of codling moth traps and monitoring for codling moth damage in the orchard. Orchard monitoring is based on the 25-tree system. Record keeping is essential (Mohr, pers comm., 2022).

Hortgro also provides a list of chemical residue restrictions annually. This includes which chemicals can be used and the period of time for which use must be avoided prior to harvest to ensure that maximum residue limits are not exceeded at harvest. The list is comprehensive and market specific, providing a valuable tool for producers (Hortgro 2022).

Van Klinken et al. (2020) investigates the effectiveness of combined independent phytosanitary risk mitigation practices to maintain trade across export markets. The factors considered are reduction of pest exposure, host vulnerability, infestation rate and establishments. The methods used to assess protocols place focus on how risk is mitigated but not how the protocols themselves are implemented. The methods in which the abovementioned factors are achieved do not take into consideration their effect on the environment. This paper claims that 82% of protocols for phytosanitary pest risk mitigation included monitoring prior to harvest indicating that this practice is viewed as pertinent to producers and further stressing the importance of a systems approach. Van Klinken et al. (2020) concludes that a systems approach is effective across produce types, internationally for phytosanitary pest risk mitigation. It does however open up questions as to what financial cost are they being implemented relative to their benefits.

## 2.5 Pest management and IPM

Integrated pest management (IPM) is considered a difficult term to define due to its vast application methods and differences between crops and geographical area. There are however set inclusions for a pest management system to be considered IPM. These include cultural practices; some form of monitoring or agro-ecosystem analysis and selective-pesticide use according to set pest and disease thresholds (Becker et al., 2015). IPM is an integrated method to pest management that holds sustainability in foresight. Practicality, environmental and human health, effectivity and economics are all borne in mind and considered forming the pillars of this practice (Dent, 1995). For a pest management strategy to be viable it must be biologically, technically, and financially feasible. It must also be conductible within legal practice of both the country of production and in which the produce will be sold. Taiwan is a sensitive market with zero tolerance for certain pests, whilst European and United Kingdom markets have strict compliance measures in terms of chemical usage and environmental sustainability. Taking this into consideration, the likelihood of being able to send fruit to an alternative market if rejected for Taiwan, depends on the management program implemented and the reliance in chemicals to control pests.

Integrated Pest Management (IPM) holds the key here by integrating use of different methods to manage pests reducing the reliance on chemicals by treating problems holistically. In this manner pest pressure is first addressed preventatively, or in some cases where possible, curatively, through various methods. Chemicals are used when alternatives are not sufficient. This ultimately reduces the reliance on chemicals. IPM is a globally accepted practice which has gained popularity and been further researched and developed continuously since its first clear public discussion and definition at a United Nations symposium in Rome in 1965 (Kogan and Bajwa, 1999).

### 2.5.1 Cultural and physical management

Cultural management methods are those in which the orchard environment is manipulated in order to make it less attractive to pests for entrance, feeding and reproduction. These methods are to a large extent indirect. These methods vary greatly not only with the type of pest but also the crop in question (Stoner et al., 1986).

There are active, passive and miscellaneous forms of physical pest management. Passive management includes approaches such as mulching under trees and the spraying of oils on fruit. Active management techniques include the physical removal of pests such as the use of air jets to blow pests out of the stem end of apples (Thakur et al., 2021). Pryke and Pringle (2008) claim that the use of physical methods postharvest that kill pests on fruit such as the use of controlled atmosphere storage is an effective method for sanitation for phytosanitary export markets. This does however assume that these markets will continuously accept presence of these pests on fruit so long as they are no longer living. Physical and cultural pest management methods are often praised for their perceived low environmental impact. Often however, these methods are labour intensive.

### 2.5.2 Biological management

Biological control of insect pests incorporates the use of natural predators to manage pest pressure within a crop. A key component of this is to ensure that the environment is favourable for predator populations to thrive. If predators are not present or are present but in insufficient quantities, additional predators can be released in the area. However, it is advisable to make use of naturally occurring predators in the area, as they will be adapted to the prevailing conditions. Examples of natural predators currently at work in the EGVV area include the parasitic wasp (*Aphelinus mali*) for the management of woolly apple aphid and various predatory mites, most commonly *Neoseiulus californicus*, for the management of phytophagous mites. More modern developments such as the Sterile Insect Technique (SIT) have been developed for the management of fruit fly (*Ceratitis*) which could hold promise for use on other pest species with further research and development (Addison et al. 2015).

Another example of biological control is the use of entomopathogenic fungi to control pests. These products are currently available for codling moth, mealybug and mite in the area. The problem however arises when coverage is problematic such as that seen with mealybug that shelter in the cracks of bark or in the stem end of fruit. The microclimate in the orchard can also negatively affect efficiency should abiotic factors not be in ideal ranges for the fungi's survival (Rai et al., 2014).

### 2.5.3 Chemical management

Chemical pest control is commonly perceived as the ideal method due to its visible effectiveness, versatility and relative ease to use in terms of time and physical labour in most cases. Over time, pressure from consumers and greater understanding of environmental impact of pesticides has led to a demand for reduced and more responsible use. Although this has become a focused topic amongst role-players, the necessity of chemical use to combat pests and diseases and maintain high crop loads to feed an ever-growing population has remained. The concept of IPM does not exclude chemical use but rather incorporates into a plan alongside alternative methods to enhance responsible and minimised use. Another point of great importance is that this amalgamation of various pest and disease methods aims to aid in resistance development due to continuous spray use of closely related formulations (Dent, 1995).

**2.5.4 Barriers to IPM implementation**

Vommi et al. (2013) investigated the barriers to adoption of IPM in corn crops in the United States of America. 98% of farmers were in agreement that typical IPM practices were important for optimal pest, disease and weed management and more than half of the respondents noted their concern of the effect of chemical usage on human health. A mere 9% were confident in their ability to identify pests and diseases in the field, hampering their ability to exercise appropriate control. This indicates that within the crucial first step of monitoring, there is a lack of farmers' knowledge. This puts the entire system at risk. This could be one of the barriers seen in South African agriculture too. This could however be overcome with education and training.

Barriers to adoption of IPM systems according to Dent (1995), include the following:

- the perceptions of farmers
- how compatible IPM is with the current farm system
- the degree of complexity
- how readily it can be adapted to current on farm trials
- the observable effect of the IPM strategy

It would be expected that a farmer would make use of a small-scale trial to observe the effect of implementing a change such as this one. However, the effects observed on this scale within a short timeline may not be overwhelming. In current conditions however, additional pressure to make use of IPM strategies has been exerted. This has been through regulatory bodies involved in commercial fruit sales both locally and internationally, as well as widespread awareness created by media.

**2.5.5 Monitoring as part of an IPM system**

In 1998 the nineteenth annual congress of the Brazilian Entomological Society gathered and was reported on by Kogan and Bajwa (1999). At this time, it was concluded that integrated pest management (IPM) is a recognized and widely accepted system for pest control and South Africa is no exception. This is due to both its efficiency in pest and pathogen management as demonstrated by Grasswitz (2019), even within small scale operations and due to compliance programs insistence on its use to enable South African pome fruit to be marketed internationally. Monitoring is an integral part of IPM, which is a key strategy adopted by pome fruit farmers in the Western Cape due to various market compliance certifications (GLOBALG.A.P. 2022). Which leads to question - why is comprehensive monitoring not being practiced?

It is crucial to the success of IPM systems that monitoring of the crop takes place to enable farmers to know when pests start to appear on the crop, which implemented methods are effective in managing the pest populations and when pest thresholds are exceeded. However, this integral part of the process is often over-looked and not conducted due to various circumstantial reasons.

## 2.6 Monitoring practices and pests on apples in South Africa

Many monitoring methods have been developed and implemented to serve a variety of crops. Examples of these include Williams and Victoria's (2018) apple and pear monitoring system in which five trees' flower clusters, leaves and fruit are inspected. It is debatable however, as to how representative this method is, given that only five sample trees per orchard are used. Monitoring systems range from simple ones based on field observations such as this, to more technologically advanced such as that used by Cros et al. (2021). Cros et al. (2021) used graphical models incorporating economic drivers and more in depth ecological traits of the orchard and pests present.

Brown and Pringle's (2006) method seems more comprehensive than that of Williams and Victoria (2018), yet simple enough to be of acceptable use by farmers with varying skill levels and access to technology. This system is suitable for monitoring orchard pests and diseases simultaneously. Brown and Pringle claim that this system optimises chemical usage through early pest and disease detection. Coined as the 25-tree per 2-hectare system, it is a respected method in South Africa, where it was developed.

25 trees per two hectares are marked, evenly spread through an orchard and used consistently for monitoring. Five shoot tips, five fruit clusters, the stem, half of the tree's leaf axils and one outside and one inside leaf per tree are inspected at least biweekly. This allows for the monitor to get an accurate representation of the whole orchard and an opportunity to identify any pest or disease and its damage regardless of which part of the tree it typically affects. Brown and Pringle's system additionally includes the use of traps for codling moth, along with fruit fly and bollworm traps. These traps are typically monitored on a weekly basis.

Dent (1995) suggests that monitoring data not only be used for current season management decisions but also to analyse the history of a field or orchard. This then gives a historic overview to aid in getting to the crux of a pest or disease issue and analyse its trends. Monitoring is also key to assess the effectiveness of currently implemented pest management strategies.

There is, of course, a monetary cost to monitoring crops, particularly when human capital and time are considered. Regardless of the extensivity of technological reliance for a chosen monitoring system, time is money and will be necessary for any method, to varying degrees. According to Brown (pers comm., 2022), for an individual to monitor a hectare, based on the 25 trees per 2-hectare system, it takes approximately 30 minutes. This needs to be repeated biweekly, in addition to weekly trap monitoring taking 15 minutes per hectare. At the current minimum wage of R25,42 this equates to a minimum of R51,24 per hectare per month. This cost would be incurred throughout the growing season, from flowering till harvest. Over this approximate six-month period, the cost equates to R307,44 per hectare. This cost seems almost negligible when considering the potential savings in pesticide use and potential improved fruit quality. One would then need to consider the number of hectares to be monitored. Brown (pers comm., 2022) claims a monitor can manage a maximum of 35 hectares.

### 2.6.1. Codling moth (*Cydia pomonella*)

*Cydia pomonella*, commonly known as codling moth, is a key pest affecting pome fruit in most countries. The adult female moth lays flat, oval eggs on the fruit and leaves of apple trees. The larvae hatch and feed on the fruit, burrowing into them and leaving a trail of frass (Prinsloo and Uys, 2015a). Once mature, the larva, with a pink body and brown head, leaves the fruit to pupate in crevices in the bark of the tree. It later matures into a 10-15mm grey speckled moth with a characteristic copper band at the forewing tips.

Codling moth is one of the most extensively monitored pest in pome fruit production in South Africa. Monitoring methods consist of pheromone traps and orchard and fruit inspections. Alternative methods for both codling moth monitoring and management have been developed due to the level of importance of this pest and its development of resistance to chemicals (Riedl et al. 1998).

Pheromone traps are typically monitored on a weekly basis. They consist of a delta trap and pheromone lure replaced on a schedule indicated by the manufacturer. The presence of three or more moths or, one to two moths for two consecutive weeks, indicates to the farmer that chemical intervention need take place. Due to the development of resistance to chemicals, alternative methods of management have become common practice according to Balaško et al. (2020). Most notable and highly effective is the technique of mating disruption. Monitoring plays a key role in ensuring that the various management strategies for this pest are working optimally and to ensure the correct timing of control measures. Timing of chemical sprays is of utmost importance as this will determine the population size of the following generations, and consequently the damage they are capable of inflicting on the crop. It should be noted that the sanitation of the orchard and ensuring there are no nearby sources for reinfestation are also key to effective management. Monitoring should therefore additionally focus on being vigilant of the surrounding area.

### 2.6.2. Woolly apple aphid (*Eriosoma lanigerum*)

*Eriosoma lanigerum*, known to producers as woolly apple aphid, originates from North America but is now a common apple pest across the world. Woolly apple aphid has two forms of reproduction, nymphs are either born live or hatch from white, oblong eggs. The nymphs are mobile and reddish-brown in colour, covered in a wax layer. The adults retain their colour with some females being winged and therefore more aerially mobile. This aphid lives in colonies and is harmful to all parts of the trees permanent structures causing galls (Prinsloo and Uys 2015c).

Woolly apple aphids overwinter underground creating lesions on tree roots, then moves up into the tree from October until after the fruit has been harvested. It is crucial to monitor trees to firstly observe the movement from roots to above ground tree parts and secondly to ascertain the effectiveness of soil applications for control prior to this migration. This will determine if additional measures should be taken, such as the pruning and removal of affected wood (Prinsloo and Uys, 2015c).

In the EGVV area, *Aphelinus mali*, a parasitic wasp species is found abundantly. The wasp parasitises above-ground colonies of woolly apple aphid, aiding in control. This also needs be monitored to influence management practices. Monitors can typically identify if a colony has been parasitised either by observation of holes in mummified aphids or by pressing the aphid between the fingers and noting if a dark red liquid is excreted (Heunis 1995). In some instances, one could also see with the naked eye, a hole within the aphid indicating parasitism. Determining how effectively *A. mali* is working is also key to planning chemical control measures as to maintain the balance between chemical and biological control, according to Bangels et al. (2021). They showed that poor timing of spraying, particularly during the *A. mali* populations first flight after overwintering in woolly apple aphid mummies, significantly reduced biological control. How could EGVV apple growers better plan their spray regime around this with the aid of monitoring to ensure the highest possible benefit from this ecosystem service?

### 2.6.3. Mealybug (*Planococcus citri, Pseudococcus longispinus* and *Pseudococcus viburni*)

According to Pringle et al. (2015), three species of mealybug are typically found in Western Cape apple orchards. They are, *Planococcus citri, Pseudococcus longispinus* and *Pseudococcus viburni*. For the purpose of this thesis, they will simply be referred to as their grouping, mealybugs. The obscure mealybug, *P viburni*, originates from Australia and the Americas, although this is debated. In the egg and nymph phase, *P. viburni* cannot be distinguished from *P. citri* or *P. longispinus.* The adult females are white and oval shaped with *P. viburni* appearing more compact with thin but short filaments and *P. longispinus*, larger and two longer filaments. Males are winged and can travel aerially (Prinsloo and Us 2015b).

Female mealybugs are wingless and this is the life stage that a monitor would typically find on the apple tree. They are found on all parts of the tree and therefore monitored for on both the shoot tips and fruit. Monitors will also typically see them in the crevices of the tree bark. When monitoring fruit specifically, monitors need to cut open the fruit to the core, as the mealybug females will burrow into the fruit through the calyx end of the apple (Prinsloo and Uys, 2015b).

Mudavanhu et al. (2011) investigated alternative *P. viburni* monitoring methods in an attempt to address the mealybug pressure increases in Western Cape pome fruit orchards. According the Mudavanhu et al. (2011), these increases were largely due to a lack of monitoring and consequently no knowledge of action thresholds being exceeded and requiring intervention. A method of monitoring was developed whereby pheromone traps were checked for flying males and three fruit per tree were cut to scout for flightless females. Due to these observations, management practices could then be swiftly implemented resulting in better mealybug management. It was claimed that this monitoring method was more efficient in terms of time, accuracy and labour requirements. This may be the case if one were to monitor exclusively for mealybug, however, when implementing a monitoring program to scout for multiple pests, a more standardized system involving practices that allow for monitoring multiple pest species would be more efficient in terms of the above mentioned three aspects. The importance of monitoring in general however, is still highlighted in this paper showing a correlation between measurement through observation of pests in orchards and being in a position to manage what you have observed timeously.

### 2.6.4. Phytophagous mites (*Panonychus ulmi, Tetranychus urticae* and *Bryobia rubrioculus*)

There are three predominant species of phytophagous mites in the EGVV area on pome fruit. They are *Panonychus ulmi* (European red mite), *Bryobia rubrioculus* (bryobia) and *Tetranychus urticae* (two-spotted mite) (Pringle and Campbell 2016). Although *Tetranycus cinnabarinus* (red spider mite) is also present, it is classified tosgether with two-spotted mite due to its closely related physical features. They will be referred to under the group title of mites, for the purposes of this thesis. According to Pringle and Heunis (2006), phytophagous mites feed on the leaves of pome fruit trees reducing their photosynthetic ability by causing chlorosis that could later develop into leaf scorching. This is rarely a major concern for local growers on apple trees specifically. However, the mites lay their eggs on the apples creating phytosanitary issues for export markets (Mohr, pers comm. 2022).

Pringle and Heunis (2006) claim that prior to the mid-90s apple growers relied on acaracides to attempt to manage mites. This is no longer common practice as more emphasis has been placed on predatory mites, such as *Neoseiulus californicus*, for management. This method greatly improved phytophagous mite management, suppressing numbers more so and for longer time periods than the use of acaracides. Pringle and Heunis (2006) analysed the cost benefit of this and found the use of *N. califonicus* to also be more financially viable.
Both mites and their predators are monitored for on the interior and exterior of apple tree leaves. Their eggs, however, are also commonly found on the fruit which ultimately poses a problem for apple exports.

## 2.6 Conclusion

The long standing South African pome fruit industry is a big player in the global market. The total production area and percentage fruit exported is growing in order for farmers to gain the best returns. This is also leading to an increasing focus on the African and Asian markets.
There are however threats to farmers in terms of market access. These are largely summed up as chemical usage in terms of which chemicals are used and when, as well as phytosanitary pests presence. Currently, the South African pome fruit industry is experiencing difficulty in maintaining market access to some Asian markets. The risk of market closure due to phytosanitary pest presence is a recurring issue.

To address this risk, monitoring as a first key step in an IPM program is important. IPM has long proven its effectiveness and relies on different management practices, being cultural, physical, biological and chemical, to ensure pests remain at acceptable levels. For phytosanitary pests however, a zero-tolerance approach is needed. In this way, monitoring acts not only as an indicator for control measure decision-making, but also can be used to identify orchards with fruit “safe” to send to markets with specific requirements.

There is little research available to assess how effective of a method monitoring would be to mitigate risk for special markets, however a solution needs to be found in order to maintain these markets. This thesis will assess the effectiveness of monitoring as a risk mitigation strategy by analysing a case in which this has been undertaken. It will also assess the economic effects of implementing such practices in comparison to relying on aggressive pesticide use for risk mitigation. In this way, both environmental and economic sustainability pillars will be addressed.

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# 3. Case study - A commercial potential risk mitigation strategy for Fuji apples in the Taiwanese market through monitoring.

## 3.1 Introduction

Fruitways is a pome fruit production, packing and marketing entity based in the Elgin, Grabouw, Villiersdorp and Vyeboom area. This area is also often referred to as the EGVV. Fruitways owns five pome fruit farms in the area and have 42 alliance growers. Alliance growers have privately owned and managed farms but pack and market their fruit through Fruitways. Alliance growers also receive additional information and assistance through research and innovation and compliance through the Fruitways group. Alliance growers' farms are situated in the EGVV area, as well as the Hemel en Aarde valley and Rawsonville.
Typical pests on pome fruit in the EGVV area that are problematic for export to special markets include codling moth (*Cydia pomonella*), mealybug species (*Pseudococcus viburni* and *P. longispinus*), woolly apple aphid (*Eriosoma lanigerum*) and phytophagous mites (*Panonychus ulmi* and *Bryobia rubrioculus).*

At the time of writing, much focus was placed on the packhouse side of the pome fruit export chain. Risk mitigation strategies include codling moth traps at the packhouse, floor to ceiling plastic curtains at entrances and fruit sample inspections on arrival. In prior seasons a 600-fruit sample taken at the packhouse on delivery of fruit was taken and inspected internally and externally for each orchard. The observations made were used to assign orchards to markets. However, this did not sufficiently resolve the problem of pest interception. Phytosanitary pests continued to be intercepted along the packing line. Operations in the packhouse were therefore halted and logistical functions negatively impacted.

Phytosanitary pest presence was still at times undiscovered and later intercepted in the importing country. This led to increased pressure for compliance and temporary market closures. Less focus was placed on the farm side of the chain. This resulted in little effective and enforced pest information gathering of the fruit before it leaves the farm gate. This led to Fruitways developing a strategy to move the packhouse mitigation strategies to be a second line of defence and place more focus on the primary issue, the farm. With this method, there could be a clearer picture of what is happening in the orchard and a pre-indication of what pests would most likely be present in a consignment prior to arrival at the packhouse. The data gathered would also be valuable to identify orchards predisposed to certain pests. This could in turn allow for data analysis to find causal factors to improve future planting and management decisions.

A program consisting of codling moth trap monitoring, biweekly scouting and a preharvest fruit damage assessment to be conducted by each grower for each Fuji orchard was compiled. Good agricultural guidelines were compiled to guide growers based on previous research and correspondence with industry experts. The following is a compilation of the methods used and analyses of the data gathered, and observations made from the first season's data after implementation of this system. This study aims to assess how effective this system was at mitigating risk of phytosanitary pest interception for special markets, and what key insights were gained in this case.

## 3.2 Materials and methods

The study was conducted across both internal and alliance growers' farms of the Fruitways group. For this study the applicable area stretches across the EGVV as well as the Hemel en Aarde Valley. 264 Fuji orchards, each considered an experimental unit, across 38 farms were used from this area.

### 3.2.1 Data collection

Preceding the pome fruit harvest season, from the end of May 2021 through to October 2021, each orchard was visited. Notes were taken of the orchard environment and tabulated. Factors identified or scored included the following:

- Fuji sub-variety
- Orchard age
- Orchard size
- Row direction
- Slope aspect
- Traffic intensity around the orchard
- Dust severity
- Type of irrigation
- Whether or not netting was used
- What surrounds the orchard?
- Presence of cover crops and where?
- Types of cover crops used if any?
- Cover crop management
- Type of organic material on the ridge if any

- Any additional notes

Template data sheets for recording weekly codling moth trap counts (Appendix A), bi-weekly (every second week) scouting data (Appendix B) and preharvest fruit damage assessment data (Appendix C) were drafted and distributed via email and hard copy to participating farmers. They were completed per orchard, according to a schedule for each and sent back to compile the data into an Excel database. Trap counts were recorded from week 42 in 2021 to week 20 in 2022. Biweekly scouting commenced at the end of September in 2021 and ceased when the preharvest assessments were done, two weeks before harvest as per industry guidelines.

The 25-tree per 2-hectare monitoring and scouting system as described by Brown and Pringle (2006) was used. The size of an orchard in hectares was multiplied by 12.5 in order to calculate the number of trees to be monitored in accordance with this system. This number of trees were marked, evenly spread throughout the orchard, avoiding the outside rows. The trees were marked in this way to get a representative indication of the pest pressures across the entire orchard. Four monitoring and scouting training sessions were provided to monitors elected by participating farmers. The final session entailed a practical and written exam. This process extended from October 2021 to February 2022. Training was provided by Lesley Brown, a pest and disease monitor training service provider. Participating farms who did not send a monitor for this training were visited by myself and received training on their respective farms. Additional informal training was provided prior to this. Training included the identification of prevalent pests and diseases in the area as well as their damage. Monitors learned the timing of the various life stages of specific pests. In the orchard, the practical aspects of scouting, preharvest assessments and trap maintenance and checks were practiced.

*Codling moth trapping*

Delta traps were placed in the orchard at a minimum density of one trap per hectare or part thereof. Growers could opt to place additional traps in codling moth hotspots such as sections of orchards bordering bin stacks. These traps were monitored on a weekly basis by counting the number of moths caught per trap. If any moths were found on a sticky pad placed in the trap, they were removed after recording the catch. Catches were recorded in the form, appendix A. Delta traps work by using artificial pheromone lures placed in the trap on the sticky pad. These lures were replaced every six weeks as per manufacturer guidelines.

*Biweekly scouting*

The following was inspected on the marked trees according to the biweekly scouting schedule and completed on the scouting form, appendix B:

- Five shoot tips – inspected for codling moth larvae and mealybug. Both the pest itself and damage inflicted by the pest was noted. 10 to 15 centimetres from the terminal end of a shoot was considered the shoot tip. The shoot tip infestation rate was calculated for each pest by dividing the total number of shoot tips with damage or presence in the orchard with (five times the number of monitored trees), and then multiplying by 100.
- Five fruit clusters – inspected for mites, phytophagus mite eggs, codling moth, and mealybugs. Both the pest itself and damage inflicted by the pest was noted. A cluster was considered a unit regardless of how many fruit within the cluster had a particular pest presence or damage. The fruit cluster infestation rate was calculated for each pest by dividing the total number of clusters with damage or presence in the orchard by (five times the number of monitored trees) and then multiplying by 100.
- One outside, and one inside leaf – inspected for mites and predatory mites. Only the presence of the pest or predator itself was noted. On cooler days, monitors cupped the leaves within their hands and breathed on them to encourage movement of mites if present to be more visible. The mite and predator infestation rates were calculated for each by diving the total number of leaves with presence on the orchard by (two, multiplied by the number of monitoring trees) and then multiplying by 100.
- Half of the tree's leaf axils – inspected for woolly apple aphid colonies and an indication as to whether they had been parasitised. If woolly apple aphid was present on a tree, it was indicated so. The number of colonies present was not recorded. If multiple colonies were present and at least one was parasitised, it was indicated that the tree was parasitised. Parasitised and unparasitised woolly apple aphid infestation rates were calculated by dividing the total number of trees within the orchard with presence by the number of monitoring trees and multiplied by 100.

*Preharvest fruit damage assessment*

The procedure for the preharvest fruit damage assessment, conducted two weeks before harvest, was done as follows: Five randomly selected fruit clusters in each marked tree were inspected. The collective number of fruits within the five clusters was recorded. Each fruit was considered a unit. Each fruit was inspected externally for mealybug, woolly apple aphid, codling moth damage and mite eggs. One fruit per cluster was split down the core to inspect internally for mealybug. The total number of fruits with external pest presence of each kind in the orchard was then divided by the total number of fruits inspected and multiplied by 100.

This value represented the percentage infestation of each pest type for the orchard. The total number of fruits with internal mealybug presence was divided by the number of clusters inspected and multiplied by 100 to represent the total percentage internal mealybug infestation for the orchard. This data was captured on the preharvest assessment form, appendix C.

*Packhouse delivery inspection*

At the time of delivery of harvested fruit at the packhouse, a random 600-fruit sample was taken, and each fruit inspected externally for mite eggs, woolly apple aphid, codling moth damage and mealybug. Each fruit was then cut open down the centre, from stem to calyx, to inspect internally for mealybug. One sample was taken per orchard. Data from this packhouse delivery inspection was available for monitored, partially monitored and unmonitored orchards. Monitored orchards refers to orchards monitored (codling moth trap monitoring and bi-weekly scouting) consistently over the growing season, partially monitored refers to orchards which were monitored inconsistently, and unmonitored orchards refers to orchards which were not monitored at all but more aggressively sprayed with pesticides to attempt to reduce phytosanitary pest pressure. The allocation of these treatments (whether to monitor or not) was determined by the growers' personal preferences. There were 84 consistently monitored orchards, 65 partially monitored orchards and 57 unmonitored orchards.

### 3.2.2 Data analyses and comparisons made

The orchard environmental data was analysed using ANOVAs with the GLM Procedure and further t-grouping to determine correlation between pest presence for each phytosanitary pest and the orchard environmental aspects recorded.

To assess how well naturally occurring predators in the area aid in managing pests as an ecosystem service, monitoring data was used to analyse the pest-predator relationship for phytophagous mites and the predatory mite, *Neoseiulus californicus*, as well as woolly apple aphid and the parasitic wasp, *Aphelinus mali*. The biweekly monitoring data from all monitored orchards was used. Average percentage infestation for orchards with presence of each and the percentage of monitored orchards with presence was calculated and plotted on a line graph for each. The data points from week 47 to week 11 were used. Week 11 was the final week of biweekly monitoring, hence no further data was available.

A comparison of packhouse delivery inspection data for monitored, partially monitored and unmonitored orchards was done to indicate if performing monitoring consistently and using the monitoring data to inform further control measures, affected the final phytosanitary pest presence at harvest. This was done by using the Kruskal-Wallis test comparing the grouped data for each pest as the data was not normally distributed. Each orchard was considered a repetition of its respective treatment.

The pest detection efficiency of a 600-fruit sample at the packhouse versus a preharvest assessment in the orchard before harvest was compared. The percentage infestation approximation determined via these two methods was tabulated side-by-side for each phytosanitary pest for each orchard. 88 orchards were included due to having both a preharvest assessment and 600-fruit sample completed. A bar graph was compiled to compare the frequency of occurrence and average severity of each pest for each method.

Prior to commencement of the implemented risk mitigation strategy, two seasons' data was to be used for analysis. However, due to the success of this method, the company mandated the use of it for an orchards fruit to qualify for consideration for export. Therefore, for comparisons made between monitored and unmonitored orchards only the 2022 seasons data was used. The same applies to the analysis of the pest-predator relationships with regards to woolly apple aphid and mites.

## 3.3 Results and discussion

The data gathered are presented and discussed below in order to gain clarity on the pest detection effectiveness of the implemented monitoring system and to establish where further input could be given. Specific orchard environmental factors that were associated with significantly higher or lower pest presence for each pest are identified and discussed. An in-depth look at the seasonal cycle of two pest species and their respective predators in the orchard over the 2022 season is presented. The effect of management practices influenced by monitoring throughout the season, on pest severity at harvest (as determined by the preharvest fruit damage assessment), is analysed and discussed below. Lastly, a comparison of monitoring-based risk mitigation methods is done to determine if a packhouse sample or in-orchard monitoring provides more reliable information when assigning orchards to a market for export.

### 3.3.1 The orchard environment and effect on pest presence

Of the identified orchard characteristics, the following showed a significant influence of each of the key pests of focus in this study. This was done in order to attempt to identify orchards which were predisposed to certain pests due to their management and environmental factors. With this information it was hoped that future management and planting decisions could be made to best situate Fuji orchards for more lucrative markets by minimizing risk in terms of phytosanitary pest presence.

**Table 3.1** Environmental factors shown to have a significant impact on either increased or decreased pest presence.

| Pest | Significantly less frequent | Significantly more frequent |
|---|---|---|
| Codling Moth | | Bordering a loading-zone |
| | Microjet irrigation | Drip Irrigation |
| | | Orchard bordering a public road |
| Mealybug | CG and M9 rootstocks | M7 rootstocks |
| | | Orchard size larger than 2 hectares |
| | No cover cropping | Cover cropping in both the tree and work row |
| | | Orchard bordering veld |
| | | Orchard bordering fynbos |
| Mite | | Orchard bordering fynbos |
| | | Orchard with a windbreak |
| | | Orchard bordering a river |
| Phytophagous Mite eggs | | Orchard bordering veld |
| | | Orchard bordering fynbos |
| | Suprema variety | Aztec variety |
| Woolly apple aphid | | High traffic past orchard |
| | No dustiness around orchard | High dust severity |
| | | Orchard bordering fynbos |
| | Benny Shogun variety | Older fuji varieties (Irradtiated etc) |
| | NE-SW row direction | N-S and NNE-SSW row directions |

The reliability of the results needs to be improved by including additional seasons pest presences in the same orchards over multiple seasons. Observations may differ from season to season due to cofounding factors such as orchard microclimate. While this data provides a starting point for further research it will not be further discussed for the purposes of answering the research question presented.

### 3.3.2 The pest-predator relationship

3.3.2a) Phytophagous mites and *Neoseiulus californicus*

The percentage of orchards that were infested by phytophagous/pest mites generally increased from week 51 to week 11, with declines occurring weeks 3 to 5 and again weeks 7 to 9 (Fig. 1.A) The percentage of orchards with predatory mites increased throughout the monitoring period. When the declines occurred in pest mites, the percentage of orchards with predatory mites continued to increase.

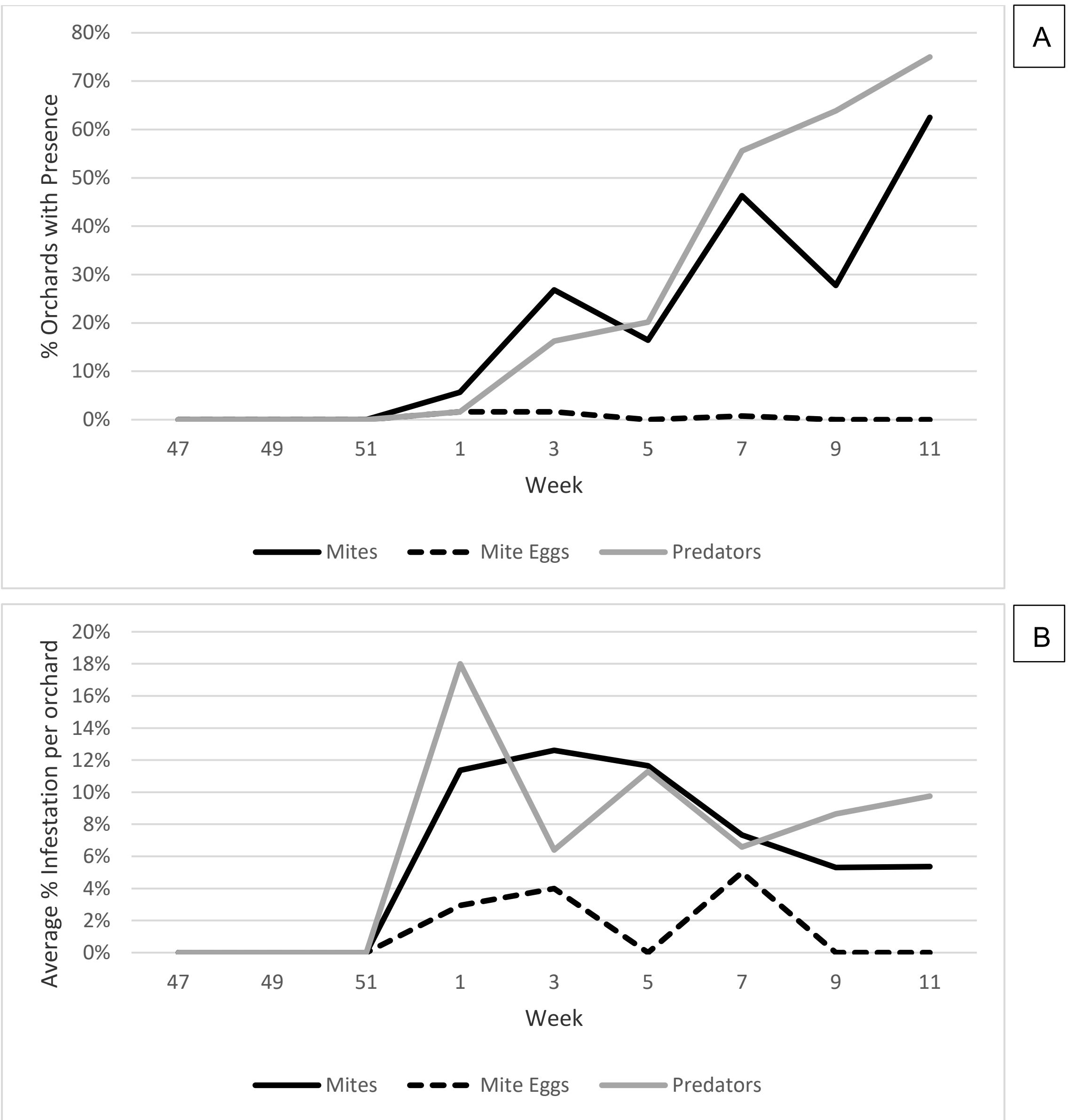


**Figure 1. A.** The percentage of monitored Fuji orchards that had mites and/or phytophagous mite eggs present from week 47, 2021 to week 11, 2022. **B.** Phytophagus mites, phytophagous mite eggs and predator populations from week 47, 2021 to week 11, 2022, expressed as an average percentage of trees infested of the trees monitored per infested orchard. The number of trees monitored per orchard was determined according to the 25 trees per two hectares system.

The intensity of phytophagous mite infestation per infested orchard was highest in week three (Fig. 1.B). However, predatory mites suppressed the rate of phytophagous mite infestation per orchard from week one onwards with a decline in phytophagous mite populations between week five and nine. The infestation rate of predatory mites was inversely correlated with phytophagous mite eggs from week three onwards. This was most likely because phytophagous mite eggs are the preferred food source for predatory mites. The predator populations continued to increase from week nine regardless of there being fewer eggs. This could be explained by the fact that phytophagous mites' movement speed decreases due to lower temperatures, resulting in them being more easily preyed upon by predators, but also by the fact that reproduction rate decreases with decreasing temperatures (Stavrinides et al. 2010).

Most phytophagous mites found in orchards were either Bryobia or European red mite species, while the two-spotted mite, or red spider mite, was absent based on leaf samples taken from various infested orchards and observed under the microscope. Predatory mites found in the area were *N. californicus*, a predator that favours mite eggs as its food source.

<u>3.3.2b) Woolly apple aphid and *A. mali*</u>

The percentage of orchards infested with parasitised woolly apple aphid (WAA) colonies increased notably from week one to eleven, while the percentage of orchards with unparasitized WAA remained relatively constant throughout the season until a decline was observed between weeks nine and eleven (Fig. 2.A).

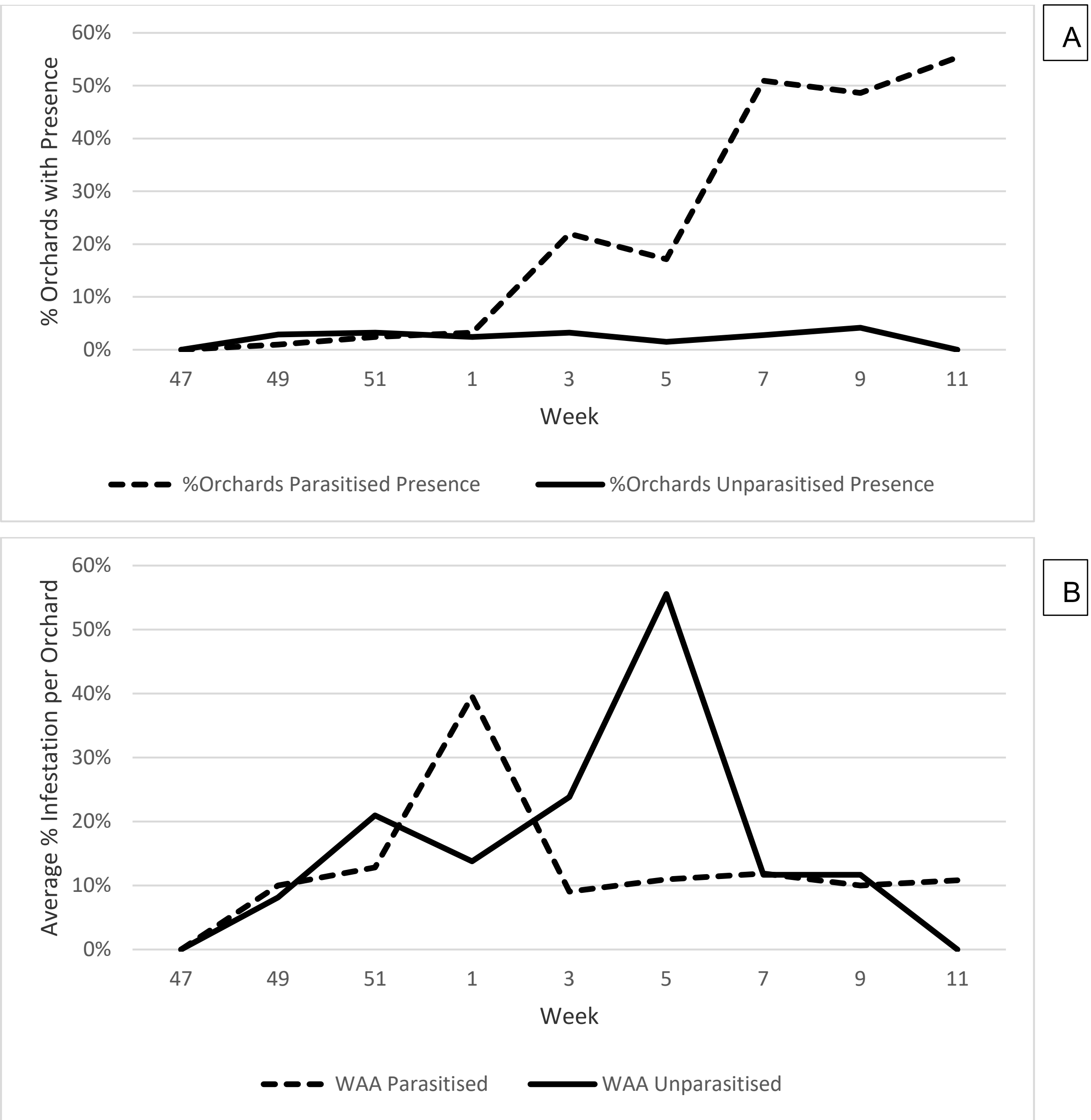


**Figure 2. A.** The percentage of monitored Fuji orchards with woolly apple aphid (WAA) presence from week 47, 2021 to week 11, 2022. **B.** WAA populations from week 47, 2021 to week 11, 2022, expressed as an average percentage of trees infested of the trees monitored per infested orchard. The number of trees monitored per orchard was determined according to the 25 trees per two hectares system.

The infestation rate in infested orchards of both parasitised and unparasitized WAA colonies increased from week 47 to 51 (Fig. 2.B). Thereafter, parasitised WAA colonies increased while unparasitized WAA colonies decreased until week one. A significant percentage of trees were infested by unparasitized WAA colonies in week five, followed by a rapid decline in these colonies towards week 11, when parasitised WAA colonies became dominant again.

The data suggests that biological control, through naturally occurring predators, could be effective in controlling living WAA colonies until week one and again later in the season between week nine and eleven. It is however important to note that the parasitized colonies are still problematic and of phytosanitary concern due to the presence of mummies on fruit.

### 3.3.3 The monitoring effect on pest severity at harvest

Orchards that were consistently monitored, partially monitored and not monitored were compared in terms of their pest severity in preharvest assessments. The results of a pairwise comparison for pest presence in the different orchards is presented in Table 3.2. Both codling moth and phytophagous mite eggs showed no significant differences across the three treatment groups. In terms of mealybug found, both internally and externally, there was a significant difference between the consistently and partially monitored treatments, and no significant difference between consistently monitored and unmonitored treatments. Woolly apple aphid was not divided into parasitized and unparasitized colonies as it was determined that in either instance, its presence on fruit was problematic for special market exports. Woolly apple aphid showed a significant difference between only the monitored and unmonitored sample.

**Table 3.2** A pairwise comparison for each pest type between each treatment group, where "A" and "B" represent samples significantly different from one another.

| Pest | Sample | Mean Infestation Percentage | Pairwise Comparison Group |
|---|---|---|---|
| Codling Moth | Partially monitored | 0,12% | A |
| | Unmonitored | 0,22% | A |
| | Consistently monitored | 0,06% | A |
| Phytophagous mite eggs | Partially monitored | 0,38% | A |
| | Unmonitored | 0,59% | A |
| | Consistently monitored | 0,27% | A |
| Internal mealybug | Partially monitored | 0,15% | A |
| | Unmonitored | 1,12% | AB |
| | Consistently monitored | 0,70% | B |
| External mealybug | Partially monitored | 0,22% | A |
| | Unmonitored | 0,83% | AB |
| | Consistently monitored | 0,45% | B |
| Woolly apple aphid | Partially monitored | 1,12% | AB |
| | Unmonitored | 0,78% | A |
| | Consistently monitored | 1,07% | B |

When referring back to spray records for each orchard and the industry guidelines for codling moth management, it was determined that all producers are largely following the same management program. There are minor differences in timing of applications of codling moth sprays due to geographical differences.

All participating growers made use of some form of mating disruption in the form of either puffers or another type of artificial pheromone dispenser. Where monitoring was not conducted, miticides were frequently found to be used. Due to no monitoring taking place throughout the season it is unknown whether or not there were predatory mites in these orchards. The active ingredients used were abamectin, fenazaquin and etoxazole (Fruitways, 2022). Mealybug is typically managed during the dormant period of the tree with prothiophos and chlorpyriphos. These applications were standard. However, mealybug was still found frequently at harvest. Significantly less so in monitored orchards indicating that knowledge of presence and pressure once fruit was present, allowed for growers to apply curative sprays, such as entomopathogenic fungi, orange peel oil and sulfoxaflor at optimal timing to reduce mealybug pressure (Fruitways, 2022).

Woolly apple aphid is treated by applying imidacloprid once every two years as a soil drench and is standard across the experimental units. There is also a large reliance on the parasitic wasp *Aphelinus mali* which is well established in the area. With monitoring in place, growers were able to assess whether or not the combination of *A. mali* and imidacloprid was sufficient for control. In the case where it was not, sulfoxaflor could be applied timeously to improve woolly apple aphid management (Fruitways, 2022).

**3.3.4 The efficiency of using a 600-fruit sample after harvest versus an in orchard preharvest assessment to assess risk**

When analysing the data on an orchard-by-orchard basis across all 88 experimental units in the sample, there was no correlation between what was found in the 600-fruit sample and the observations in the preharvest assessment. This was due to not only differing pests. The preharvest assessment was significantly more thorough and risk averse in terms of phytosanitary pests finding their way to destination markets. In only 10% of cases did the preharvest assessment overlook detrimental pest presence where it was picked up in the 600-fruit sample that resulted in disqualification for export. There were, however, three instances in which the 600-fruit sample picked up a particular pest presence that was missed in the preharvest assessment. However, these orchards would have been disqualified based on other pests found in the preharvest assessment. If only the 600-fruit sample at the packhouse was considered, 44% of high risk orchards would have been allowed for export.

Figure 3 A and B show that both in frequency of occurrence and intensity for all pests, the orchard-based preharvest assessment detects considerably more pest presence than the 600-fruit sample. More is being missed and therefore increasing the risk of interceptions, should the 600-fruit sample method alone be used. One exception occurs in the case of codling moth detection, where the frequencies are equal. However, the detections seen for codling moth for the two methods were for different orchards.

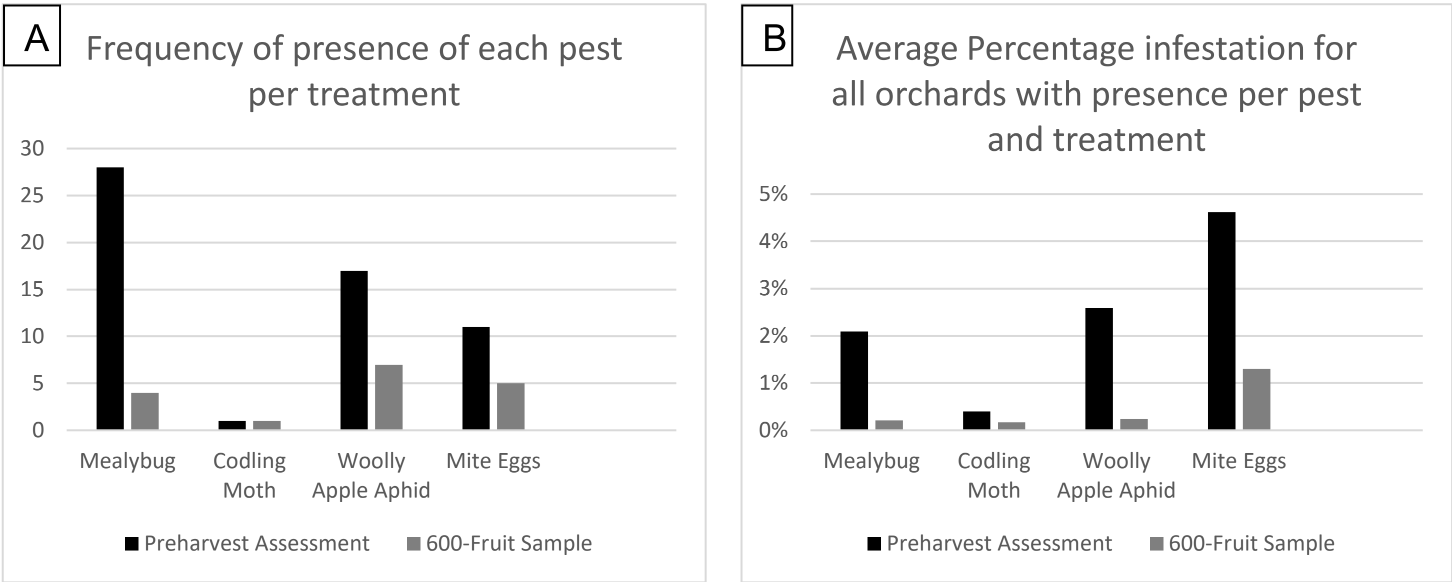


**Figure 3.A.** The number of orchards with a particular phytosanitary pest presence at the preharvest assessment and 600-fruit packhouse sample inspection. **B.** Percentage infestation of each phytosanitary pest in infested orchards detected during the preharvest assessment and the 660-fruit packhouse sample inspection.

A 600-fruit sample on arrival at the packhouse is therefore insufficient to truly gauge the presence of phytosanitary pests in an orchard. The sample is not representative enough to give a clear picture of the entirety of the orchard, where certain parts of the orchard could be more severely affected by pests than others. This could be improved with a larger sample size, including more fruit. A preharvest assessment in the orchard considers the entire orchard and provides the most accurate insight as fruit is sampled from trees across the area.

## 3.4 Conclusion

This study aimed to answer the question - how effectively can a pest monitoring program serve as a method to mitigate risk and secure special market access for export Fuji apples in the EGVV production region as the largest contributing pome-fruit producing area in South Africa?

Key findings include the following - Either monitoring on a fixed schedule or implementing an extensive spray program results in significantly lower mealybug pressure, while woolly apple aphid presence was best managed following a regular monitoring program. This shows that a holistic monitoring program must be followed strictly to improve an orchards probability for being approved for export. Predatory mites proved to be an effective control measure for phytophagous mites in the 2022 harvest season. This showed their efficiency as an ecosystem service and further encourages producers to be mindful of maintaining an optimal orchard environment for these predators to thrive. The parasitic wasp, *A. mali*, while parasitising a significant number of colonies, did not manage to effectively control woolly apple aphid colonies in the 2022 season. Additionally, although many colonies were parasitised, their presence on fruit is still problematic for special market access. This prompts the search for alternative biological methods that remove the colonies completely from the fruit. A 600-fruit sample taken post-harvest proved ineffective compared to a pre-harvest assessment as it shows only a small part of the full orchard's picture. The packhouse inspection sample cannot be relied upon solely to make an orchard's market allocation but is still useful as a second line of defence.

A number of limitations influenced this study. A typical experimental design with an equal number of repetitions per treatment for each area of data analysis would have been ideal. Furthermore, the use of a randomised block design trial layout would have resulted in improved reliability of statistical results. However, due to the nature of the scenario where growers could opt for which methods to follow in the 2022 harvest season, as well as the naturally differing geographical areas in which growers were based, made it impossible. Other limitations include, at times, a lack of co-operation from growers. This was mainly attributed to prioritizing labour for picking during peak harvest times and therefore not having monitors available to complete their monitoring tasks. In some cases, growers did not see the value in monitoring and were therefore reluctant to participate. This did however provide valuable control groups for research comparisons and statistical analyses.

Potential future research could be aimed at doing extended studies to see how the results produced here are influenced seasonally, and incorporating micro climatic conditions effect on each pest. Comparing monitoring methods used and resultant export rejections of different systems within different groups could also prove useful to develop the most efficient industry standard.

This research shows that monitoring using the suggested system provides meaningful information on phytosanitary pest presence and pressure in orchards. This information can then be used to make vital pest management decisions and more accurately assign orchards to appropriate markets. It also provides an indication of how efficiently current management methods, such as the use of predators, progresses through the season. Overall, this pest monitoring program served as an effective method to mitigate risk and secure special market access for export Fuji apples in the EGVV area.

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# Appendix A

**Monitoring Form - Trap Counts**

**Farm:_________________________ Monitor:_________________ Date:____________________________**

| | | **Codling Moth** | |
|---|---|---|---|
| **Block nr.** | **Cultivar** | *Trap code* | *Nr.* |
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# Appendix B

## Monitoring Form - Scouting

**Farm:** ______________________ **Monitor:** _______________ **Block nr.:** _____ **Cultivar:** _____ **Date:** __________

| | | | Tree nr. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| **5 Fruit clusters** | *Codling Moth* | Nr. of clusters | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Mealybug* | Nr. of clusters | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Spider Mite* | Nr. of clusters | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Other* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **5 Shoot tips** | *Mealybug* | Nr. of shoot tips | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Codling Moth* | Nr. of shoot tips | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Other* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **2 Leaves** | *Spider Mite* | Nr. of leaves | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Predators | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Leaf axils** | *WAA* | Damage/Pest | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Parasitised | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Appendix C

**MB/WL**: Mealybug/Witluis
**CM/KM**: Codling Moth/Kodling Mot
**WAA/BL**: Woolly Apple Aphid/Bloedluis

*Inspect 5 fruit clusters per monitoring tree and cut one fruit per cluster
%Damage = Nr fruit damaged divided by the number of fruit inspected

Farm:________________________________ Block Nr:__________ Date:__________________

| Tree Nr: | Nr Fruit: | Nr MB/WL | Nr MB/WL (inside) | Nr CM | Nr WAA/BL | Nr Mite | Nr Mite Eggs |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |
| 9 | | | | | | | |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | |
| 13 | | | | | | | |
| 14 | | | | | | | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | | | | | |
| 22 | | | | | | | |
| 23 | | | | | | | |
| 24 | | | | | | | |
| 25 | | | | | | | |

| Total Fruit | %MB/WL | %MB/WL (inside) | %CM/KM | %WAA/BL | %Mite | %MiteEggs |
|---|---|---|---|---|---|---|
| | | | | | | |

# 4. Cost and revenue assessment of monitoring Fuji apple orchards

## 4.1 Introduction

Pesticides are frequently used in agricultural to manage pests. However, their use has the potential to have serious negative effects on the environment, such as soil, water, and air pollution, as well as biodiversity loss. Contamination of soil and water is one of pesticides' biggest effects on the environment. Pesticides can linger in the environment for many years and can infiltrate the soil by spray drift, runoff, or leaching. As a result, pesticides may build up in the soil, reducing its fertility and harming soil-dwelling species, as well as microbial ecosystems. According to Carvalho (2013), pesticides can contaminate water sources and have hazardous effects on aquatic life as well as people who drink contaminated water.

The extinction of species is a potential negative effect of pesticides on the ecosystem. Beneficial insects and pollinators are among the non-target organisms that pesticides kill, decreasing their population sizes. As a result, ecosystems may experience a cascade of negative effects, such as decreased crop yields from insufficient pollination and a rise in insect populations from the extinction of natural predators (Goulson, 2013). The sustained use of pesticides can lead to the emergence of secondary pests that may take over in the absence of natural predators, as well as the development of pests that are resistant to pesticides (Fernandez-Cornejo and McBride, 2002).

An important agricultural sector that makes a considerable economic contribution to South Africa is the apple industry. South Africa might experience fluctuations in the cost and availability of pesticides due to a variety of circumstances. The variation in worldwide supply and demand is one of the major factors determining the cost and accessibility of pesticides in South Africa's apple industry. Most pesticides used in South Africa are imported, and the world market impacts on their cost. Prices in South Africa are sensitive to supply and demand for pesticides in other regions. Fuel price increases and shipping challenges resulting in container shortages and price hikes are primary causes of shortages and high pricing (Marais, pers comm., 2023).

The cost of production can also affect pesticides affordability in the South African apple industry. The final price of pesticides is affected by the cost of energy and raw materials. The development, testing and registration of chemical compounds comes at a considerable cost. Registration in the country of use necessitates additional field testing and time. This could imply that the active ingredient or a product comparable to it is readily available, but cannot be utilized because it is not registered (Marais, pers comm., 2023). Farmers are impacted by the erratic cost and lack of supply of pesticides in South Africa's agricultural industry. Alternative pest control techniques, such as integrated pest management and biological control, can thereby affect management and profitability by lowering growers' reliance on pesticides.

By enabling growers to target pests and diseases more accurately, orchard monitoring can help reduce the usage of pesticides in apple orchards. Regular orchard inspections to identify diseases, pest presence and population levels are part of monitoring. Monitoring can also be used to evaluate environmental factors that might influence the population growth rate of pests.

By monitoring the orchard, growers can spot pest and disease outbreaks early and adopt the most efficient, least damaging measures to control them. For example, as an alternative to chemical pesticides, with low pest populations, biological alternatives can be used to control the pests, such as introducing natural predators (Srinivasan et al., 2022).

Growers may enhance the sustainability and profitability of their farming operations by adopting orchard monitoring to decrease the usage of pesticides and providing financial benefit. To assess the financial implications of replacing some chemical applications, requires a method that relates chemical use to the overall financial profitability of an enterprise. Farming is inherently complex and multifaceted and isolating a cost or activity causes a danger of misinterpretation. The systems approach allows for the studying of a factor within the broader farm system. Financial simulation modelling is a valuable tool in agriculture for comparing alternatives and informing decision-making. Financial modelling integrates socio/economic factors with physical/biological factors of the farm system and interprets changes in terms of its expected effect on profitability (Tkachev, 2018).

One such method is budgeting. Budget models adhere to standard accounting principle and thus establish comparability and replicability of research. By running financial models, alternative decisions can be analysed in terms of expected financial implications. Simulation is a cost and time efficient way of testing the financial performance of alternative management options in farming systems. Budget models give the added advantage of being widely used and producers can easily interpret research results (Mattessich, 1961).

Taiwan is an important market for South African Fuji apples. This is due to a premium price compared to alternative markets. Marketing fruit to Taiwan is challenging due to strict exclusion of phytosanitary pests. The previous chapter showed that the use of an efficient monitoring program or alternatively, an aggressive spray program is best suited to mitigate the market associated risk of these pests. This chapter explores the benefit to environmental and economic sustainability in the reduction of chemical costs by implementing monitoring on a farm exporting Fuji apples to Taiwan. For this purpose, a partial budget model was used. Two main approaches were taken by growers; one was to implement a monitoring program to gain knowledge of pest presence and pressures in the orchard and to act accordingly, and the second was to implement a more aggressive chemical spray program.

## 4.2 Materials and methods

This study is of an exploratory nature. Market and management consideration was gathered from industry with specific focus on the EGVV area to provide the most appropriate local context. Table 4.1 shows chemical active ingredients commonly used in the area and the targeted phytosanitary pest. The specific chemical products largely impact the model's outcomes. These choices of products used are influenced by the need to alternate the chemical group use to reduce the development of resistance, availability, cost, and recommendations by chemical advisors.

**Table 4.1** Active ingredients and target pests for the EGVV apple production area

| Active chemical compound | Target pest |
|---|---|
| Abamectin | Mite |
| Acetamaprid | Codling moth, mealybug |
| Chlorantraniliprole | Codling moth |
| Cyantraniliprole | Codling moth |
| Emamectin benzoate | Codling moth |
| Etoxazole | Mite |
| Imidacloprid | Woolly apple aphid |
| Novaluran | Codling moth |
| Prothiophos | Mealybug |
| Spinetoram | Codling moth |
| Sulfoxaflor | Mealybug, woolly apple aphid |
| Fenazaquin | Mite |

Source: Industry norms prescribed by chemical suppliers

A simulation model is in essence an observation of actual systems or situations. Quantitative simulation models are mostly based on mathematical equations. The sophistication of mathematical models lies in the mathematical equation itself. Farm budget models are also a type of simulation model that mimics the financial outcome of a farm system. The sophistication of budget models lies in the number of variables it can incorporate, and through sequences of equations.

Computerised budget models integrate physical/biological data and financial performance of systems. The level of sophistication is limited only by the ability of the model developer. Farm management budget models are commonly used as practical planning tools by producers. The main aims are normally to assess sensitivity of expected price and physical input-output relationships on expected profitability. It is secondly used to measure the expected financial outcome of alternative management options (Jones et el., 2017; Kuehne et al., 2017). And thirdly, it is used to identify key drivers of profitability. Budget models are also widely used as research tools (Cullis et el. And McCown et al., 2006).

Budgeting offers a unique ability to incorporate large sets of data into systems that measure the financial implications of research-based information. The models allow for financial interpretation of research results done by natural scientists such as horticulturalist, agronomists, soil scientists, livestock scientists, viticulturalists and geneticists. The benefit is that the impact on profitability can be instantly measured, and in terms that producers understand well.

There are various types of budgets that are developed for specific purposes. Whole farm budgets, break-even budgets, enterprise budgets, cash flow budgets and partial budgets. Partial budgets are used to assess the financial impacts of specific alternatives that would not necessarily require the assessment of impact on other components of the farm. Typical uses include considerations of converting from manual labour to mechanization, alternative crops within existing production systems, converting energy use systems such as adopting solar energy, or genetic material considerations (Bir et al, 2022; Doyle, 2018; Reed et al., 2021).

A partial budget is divided into four dimensions namely, additional costs, additional returns, reduced returns, and reduced costs. The sum of the additional costs and reduced returns is deducted from the sum of additional returns and reduced costs to calculate the total monetary difference between alternatives. In this way, it can be determined if one alternative has a financial advantage over another. In this research it is applied when looking at specific alternative pest management scenarios. The key contribution of the partial budget method is that it can translate the ecological dimension of sustainable consideration into a financial viewpoint, considering all impacting factors, and thus simultaneously considering both environmental and economic pillars of sustainability. Values also include, to a large extent, consumer perception and preference, and thus embed some aspect of the social dimension of sustainability.

Provision was made to capture certain key value components necessary for the model's output. These included; expected tonnage per hectare, average pack-out percentage, number of Fuji hectares on the farm unit, Taiwan premium per ton, monitor training fee, hourly wage per monitor, diesel price per litre, average travel between Fuji orchards in kilometers, vehicle fuel consumption (km per litre), moth trap cost per unit, pheromone lure cost per unit, sticky pads cost per unit, the DALRRAD fee (added to packing fee/ton) and the special market registration fee. It should be noted that the expected harvest input variable excludes fruit culled in the orchard. This value only considers fruit destined for the packhouse. Various factors are considered when constructing a partial budget model to assess phytosanitary pest monitoring for special markets versus sending fruit to alternative markets. These variables were calculated as subsections of the output of the model.

- <u>Additional costs:</u>
  - Monitor Training

Monitor training costs are dependent on the service provider used. The model uses data in the form of total cost per monitor to be trained. This value is then divided by the number of hectares that need be monitored to get a per hectare value.

  - Monitor

The time needed to monitor a hectare of Fuji apples can be broken down as follows;

- one hour every two weeks for 14 weeks,
- one hour for a preharvest assessment per hectare and
- 15 minutes per week for trap counts for 30 weeks.

This is a total of roughly 16 hours which includes average travel time. The 16 hours is then multiplied by the hourly wage. The minimum wage for agricultural workers was used in this model.

  - Fuel – Monitoring

The fuel costs are calculated by dividing the average travel between Fuji orchards on a farm by the product of the fuel consumption of the vehicle used, the fuel price per litre and the number of times a hectare is visited in a production cycle.

  - Moth Traps

Codling moth traps are a requirement for Taiwan from week 42 to week 20 of the following year when the fruit will be harvested. This is a total of 30 weeks with pheromone lure replacement occurring every six weeks. Moth traps are a once off purchase that typically maintain their integrity for at least one production season. One trap per hectare is required, as a result, the cost per unit price is used as is in the model.

- Sticky pads

Sticky pads used to line the traps and capture the moths which land on them are replaced weekly upon inspection if any moths have been caught. The model uses the maximum number of potential replacements, 30 and multiplies this with the cost per unit price.

- Moth Pheromone

As stated, pheromone lures are replaced on a six-week cycle according to best practice guidelines. Therefore, five lures are used per production cycle. The calculation uses the cost per unit to reduce potential errors in calculation from variability in pack size purchased. The price per unit is then multiplied by five as replacements are used over the 30-week period that the traps are used for per season or year.

- DALRRD fee

The Department of Agriculture, Land Reform and Rural Development (DALRRD) of South Africa charge a fee to cover packhouse inspections. This is worked into packaging costs for the farmer which equates to R60-R70 per ton. The packhouse is regularly invoiced for this as inspections take place. The farmer absorbs the cost in the manner explained above (Mohr, pers comm. 2022).

- Special Market registration fee

A Special market registration fee is applicable per year per grower for the entirety of that specific grower's farm. This is R750 equally divided amongst 6 markets being China (apples), China (pears), Taiwan, Mexico, Kenya (apples) and Kenya (pears). Only China (apples) and Taiwan are applicable for Fuji apples resulting in a special market registration fee of R250 per grower (Mohr, pers comm. 2022).

- <u>Additional returns:</u>
  - Premium for Taiwan

The additional premium for sending fruit to Taiwan is calculated by multiplying the yield (tonnes) per hectare by the pack-out percentage and then by the additional income per ton for this market. The pack-out percentage is a reflection of the percentage fruit of a high enough quality standard to be exported to the identified market. Each market has its own unique specifications with regards to blemishes, defects, colour and size.

- Reduced returns:

When comparing monitoring versus not monitoring, and the subsequent export of Fuji apples to Taiwan, no reduced returns were anticipated. Therefore, no reduced returns appear in the model.

- Reduced costs:

Pesticides were considered a reduced cost in one particular scenario as explained below. Further there were no other reduced costs to incorporate into the model.

Pesticide costs are influenced by the specific products ultimately used and how many sprays of each were applied. This is situation-specific as each orchard is treated as a unique entity and conditions differ from season to season. The value incorporated in the model was based on exploratory results expected should monitoring be carried out efficiently and no adverse events take place. Typically, an orchard would undergo a spray program regardless of its destined market, certain pest would technically be not considered as essential for Taiwan. The pesticide component includes only chemicals used preventatively or curatively for phytosanitary pests of concern to Taiwan. A list of all locally used active ingredients for each of four phytosanitary pests was compiled and is presented in Table 4.3.

**Table 4.3** Locally registered chemical active ingredients for four phytosanitary pests

| Active | Target Organism |
|---|---|
| Abamectin | Mites |
| Acetamaprid | Codling moth, mealybug |
| Alpha-Cypermethrin | Codling moth |
| Carbaryl | Codling moth |
| Chlorantraniliprole | Codling moth |
| Chlorantraniliprole + Abamectin | Codling Moth |
| Chlorphenapyr | Mite |
| Chlorpyriphos | Mealybug, woolly apple aphid |
| Cyantraniliprole | Codling moth |
| Dichlorfos | Mealybug |
| Emamectin benzoate | Codling moth |

| | |
|---|---|
| Etoxazole | Mites |
| Imidacloprid | Woolly apple aphid (prevention) |
| Indoxacarb | Codling moth |
| Novaluran | Codling moth |
| Prothiophos | Mealybug |
| Spinetoram | Codling moth |
| Sulfoxaflor | Mealybug, woolly apple aphid |
| Sulphur | Mites |
| Thiacloprid | Codling moth |

Source: Industry norms prescribed by chemical suppliers

The chemical products selected by the farmers significantly impact the expected outcome. These choices capture the need to alternate chemical group use to negate the development of resistance, as well as the availability, cost and what is recommended by chemical representatives or advisors. This information was transformed into a database to contain dosage of each active ingredient per hectare and the minimum and maximum number of sprays that could be applied in a production season. This information was used to compile two different spray program scenarios:

1. An optimal program where ideal monitoring and external factors lead to the minimum required applications and followed the IPM approach.
2. An aggressive program aimed at minimising all phytosanitary pests through the maximum number of chemical applications (not following the desired IPM strategy).

The spray programs for the two scenarios, presented in Tables 4.4 and 4.5, were assembled with the assistance of a chemical advisor with knowledge of the study area.

**Table 4.4** A typically used IPM spray program in the EGVV area for apples.

| Active Ingredient | Pest | Number of Applications |
|---|---|---|
| Emamectin benzoate | Codling Moth | 4 |
| Chlorantraniliprole | Codling Moth | 2 |
| Prothiophos | Mealybug | 2 |
| Imidacloprid | WAA | 0.5 |

**Table 4.5** An aggressive spray program adopted in an attempt to ensure a phytosanitary pest-free apple orchard through chemical use.

| Active Ingredient | Pest | Number of Applications |
|---|---|---|
| Emamectin benzoate | Codling Moth | 4 |
| Chlorantraniliprole | Codling Moth | 3 |
| Prothiophos | Mealybug | 2 |

| | | |
|---|---|---|
| Imidacloprid | WAA | 0.5 |
| Fenazaquin | Mite | 1 |
| Etoxazole | Mite | 1 |
| Cydia pomonella granulosis virus | Codling Moth | 4 |

Note: The number of applications is indicated as a half for imidacloprid, as it is only applied every alternate season.

Both alternative spray programs would typically include Chlorpyrifos however, Chlorpyrifos will no longer be sold in South Africa or permitted for use post December 2023 (Bradley, pers comm. 2022). Therefore, it has been excluded. An alternative of two Tokuthion applications has been included as opposed to one Tokuthion and one Chlorpyrifos application as the active ingredient of Tokuthion, prothiophos, will still be permitted for use.

The two options incorporated into the model were as follows:

- Option one – the total cost of an optimal spray program inclusive of monitoring was deducted from the total cost of an aggressive spray program 2 and included as reduced costs.
- Option two – the cost of an aggressive spray program less the cost of an optimal spray program was included as additional costs.

The boundary of the system being analysed in this model is around the Western Cape apple industry, and includes the specific farm being assessed, the associated packhouse and DALRRD's financial impact.

## 4.3 Results and discussion

The model was run using the following average values for a bearing Fuji orchard in full production where input data was required. 75 tons per hectare was used in the example as a conservative average estimate. It should be borne in mind that Fuji is highly prone to alternate bearing which could result in much higher values (Craven, pers. comm 2022). The pack-out percentage used in this scenario was obtained via the average pack-out percentage for Fuji for Taiwan at a local large-scale packhouse over a five-season period. These inputs can be adjusted s with specific values applicable to their scenario. Table 4.6 show the cost information captured in the partial budget.

**Table 4.6** Cost assumptions captured in the partial budgets.

| Expected tonnage/ha: | 75 |
|---|---|
| Average pack-out % | 64.12% |
| Premium per ton | R4 000.00 |
| Monitor Training fee | R3 000.00 |
| Hourly wage per monitor | R23.19 |
| Diesel price/l | R27.00 |
| Average travel between Fuji orchards (km) | 0.90 |
| Vehicle fuel consumption (km/l) | 30.00 |
| Moth trap cost (per unit) | R119.86 |
| Pheromone lure cost (per unit) | R63.72 |
| Sticky pads | R19.88 |
| DALRAD fee (added to packing fee/ton) | R65.00 |
| Special Market registration fee (per grower) | R250.00 |

The pack-out percentage was obtained by using the three-year average for a commercial local packhouse for Fujis. The values used are subject to change, such as labour costs and fuel prices. Changes to these values do not significantly affect the outcome of the partial budget model as the additional income from the Taiwan premium is so large.

Using these values, an expected positive value of R199 869.78 per hectare was generated by the model. This indicated that the successful implementation of a monitoring program with subsequent Taiwan market approval and sales resulted in an additional earning of R199 869.78 per hectare.

From the first ton off an orchard, theoretically, the financial gain already offsets the costs outlined for export to Taiwan, when variable costs used are those typically seen within the boundary.  A pome fruit farmer in this area will typically harvest more than this even in the orchards first harvest, being above 10 tons per hectare.

Changing the pack-out percentage to zero percent nullify additional returns. However, this is not a typically expected scenario. Even with zero packing out percentage would still be positive benefit in this scenario, but not from a special market. The positive output, or net profit, of this model would return a value of R7 509.78 due to reduced pesticide cost. Should the farmer however use the aggressive spray program, negating monitoring costs apart from those required by Taiwan, the output value would be negative R10 540.91. In this case, income to offset costs would then need to be acquired from juicing fruit.

According to Steenkamp (2022), in association with Hortgro, the average production cost for apples, per hectare, are R232 000 excluding packing and marketing fees. This value was calculated for an established orchard in full bearing. Production costs do not significantly differ for different apple varieties at this stage in the orchard's lifetime. Packing and marketing fees will be highly dependent on the associated packing and marketing companies to which the growers belong. The model suggests that if using the monitoring approach, the net additional gain from the Taiwan market would offset 86% of annual production costs. This is under the assumption of a conservative 75 ton per hectare harvest for Fuji apples. An additional 10 tons to the harvest would offset production costs completely.

Crop budgets for pome fruit (Hortgro, 2021a) indicates that the annual costs of production, packaging and marketing on average equates to R517 812 for full bearing orchards. This inclusion of post-harvest costs indicates the contribution of packing and marketing fruit to total production cost. When considering these costs, the net gain of monitoring and fruit being sold to Taiwan covers 39% of production costs. When using the total revenue inclusive of the Taiwan premium, the 75-ton production used in the model results in a total income of R1 210 875. This value was taken from the Hortgro (2021b) key deciduous fruit statistics at an average price for export apples of R12 145 per ton. Less costs, returns a 132% return on direct cost per hectare.

Without the Taiwan premium per bin, a 75% return on direct cost and is still inclusive of following a monitoring program. With neither the Taiwan premium nor the additional monitoring costs the change in return on direct cost from including monitoring costs but not receiving the Taiwan premium is insignificant. It is important to note that although monitoring or an aggressive spray program may be used, the orchard in question could still be barred from the Taiwan market. This occurs when despite best efforts from the grower, the orchard still has phytosanitary pest presence. This can occur for a variety of different reasons. However, the use of either of these two methods to mitigate risk significantly reduces the chance of market restriction occurring as displayed in the previous chapter.

Assumptions and limitations

When using a partial budget model in agriculture, several assumptions ensure the accuracy and reliability of the analysis. These assumptions are based on the nature of the agricultural system, the type of data available, and the specific objectives of the analysis. The following are key assumptions often made when using a partial budget model for agriculture and are applicable to the scenario analysed:

- Costs and benefits are proportional to the level of production. This implies that the cost and benefits are constant across different levels of production. This may not hold in practice due to factors such as economies of scale, input-output price relationships, or changing market conditions. The effect on the two options under consideration will be consistent as the same production level dependent factors will hold in that situation.
- Input and output prices are assumed as constant for the calculations. The prices of inputs and outputs may change over time, which is often not the due to factors such as seasonal price fluctuations, weather events, or changes in demand and supply. This is could be exasperated by current events globally such as shipping shortages and the Ukrainian war.
- Inputs are available in the required quantities and qualities. Farmers have access to the inputs they need to implement their chosen management practices or technologies. Input availability can be affected by various factors such as market availability and government policies.
- Outputs can be sold at market prices. This assumption assumes that the farmer can sell their produce at the prevailing market prices. However, market conditions can change quickly, affecting both the price and demand for the produce. This includes scenarios such as sudden Taiwan market closure.
- Time and labour costs are considered. This recognizes that farmers need to invest time and labour in implementing their chosen management practices. Time and labour costs need to be accurately assessed to avoid underestimating the true costs of a given change. This includes training costs such as pest monitoring training.
- Fixed costs are not affected. Fixed costs of the farm operation remain constant regardless of the changes made. Some changes may require structural adjustment, which may increase the fixed costs of the operation. An example would be if the scale of the operation allows for a permanent position of monitor and dedicated transport provision.

It is essential to recognize the implications of these assumptions and to adjust the analysis for farm or location specific operations and the local context. This has to a large extent been addressed for making allowances in the model for user input based on the specific grower scenario at hand.

The sensitivity of expected financial implications to exchange rate change is absorbed by the model allowing for the price premium for Taiwan per ton entered in South African Rands. The output however will still naturally be affected.

The main limitation identified to the choice of management is the unpredictable closure of the Taiwanese market. This is a potential reality and would result in the loss of the additional income but maintained additional costs. This would still be offset to an extent with the incorporation on pesticide reduction and therefore savings under reduced costs.

Although optimal monitoring or aggressive spraying could be used, there is still potential for an orchard to be rejected for Taiwan. This happens when despite best efforts of the grower, there is still phytosanitary pest presence at harvest. This can happen for a variety of reasons and at times an orchard can be more predisposed to certain pests as seen with codling moth in orchards near bin stacks. These scenarios may not be within the grower's control. Monitoring is still however valuable as it allows the grower to identify if an orchard should be marketed elsewhere. This is important as inception of these pests in Taiwan could result in temporary or permanent market closure on an industry wide level.

## 4.4 Conclusion

This study sought to determine the most profitable way to mitigate phytosanitary risk for special market access between two options, either a holistic monitoring program, or increasing pesticide spray usage. The explorative analysis determined that the use of monitoring was the most cost-effective approach to follow. This also held the additional benefit of being more environmentally sustainable.

The findings of this study provide evidence of financial gain for producers to prioritize South African Fuji apple exports to Taiwan by using a method that is also more environmentally friendly. Financial evidence is often useful when convincing growers to change methods, as a farm is a business, and needs to prioritise profitability. Using the more efficient method highlighted here, could show an expected increase of 62% return on direct production cost annually, on a per hectare basis for Fuji apples. South African growers could focus on working with nature and managing pests without attempting to unsustainably eliminating them. However, there is zero tolerance for phytosanitary pests. Producers could focus on ensuring that only Fuji apples from the most appropriate orchards are presented for export, and this can only be done through effective monitoring.

Future research needs to be focused on how industry leaders can make the market more sustainable through international relations. Additionally, alternative markets for Fuji apples, that can also provide farmers with worthwhile remuneration need to be explored, should there be market closure.

Overall, this study contributes to the understanding of the financial implications of phytosanitary pest risk mitigation for South African Fuji apples in special markets, such as Taiwan. It provides considerations for local industry when making guidelines for producers to reduce chances of lucrative market closure while bearing in mind environmental impacts.

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# 5. Conclusion

South Africa’s pome fruit industry benefits greatly from Fuji Apple exports to Taiwan. This market is however unstable due to phytosanitary pest interceptions which need to be addressed to reduce the risk of losing this lucrative market. Alternative markets for Fuji result in the loss of the premium price. To aid in mitigating this risk, pest monitoring has proven to be beneficial. Not only can growers better manage their crop in terms of pests, but also effectively identify if a particular orchard is clean and should be presented for export at harvest. By implementing the suggested monitoring method correctly, growers can significantly reduce mealybug and woolly apple aphid presence. Monitoring also ensures that growers gain knowledge on how pests such as mites are being managed with predatory mites, and on the level of parasitism of woolly apple aphid, potentially impacting the future season’s management strategy.

Knowledge was gained on how the orchard environment impacts pest presence, although this needs to be further investigated over multiple seasons. Orchard monitoring proves more effective and efficient in comparison to samples taken post-harvest that may not be as representative, taken at the packhouse. This provides an overall better approach to ensuring phytosanitary pests do not cause market closure, temporarily or permanently and improved logistical efficiency within the packhouse environment.

When analysing the financial aspect of implementing monitoring, it was found that growers could potentially increase their annual return on investment by as much as 62%, and simultaneously be more environmentally sustainable by reducing chemical spray applications. Given this, the method introduced proved successful in resolving the problem of risk mitigation for export Fuji apples, while keeping the growers profitability in mind.

One of the aims of this study was to assess how chemical spray usage was affected by implementing the monitoring program outlined. This became near impossible due to the methods with which farmers were building their spray programs. Firstly, most pest sprays are preventative and have extensive withholding periods. This leads to farmers not being able to amend spray programs for the current crop during the current season when the fruit is on the tree and monitored. Alternatively, they would then need to use the previous seasons’ monitoring data to try and get an indication of specific pest problems per orchard for the current seasons spray program. Secondly, most of the pome fruit farmers in the group make use of chemical representatives and advisors. It was brought to my attention that the spray programs suggested to the farmers in many cases were based on very limited observation by their chemical representatives or advisors. No structured and consistent monitoring was used to make chemical spray recommendations. Unfortunately, due to this the effect of monitoring on the spray program could not be reported and the specific reduced spraying costs could not be incorporated into the partial budget model.

A lack of communication from some farms, although few, made it difficult to gain certain data. Although most farms provided what was needed, time was wasted in instances where information was not provided. At the end of the harvest season, datasets for some orchards could not be completed and therefore were not used for the study.

Potential future research should focus on the feasibility of using monitoring data to set up the coming season's spray program. The effect on chemical expenses, pest pressures and the environment can then be further analysed. This would however require buy-in from chemical representatives and chemical consultants. Seasonal differences should also be investigated along with prevailing microclimatic conditions, to assess how this affects an orchards predisposition to certain pests.

It is recommended to use a biweekly orchard scouting program with the compulsory weekly trap counts in order to gain the clearest perspective of management decisions that should be taken to best avoid phytosanitary pest presence whilst still maintaining environmental sustainability in terms of minimising pesticide use. Two weeks before harvest, a preharvest fruit damage assessment should be completed in order to ensure the effectiveness of management during the growing season and minimize incorrect market allocation of fruit to markets with stringent rules preventing phytosanitary pest presence on fruit. A packhouse sample proves useful as a secondary line of defence within the packhouse but yielded less accurate data than the preharvest assessment. The export market is a vital one for South African apple growers. The proposed method provides a framework for maintaining market access to these lucrative markets.