SOURCE AND IDENTITY OF INSECT CONTAMINANTS IN EXPORT CONSIGNMENTS OF TABLE GRAPES

James Stephen Pryke

Submitted in partial fulfilment of the
requirements for the degree of
Master of Science

Department of Entomology and Centre for Agricultural Biodiversity
Faculty of Science
University of Stellenbosch

Supervisor: Professor M. J. Samways
Co-supervisor: Dr. K. L. Pringle

April 2005

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree

Signature: …………………….

Date: ………………………….

GENERAL SUMMARY

The South African table grape industry exports approximately 60% of the table grapes produced. A major threat to the export of these grapes is the phytosanitary risk that insect pests pose. This study was conducted in the Hex River Valley, South Africa's main table grape producing area. The aim of this study was to reduce the number of phytosanitary rejections from insects on table grapes from the Hex River Valley. Thus the main objectives of the study were to identify the most important phytosanitary pests in the Hex River Valley; the determination of their presence in the vineyards with possible means to control them; and to assess the possibility of using postharvest quarantine treatments in the Western Cape. Further aims were to determine the effect of different colour harvesting crates on the phytosanitary pests and whether the phytosanitary pests infested the grapes via packhouses.

The most important phytosanitary pests of table grapes of the Hex River Valley are in order of importance: *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae), *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae), *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) and *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae). 12.71% of rejections were from species that were not identified, while a further 33% of the rejections were possibly identified incorrectly.

Phytosanitary control of *P. callosus* appeared to be far more effective using Plantex® than pesticides. Weather conditions appeared to affect the abundance of *P. callosus*, especially warm weather, while bunches harboured less *P. callosus* later in the day. Control of *E. acerbella* with DiPel® (*Bacillus thuringiensis* var. *kurstaki*) appeared to at least reduce the population within the vineyards, and so its use is recommended. *P. ficus* is a non-actionable species for the USA market and is not listed as a phytosanitary pest for the Israeli market and so should not be causing any phytosanitary rejections. *C. capitata* appeared to be successfully controlled by the fruit fly sterile release program and the cold sterilisation it currently undergoes. *G. simplex* caused few rejections. It is still unclear where this pest infests the grapes, as it was found in both the field and in the packhouses. *D. fasciatus* occurrence on grapes was probably accidental. It was shown that picking during the early and late parts of the day, when this species was less active, reduced its occurrence in bunches. *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae), although not reported as a reason for rejections in table grapes for the past two years, was an actionable species that was present in large numbers in the Hex River Valley. There was a strong correlation between increasing quantities of pesticides and higher abundances of *G. bimaculatus*. It appeared to be an indicator of the overuse of pesticides. Results of this study showed that infestation by the phytosanitary pests came from neighbouring vineyards. The creation of barriers to prevent the movement of these pests between vineyards is suggested.

Methyl bromide is the most commonly used postharvest quarantine treatment. Owing to the ozone-depleting properties of methyl bromide, it is scheduled to be outlawed in many countries from 2005. Alternative postharvest treatments are irradiation, extreme temperatures, forced air, vapour-heat treatments and the use of controlled atmospheres. Irradiation treatments appeared to control the pests at doses that do not damage the grapes. Controlled atmosphere treatments also have a high probability of success, although more research is required on this treatment. Low temperature treatments are relatively cheap as most exported fruit already undergoes cold storage, and appears to control species in the families Pseudococcidae and Tephritidae, although further research is required for the other pest.

Colour or location of the harvesting crates in the vineyards appeared not to influence the number of phytosanitary pests collected, as they were not attracted to these crates.

ALGEMENE OPSOMMING

Die Suid-Afrikaanse tafeldruifbedryf voer ongeveer 60% van alle geproduseerde tafeldruiwe uit. ‘n Groot bedreiging vir die uitvoer van die druiwe word gevorm deur die fitosanitêre risiko sover dit insekplae betref. Hierdie studie is in die Hexriviervallei, Suid-Afrika se belangrikste tafeldruif produksie area, onderneem. Die doel van die studie was om die aantal fitosanitêre verwerpings te wyte aan insek-besmette druiwe van die Hexriviervallei te verminder. Die hoofdoelwitte van die studie was om die mees belangrike fitosanitêre plae in die gebied te identifiseer; hulle teenwoordigheid in die wingerde te bepaal met moontlike metodes om hulle te beheer; en om die moontlikheid om na-oes kwarantyn behandelings in die Wes-Kaap te gebruik, te ondersoek. Verdere doelstellings was om die uitwerking van verskillend gekleurde oeskratte op die fitosanitêre plae te bepaal en of die bepaalde plae uitvoerdruiwe tydens verpakking kon besmet..

Die belangrikste fitosanitêre plae van tafeldruiwe in die Hexriviervallei, in volgorde van belangrikheid, was: *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae), *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae), *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) en *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae). 12.71% van fitosanitêre verwerpings was van ongeïdentifiseerde spesies, met ‘n verdere 33% van die verwerpings moontlik verkeerd geïdentifiseer.

Fitosanitêre beheer van *P. callosus* was meer doeltreffend met die gebruik van Plantex® as met plaagdoders. Dit lyk of weerstoestande, veral warm weer, die volopheid van *P. callosus* beïnvloed met druiwetrosse wat later in die dag minder *P. callosus* huisves. Beheer van *E. acerbella* met DiPel® (*Bacillus thuringiensis* var. *kurstaki*) verminder oënskynlik die bevolking in wingerde en die gebruik van die middel word derhalwe aanbeveel. *P. ficus* is ‘n plaag waarteen geen fitosanitêre maatreëls vir die VSA mark nodig is nie en die insek word ook nie as ‘n fitosanitêre plaag vir die Isrealiese mark gelys nie en behoort dus geen fitosanitêre verwerpings te veroorsaak nie. Dit lyk asof *C. capitata* suksesvol deur die vrugtevlieg steriele loslatingsprogram

en koue sterilisering van vrugte, beheer word. Huidig veroorsaak *G. simplex* weinig verwerpings en dit is steeds nie duidelik of die plaag wel die druiwe besmet aangesien die insek in beide die veld en in pakstore aangetref word. Die voorkoms van *D. fasciatu*s op druiwe is waarskynlik toevallig. Dit is aangetoon dat inoesting gedurende die vroeë en laat dag, wanneer die spesies minder aktief is, hulle voorkoms in trosse verminder. *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae), alhoewel nie gerapporteer as ‘n rede vir verwerpings in tafeldruiwe vir die afgelope twee jaar nie, is ‘n spesies waarteen maatreëls verwag word en in groot getalle in die Hexriviervallei aanwesig is. Daar is ‘n sterk verband tussen die gebruik van toenemende hoeveelhede plaagdoders en hoër voorkoms van *G. bimaculatus*. Dit lyk dus asof die kriek ‘n aanduider kan wees van die oormatige gebruik van plaagdoders. Resultate van hierdie studie toon dat besmetting deur die fitosanitêre plae vanaf aangrensende wingerde geskied. Die skepping van hindernisse om die beweging van hierdie plae tussen wingerde te voorkom, word voorgestel.

Metielbromied is die mees algemeen gebruikte na-oes kwarantyn behandeling. As gevolg van die osoon verminderende eienskappe van metiel bromied, word dit in baie lande beoog om vanaf 2005 die gebruik daarvan onwettig te verklaar. Alternatiewe bestrydingsmetodes sluit bestraling, uiterste temperature, geforseerde lug, damp-hitte behandelings en die gebruik van beheerde atmosfeer in. Bestraling beheer die plae teen dosisse wat nie die druiwe beskadig nie. Beheerde atmosfeer behandeling het ook ‘n hoë waarskynlikheid van sukses, alhoewel verdere navorsing omtrent hierdie behandeling nodig is. Lae temperatuur behandeling teen insekte is relatief goedkoop en omdat meeste vrugte voor en tydens uitvoer verkoel word, wil dit voorkom asof die behandeling spesies van die families Pseudococcidae en Tephritidae beheer, maar verdere ondersoek is nodig vir die ander plaag families.

Dit lyk nie asof die kleur of plasing van die oeskratte, wat in die wingerde gelos word, die getalle van aanwesige fitosanitêre plae nadelig beïnvloed nie aangesien hulle nie na sulke kratte aangelok word nie.

ACKNOWLEDGEMENTS

This project was financially supported by the Deciduous Fruit Producers Trust (DFPT), and I would like to thank them for giving me this opportunity.

Further acknowledgement must go to my supervisor Prof. Michael Samways for setting up the project and for advice and encouragement throughout its duration.

I give my sincerest gratitude to my co-supervisor Dr Ken Pringle who helped with setting up the phytosanitary database, the statistical analysis and for taking on the unenviable task of proof reading the manuscript.

I would like to thank the following producers for the use of their farms: De Wet Conradie (Kanetvlei), Louis de Kock (Moreson), Andre du Toit (Somerlus), Stephaan Jordaan (Bella Vista, Ruimsig and Tesame), Bester Michael (Cairngorm), Charl Palm (De Hoop), Hein Scheun (Protea) and Chris van Wyk (Idlewinds).

I would like to express gratitude to George Hendrikse of the DFPT for help especially in regard to acquiring the inspection data, Prof Henk Geertsma for help with the opsomming and general entomological problems and to all those people who took an interest in my project and helped me in numerous ways.

Special thanks should also go out to Paul Grant for all the much needed beers shared throughout the project and to all my friends in Stellenbosch, Pietermaritzburg and even to those who found themselves on the other side of the world, for helping keep my sanity.

Finally I have to thank my family, my sister Sarah for not really understanding the term ‘half-measures’ and being a constant source of inspiration and my parents for their limitless love and support and their countless sacrifices to allow me to follow my chosen path(s).

“We hope that, when the insects take over the world, they will remember with gratitude how we took them along on all our picnics.” William “Bill" Vaughan (1915 – 77)

CONTENTS

> "Bugs are not going to inherit the earth. They own it now. So we might as well make peace with the landlord."
>
> Thomas Eisner (1989)

Chapter 1

GENERAL INTRODUCTION

South Africa is the 6th largest table grape producer and the 4th highest exporter of table grapes out of the 12 countries listed as table grape producing countries by the USDA. Also included are Argentina, Chile, China, France, Greece, Italy, Japan, Mexico, Spain, Turkey and the USA (USDA 2004). South Africa is also the 2nd largest producer and exporter of table grapes in the southern hemisphere after Chile. Table grape exports are the 4th largest fruit export commodity from South Africa after oranges, apples and pears (Giles 2001). The South African table grape industry is rapidly growing, as both production and export of table grapes has increased 3.4 times in the last 14 years (table 1.1). This represents a mean annual growth in production of 19 313 tonnes and a mean annual growth in export of 11 049 tonnes of grapes. South Africa exports approximately 60% of the table grapes it produces. A major threat to the export of table grapes is the phytosanitary risk that certain insect species pose.

Table 1.1 Production and export of South African table grapes for the past 14 years

Year	Production (metric tonnes)	Export (metric tonnes)	References
1991	112 212	65 313	Nishiura (1993); Kreamer *et al* (1995).
1992	126 995	77 495	Nishiura (1993); Kreamer *et al* (1995).
1993	113 075	67 075	Kreamer *et al* (1995); Bean & Strzlecki (1996)
1994	143 463	93 755	Kreamer *et al* (1995); Bean & Strzlecki (1996)
1995	139 000	90 000	Kreamer *et al* (1995); Bean & Strzlecki (1996)
1996	152 000	98 000	Bean & Strzlecki (1996); USDA (1999)
1997	171 537	124 223	USDA (1999)
1998	195 673	148 759	USDA (1999)
1999	227 671	183 716	USDA (2004)
2000	208 000	168 000	USDA (2004)
2001	346 060	181 834	USDA (2004)
2002	368 583	207 279	USDA (2004)
2003	359 200	204 000	USDA (2004)
2004	382 600	220 000	USDA (2004)

The movement of exotic organisms is fast becoming a major problem world wide. These newly introduced organisms risk becoming pests not only in agriculture but also to natural ecosystems of the destination country. These exotic pests are able to outcompete or decimate indigenous species in the absence of their own natural enemies and so can cause major losses to biodiversity (New 1994; Begon *et al.* 1996). These species can disrupt the ecology of an ecosystem and thus lead indirectly to further losses of species (Begon *et al.* 1996).

Within agriculture, these exotic organisms risk becoming crop pests. Introduction of new pests can cause major financial losses, not only from damage caused but also from the need to develop and utilise new technology to eradicate or control them (Baker & Cowley 1989; Kahn *et al.* 2000). There is also the loss of potential markets from quarantine requirements due to the presence of these pests (Baker & Cowley 1989). The movement of fresh plant material, such as fruits, provides an easily accessible route for these pests to move into new areas (Gonzalez 1977; Kahn *et al.* 2000). Thus there are strict regulatory controls for the movement of fresh commodities between countries.

Although the USA market is a small market (only 2 529.4 tonnes were exported there in 2003), it has one of the strictest inspection protocols, thus methods that reduce rejections to the USA should help to reduce rejections for all table grape markets.

There are ultimately two areas in which phytosanitary pests can be controlled, namely, preharvest and postharvest. Preharvest control involves the management of phytosanitary pest populations within the vineyards and thus reduces the chance of collecting the pests while harvesting. Traditionally the control of many of these pests was achieved through chemical sprays. Pesticides are becoming more problematic with broad spectrum toxicity, target resurgence, secondary pest outbreaks and resistance (Begon *et al.* 1996). In addition restrictions are placed on placed on insecticide residue levels by many importing countries. Alternatives are being sought through Integrated Pest Management (IPM) practices such as the encouragement of biodiversity within agriculture (Altieri 1994; Dent 1995).

Postharvest control involves disinfestation of commodities when they are in the packhouses, storage or in transit using measures that either kill or sterilise the pests, while not damaging the commodities (Paull & Armstrong 1994; Fields & White 2002; Neven 2003). Methyl bromide has been used since the 1930's as a quarantine treatment, but it is to be banned in 2005 due to its ozone-depleting properties (Fields & White 2002). The main alternatives to methyl bromide are irradiation, controlled atmospheres along with hot and cold temperature treatments, although there are many other potential treatments (Paull & Armstrong 1994; Fields & White 2002; Neven 2003).

This study was conducted in the Hex River Valley, which is located in the centre of the Western Cape and is South Africa's main table grape producing area (Barnes & Eyles 2000).

The project concentrates on *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae), *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) and *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae) as they are the major phytosanitary pests found within the Hex River Valley (chapter 3). *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae) was also looked at in this study, as it was found in high numbers in the Hex River Valley. It is an actionable species for both the USA and Israeli markets (PPIS 2004; USDA-APHIS & SAAFQIS 2004).

P. callosus is indigenous to South Africa and has been reported to cause major damage to apples, nectarines and grapes (van den Berg 1971; Barnes & Swart 1977; Barnes 1987; 1989; Barnes & Giliomee 1992). *P. callosus* is adapted to hot, dry summers and wet winters (Annecke & Moran 1982; Barnes 1989) and in South Africa has only been recorded below latitudes of 33 ºS (Barnes 1987; 1989). The presence of this pest on grapevines was first reported during the 1890's (Barnes & Swart 1977) and is regarded as one of the most serious pests of grapes in the Western Cape (van den Berg 1971; Barnes 1989). Chemical sprays are usually applied to vineyards to control *P. callosus*. An alternative form of control is the use of sticky trunk barriers to exclude *P. callosus* from the canopy. This physical control mechanism has been reported to be more effective than chemical sprays (Barnes *et al.* 1994; 1995; 1996).

E. acerbella is indigenous to South Africa and is a serious pest of ornamental and garden flowers (Bolton 1979; Razowski 2002). It has been introduced into Europe and is now found in Spain, France, Italy, England, Germany and Denmark (Razowski

2002). Very little literature could be located for *E. acerbella*. This may be due to it only recently becoming a problematic pest. Annecke & Moran (1982) reported *E. acerbella* as a minor pest on apples, peaches, pears and plums, but did not mention grapes as a host. Furthermore, Bell & McGeoch (1996) regarded *E. acerbella* as a pest with a restricted distribution, low economic importance and a single low market value host crop. Recently, there have been reports of *E. acerbella* as one of the most important pests of table grapes in the Hex River Valley, especially in regard to rejections due to phytosanitary reasons (Anon 1997; Blomefield & du Plessis 2000). The control of *E. acerbella* is generally achieved through chemical means, although alternatives include sprays of DiPel® (*Bacillus thuringiensis* var*. kurstaki*) or the control of the cover crop (Blomefield & du Plessis 2000).

G. simplex is the most destructive and widespread of the *Gonocephalum* species (Drinkwater 1999). *G. simplex* feeds on bark and has been known to ring large plants, while felling smaller ones (Picker *et al* 2002). It is a major pest of sunflower and maize in South Africa (Drinkwater 1992; 1999), along with being reported as a minor pest on chicory and tobacco (Annecke & Moran 1982). *G. simplex* does not appear to be a major pest of grapes, although it causes losses through phytosanitary rejections. The control of Tenebrionidae elsewhere in the world is mainly through poisoned baits, although in South Africa control is almost exclusively by chemical control (Allsopp 1980; Drinkwater 1992).

The Pyrrhocoridae are medium sized, brightly coloured bugs, with all southern African species being phytophagous (Jacobs 1986; Picker *et al* 2002). *D. fasciatus* is wingless, feeds on seeds and is regarded as one of the most problematic species in the Pyrrhocoridae (Jacobs 1986; Picker *et al* 2002). *D. fasciatus* is a major pest on cotton and damage is primarily caused through the transmission of the *Nematospora* fungus (Annecke & Moran 1982; Jacobs 1986). Although it does not cause damage to grapes, it is considered a phytosanitary pest. Annecke & Moran (1982) reported that chemical control was successful for the control of *D. fasciatus.*

G. bimaculatus is a large-bodied (25 mm in length), omnivorous cricket (de Villers 1986; Picker *et al* 2002). It is nocturnal and has a widespread distribution, being found in Africa, Europe and Asia, typically found in association with human habitation

(Picker *et al* 2002). It is only regarded as a minor pest of lawn grasses (Annecke & Moran 1982), although it is an actionable species for both the Israeli and USA markets if found in grape consignments (PPIS 2004; USDA-APHIS & SAAFQIS 2004).

The overall aim of this project was to identify ways to reduce the phytosanitary rejections of table grapes from the Hex River Valley. To achieve this, the project had three main objectives. The first objective was the identification of the major phytosanitary pests of the Hex River Valley. To be to able control and rectify the phytosanitary pest problem in the Hex River Valley we needed first to know what the most important phytosanitary pest species are. The second objective was to look at whether these pests were present in the vineyards of the Hex River Valley, and if so, how best to control them. This was achieved by determining which of the current control methods offered the greatest protection from these pests and also by determining how these pests were affected by factors within the vineyard. The third objective of this study was to assess which of the postharvest quarantine treatments would have the highest likelihood of success in the Western Cape, by building a database to compare the tolerance of insects with that of commodities to different treatments. Further objectives were assessing the attractiveness of different coloured harvesting crates, and whether the position of these crates in the vineyard affected phytosanitary pest infestations. In addition the possibility of the phytosanitary pests infesting the grapes in packhouses was investigated.

References

ALLSOPP, P. G. 1980. The biology of false wireworms and their adults (soil-inhabiting Tenebrionidae) (Coleoptera): a review. *Bulletin of Entomological Research* 70: 343-379.

ALTIERI, M. 1994. *Biodiversity and Pest Management in Agroecosystems.* Food Products Press, New York.

ANNECKE, D. P. & MORAN, V. C. 1982. *Insects and Mites of Cultivated Plants in South Africa.* Butterworth, Durban.

ANON. 1997. Ou plaag met nuwe status. *Deciduous Fruit Grower* 47: 256-257.

BAKER, R. & COWLEY, J. 1989. Evaluation of the economic impact of newly introduced pests. *New Zealand Journal of Forestry Science* 19: 330-334.

BARNES, B. N. 1987. *Bionomics, Behaviour and Monitoring of the Vine Snoutbeetle,* Phlyctinus callosus *Boh., in Deciduous Fruit Orchards, with Proposals for an Improved Control Strategy.* University of Stellenbosch (PhD Thesis)., Stellenbosch.

BARNES, B. N. 1989. Different life and seasonal cycles of banded fruit weevil, *Phlyctinus callosus* (Coleoptera: Curculionidae), in apple orchards in the south-western Cape. *Phytophylactica* 21: 147-157.

BARNES, B. N. & EYLES, D. 2000. Feasibility of eradicating *Ceratitis* spp. fruit flies from the Western Cape of South Africa by the sterile insect technique. In: *Area-Wide Control of Fruit Flies and Other Insect Pests. Joint Proceedings of the International Conference on Area-Wide Control of Insect Pests, 28 May-2 June, 1998 and the Fifth International Symposium on Fruit Flies of Economic Importance, Penang, Malaysia.* 449-455.

BARNES, B. N. & GILIOMEE, J. H. 1992. Fruit-feeding behaviour of banded fruit weevil, *Phlyctinus callosus* (Schonherr) (Col., Curculionidae), in apple orchards. *Journal of Applied Entomology* 113: 407-415.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1994. Trunk barriers provide effective control of banded fruit-weevil on apples and nectarines. *Deciduous Fruit Grower* 44: 327-332.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1995. Effective weevil control on apple trees with batting trunk barriers. *Deciduous Fruit Grower* 45: 376-378.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1996. Latest results with trunk exclusion barriers for weevil control on apples. *Deciduous Fruit Grower* 46: 284-287.

BARNES, B. N. & SWART, P. L. 1977. A new look at snoutbeetles on apples. *Deciduous Fruit Grower* 27: 258-263.

BEAN, C. & STRZLECKI, K. K. 1996. World update on apples, pears, and table grapes, and U.S. export performance. *World Horticultural Trade & US Export Opportunities* 11-30.

BEGON, M., HARPER, J. L., & TOWNSEND, C. R. 1996. *Ecology.* Blackwell Science, Oxford.

BELL, J. & MCGEOCH, M. 1996. An evaluation of the pest status and research conducted on phytophagous Lepidoptera on cultivated plants in South Africa. *African Entomology* 4: 161-170.

BLOMEFIELD, T. & DU PLESSIS, N. 2000. Pear leafroller: a simple matter of weed control? *Deciduous Fruit Grower* 50: 12-13.

BOLTON, M. C. 1979. Some effects of temperature, humidity and larval diet on the life cycle of the South African carnation worm, *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae). *Journal of the Entomological Society of Southern Africa* 42: 129-135.

DE VILLERS, M. W. 1986. Order Orthoptera (grasshoppers, locust, cricket). In: Scholtz, C.H. & Holm, E. (Ed.) *Insects of Southern Africa.* 78-95. Butterworths and Co., Durban.

DENT, D. R. 1995. Introduction. In: Dent, D.R. (Ed.) *Integrated Pest Management.* 1-7. Chapman & Hall, London.

DRINKWATER, T. W. 1992. Laboratory evaluation of insecticide baits for control of the dusty surface beetle, *Gonocephalum simplex* F. (Coleoptera: Tenebrionidae). *Crop Protection* 11: 380-384.

DRINKWATER, T. W. 1999. Regional distribution of *Gonocephalum* species (Coleoptera : Tenebrionidae) in maize fields in South Africa. *African Entomology* 7: 183-187.

FIELDS, P. G. & WHITE, N. D. G. 2002. Alternatives to methyl bromide treatments for stored-product and quarantine insects. *Annual Review of Entomology* 47: 331-359.

GILES, J. 2001. What are the future prospects for South Africa in international fruit markets? *Deciduous Fruit Grower* 51: 42-57.

GONZALEZ, R. H. 1977. Entomological. In: Hewitt, W.B. & Chiarappa, L. (Ed.) *Plant Health and Quarantine in International Transfer of Genetic Resources.* 25-29. CRC Press, Cleveland, Ohio.

JACOBS, D. H. 1986. Order Hemiptera (bugs, leafhoppers, cicadas, aphids, scale-insects, etc.). In: Scholtz, C.H. & Holm, E. (Ed.) *Insects of Southern Africa.* 112-175. Butterworths and Co., Durban.

KAHN, R. P., CAVE, G. L., GREIFER, J. K., & IMAI, E. 2000. Quarantines and regulations, pest risk analysis, and international trade. In: Rechcigl, J.E. & Rechcigl, N.A. (Ed.) *Insect Pest Management: Techniques for Environmental Protection.* 305-336. CRC Press, Boca Raton, Florida.

KREAMER, R., DAVIS, L., & STRZLECKI, K. K. 1995. Table grape situation for selected countries. *World Horticultural Trade & US Export Opportunities* 10-20.

NEVEN, L. G. 2003. Physiological effects of physical postharvest treatments on insects. *Horttechnology* 13: 272-275.

NEW, T. R. 1994. *Exotic Insects in Australia.* Gleneagles Publishing, Adelaide.

NISHIURA, K. 1993. Table grape situation and outlook. *Horticultural Products Review* 17-20.

PAULL, R. E. & ARMSTRONG, J. W. 1994. Introduction. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 1-33. CAB International, Wallingford, UK.

PICKER, M., GRIFFITHS, C. & WEAVING, A. 2002. *Field Guide to Insects of South Africa.* Struik, Cape Town.

PPIS 2004. *Bilateral Quarantine Agreement between the Plant Protection and Inspection Services of Israel (PPIS) and the National Department of Agriculture Directorate: Plant Health and Quality of the Republic of South Africa (DPHQ) Regarding the Conditions for the Importation of Fresh Grapes (*Vitis vinifera*) From the Republic of South Africa into Israel.* State of Israel, Ministry of Agriculture and Rural Development, Plant Protection and Inspection Services, Bet-Dagan, Israel.

RAZOWSKI, J. 2002. *Tortricidae of Europe Volume 1, Tortricinae and Chidanotinae.* František Slamka, Bratislava.

USDA 1999 World horticultural trade and U.S. export opportunities. *FAS Quarterly Reference Guide to World Horticultural Trade, USDA.* FHORT 11-99

USDA 2004 World production, supply, and distribution of key products. *FAS Quarterly Reference Guide to World Horticultural Trade, USDA.* FHORT 1-04

USDA-APHIS & SAAFQIS 2004. *Preclearance Inspection and Cold Treatment of South African Deciduous Fruit Designated for Export to the United States of America.* South African Department of Agriculture, Directorates Plant Health, Pretoria.

VAN DEN BERG, H. C. 1971. The biology and control of vine snout beetles. *Deciduous Fruit Grower* 21: 83-85.

Chapter 2

STUDY AREA AND SITES

2.1 Study Area

The Hex River Valley (33º28 S, 19º38 E) is located in the centre of the Western Cape, approximately 85 kilometres northwest of Cape Town and is South Africa's main table grape producing area (Barnes & Eyles 2000). It is a steep sided valley surrounded by high rocky mountains, with a single main road running through it, and only one small village within the valley (De Doorns) (figure 2.1). Production of table grapes is restricted to the valley itself, which is 23 kilometres long and between 0-5 kilometres wide (Weaver 1993). The valley floor consists of alluvials overlaying shales of the Bokkeveld Group (Weaver 1993) and ranges in elevation from 340 to 640 metres above sea level. The soil of the Hex River Valley is sandy and moderately deep with rapid infiltration and permeability, but the rock layer sends water sideways to the nearest river, resulting in the Hex River being vulnerable to pollution from pesticides (London *et al.* 2000). The surrounding mountains consist of quartzites of the Table Mountain group (Weaver 1993). Matroosberg at 2249 metres above sea level forms not only the highest summit surrounding the Hex River Valley, but also of the entire Western Cape (Boelhouwers 1999).

The Hex River Valley climate is Mediterranean to semi-arid, with predominately winter rainfall and the rainfall ranges between 240-320 mm per annum (Smitheman & Perry 1990; Weaver 1993; Saayman & Lambrechts 1995; London *et al.* 2000). Due to the sandy soils and boulderbeds of the Hex River Valley along with the aridity of the area, irrigation is essential for table grape production (Saayman & Lambrechts 1995). Precipitation due to irrigation in December and January is 125 mm per month, which is higher than the average maximum monthly rainfall in of 55 mm June (Weaver 1993).

The Hex River Valley falls within the fynbos biome and furthermore within the Cape Floristic Kingdom (Low & Rebelo 1996). Four different vegetation types are found in the Hex River Valley and the surrounding mountains. The valley still has remnants of the Ashton inland renosterveld. The mountains to the northwest of the valley are the Matroosberg Mountain fynbos complex, the mountains to the east have Matjies inland renosterveld and the southern mountains consist of Koo Langeberg Mountain fynbos (figure 2.1).

The growing area of the Hex River Valley comprises about 4000 ha, which is farmed by about 140 producers with an average farm size of 18 ha (Barnes & Eyles 2000). Table grapes destined for international markets are packed by the producers, and then placed in cold storage. Prior to the grapes leaving the Hex River Valley they undergo phytosanitary and quality inspections. 60% of the table grapes exported from South Africa to the USA come from the Hex River Valley.

Control of pests is predominately done by the producers themselves, with the exception of the sterile fruit fly release program. This project is aimed at locally eradicating *C. capitata* from the Hex River Valley (Barnes 2000a; 2000b). It has had considerable success in controlling *C. capitata* since 1997 (Barnes 2000b). Flies are bred and sterilised in a facility in Stellenbosch, then released over the Hex River Valley twice weekly (Barnes & Eyles 2000; Barnes 2000a; 2000b).

2.2 Study sites

Ten farms were used for the present study (figures 2.2 - 2.11). On each farm two vineyards and their packhouses were surveyed for phytosanitary pests. All the farms fell within the Hex River Valley with the exception of Protea (33º36 S, 19º24 E). Protea is located 4 kilometres north of Worcester in the Brandwagt area, approximately 8.5 kilometres southwest of the Hex River Valley. All these farms export their produce to the USA.

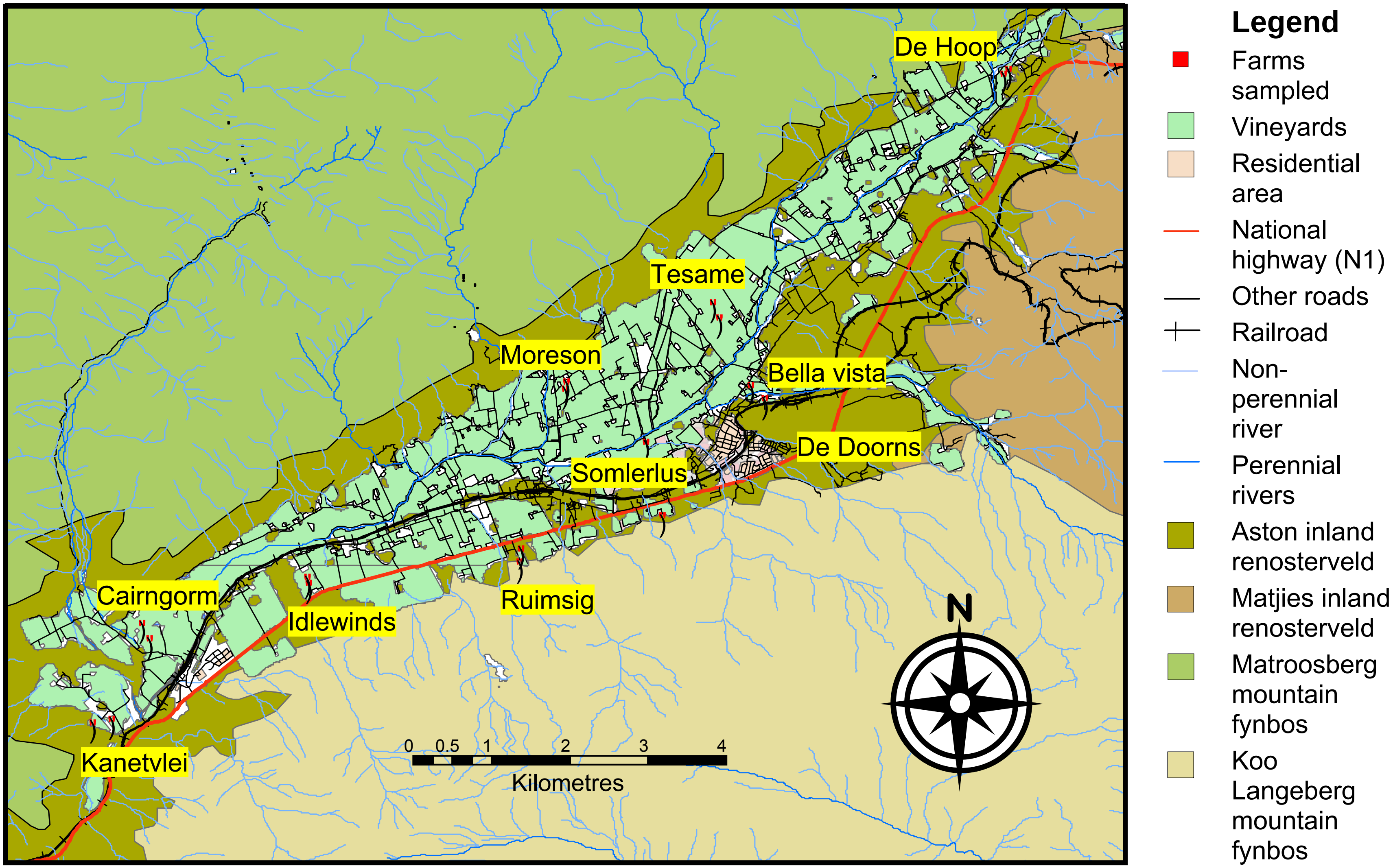

Figure 2.1 Map of the Hex River Valley, showing all the farms sampled in this study, with the exception of Protea, which is 8.2 km SW of the valley, along with the surrounding natural vegetation.

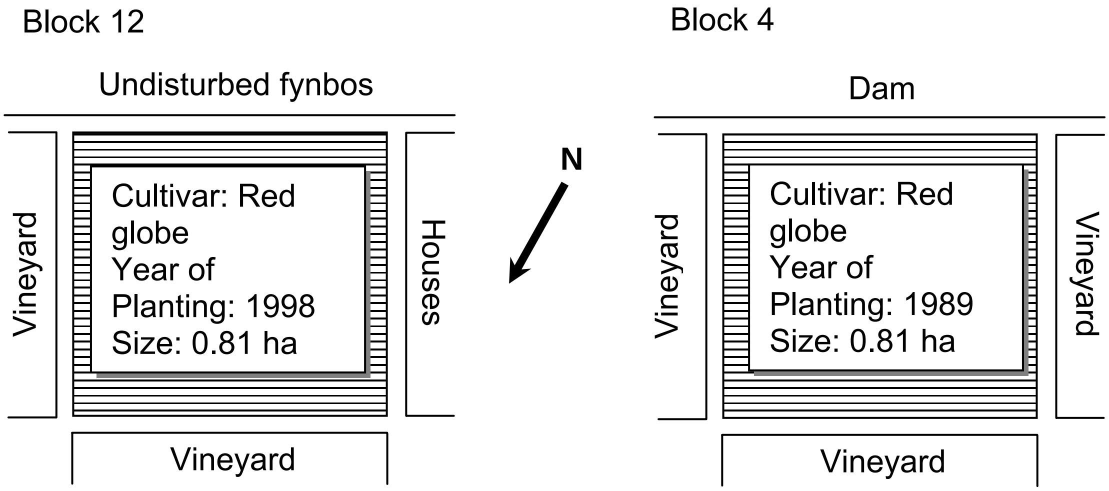

Figure 2.2 Vineyards sampled at Bella vista with their surrounding features.

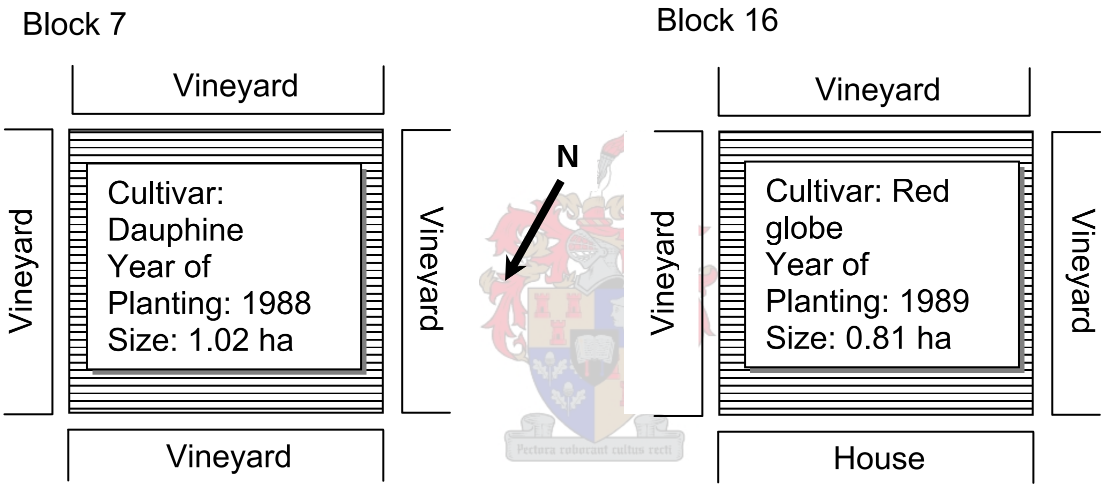

Figure 2.3 Vineyards sampled at Cairngorm with their surrounding features.

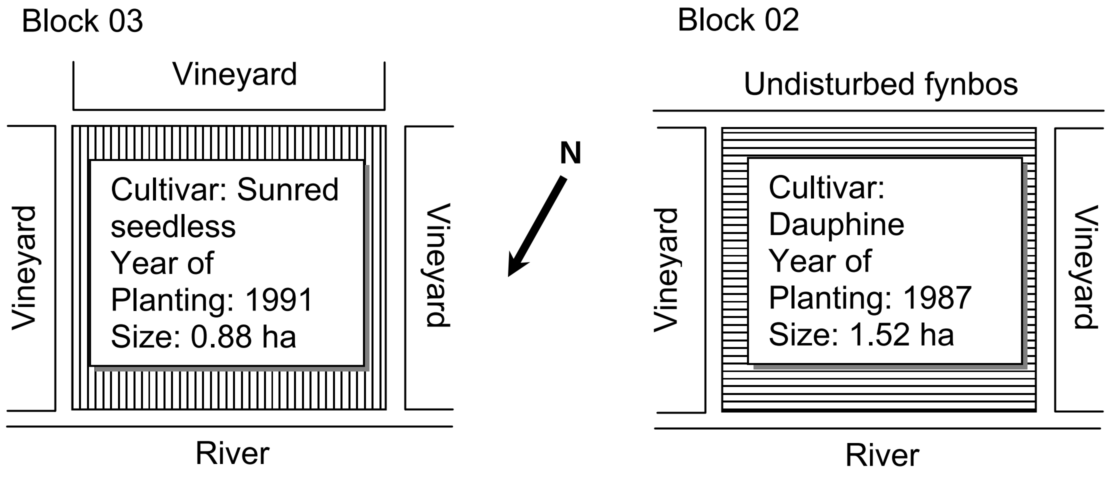

Figure 2.4 Vineyards sampled at De Hoop with their surrounding features.

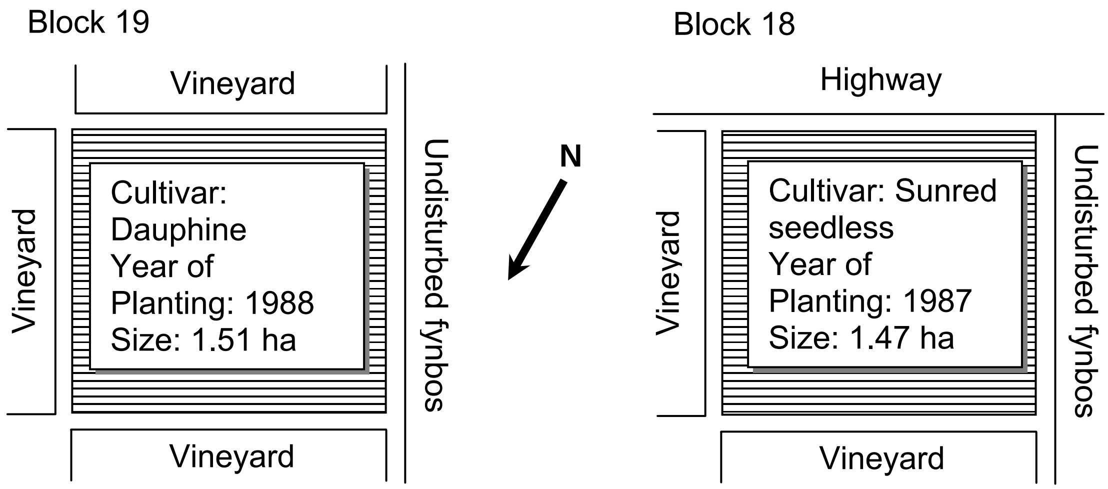

Figure 2.5 Vineyards sampled at Idlewinds with their surrounding features.

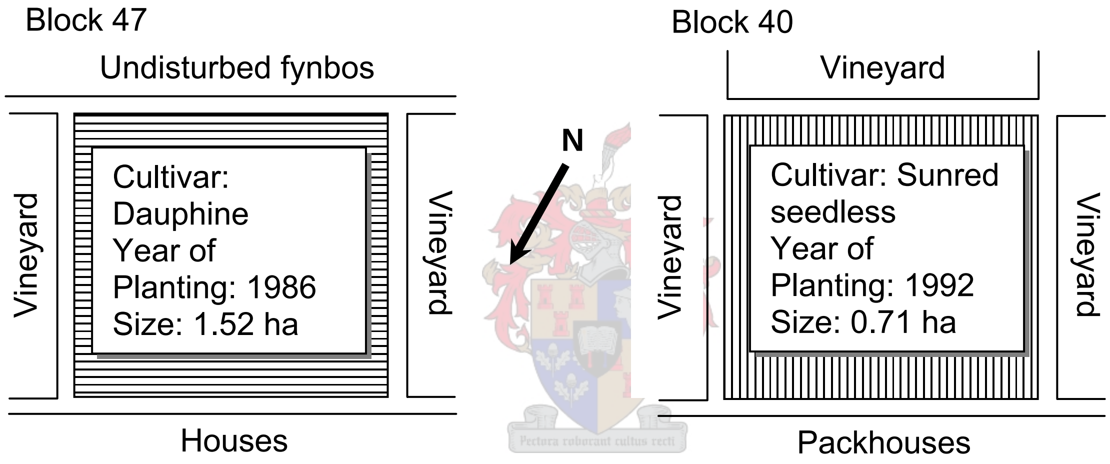

Figure 2.6 Vineyards sampled at Kanetvlei with their surrounding features.

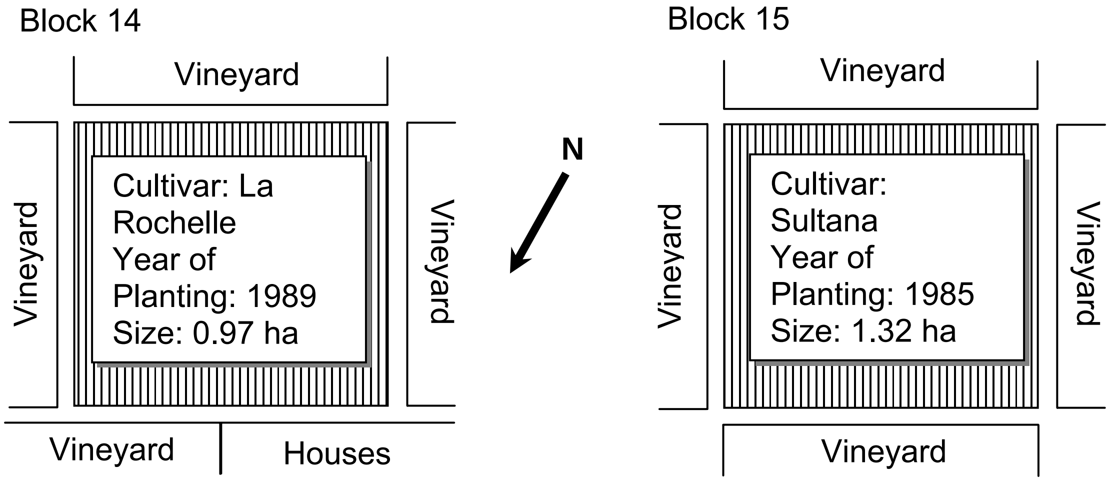

Figure 2.7 Vineyards sampled at Moreson with their surrounding features.

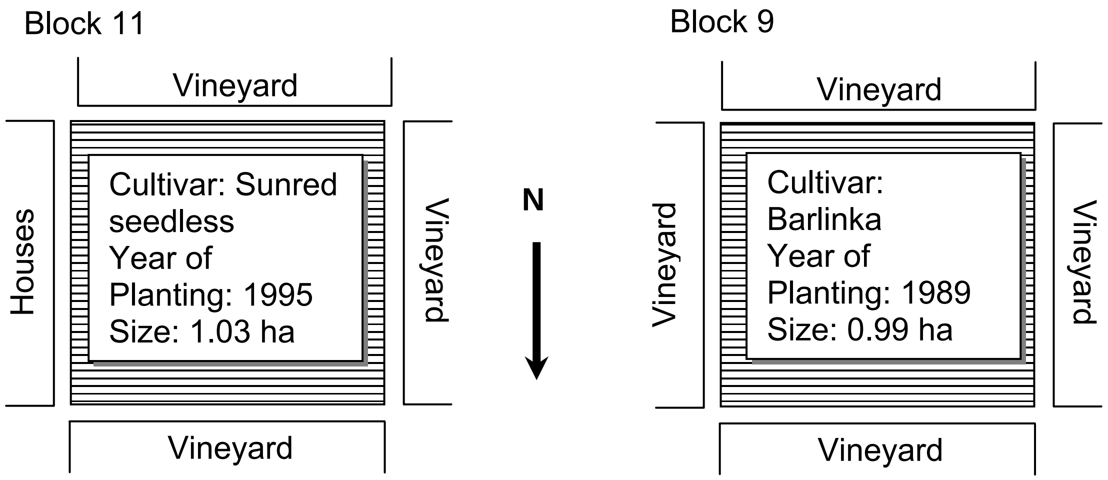

Figure 2.8 Vineyards sampled at Protea with their surrounding features.

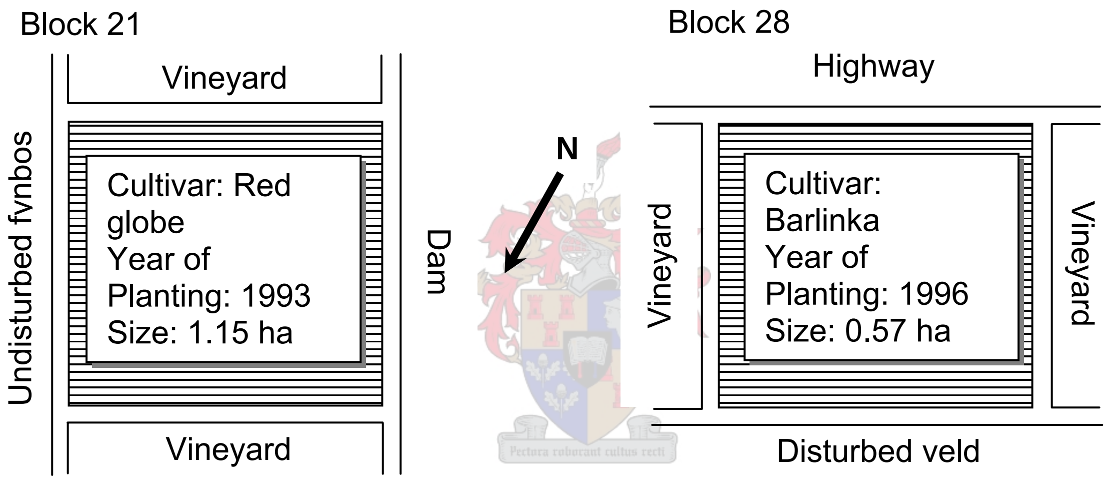

Figure 2.9 Vineyards sampled at Ruimsig with their surrounding features.

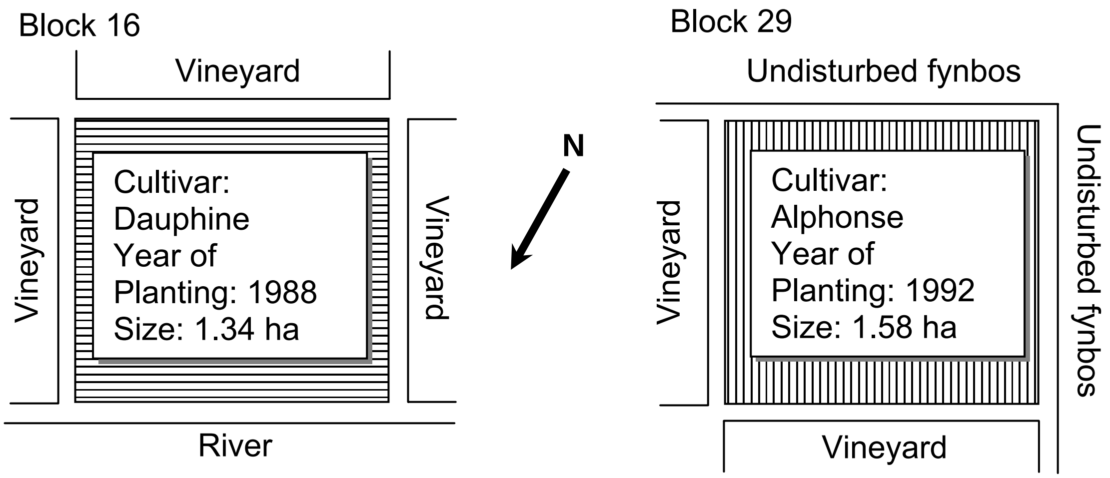

Figure 2.10 Vineyards sampled at Somerlus with their surrounding features.

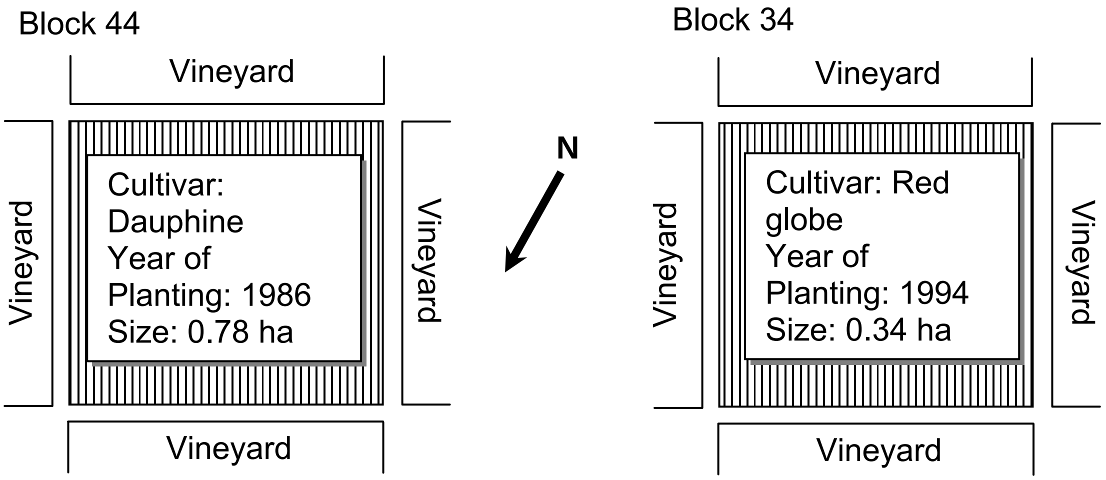

Figure 2.11 Vineyards sampled at Tesame with their surrounding features

2.3 References

BARNES, B. N. 2000a. Fruit flies of economic importance in South Africa: an overview. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 101-107. Indian Ocean Commission, Flic en Flac, Mauritius.

BARNES, B. N. 2000b. Monitoring and control of fruit flies in South African fruit orchards. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 147-152. Indian Ocean Commission, Flic en Flac, Mauritius.

BARNES, B. N. & EYLES, D. 2000. Feasibility of eradicating *Ceratitis* spp. fruit flies from the Western Cape of South Africa by the sterile insect technique. In: *Area-Wide Control of Fruit Flies and Other Insect Pests. Joint Proceedings of the International Conference on Area-Wide Control of Insect Pests, 28 May-2 June, 1998 and the Fifth International Symposium on Fruit Flies of Economic Importance, Penang, Malaysia.* 449-455.

BOELHOUWERS, J. C. 1999. Relict periglacial slope deposits in the Hex River Mountains, South Africa: observations and palaeoenvironmental implications. *Geomorphology* 30: 245-258.

LONDON, L., DALVIE, M.A., CAIRNCROSS, E., & SOLOMON, A. 2000. *The quality of surface and groundwater in the rural Western Cape with regard to pesticides.* WRC Report No. 795/1/00. Water Research Commission, Pretoria.

LOW, B. A. & REBELO, A. G. 1996. *Vegetation of South Africa, Lesotho and Swaziland.* Department of Environmental Affairs and Tourism, Pretoria.

SAAYMAN, D. & LAMBRECHTS, J. 1995. The effect of irrigation system and crop load on the vigour of Barlinka table grapes on a sandy soil, Hex River Valley. *South African Journal for Enology and Viticulture* 16: 26-34.

SMITHEMAN, J. & PERRY, P. 1990. A vegetation survey of the Karoo National Botanic Garden Reserve, Worcester. *South African Journal of Botany* 56: 525-541.

WEAVER, J. M. C. 1993. *A preliminary survey of pesticide levels in groundwater from a selected area on intensive agriculture in the Western Cape*. WRC Report No. 286/1/93. Water Research Commission, Pretoria.

Chapter 3

DETERMINATION OF THE MOST IMPORTANT PHYTOSANITARY INSECT CONTAMINANTS IN THE HEX RIVER VALLEY AND HOW INFESTATIONS ARE AFFECTED BY THE COLOUR OF HARVESTING CRATES AND BY PACKHOUSES

Fresh produce exported from South Africa to the USA and Israel has to undergo strict phytosanitary inspection prior to exportation. It is currently unclear as to exactly what insects are causing these rejections. Colour of the harvesting crates may attract phytosanitary pest species as some insects are positively phototaxic to colours. Packhouses and their associated lights may also be responsible for some infestations. Rejection data for 2002 and 2003 were analysed and the most important phytosanitary pests were identified. Historical and current records were then examined and pest species that were not recorded or rarely found on grapes but given as reasons for rejections were considered incorrect, and closely related but more likely alternatives were suggested. Colour traps and crates with clear traps inside were placed in the vineyards. Packhouses were inspected for phytosanitary pests by examining their perimeters and their light traps. The most important phytosanitary pests identified were: *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae) (46.76%), *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae) (27.57%), *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) (4.61%), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) (3.84%), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) (3.20%) and *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae) (0.99%). There were a further 12.71% of rejections due to unknown species. No phytosanitary pests were caught in the colour traps or crates, thus the colour of the harvesting crates had no effect on the phytosanitary pests. Eight *G. simplex* were caught in the light traps within the packhouses so only *G. simplex* potentially infests the grape consignments via the packhouses. *C. capitata* for both the USA and Israeli markets is now controlled using cold storage, while *P. ficus* is a non-actionable species for the USA market and is not listed as a phytosanitary pest for the Israeli market and so these pests are no longer phytosanitary threats. A combination of both the USA and Israeli inspection process is recommended as this offers the most protection to both the producers and the importers.

3.1 Introduction

The principle objective of plant quarantine is the exclusion of exotic plant pests and pathogens along man-made pathways (Kahn *et al.* 2000). The movement of pests between countries through export programmes is of great concern to importing countries as these pests are potentially detrimental to their crops (Baker & Cowley 1989; Kahn *et al.* 2000). Introduction of new pests can cause major financial losses, not only from damage caused by the pests but also from the need to develop and utilise new technology to eradicate or control them, along with the loss of export market access (Baker & Cowley 1989; Kahn *et al.* 2000). Insects have a higher probability of becoming pests in areas of the world that are climatically similar to areas from which they originate, as they find themselves in conditions that suit them, without their natural enemies (Begon *et al.* 1996). The Western Cape, California-Arizona in the USA and Israel all share similar Mediterranean-type climates (Catling *et al.* 1988), and so exportation of natural products between these three countries is very strictly controlled.

Table grapes destined for exportation to the USA are inspected in South Africa. This inspection is done before any postharvest quarantine treatments are applied to the consignment (USDA-APHIS & SAAFQIS 2004). If any of the pests in appendix I are found alive, the entire consignment is rejected. Each producer is given two warnings after which the presence of an actionable species results in suspension from the export program for the remainder of the season. The producers must also demonstrate implementation of measures to rectify the problem before they can be reinstated during following years. There is a 21-day running average for all consignments presented for inspection. If 20% of the consignments or more are rejected, all shipments may be suspended (USDA-APHIS & SAAFQIS 2004). There is only one postharvest treatment applicable to the grapes of the Hex River Valley and that is a cold storage treatment of 1.11 ºC or below for 14 days for all Tephritidae. Therefore consignments cannot be rejected on phytosanitary grounds if any Tephritidae are found during inspections (USDA-APHIS & SAAFQIS 2004).

The Israeli program differs from the USA program, in so far as inspections are conducted in Israel and there is also infield monitoring for *Ceratitis rosa* Karsch

(Diptera: Tephritidae) three months prior to harvesting (PPIS 2004). There are two types of postharvest quarantine treatments for Hex River Valley table grapes; a cold treatment of -0.55 ºC or below for 22 days and a methyl bromide fumigation of 24 g/m^3 at 27 ºC for 2 hours (PPIS 2004). As the inspections are done in Israel, phytosanitary rejections are for all live pests given in appendix I.

A potential infestation route may be the phytosanitary pests attracted to the crates used in harvesting. Insects are able to see a wide spectrum of colours (Mazokhin-Porshnyakov 1969; Borror *et al.* 1989; Lin & Wu 1992; Chapman 1998) and many insect species are positively phototatic to certain colours (Kevan 1978; Koštá 1991; Vargas *et al.* 1991; Weiss 1997; Mizell & Tedders 1999; Hoback *et al.* 1999; Oberrath & Böhning-Gaese 1999; Giurfa & Lehrer 2001; Strom & Goyer 2001; Legrand & Los 2003). The crates used for harvesting are predominately yellow, with some red crates. Crates are often left in the vineyards under the vines, with and without grapes in them so that they remain relatively cool. Therefore not only colour of crates but also their position in the vineyard could potentially affect the number of phytosanitary pests infesting them.

Lights in and around the packhouses may also attract phytosanitary insects. Some insects are phototaxic to certain lights (Mazokhin-Porshnyakov 1969; Muirhead-Thomas 1991). Bowden & Church (1973) found representatives of nearly all orders of insects in a study conducted in Uganda and Ghana using only light traps.

To control and rectify the phytosanitary pest problem in the Hex River Valley, we need first to know what the most important phytosanitary pest species are. Thus, the first objective of this study was to determine what pests were causing phytosanitary rejections. Further objectives were determining the attractiveness of different colour harvesting crates, and whether the position of these crates in the vineyard affected phytosanitary pest infestations, and to determine if the phytosanitary pests can potentially infest the grapes in packhouses.

3.2 Materials and methods

3.2.1 Inspection data

Rejection data for table grapes from the Hex River Valley were obtained from the Deciduous Fruit Producers Trust (DFPT) for 2002 and 2003, as information for other years was unavailable. The mean mass of grapes that were rejected was calculated for each of these seasons. The reasons for rejections were then ranked, and species that caused the most rejections were determined. Rejection conformed with homogeneity of variances (Bartlett's Test) once they were square-root transformed (Underwood 1997). As a result, these data were square-root transformed and then analyzed using analysis of variance (ANOVA) in Statistica 6.0. Fisher's LSD was used to determine the differences between the reasons for rejection (Steel & Torrie 1980).

For incidences where the reason for rejection was for a pest not normally found on grapes, or if there was another similar species that was more abundant, the reason for rejection was regarded as incorrect.

3.2.2 Colour traps

Colour traps consisting of an A4 size colour plastic sheet with a second clear plastic sheet smeared with Plantex® on top were used to determine whether or not phytosanitary insects were attracted to specific colours. The traps were placed out between the 25th of January and the 13th of February 2004 on all vineyards in Chapter 2. Colours used were dark blue, white, dark red and dark yellow. All four traps were placed in a line within the first 10 m from the edge of the vineyard and the rest at 10 m intervals (figure 3.1). The order of the different colour traps was random. Each line of traps was placed in vineyards for two hours, with 16 replicates. The number of phytosanitary insects, total number of insects, colour and position of the traps in the vineyard were recorded.

A similar technique was used for the different colour crates that were tested. Only three colours of crates were available, dark green, red and yellow. These were placed out between the 23rd of February and the 11th of March 2004, with 17 replicates of 2 hours each. They were also set out in the random order described for the colour traps (figure 3.1 & 3.2).

Both the colour trap and the crate trap data were shown by the Bartlett's Test and Levene's Test to have the greatest homogeneity of variances and by the Anderson-Darling Normality Test to have a normal distribution when log transformed (Underwood 1997). Therefore, a factorial ANOVA was use to analyze the log of these data to differentiate between colour and position, this test was performed using the Statistica 6.0 software.

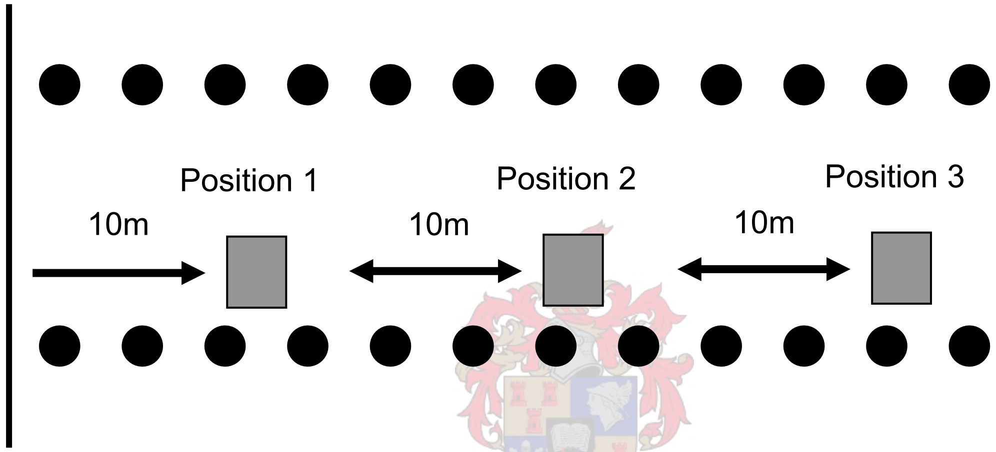

Figure 3.1 Arrangement of colour and crate traps in a vineyard. Circles represent the vines, the single line indicates the edge of the vineyard, and the grey squares the colour or crate traps.

3.2.3 Packhouses

Packhouses were periodically inspected for phytosanitary insects. Two methods were used. The first was to inspect the corners and edges of the packhouses. The second involved cleaning out the commercial light traps ('bug traps') (figure 3.3) and inspecting the contents. Only four packhouses had these traps. Each packhouse was inspected three times throughout the harvesting period from the beginning of December 2003 to the end of April 2004.

Figure 3.2 Crates placed in a vineyard to test the attractiveness of different colour crates to phytosanitary insects

Figure 3.3 Commercial light traps found in packhouses within the Hex River Valley

3.3 Results

3.3.1 Rejection of table grape consignments from the Hex River Valley in 2002 and 2003

Total amount of rejected grapes for 2002 and 2003 in the Hex River Valley was 357.20 and 316.71 tonnes, respectively. This constitutes 40.98% of the total consignments for 2002 and 17.19% for 2003. *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae) caused a significantly higher tonnage of grapes to be rejected (157.57 tonnes) of grapes per year ($P \leq 0.05$) than any of the other phytosanitary pests (figure 3.4). *Tortrix capensana* (Walker) (Lepidoptera: Tortricidae) caused the second highest rejections with a mean of 90.92 tonnes of grapes per year. There was no significant difference between Coleoptera, Pseudococcidae, Cydnidae, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) and *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae), caused mean rejection rates of 23.76, 15.54, 15.27, 12.95, 10.79 and 3.34 tonnes of grapes per year, respectively (figure 3.4). *Cryptophlebia leucotreta* (Meyrick) (Lepidoptera: Tortricidae), Lepidoptera, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), Hemiptera, Heteroderes and Helicidae had mean rejection rates of 1.89, 1.89, 1.12, 0.88, 0.55 and 0.49 tonnes per year respectively.

The identity of *T. capensana* and *C. leucotreta* can be questioned, as neither of these tortricid moths were commonly found on grapes, while *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae) was found to be a common pest to the grapes of the Hex River Valley (Anon 1997; Blomefield & du Plessis 2000). As these rejections are based mainly on the presence of larval stages and there is no reliable key or other means of identifying the difference between the various larval stages of the South African tortricid moths there is a high probability that this information is incorrect. Therefore, in figure 3.5 the incorrectly identified proportion consists of *T. capensana* and *C. leucotreta.* 16% of the rejections were also classified at either family level or order level. Thus, 49% of the reasons for rejection were probably incorrectly identified or not identified to below the family level.

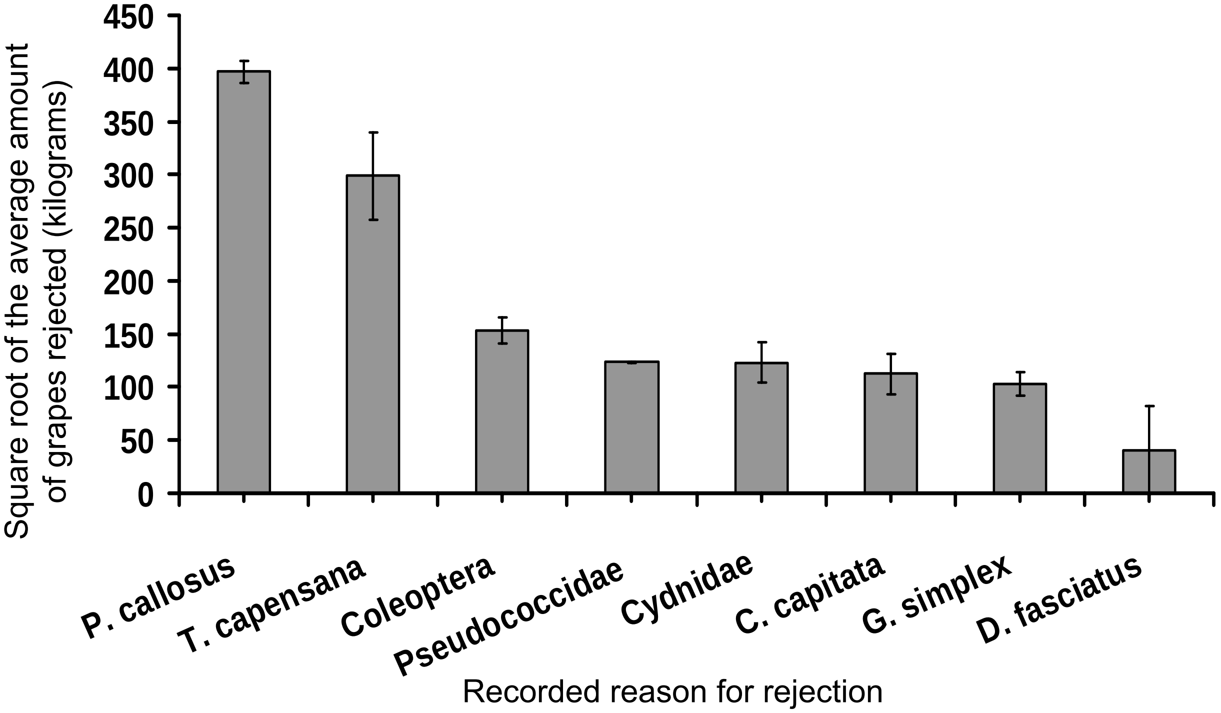

Figure 3.4 Mean (± 1 SE) rejection of grapes for 2002 and 2003 per rejection reason.

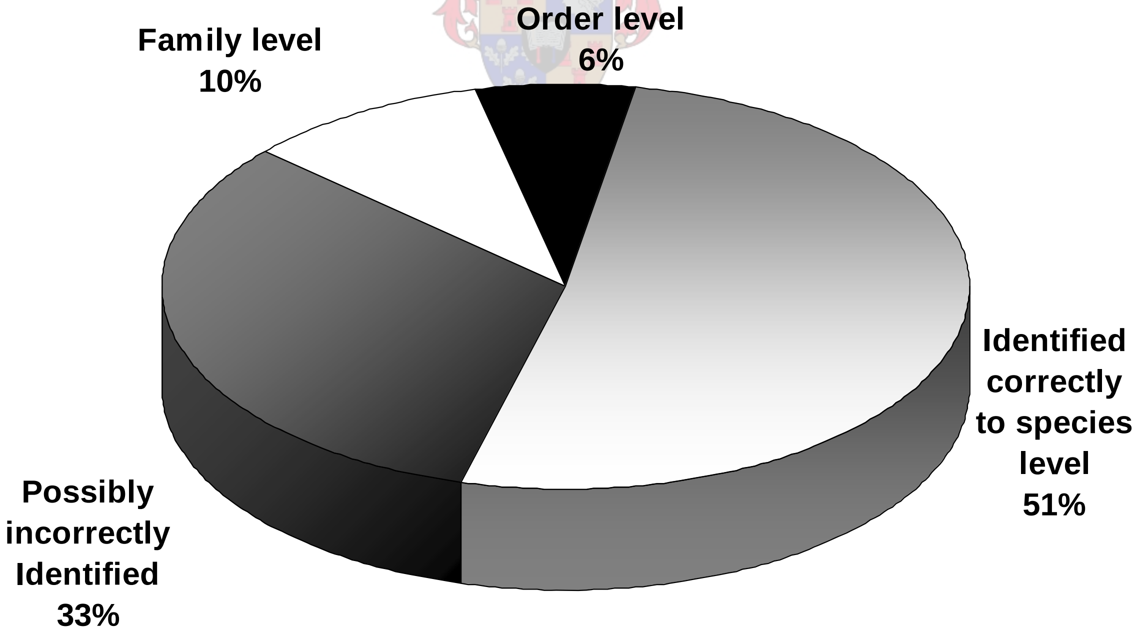

Figure 3.5 Classification of the rejection data for 2002 and 2003.

3.3.2 *Colour trapping for phytosanitary pests and other insects in the vineyards*

Neither the colour traps nor the crates caught any phytosanitary pest species. Red and yellow caught the least number of insects for both the colour traps and the crates (figure 3.6 (a & b)). There were no significant differences between either of the main effects (colour; position) or in the interactions in the number of insects caught (table 3.1 & 3.2) in either of the experiments. There was a general trend for fewer insects to be caught the farther the colour traps or crates were placed into the vineyard, although there was no significant difference between the positions of these traps (table 3.1 & 3.2, figure 3.6 (c & d)).

Table 3.1 A factorial analysis of variance table for the number of insects caught in colour traps per colour and position.

	df	SS	MS	F	*P*
Colour (c)	3	1.90855	0.636184	1.289518	0.290000
Position (p)	3	0.35561	0.118536	0.240267	0.870000
Both (c x p)	9	4.06974	0.452193	0.916576	0.870000
Residual	48	23.68080	0.493350		
Total	63	30.01470	0.476424		

Table 3.2 A factorial analysis of variance table for the number of insects caught in crates per colour and position.

	df	SS	MS	F	*P*
Colour (c)	2	0.18242	0.091211	0.379326	0.690000
Position (p)	2	0.72732	0.363662	1.512387	0.230000
Both (c x p)	4	0.43772	0.109429	0.455091	0.770000
Residual	42	10.09914	0.240456		
Total	50	11.44660	0.228932		

3.3.3 *Faunal diversity of the packhouses*

The only phytosanitary species recorded in the packhouses was *G. simplex.* A total of eight individuals were recorded in all the light traps combined.

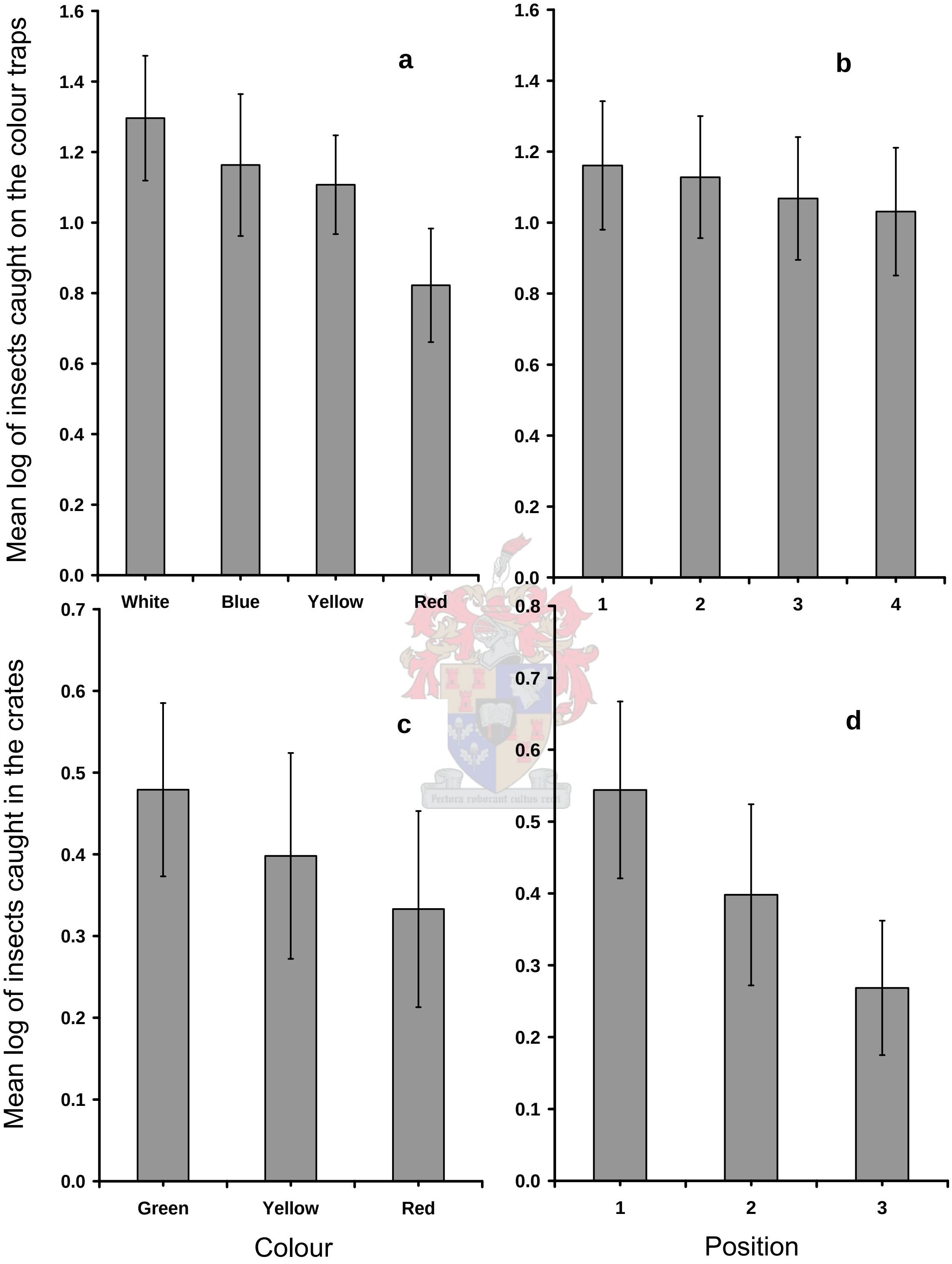

Figure 3.6 Insects caught in: **a** colour of colour traps, **b** position of colour traps, **c** colour of crates and **d** position of crates, mean (± 1 SE).

3.4 Discussion

3.4.1 Most important phytosanitary insects of the Hex River Valley and the inspection process

Inspection results show that *P. callosus* and *T. capensana* were the most numerous reasons for rejections of grapes, during the 2002 and 2003 seasons, representing 46.8% and 27.0% of the rejections respectively (figure 3.4). Following this, the reasons for rejections in descending order were: Coleoptera, Pseudococcidae, Cydnidae, *C. capitata*, *G. simplex* and *D. fasciatus*.

T. capensana is considered mainly a pest of citrus (Taylor 1957; Begemann & Schoeman 1999), although it has been reported on apples and pears by Myburgh & Basson (1961). Since then, it has also been reported on granadillas and marulas (Barrow 1977); apricots, plums and peas (Annecke & Moran 1982); peaches and roses (Begemann *et al.* 1998); avocadoes (van den Berg *et al.* 1999) and macadamias (van den Berg 2001). Eleven indigenous plants have also been reported as hosts of *T. capensana* (Dickson 1947; Taylor 1957; Myburgh & Basson 1961; Begemann & Schoeman 1999). No reports of *T. capensana* on grapes could be found. Furthermore, *E. acerbella* has been reported as the most abundant and important tortricid moth on table grapes in the Hex River Valley (Anon 1997; Blomefield & du Plessis 2000). This, coupled with the fact that there is no reliable means of identifying the difference between the various larval stages of the South African tortricid moths, strongly suggests that those *T. capensana* reported by the inspectors were in fact *E. acerbella*.

C. leucotreta is a major pest of citrus in the Western Cape although not a pest of grapes (Newton 1998). It was also reported on 20 other cultivated host plants by Schwartz (1981), of which none were grapes. Only Annecke & Moran (1982) reported *C. leucotreta* on grapes, but this has not been verified by primary research. The low numbers of this pest reported by the inspectors may represent this low occurrence of *C. leucotreta* although it is more likely that this is also due to confusion with *E. acerbella.*

The third, fourth and fifth most common reasons for rejections were family or order level. This makes it very difficult to solve phytosanitary problems as it is unclear as to what species were causing the rejections in the first place. The order Coleoptera is the largest order of living organisms in the world (Endrödy-Younga 1986) and the control of all Coleoptera is unrealistic and potentially counter productive as many are predators of pests found in vineyards (Wratten 1987; Altieri 1994). The specific Coleoptera requiring control will have to be identified.

The Pseudococcidae recorded by the inspectors are likely to all be *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) as this is the most abundant Pseudococcidae found on grapes in the Western Cape (Walton 2003; Walton & Pringle 2004). Although there other species are found in the Hex River Valley the problem is it is very difficult to differentiate between the different species of Pseudococcidae (Walton & Pringle 2004). Furthermore, this pest is listed as a non-actionable species for exports to the USA (USDA-APHIS & SAAFQIS 2004) and is not listed as a phytosanitary threat for Israel (PPIS 2004).

Thus the most likely reasons for rejections are: *P. callosus* (46.76%), *E. acerbella* (27.57%), *P. ficus* (4.61%), *C. capitata* (3.84%), *G. simplex* (3.20%), *D. fasciatus* (0.99%), *S. zeamais* (0.33%) and unknown species (12.71%). *S. zeamais* is probably a mistake by the inspectors as it is not listed as a phytosanitary pest by either the USA or Israel (PPIS 2004; USDA-APHIS & SAAFQIS 2004). It is a cosmopolitan pest of stored grain.

The unknown species component causing grape rejection is a loss of 42.82 tonnes per year. A central collection of all the insects found, whether identified or not, should be made available to researchers of phytosanitary problems. This would help solve the misidentification of insects as it would allow verification of previously identified pests and identification of the unknown pests.

Of the two inspection methods examined during this study, the Israeli system appeared to give the most security to the importing nation, while the USA system reduced the risk of rejection to the producers. In field inspections and monitoring done by the Israelis, provided a logical first step for phytosanitary protection. If pests are present in the field in high numbers they are likely to be present in the fruit after harvesting. The Israeli inspections after postharvest treatments added to the security of the inspection procedure as the inspectors could be sure that these treatments were effective. The USA system allowed the producers to redirect their produce into local or other markets with less stringent phytosanitary controls if rejected, resulting in financial loss. A combination of these two techniques would minimise the phytosanitary risk and reduce the financial loss to producers.

Preharvest vineyard monitoring of phytosanitary pests should be done by the producers as this allows them to decide on which grapes they should submit to these two risky markets. There should also be an inspection before the consignment is presented for export in the Hex River Valley. Consignments infested with phytosanitary pests for which there are no mitigation treatments would not be presented for export. This would limit the financial loss to the producers resulting from rejections. This inspection should be carried out by the South African Quarantine and Inspection Services (SAAFQIS), as it is in the South African government's best interest to present produce free from phytosanitary pests to maintain these markets. A second post-treatment inspection could be carried out by the destination country upon arrival, to ensure the postharvest treatments are effective and a second inspection would also minimise the risk of phytosanitary pests entering the importing countries. The USA system of two warnings and then suspension from the market would also ensure that the producers do not submit grapes that have a high likelihood of being infested with phytosanitary pests. Furthermore, this would ensure that producers have a long-term interest in phytosanitary control on their farms.

3.4.2 Effect of the colour and position of the crates in the vineyards on phytosanitary pests

As no phytosanitary pests were found in the any of the crates or the colour traps left in the vineyard, it appeared that the colour and the position of the crates left in the vineyards did not affect the phytosanitary pests. Colours that attracted the least number of insects in the vineyards were yellow and red. Therefore, the current colours being used are the most suitable for the collection of the grapes. Leaving the crates under the vines during the harvesting period appeared to be a safe practice. Position of the traps and crates affected the number of insects caught, with more insects caught closer to the edge of the vineyard than towards the middle.

3.4.3 Packhouses as infestation routes for phytosanitary pests

Only one species of phytosanitary pest was found in the packhouses and that was *G. simplex*. The fact that this species was found in light traps indicates that it was attracted to light. This species was also found in the field in low numbers (Chapter 4), although further sampling is required to verify these results. It was unclear whether the *G. simplex* was brought in to the packhouses in bunches collected in the vineyards before being packed, or whether they were attracted to the packhouse lights. The fact that a phytosanitary pest species was found in the light traps questions the fact that only 40% of the packhouses sampled actually had these traps.

3.4.4 Conclusions

The two most important phytosanitary pests of the Hex River Valley are *P. callosus* and *E. acerbella*. *G. simplex* and *D. fasciatus* are also phytosanitary threats although only causing a low number of rejections. *C. capitata*, while causing rejections during the 2002 and 2003 seasons, is no longer a phytosanitary threat due to the use of a postharvest cold sterilization procedure, which provides the required security against this pest. *P. ficus* is not regarded as a phytosanitary risk to either the USA or Israel, thus it should not be the reason for any phytosanitary rejection either. Although this is complicated by the difficulties involved in identifying Pseudococcidae species, as some species are actionable. It should be noted though, that these two, like any other species of insect, if sufficiently abundant in the consignments, could still cause quality rejections. Unknown insects that cause rejections need to be identified, so that research into management techniques to control these pests can be initiated. Also, a collection of the pests that cause rejections needed, so that these can be verified.

Colour and position of the harvesting crates in the vineyards did not affect the phytosanitary pests of this study. Only one species (*G. simplex*) was found to potentially infested grape consignments in the packhouses, and thus light traps are recommended for all packhouses as an additional monitoring exercise.

3.5 References

ALTIERI, M. 1994. *Biodiversity and Pest Management in Agroecosystems.* Food Products Press, New York.

ANNECKE, D. P. & MORAN, V. C. 1982. *Insects and Mites of Cultivated Plants in South Africa.* Butterworth, Durban.

ANON 1997. Ou plaag met nuwe status. *Deciduous Fruit Grower* 47: 256-257.

BAKER, R. & COWLEY, J. 1989. Evaluation of the economic impact of newly introduced pests. *New Zealand Journal of Forestry Science* 19: 330-334.

BARROW, M. R. 1977. *The Biology, Economic Significance and Control of* Tortrix capensana *(Walker) (Lepidoptera: Tortricidae) on Citrus at Zebediela Estate.* University of Natal, Pietermaritzburg (MSc Thesis), Pietermaritzburg.

BEGEMANN, G. J., BARROW, M. R., & BEDFORD, E. C. G. 1998. Apple leaf roller, *Tortrix capensana* (Walker). In: Bedford, E.C.G., van den Berg, M.A., & de Villiers, E.A. (Eds) *Citrus Pests in the Republic of South Africa.* 200-207. ARC - Institute for Tropical and Subtropical Crops, Nelspruit.

BEGEMANN, G. J. & SCHOEMAN, A. 1999. The phenology of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), *Tortrix capensana* (Walker) and *Cryptophlebia leucotreta* (Meyrick) (Lepidoptera: Tortricidae) on citrus at Zebediela, South Africa. *African Entomology* 7: 131-148.

BEGON, M., HARPER, J. L., & TOWNSEND, C. R. 1996. *Ecology.* Blackwell Science, Oxford.

BLOMEFIELD, T. & DU PLESSIS, N. 2000. Pear leafroller: a simple matter of weed control? *Deciduous Fruit Grower* 50: 12-13.

BORROR, D. J., TRIPLEHORN, C. A., & JOHNSON, N. F. 1989. *An Introduction to the Study of Insects.* Saunders College Publishing, Orlando, Florida.

BOWDEN, J. & CHURCH, B. M. 1973. The influence of moonlight on catches of insects in light-traps in Africa. Part II. The effect of moon phase on light catches. *Bulletin of Entomological Research* 63: 129-142.

CATLING, P. C., DAGET, B. J., FOX, P., GREENSLADE, J. D., MAJER, J. D., ORSHAN, G., RUNNDEL, P. W., SPECHT, R. L., & WESTMAN, W. E. 1988. Climate, vegetation, vertebrates and soil/litter invertebrates of Mediterranean-type ecosystems. In: Specht, R.L. (Ed.) *Mediterranean-Type Ecosystems a Data Source Book.* 3-12. Kluwer Academic Publishers, Dordrecht.

CHAPMAN, R. F. 1998. *The Insects Structure and Function.* Cambridge University Press, Cambridge.

DICKSON, C. G. C. 1947. Recently observed food-plants of some Cape Lepidopterous larvae (3rd series). *Journal of the Entomological Society of Southern Africa* 10: 130.

ENDRÖDY-YOUNGA, S. 1986. Order Coleoptera (Beetles). In: Scholtz, C.H. & Holm, E. (Eds) *Insects of Southern Africa.* 188-280. Butterworths and Co., Durban.

GIURFA, M. & LEHRER, M. 2001. Honeybee vision and floral displays: from detection to close-up recognition. In: Chittka, L. & Thomson, J.D. (Eds) *Cognitive Ecology of Pollination, Animal Behavior and Floral Evolution.* 61-82. Cambridge University Press, Cambridge.

HOBACK, W. W., SVATOS, T. M., SPOMER, S. M., & HIGLEY, L. G. 1999. Trap color and placement affects estimates of insect family-level abundance and diversity in a Nebraska salt marsh. *Entomologia Experimentalis et Applicata* 91: 393-402.

KAHN, R. P., CAVE, G. L., GREIFER, J. K., & IMAI, E. 2000. Quarantines and regulations, pest risk analysis, and international trade. In: Rechcigl, J.E. & Rechcigl, N.A. (Eds) *Insect Pest Management: Techniques for Environmental Protection.* 305-336. CRC Press, Boca Raton, Florida.

KEVAN, P. G. 1978. Floral coloration, its colorimetric analysis and significance in ant ecology. In: Richards, A.J. (Ed.) *The Pollination of Flowers by Insects.* 51-78. Academic Press, London.

KOŠTÁ, V. 1991. The effect of colour of the substrate on the landing and oviposition behaviour of the cabbage root fly. *Entomologia Experimentalis et Applicata* 59: 189-196.

LEGRAND, A. & LOS, L. 2003. Visual responses of *Lygus lineolaris* and *Lygocoris* spp. (Hemiptera: Miridae) on peaches. *Florida Entomologist* 86: 424-428.

LIN, J. T. & WU, C. Y. 1992. A comparative-study on the color-vision of 4 coleopteran insects. *Bulletin of the Institute of Zoology Academia Sinica* 31: 81-88.

MAZOKHIN-PORSHNYAKOV, G. A. 1969. *Insect Vision.* Plenum Press, New York.

MIZELL, R. F. & TEDDERS, W. L. 1999. Evaluation of trap type and color for monitoring *Hylobius pales* and *Pachylobius picivorus* in Florida. *Florida Entomologist* 82: 615-624.

MUIRHEAD-THOMAS, R. C. 1991. *Trap Responses of Flying Insects.* Academic Press, London.

MYBURGH, A. C. & BASSON, S. G. 1961. *Tortrix capensana* (Wlk) and *Epichorista ionephla* (Meyr.) as pests new to apples and pears (Lepidopt.: Tortricidae). *Journal of the Entomological Society of Southern Africa* 24: 348-349.

NEWTON, P. J. 1998. False codling moth, *Cryptophlebia leucotreta* (Meyrick). In: Bedford, E.C.G., van den Berg, M.A., & de Villiers, E.A. (Eds) *Citrus Pests in the*

Republic of South Africa. 192-200. ARC - Institute for Tropical and Subtropical Crops, Nelspruit.

OBERRATH, R. & BÖHNING-GAESE, K. 1999. Floral color change and the attraction of insect pollinators in lungwort (*Pulmonaria collina*). *Oecologia* 121: 383-391.

PPIS 2004. *Bilateral Quarantine Agreement between the Plant Protection and Inspection Services of Israel (PPIS) and the National Department of Agriculture Directorate: Plant Health and Quality of the Republic of South Africa (DPHQ) Regarding the Conditions for the Importation of Fresh Grapes (*Vitis vinifera*) From the Republic of South Africa into Israel.* State of Israel, Ministry of Agriculture and Rural Development, Plant Protection and Inspection Services, Bet-Dagan, Israel.

SCHWARTZ, A. 1981. *'n Bydrae Tot Die Biologie En Beheer Van Die Valskodlingmot* Cryptophebia leucotreta *(Meyr.) (Lepidoptera: Eucosmidae) Op Nawels.* University of Stellenbosch (PhD Thesis), Stellenbosch.

STEEL, R. G. D. & TORRIE, J. H. 1980. *Principles and Procedures of Statistics.* McGraw-Hill Kogakusha., Toyko.

STROM, B. L. & GOYER, R. A. 2001. Effect of silhouette color on trap catches of *Dendroctonus frontalis* (Coleoptera : Scolytidae). *Annals of the Entomological Society of America* 94: 948-953.

TAYLOR, J. 1957. Notes on the Lepidoptera in the Eastern Cape Province (Part IV). *Journal of the Entomological Society of Southern Africa* 20: 312-332.

UNDERWOOD, A. J. 1997. *Experiments in Ecology, Their Logical Design and Interpretation Using Analysis of Variance.* Cambridge University Press, Cambridge.

USDA-APHIS & SAAFQIS 2004. *Preclearance Inspection and Cold Treatment of South African Deciduous Fruit Designated for Export to the United States of*

America. South African Department of Agriculture, Directorates Plant Health, Pretoria.

VAN DEN BERG, M. A. 2001. *Tortrix capensana* Walker, Apple leaf roller. In: van den Berg, M.A., de Villiers, E.A., & Joubert, P.H. (Eds) *Pests and Beneficial Arthropods of Tropical and Non-Citrus Subtropical Crops in South Africa.* 314-316. ARC - Institute for Tropical and Subtropical Crops, Nelspruit.

VAN DEN BERG, M. A., DE VILLIERS, E. A., & JOUBERT, P. H. 1999. *Identification Manual for Avocado Pests.* ARC - Institute for Tropical and Subtropical Crops, Nelspruit.

VARGAS, R. I., STARK, J. D., PROKOPY, R. J., & GREEN, T. A. 1991. Response of oriental fruit-fly (Diptera, Tephritidae) and associated parasitoids (Hymenoptera, Braconidae) to different-color spheres. *Journal of Economic Entomology* 84: 1503-1507.

WALTON, V. M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa.* University of Stellenbosch (PhD Thesis), Stellenbosch.

WALTON, V. M., & PRINGLE K. L. 2004. A survey of mealybugs and associated natural enemies in vineyards in the Western Cape province, South Africa. South African Journal of Enology and Viticulture 25: 23-25.

WEISS, M. R. 1997. Innate colour preferences and flexible colour learning in the pipevine swallowtail. *Animal Behaviour* 53: 1043-1052.

WRATTEN, S. D. 1987. The effectiveness of native natural enemies. In: Burns, A.J., Coaker, T.H., & Jepson, P.C. (Eds) *Integrated Pest Management.* 89-112. Academic Press, London.

Chapter 4

FACTORS INFLUENCING THE ABUNDANCE OF PHYTOSANITARY PESTS IN TABLE GRAPE VINEYARDS OF THE HEX RIVER VALLEY: IMPLICATIONS FOR CURRENT AND POTENTIAL CONTROL

Successful long-term reduction of phytosanitary rejections in the Hex River Valley requires the successful control of phytosanitary pests within vineyards. Currently *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae) is controlled using either Plantex® stem bands or chemical control, while *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae) is controlled using DiPel® (*Bacillus thuringiensis* var. *kurstaki*) or chemical sprays. Other phytosanitary pests considered here are *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae) and *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae). Ten farms were selected, and two vineyards from each farm were sampled at the end of 2003 and during the 2004 season. Bunches in vineyards were inspected for all phytosanitary pests by both directly inspecting them and by shaking individual bunches and collecting pests that fell out. Trunk bands were placed on the vines to collect insects moving up the vine stems, while the head and the base of the vines were inspected. Cover crops and surrounding habitats were sampled by sweep netting and pheromone traps were placed in vineyards with *E. acerbella* pheromone capsules. Abundance of pests was compared to spray records of the individual blocks sampled, presence or absence of a sticky trunk barrier (Plantex® ring), use of DiPel® on *E. acerbella,* weather data for the sampling period, height and type of vegetation in the cover crop, surrounding habitats, times of day pests were apparent and the different farms. Plantex® was the most effective means of controlling *P. callosus*, while DiPel® was effective against *E. acerbella*. There were no significant differences between the number of phytosanitary pests and insecticides used, questioning the effectiveness of these insecticides. Most phytosanitary pests appeared to infest vineyards from adjoining vineyards, with very few found in the cover crops or surrounding habitats. These surrounding areas could be used to encourage natural enemies of these pests. *P. callosus* numbers increased after high ambient temperatures, while *E. acerbella* decreased in numbers following periods of rainfall.

4.1 Introduction

Successful long-term control of phytosanitary pests requires successful control of these pests within the vineyard, as this is the most likely source of infestation. Currently there are management techniques in place for the control of some of these phytosanitary pests, as many of them also cause damage to the vines. The two most important phytosanitary pests in the Hex River Valley are *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae) and *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae) (Chapter 3). This study also considers *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae) and *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae), as they have caused rejections in the past (Chapter 3) and *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae), an actionable species for the USA and Israel (PPIS 2004; USDA-APHIS & SAAFQIS 2004). A further two phytosanitary pests occur in the vineyards of the Hex River Valley. The Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), which is currently under control through a sterile insect release program (Barnes 2000b) and cold sterilization (USDA-APHIS & SAAFQIS 2004), no longer appears to be a major phytosanitary threat in the Hex River Valley. Control of *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) has been investigated by Walton (2003). It is listed as a non-actionable species for exports to the USA (USDA-APHIS & SAAFQIS 2004) and is not listed as a phytosanitary threat for Israel (PPIS 2004).

Pesticides are becoming more problematic with broad spectrum toxicity, target resurgence, secondary pest outbreaks and resistance (Begon *et al.* 1996). Weaver (1993) reported pesticide levels at acceptable levels in the water sources of the Hex River Valley. However, high levels of endosulfan and chlorpyrifos (London *et al.* 2000; Dalvie *et al.* 2003) have been reported since then. Walton & Pringle (1999) showed that over-spraying caused mealybug resurgence, as insecticides are detrimental to the mealybug parasitoid *Coccidoxenoides perminutus* (Timberlake) (Hymenoptera: Encyrtidae). The excessive use of insecticides has also triggered infestations of the red spider mite, *Tetranychus urticae* Kock (Acari: Tetranychidae), in the Hex River Valley, due to the loss of its natural enemy *Amblyseius addoensis* van der Merwe &

Ryke (Acari: Phytoseiidae) (Schwartz 1990). Furthermore, there are a number of recent reports of resistance to insecticides by the tortricid moths *Cydia pomonella* (Linnaeus) (Lepidoptera: Tortricidae) (Sauphanor *et al.* 1998), *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) (Waldstein *et al.* 1999) and *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae) (Kanga *et al.* 1999). *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) has become resistant to both carbofuran and dieldrin in Uganda (Gold *et al.* 1999). Importing countries are also becoming stricter with regards to the amount of pesticide residue found on the produce (Benbrook *et al.* 2003).

Cultural control practices are non-chemical control measures that make the environment unfavourable for pests (Begon *et al.* 1996). Sticky trunk barriers, which are intended to prevent the movement of *P. callosus* up the trunk, and into the vine canopy where they are able to do the most damage, are used on some farms in the Hex River Valley. Trunk barriers are used with various levels of success against the species in the Curculionidae. These barriers were highly successful in preventing *Lepesoma lecontei* (Casey) (Coleoptera: Curculionidae) damage to Douglas-Fir (Sexton & Schowalter 1991). However, Joubert & Labuschagne (1995) showed that trunk barriers on mango trees were ineffective in preventing damage from *Sternochetus mangiferae* (Fabricius) (Coleoptera: Curculionidae). *P. callosus* has shown effectively excluded from apple, nectarine and grape canopies by trunk barriers (Schwartz 1988; Barnes *et al.* 1994), although different products have different degrees of effectiveness (Barnes *et al.* 1995; 1996).

The sterile fruit fly release project currently being run in the Hex River Valley is aimed at locally eradicating *C. capitata* (Barnes 2000a; Barnes 2000b). This project has been running since 1997 and has had great success in controlling *C. capitata* (Barnes 2000b). Flies are bred and sterilised in a facility in Stellenbosch, then released over the Hex River Valley twice weekly (Barnes & Eyles 2000; Barnes 2000a; 2000b).

Adult male *P. callosus* is attracted to frass of the females (Barnes & Capatos 1989), thus the development of pheromone control for this pest is conceivable. Use of pheromones through mating disruption to control tortricid moths is well documented, with most of the work in vineyards being done on *Lobesia botrana* Denis & Schiffermüller (Lepidoptera: Tortricidae) (Roehrich & Boller 1991; Addante & Moleas 1996). There are currently mixed results with regard to its effectiveness. Moschos *et al.* (2004) show that mating disruption cannot effectively protect grapes from *L. botrana*, while Shorey *et al.* (1995) showed that it was very effective in controlling *Platynota stultana* Walshingham (Lepidoptera: Tortricidae). The pheromone of *E. acerbella* was first isolated by Lalanne-Cassou & Frérot (1980) and *E. acerbella* pheromone is soon to be made commercially available for mating disruption (Labuschagne pers. comm.).

Within the Hex River Valley, the main form of biological control is the use of DiPel® (*B. thuringiensis* var. *kurstaki*) for lepidopteran pests. *B. thuringiensis* is a bacteria that produces a crystal protein that is extremely toxic to Lepidoptera, Coleoptera and Diptera, with the subspecies *kurstaki* being highly effective against Lepidoptera (Tabashnik 1994). *B. thuringiensis* was first introduced to South Africa in 1968 to control *Nudaurelia cytherea cytherea* Fabricius (Lepidoptera: Saturniidae) in commercial pine forests (Geertsema 1973). Although there are no direct studies on the effect of *B. thuringiensis* on *E. acerbella*, it is effective on the Lepidoptera as a whole, including the tortricid moths (Massé *et al.* 2000; van Frankenhuyzen *et al.* 2000; Ifoulis & Savopoulou-Soultani 2004). *P. callosus* and *E. acerbella* may have certain local natural enemies that could be used for biocontrol. There have also been small scale releases of *A. addoensis* and *C. perminutus* to control the red spider mite *T. urticae* and Pseudococcidae respectively.

Agroecosystems are often unfavourable environments for most natural enemies owing to their high levels of disturbance (Landis *et al.* 2000). A wide variety of natural enemies often provides the best protection, with both specific predators, which maintain low pest numbers, and polyphagous predators which suppress outbreaks (Wratten 1987). To achieve the insect diversity required, high vegetational diversity is usually needed (Andow 1991). Thus the cover crop and surrounding habitats could be used to increase the diversity of natural enemies in the Hex River Valley.

Cover crops are used predominantly in perennial orchards and vineyards, which are deemed to be more stable ecosystems than annual crops (Altieri 1994). Cover crops influence the soil, availability of water, fertility levels, microclimate and the pests within the vineyard (Skroch & Shribbs 1986). Cover crops can directly and indirectly affect beneficial and pest insects, thus care is needed when choosing the correct cover crop (Bugg & Waddington 1994). Current literature suggests that a great deal of benefit can be derived from utilizing cover crops for pest control. *Erythroneura* spp. (Hemiptera: Cicadellidae) (Nicholls *et al.* 2000; Costello & Daane 2003; English-Loeb *et al.* 2003; Hanna *et al.* 2003), *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae) (Orr *et al.* 1997), *Cacopsylla pyri* (Linnaeus) (Hemiptera: Psyllidae) (Rieux *et al.* 1999) and the mite *Panonychus citri* (Mc Gregor) (Acari: Tetranychidae) (Liang & Huang 1994) are controlled by increasing the abundance of their natural enemies in the cover crop. Costello & Daane (1995; 1998) have shown that cover crops can increase the number of spiders, the most abundant and important natural predator in Californian vineyards.

Disadvantages of cover crops lie mainly in competition with the vines (Harris 1986). In addition, they are sometimes of benefit to pest species (Blomefield & du Plessis 2000) as pests may use the cover crops as an alternative food source. *E. acerbella* larvae feed in the cover crop during winter, although they were only associated with two particular weeds (Blomefield & du Plessis 2000). A further disadvantage of a cover crop with regard to phytosanitary pests is that tall vegetation allows easier access into harvesting containers left in the vineyard.

Duelli *et al.* (1990) showed that there was movement between natural and cultivated areas by almost all arthropod species, thus both natural enemies and pest species are able to enter the vineyards if they are present in the surrounding habitats. Natural enemies can also benefit from surrounding habitats by utilising them as sites to overwinter and as additional food sources (Corbett & Rosenheim 1996). Thomas *et al.* (1991; 1992) have shown that by sowing grass ‘islands’ to break up the uniform monoculture of cereal crops, the number of pests in the crop were suppressed.

Pest species can also use the surrounding habitats. *Endopiza viteana* Clemens (Lepidoptera: Tortricidae) was interactive between vineyards and their wild host (Botero-Garces & Isaacs 2003). It could reasonably be expected that indigenous pest species such as *P. callosus* and *E. acerbella* would utilise surrounding habitats, as wild host plants are likely to be present. However, having a major source of natural enemies should outweigh the advantage the pest species may have in this refuge.

Weather affects not only the physiological and behavioural characteristics of individual insects, but can also affect their population and community dynamics (Kingsover 1986). Torticid moth populations are affected by weather. *C. pomonella* was more active during warm evenings (Pitcairn *et al.* 1990), while the abundance of *Epiphyas postvittana* (Walker) was significantly correlated to both temperature and rainfall (Danthanarayana *et al.* 1995). Soil moisture levels are very important triggers for the emergence of *P. callosus* (Barnes 1987). Larvae of *Diaprepes abbreviatus* (Linnaeus) (Coleoptera: Curculionidae) needed certain thermal requirements for development (Lapointe 2000).

Time of day changes many variables such as the temperature, humidity and illumination (Matthews 1997), while all these variables affect insects both behaviourally and physiologically (Chapman 1998). Activity of insects is associated with temperature, so insects with high thermal tolerance would be expected to be more active during the warmer times of day to take advantage of their higher metabolic rates, while those that are less thermally tolerant can be expected to be resting during this time to avoid thermal stress (Schmidt-Nielsen 1979). Dixon *et al.* (1999) reported that *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae) movements were greatly affected by the time of day.

Although there are approximately 10 000 known cultivars of grapes (Mullins *et al.* 1992), only about 21 are used in table grape production in the Western Cape. Differences in the cultivars may affect the pest. For instance, cultivars with tighter bark may have less *P. callosus* as they would struggle to move up these vines to feed and shelter under bark. Also, bunches differ between cultivars, which may be relevant, especially the density of these bunches.

Age of the vines could affect the abundance of the different pest species in many ways. Accumulation of the pest over time may influence their current abundance. Certain phytosanitary pests may need some kind of succession, either of the cover crop or arthropod community (Begon *et al.* 1996). These pests may also require some kind of physical feature only found in mature vines such as loose old bark or features such as dense bunches or canopy.

The most important phytosanitary pests of the Hex River Valley were determined in chapter 3. This study was conducted to determine whether these phytosanitary pests were present in vineyards of the Hex River Valley, and if so, how best to control them. To achieve this, the study aimed to determine which of the current control methods offered the best protection from these phytosanitary pests and also to determine what effects cover crop, surrounding habitats, weather, time of day and the different farms had on the abundance of these phytosanitary pests potential control methods arising from their response to these variables are discussed.

4.2 Materials and methods

Phytosanitary pests were sampled in and around the vineyards using a variety of sampling techniques on the farms mentioned in Chapter 2.

4.2.1 Sampling of the bunches

Grape bunches were inspected for phytosanitary pests on all the farms and blocks (table 4.1). These bunches were inspected from when bunches were suitable for harbouring pests (figure 4.1) until all bunches had been harvested. Inspection of bunches was conducted every second week from the 4th of January until the 20th of April 2004.

Bunches were inspected using two methods. The first was by physically looking in 25 randomly selected bunches in three rows. Any phytosanitary insects found were recorded. In the second method a white cloth sheet (2.5 x 1.5 m) was placed under the canopy, and each bunch was firmly shaken ten times (figure 4.2). Insects that fell onto the sheet were recorded. This method is an extension of the limb-jarring method used by Barnes (1987; 1991) to sample *P. callosus* in apple orchards. Furthermore, Southwood (1978) suggested that the members of the family Curculionidae fall from the host plants in sufficient numbers when disturbed for this to be considered an absolute method. Although limb-jarring is mainly used for Curculionidae, Adams & Los (1989) reported its effectiveness for *Psylla pyricola* (Foerster) (Hemiptera: Psyllidae), Costello & Daane (1998) used it for spiders and Rieux *et al.* (1999) used this method to sample all arthropods in pear trees. As the two methods used exactly the same bunches, the total number of phytosanitary pests collected per bunch were treated as an absolute number.

Table 4.1 Sampling locations and block number used on each farm and a Plantex® band or DiPel® was used (un= unknown, Phero. = Pheromone).

Farm and block no.		**Bunches**	**Trunk bands**	**Vines trunks**	**Cover crop**	**Phero. traps**	**Plantex**	**DiPel®**
Bella vista	4	x		x	x		yes	no
	12	x	x	x	x	x	yes	no
Cairngorm	7	x	x	x	x	x	no	un
	16	x		x	x		no	un
De Hoop	2	x		x	x		no	un
	3	x	x	x	x	x	yes	un
Idlewinds	18	x	x	x	x	x	yes	un
	19*	x		x	x		no	un
Kanetvlei	47	x	x	x	x	x	yes	yes
	40	x		x	x		yes	yes
Moreson	14	x	x	x	x	x	no	no
	15	x		x	x		no	no
Protea	9	x		x	x		no	yes
	11	x	x	x	x	x	no	yes
Ruimsig	21	x	x	x	x	x	yes	no
	28	x		x	x		yes	no
Somerslus	16	x	x	x	x	x	no	yes
	29	x		x	x		no	yes
Tesame	34	x		x	x		yes	no
	44	x	x	x	x	x	yes	no

***** Idlewinds block 19 was removed after the 23rd of March 2004, so could not be sampled after this date for any of the sampling techniques.

4.2.2 Sampling using of trunk bands

Trunk bands were placed on the vines between the 24th and 27th of November 2003 for all farms except Idlewinds, where the bands were placed on the vines on the 8th of December 2003. Each band was a 140 mm wide strip of single-faced, corrugated cardboard, and was long enough to encompass the entire trunk. Corrugations of the barriers run vertically once placed on the vine with corrugations facing inward toward the bark to allow the insects to move under the bands (Barnes 1982). Due to the time required to monitor and correctly utilise these traps, only one block from each farm was used (table 4.1). After the initial setting up, the bands were checked every two weeks. Although the trunk bands were placed to specifically catch *P. callosus*, all phytosanitary pests found in the bands were recorded. All bands were removed between the 19th and the 21st of April 2004, once all bunches on all the vineyards had been harvested.

Lose bark was first removed from the vine (Phillips 1989), then the bands were secured using a single strand of wire, not tight enough to prevent insect movement (Barnes 1982) (figure 4.3). Bands were placed above the irrigation watering line, as Barnes (1987; 1991) reported a reduction in the effectiveness of wet trunk bands. Bands were placed below the Plantex® ring if present, as this would affect the number of insects able to reach the bands. Bands were set up in a square 10 x 3 cm, with 10 bands per row. Banded vines were 10 vines apart and there were 5 rows of vines between each of these three banded rows. After each count, the band was moved onto the adjacent unbanded vine. This was done to prevent a bias from favoured vines (Barnes 1982). Damaged and flattened bands were replaced.

4.2.3 Sampling the trunk of the vines

The trunks of vines were inspected every second week for phytosanitary pests from the 8th of December 2003 until the 21st of April 2004, once all the vineyards had been harvested.

A 4 x 30 cm strip of bark was pulled back from the base and the head of each vine. All phytosanitary pests found on and under the bark were recorded. Two rows of ten randomly selected vines each were inspected per vineyard. As this sampling method removes the bark, the same vines could not be inspected more than once, so new vines were inspected on each sampling occasion. Vine rows used for the trunk banding were not included, to prevent the disturbance of the pests and their pathways. Presence and absence of Plantex® was recorded.

4.2.4 Sampling the cover crop and surrounding habitats

The cover crop and surrounding habitats were sampled from the 8th of December 2003 until the 21st of April 2004.

Cover crop sampling consisted of two sets of 100 sweeps using a 40 cm diameter sweepnet. This was performed between rows. Insects were collected and sorted. Only phytosanitary pests were recorded. Cover crop type was recorded as one of five categories (grassy, herbaceous, dry, mixed or barren). Vegetation height was also classified into four classes; 1 was less than 20 mm, 2 between 20 mm and 70 mm, 3 between 70 mm and 150 mm and 4, more than 150 mm in height.

Surrounding habitats were sampled with 50 sweeps of a 40 cm diameter sweepnet. Two different vegetation types were sampled per farm every two weeks. Surrounding habitats consisted of any vegetation outside the vineyards and ranged from fynbos on the side of the mountains to disturbed vegetation right next to the vineyards. Type of vegetation, distance to the nearest vineyard and numbers of phytosanitary pests were recorded.

4.2.5 Sampling **Epichoristodes acerbella** *using pheromone traps*

Pheromone traps were placed in vineyards between the 26th and 30th of January 2004 and were checked fortnightly until the 21st of April 2004. Due to the limited availability of *E. acerbella* pheromone capsules, only one vineyard per farm had a trap (table 4.1). Pheromone traps consisted of a yellow delta trap, with a sticky pad on the inside (Chempak) and a Pherocon carnation worm (*E. acerbella*) pheromone capsule placed in the middle of the sticky pad. Pheromone traps were placed in the middle of the vineyard to eliminate potential effects reported by Hoffman & Dennehy (1989) and Hoffman *et al.* (1992) with the grape berry moth, *Endopiza viteana* Clemens (Lepidoptera: Tortricidae). A further two traps were placed in the surrounding fynbos vegetation. Every four weeks the sticky pads were replaced.

4.2.6 Comparison of current management techniques

Pesticide spray data were obtained from individual farm records. De Hoop, Cairngorm and Idlewinds spray data were not used, due to difficulty in obtaining the data or because of missing data. Each farm was scored using the AgChem Committee for Integrated Production of Fruit and Wine's (IFP) evaluation scoring system. This scoring system is used to evaluate pesticide use on the basis of potential risk to human health and safety, the environment, and adverse effects on beneficial insects and mites. It incorporates all forms of pesticides, so a second score was obtained using the same system but including insecticides only. The occurrence of all the phytosanitary pests found on each of the above sampling locations was then compared to both IFP scores.

P. callosus abundance high in the vines, i.e. at the head of the vine, or in the bunches, was compared to the presence or absence of Plantex®. Abundance of *E. acerbella* in vineyards sprayed with DiPel® (*B. thuringiensis* var. *kurstaki*) was compared to those vineyards not sprayed with DiPel®.

4.2.7 Other variables considered in this study

Weather data were acquired from the South African Weather Service for Worcester, the closest major weather station to the Hex River Valley. These climate data consisted of daily Maximum and minimum temperatures, along with daily rainfall. Fortnightly averages were obtained from the data. Comparisons were then made to the abundance of each of the phytosanitary pests found using each of the sampling methods.

The time of day the sampling occurred was recorded for every sampling method except for the pheromone traps as the time that *E. acerbella* entered the trap was not known. These times were then sorted into hourly intervals. Abundance of the phytosanitary pests was then compared to these time intervals. The immediate surrounds of the vineyards and the different farms were compared to the number of phytosanitary pests found in the vineyards per sampling location.

4.2.8 Statistical analysis of the data

Data from the sampling locations, namely bunches, stems, trunks of the vines and cover crops for all phytosanitary pests found were not normally distributed (Anderson-Darling Normality Test) (Steel & Torrie 1980; Sheskin 2000). The variances were heterogeneous (Bartlett's Test and Levene's Test). These three tests were run in the program Minitab 14. The data were log transformed and square-root transformed (Underwood 1997), but the transformed data still were not normally distributed and and the variances were still heterogeneous. As a result, a non-parametric statistical analysis, the Kruskal-Wallis Test, was performed (Steel & Torrie 1980; Sheskin 2000). This was done to compare abundance of phytosanitary pests found per week during the sampling period, the different times of the day the pests were caught, the number of surrounding vineyards and the different farms. Pests found in the cover crop were further compared to the cover crop type and height. For each Kruskal-Wallis Test, there were multiple comparisons of mean ranks for all groups using the Statistica 6.0 software. Abundance of *P. callosus* found in the bunches, for those vines with and without Plantex® was analyzed using the Mann-Whitney Test (Sheskin 2000).

Temperature and rainfall were plotted against the abundance of the phytosanitary pests. No statistical analysis was conducted on this data due the short time period that monitoring took place and the lack of replicates (seasons).

Numbers of *E. acerbella* found in the pheromone traps were normally distributed and the variances were homogeneous after a log transformation (Underwood 1997). Numbers of *E. acerbella* found in the pheromone traps were analyzed for the different weeks during the sampling period, the number of vineyards surrounding the sampled vineyard, the different cultivars and year the vineyards were planted using Analysis of Variance (ANOVA) in Statistica 6.0. A Fisher's LSD was used to compare pairs for each of means. A t-test was performed to determine whether there was a difference in the number of *E. acerbella* found in vineyards that received DiPel®, compared to those that had no DiPel® spray.

No statistical analysis could be performed on the number of phytosanitary pests found in the surrounding habitats as only two individual phytosanitary pests were recorded.

Figure 4.1 Youngest age of bunches inspected for pests

Figure 4.2 Cloth sheet used to collect pests shaken loose from the bunches.

Figure 4.3 A Plantex® ring (above) and a trunk band (below).

Figure 4.4 Cover crop of a vineyard.

Figure 4.5 Pheromone trap within a vineyard.

Figure 4.6. Vineyard surrounded by the indigenous vegetation.

4.3 Results

4.3.1 Changes in phytosanitary pest populations during the picking period

The only location on the vines at which *P. callosus* showed any significant difference in population levels during the entire harvesting period were for those found at the head and base of the vines (table 4.2). *P. callosus* means per week ranged from 0.083 per vine base for the 9th week to 0.005 per vine base for the 17th week.

D. fasciatus population levels in bunches and on vines had a significant difference during the whole picking period (table 4.2). *D. fasciatus* numbers in the bunches ranged from 0 per bunch for the 3rd and 15th weeks, to 0.016 per bunch for the 9th week. Whereas on the trunk of the vines they ranged from 0.05 per vine (7th week) to 0.25 per vine (13th week).

At all the locations sampled *G. simplex* numbers differed significantly between weeks the for entire picking period (table 4.2). *G. simplex* was only found in the bunches during two weeks, the 7th and the 9th. Those found on the trunk of the vines and under the trunk bands had a similar pattern of occurance. None were found from the 50th to the 5th weeks, with the most caught during the 15th week (0.013 per vine trunk and 0.016 per trunk band).

There was a noticeable change in abundance of *G. bimaculatus* during the entire picking period (table 4.2). *G. bimaculatus* numbers differed significantly between weeks 50 to 7, 9 to 11 and 13 to 17. The differences between week 11 and 17 was not significant (figure 4.7 (a)). Abundance of *G. bimaculatus* ranged from 0 during weeks 50 and 1, to a peak of 0.7 per band during week 15.

There was a significant difference in weekly abundance of *E. acerbella* caught in pheromone traps during the entire picking period ($F = 395.80$; $df = 57$; $P < 0.01$) (figure 4.7 (b)). Numbers caught during weeks 15 and 17 were significantly lower than the other weeks ($P < 0.05$). Numbers of *E. acerbella* caught ranged from 15.4 per trap during the 13th week to 3.0 per trap in the 15th week.

Table 4.2 Results of Kruskal-Wallis tests for four phytosanitary insects at three sampling locations on vines. *H* = Kruskal-Wallis coefficient, *N* = sample size, *P* = probability.

Species	**Location on vines**	***H***	***N***	***P***
Phlyctinus callosus	Bunches	7.90	474	0.34
	Trunk bands	6.67	2970	0.67
	Vine trunks	67.97	3960	<0.01
Dysdercus fasciatus	Bunches	14.17	474	0.05
	Trunk bands	17.76	2970	0.38
	Cover crop	10.55	436	0.39
	Vine trunks	21.16	3960	0.01
Gonocephalum simplex	Bunches	15.65	474	0.03
	Trunk bands	20.03	2970	0.02
	Vine trunks	25.35	3960	<0.01
Gryllus bimaculatus	Trunk bands	421.18	2970	<0.01

Moreson block 14 had the highest number of *P. callosus.* Therefore, these data were used to illustrate the population fluctuations of *P. callosus* in an individual vineyard. Although there does not appear to be a pattern of *P. callosus* movement to locations higher on the vines during the season, bunches did retain a greater abundance later in the season than anywhere else on the vine (figure 4.8 (a)). The maximum number of *P. callosus* found at the head of the vines appeared later than at the base (figure 4.8 (b &d)). For all locations on the vines, with the exception of bunches, there was a decline in the population after the 11th week. Maximum number of *P. callosus* found under trunk bands occurred in the 5th week (figure 4.8 (c)), the earliest peak for any of the locations.

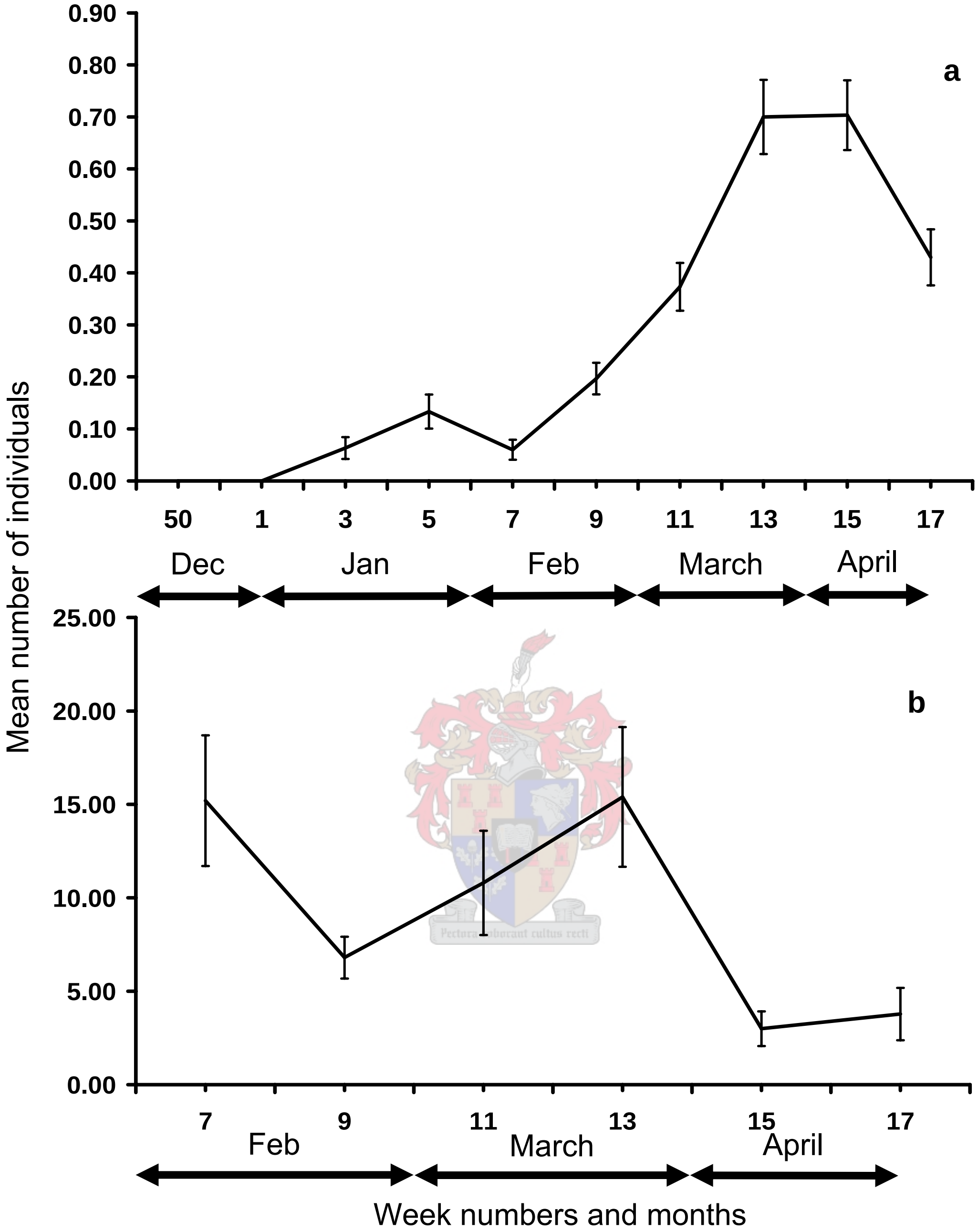

Figure 4.7 *Gryllus bimaculatus* and *Epichoristodes acerbella* abundance during the picking period **a** *G. bimaculatus* under trunk bands, and **b** the mean number of *E. acerbella* caught in pheromone traps. Mean (±1 SE).

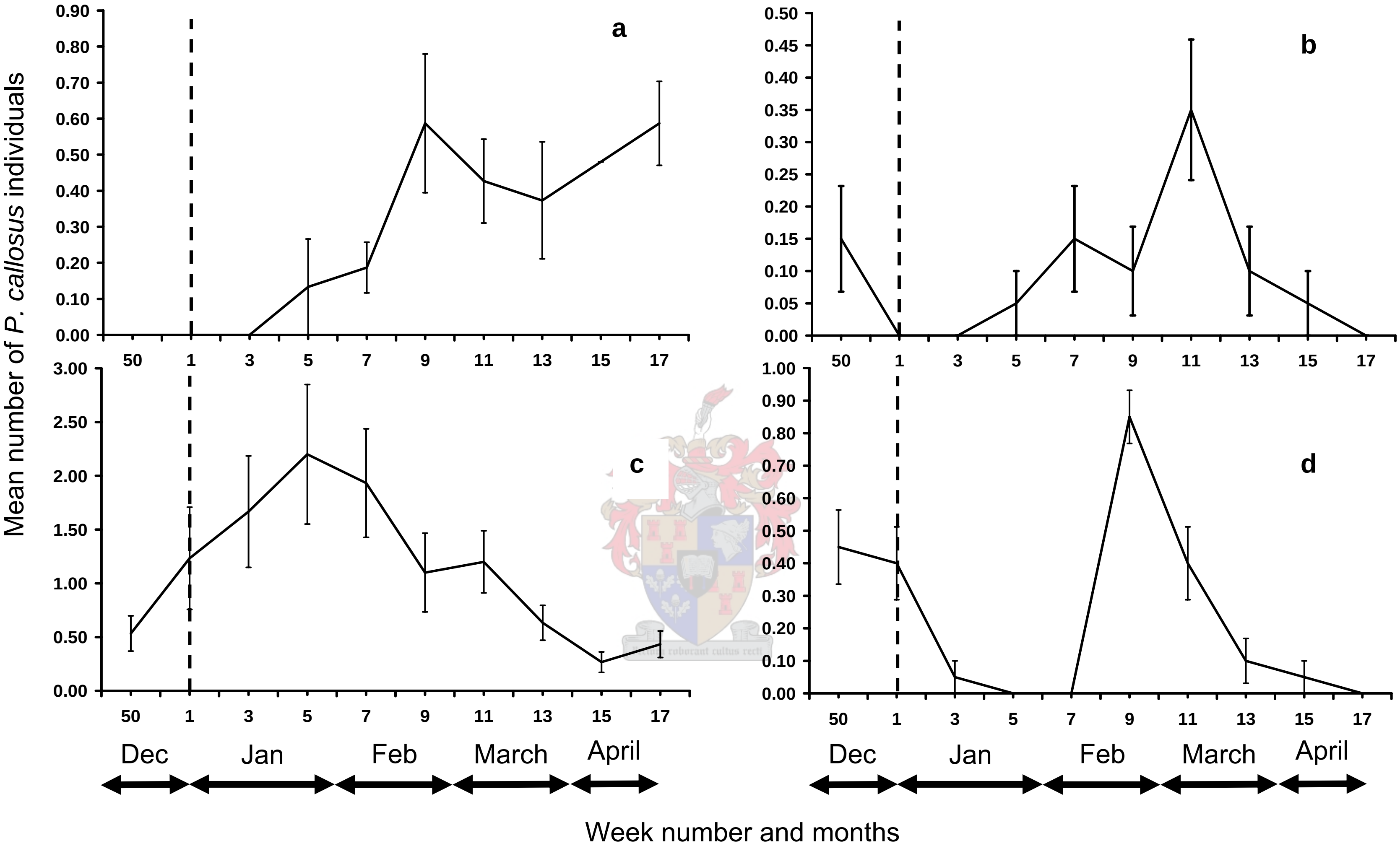

Fig 4.8 Mean number of *Phlyctinus callosus* recorded at various locations on the vines in the Moreson block 14: **a** in bunches, **b** head of vines, **c** under trunk bands and **d** base of vines. Dotted line indicates application of omethoate. Mean (±1 SE).

4.3.2 Effect of spray regimes on phytosanitary pests

There was no correlation between overall IFP scores and IFP insecticide scores (Spearman's rank order correlation = 0.03). *P. callosus* at sampling locations high on the vines (i.e. head of the vines and in bunches) was positive correlation with the amount of insecticides used (table 4.3). The strongest correlation was between the amount of pesticides applied and abundance of *G. bimaculatus* found under trunk bands. There was no relationship between *D. fasciatus*, *G. simplex* and *E. acerbella* to the amount of pesticides or insecticides applied.

Table 4.3 Spearman's rank order correlation between different phytosanitary pest species at different locations on vines and both overall AgChem Committee for Integrated Production of Fruit and Wine's (IFP) scores and insecticide only IFP scores (* indicates a significance level of $P \leq 0.05$).

Species	**Location on the vines**	**IFP (overall)**	**IFP (insecticides)**
Phlyctinus callosus	Bunches	0.07	0.63*
	Trunk bands	0.29	0.17
	Vine head	0.19	0.64*
	Vine base	0.34	0.44
Dysdercus fasciatus	Bunches	0.37	0.40
	Trunk bands	0.15	0.44
	Cover crop	0.39	0.33
	Vine trunks	0.28	0.27
Gonocephalum simplex	Bunches	0.45	0.30
	Trunk bands	0.45	0.30
	Vine trunks	-0.11	0.03
Gryllus bimaculatus	Trunk bands	0.86*	-0.46
Epichoristodes acerbella	Pheromone traps	-0.14	0.36

The effects of the omethoate on *P. callosus* at the different differed according to the location on the vines in the Moreson block 14. Application of the spray was too early to affect the population in the bunches (figure 4.8 (a)). It also did not appeare to affect numbers caught under trunk bands (figure 4.8 (c)) or on the trunk of the vines, particularly at the base (figure 4.8 (b & d). Six weeks after the application of omethoate, numbers of *P. callosus* increased sharply.

4.3.3 Effect of Plantex® on **P. callosus** *and DiPel® on* **E. acerbella**

Not a single *P. callosus* was found at the head of the vines with Plantex rings, while a total of 32 *P. callosus* were recorded at the head of vines with no Plantex® ring. A total of 105 *P. callosus* was found in bunches on vines without Plantex® rings and only four in bunches on vines with a Plantex® ring (Mann-Whitney test: adjusted Z = 3.87; $P < 0.01$) (figure 4.9). Of these four *P. callosus* one was found in the 11th week, while the remaining three were found during the final week of sampling (17th week).

Abundance of *E. acerbella* was significantly less in vineyards in which the bio-control agent DiPel® (*B. thuringiensis* var. *kurstaki*) was applied compared to those that were untreated (t = 3.10; *df* = 40; $P < 0.01$) (figure 4.10).

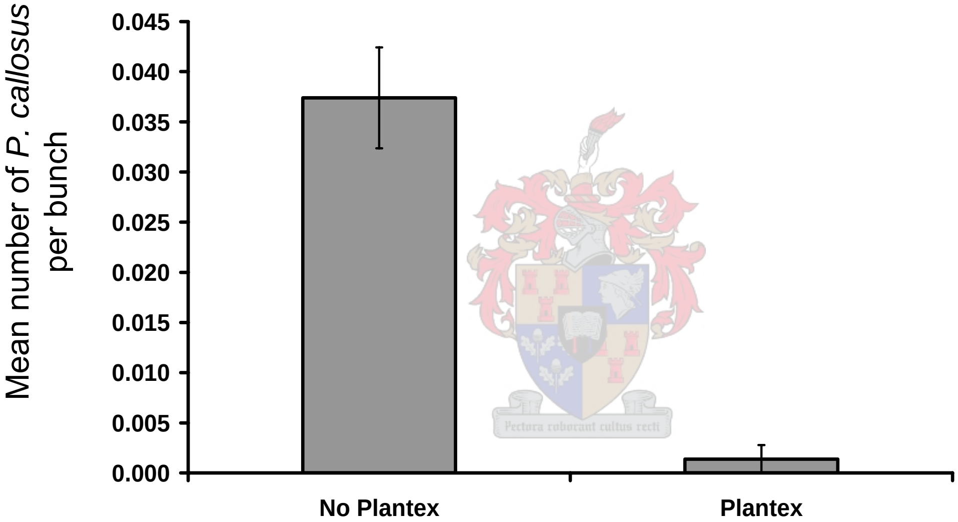

Figure 4.9 Mean number of *Phlyctinus callosus* found in bunches in vineyards with and without Plantex on their trunks. Mean (± 1 SE).

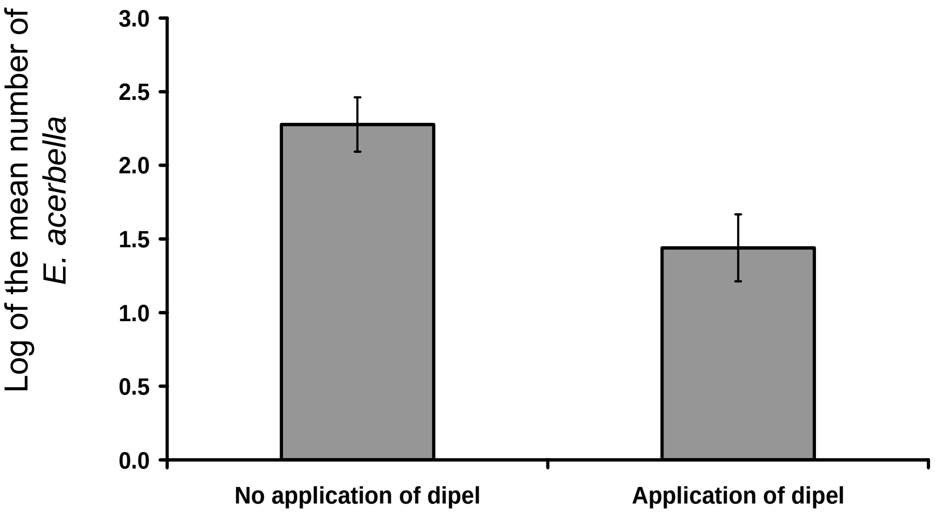

Figure 4.10 Log of the mean number of *Epichoristodes acerbella* found in pheromone traps for those vineyards that did not and did apply the bio-control agent DiPel® (*Bacillus thuringiensis kurstaki*). Mean (±1 SE).

4.3.4 Effect cover crop and surrounding vegetation on the presence of phytosanitary pests

During the entire sampling period, only two *P. callosus* and six *G. simplex* were found in the cover crop. *D. fasciatus* had the highest abundance for all the phytosanitary pests in the cover crop with 104 individuals. Numbers of *D. fasciatus* did not appear to be affected by vegetation type (H = 3.07; N = 436; P = 0.38) or height (H = 3.87; N = 436; P = 0.28).

In the surrounding habitats only two *D. fasciatus* individuals were found (one next to a road and the other next to a stream). No other phytosanitary pests were found. The two pheromone traps in the surrounding fynbos did not catch any *E. acerbella*.

The number of vineyards surrounding the sampled vineyard had a significant effect on numbers of *P. callosus* at all locations on the vines (table 4.4). At all sampling locations, the highest mean number of *P. callosus* was in blocks surrounded completely by other vineyards (four adjacent vineyards), than by blocks with three adjacent vineyards, with the least number in blocks with just two adjacent vineyards (figure 4.11

(a)). There was a significant difference between the mean number of *P. callosus* caught in the trunk bands and in blocks surrounded by four vineyards, and in those with either two or three adjacent vineyards (figure 4.11 (a)).

The numbers of *D. fasciatus* found differed between vineyards in regard to the number of other vineyards that surround them, with an exception of those found in the cover crop (table 4.4). Blocks completely surrounded by other vineyards had, the highest mean number of *D. fasciatus* in all locations. Significant more *D. fasciatus* ($P < 0.01$) more recorded on the vine trunks of blocks completely surrounded by vineyards than in those surrounded by either two or three vineyards (figure 4.11 (b)).

Only the *G. simplex* found on the vine trunk showed a significant relationship to the number of surrounding vineyards (table 4.4). The mean number of *G. simplex* on vine trunks was highest in vineyards surrounded by three adjacent vineyards, followed by those completely surrounded by vineyards, while none were recorded in the bunches with just two adjacent vineyards.

Blocks surrounded by either three or four vineyards had a significantly higher mean number of *G. bimaculatus* per trunk band than blocks surrounded by two vineyards. Those surrounded by four vineyards had the highest number (table 4.4, figure 4.11 (c)).

The mean number of *E. acerbella* found in pheromone traps differed according to the number of surrounding vineyards ($F = 65.02$, $df = 57$, and $P < 0.01$). There was an increase in the abundance of *E. acerbella* as the number of surrounding vineyards increased (figure 4.11 (d)). Fewer moths were caught in traps placed in vineyards surrounded by just two other vineyards than in those completely surrounded by vineyards .

Table 4.4 Results of Kruskal-Wallis tests between phytosanitary insects and the locations that they were sampled at in vineyards to number of surrounding vineyards. *H* = Kruskal-Wallis coefficient, *N* = sample size, *P* = probability.

Species	**Location on the vines**	***H***	***N***	***P***
Phlyctinus callosus	Bunches	39.54	474	<0.01
	Trunk bands	213.75	2970	<0.01
	Vine head	3.38	3960	0.18
	Vine base	26.73	3960	<0.01
Dysdercus fasciatus	Bunches	36.43	474	<0.01
	Trunk bands	19.02	2970	<0.01
	Undergrowth	1.57	436	0.46
	Vine trunks	75.33	3960	<0.01
Gonocephalum simplex	Bunches	3.19	474	0.20
	Trunk bands	3.04	2970	0.22
	Vine trunks	8.18	3960	0.02
Gryllus bimaculatus	Trunk bands	27.72	2970	<0.01

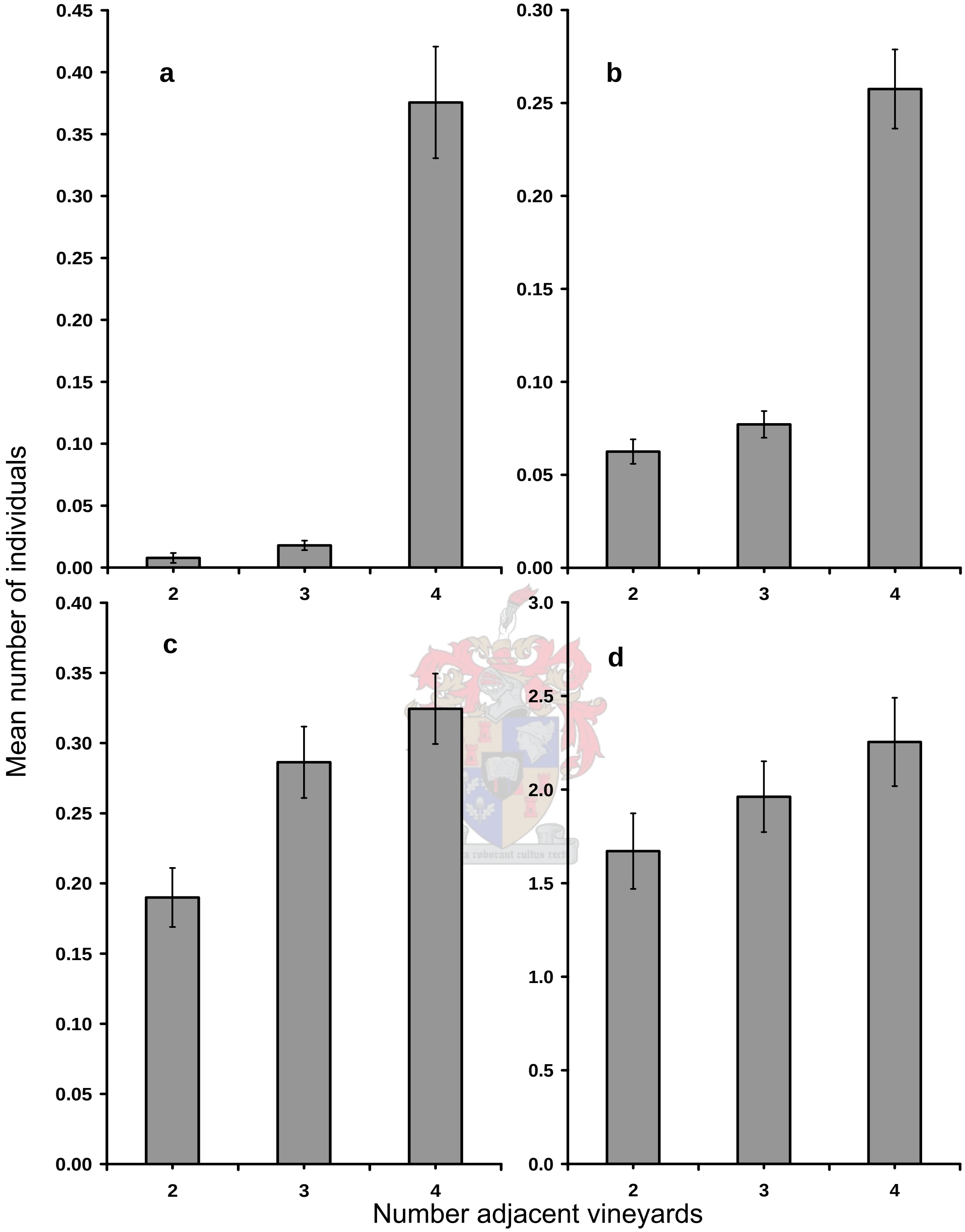

Figure 4.11 Mean number of *Phlyctinus callosus*, *Dysdercus fasciatus*, *Gryllus bimaculatus* and *Epichoristodes acerbella* found per adjacent vineyards. **a** *P. callosus* found under trunk bands, **b** *D. fasciatus* on vine trunks, **c** *G. bimaculatus* found under trunk bands and **d** *E. acerbella* found in pheromone traps. Mean (±1 SE).

4.3.5 Weather

As expected, there was a negative correlation between rainfall and temperature (R^2 = 0.52; *t* = -2.93 and *P* = 0.02) (figure 4.12).

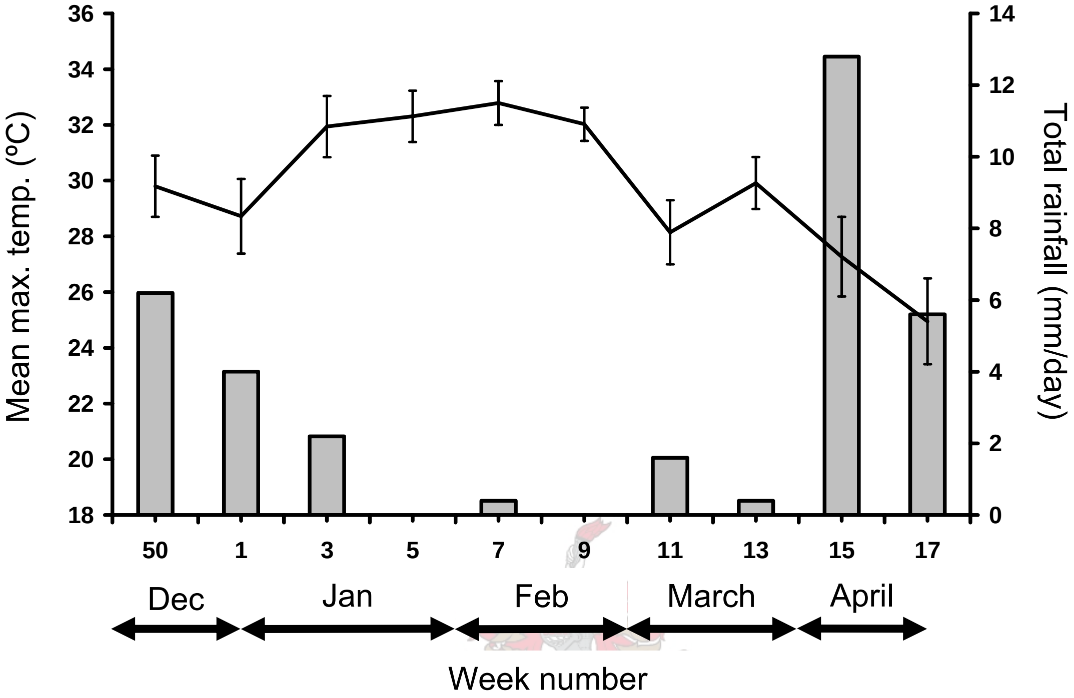

Figure 4.12 Mean maximum temperature and total rainfall. Line represents temperature, mean (±1 SE). Histogram shows total rainfall per two week intervals throughout the study period (weather data from the South African Weather Service).

4.3.5.1 Temperature

P. callosus appeared to have the highest correlation with temperature for all of the phytosanitary pests included in this study. The mean number of *P. callosus* on the vines (figure 4.13 (c)) and under trunk bands (figure 4.13 (b)) appeared to increase and decrease as the ambient temperature increased and decreased. *P. callosus* in the bunches showed the opposite relationship with numbers unusually increasing when the ambient temperature decreased (figure 4.13 (a)). Thus during periods of warmer weather, *P. callosus* may move up the vines to shelter under trunk bands during the day. After long periods of warm weather, there appeared to be a high number on the trunk of the vines, while during periods of cool weather they appear to settle in bunches. It is unclear whether this is due to the temperature or other factors such as the photoperiod or the bunches becoming more attractive as sites for sheltering later in the season.

Temperature appeared to have no affect on the numbers of *D. fasciatus, G. simplex* and *E. acerbella* at any locations on the vines. *G. bimaculatus* appeared to be trapped under trunk bands far more often during periods of low temperatures than warm temperatures.

4.3.5.2 Rainfall

There appeared to be fewer *P. callosus* in the trunk bands during periods of rainfall, similar to those results reported by Barnes (1982), (figure 4.14 (a)).

D. fasciatus in bunches appeared to be negatively correlated with rainfall. During periods of rainfall the there were fewer *D. fasciatus* in bunches (figure 4.14 (b)). The number of *D. fasciatus* under trunk bands was positively correlated with rainfall as there were more *D. fasciatus* in the trunk bands after periods of rain (figure 4.14 (c)). This possibly represented a movement from trunk bands to bunches during periods of rain, although it is unclear as the rainfall occurred mainly at the end of the season, and this may be coincidental with the population changes with *D. fasciatus*.

G. simplex numbers under the trunk bands and on the trunk of the vines were positively correlated to rainfall (figure 4.15 (a & b)). This may also be a coincidental occurrence with rainfall at the end of the season.

There was no correlation between *G. bimaculatus* and amount of rainfall. *E. acerbella* was sampled for only a short time period. Therefore, it was difficult to determine whether the decrease at the end of the season (figure 4.15 (c)) was due to rainfall or some other factor.

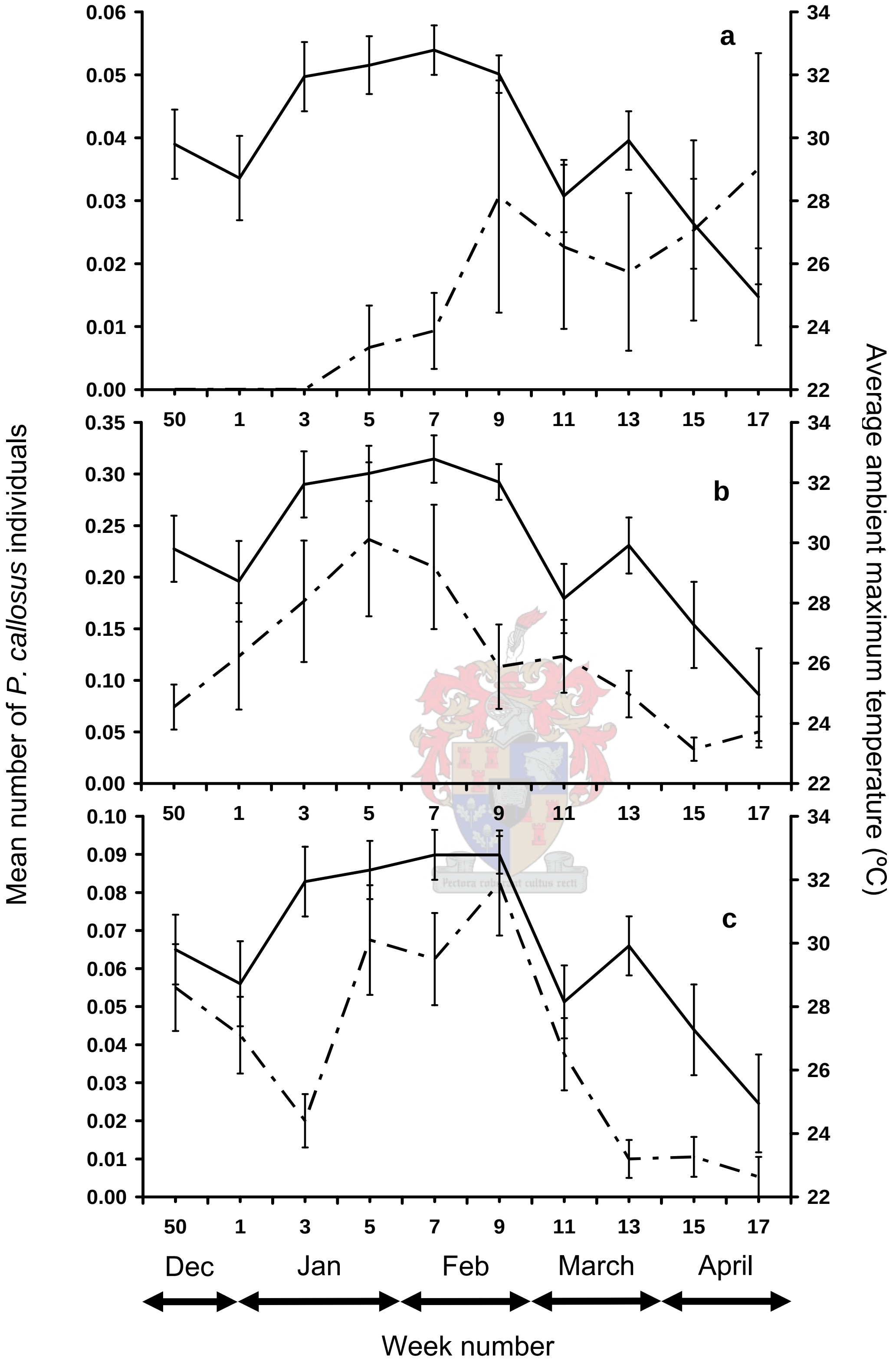

Figure 4.13 Mean number of *Phlyctinus callosus* and average maximum temperature per week, for each of the sampling locations on the vines; **a** in bunches, **b** under trunk bands and **c** at the base of the vines. Dashed line represents mean number of *P. callosus* and the solid line represents mean temperature. Mean (±1 SE).

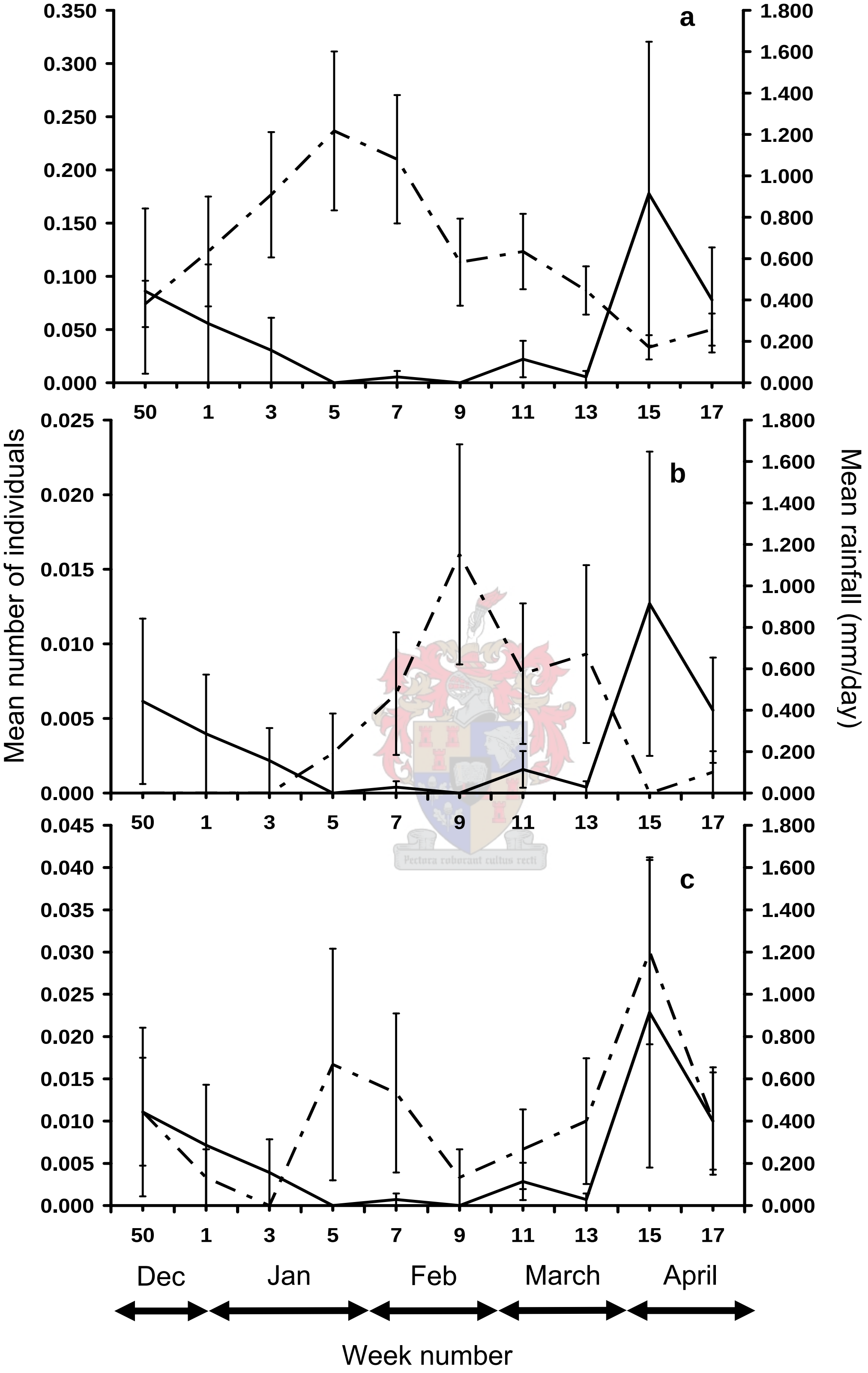

Figure 4.14 Mean number of *Phlyctinus callosus* and *Dysdercus fasciatus* (dashed lines) and mean rainfall (solid line) for two week periods; **a** *P. callosus* found under trunk bands, **b** *D. fasciatus* in bunches and **c** *D. fasciatus* found under trunk bands. Mean (1 ± SE).

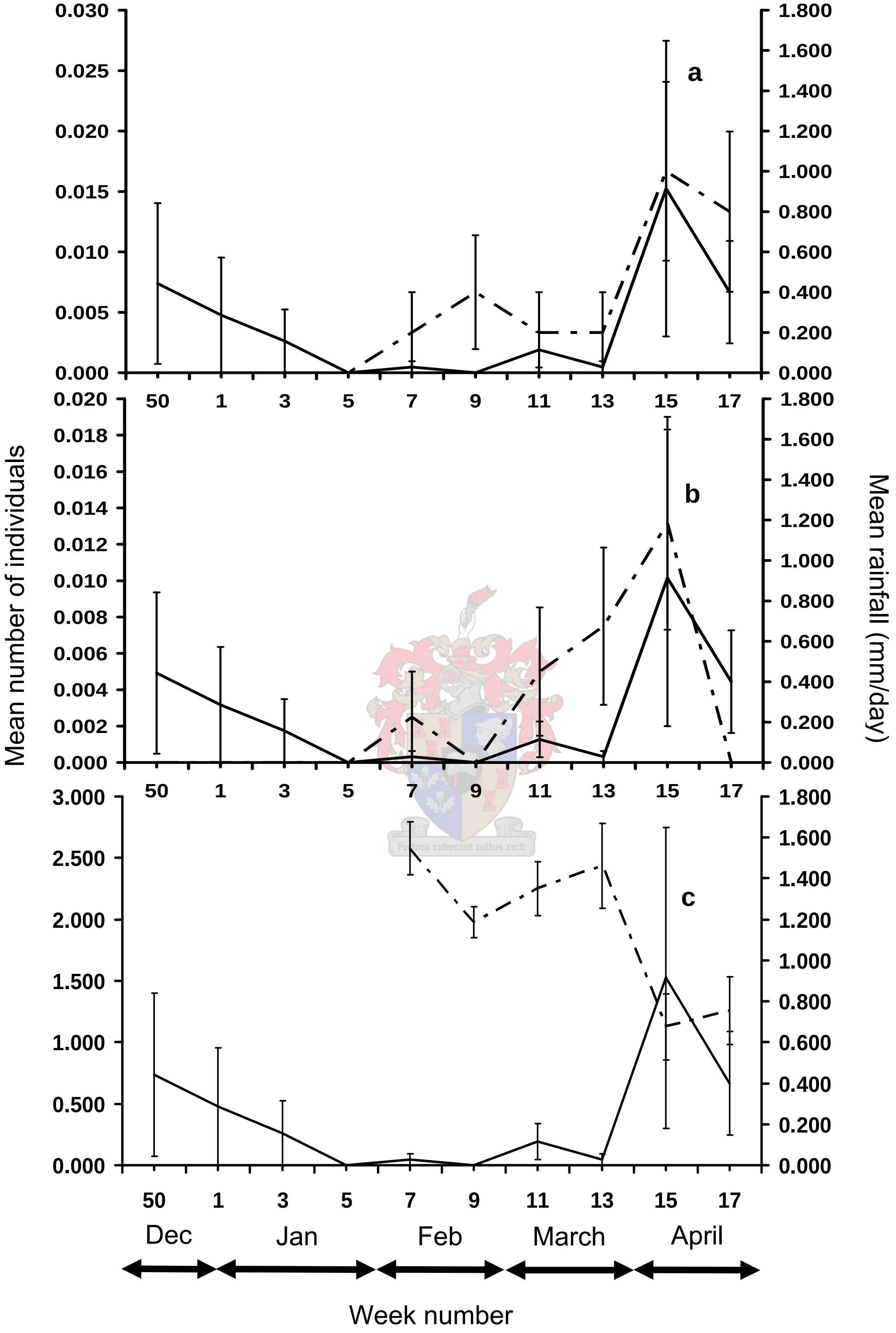

Figure 4.15 Mean number of *Gonocephalum simplex* and *Epichoristodes acerbella* (dashed lines) and mean rainfall (solid line) per week; **a** *G. simplex* under trunk bands, **b** *G. simplex* on the vines and **c** *E. acerbella* in pheromone traps. Mean (1 ± SE).

4.3.6 Time of day

Time of day had a significant effect on the mean number of *P. callosus* for all sampling locations on the vine (table 4.5). The mean number of *P. callosus* found at the base of the vine, had the highest abundance between 9h00 and 13h00 (figure 4.16 (b)). *P. callosus* numbers at other locations had a single peak period. In bunches, this was between 10h00 and 11h00 (figure 4.16 (a)), while under trunk bands and at the head of the vines the peak numbers were recorded between 9h00 and 10h00.

The mean number of *D. fasciatus* differed significantly according to hour of the day at all the locations on the vine, except under trunk bands (table 4.5). The mean number of *D. fasciatus* on the trunk of the vines differed between 11h00 and 12h00 from all other time periods ($P < 0.05$) (figure 4.17 (b)). Abundance of *D. fasciatus* in bunches peaked between 11h00 and 12h00, after which none were found (figure 4.17 (a)). The highest numbers in the cover crop were between 12h00 and 13h00 (figure 4.17 (c)). The average number of *D. fasciatus* under trunk bands was not affected by the time of day. The highest number was between 9h00 and 11h00, and after 15h00.

The only relationship between *G. simplex* and hour of day was under trunk bands, although no trend was discernable (table 4. 5). *G. bimaculatus* numbers were highest under trunk bands at both the earliest (7h00 - 8h00) and latest (15h00 - 16h00) time intervals (figure 4.16 (c)).

Table 4.5 Results of Kruskal-Wallis tests between mean number of phytosanitary insects at different locations in the vineyards to time of day. *H* = Kruskal-Wallis coefficient, *N* = sample size, *P* = probability.

Species	**Location on the vines**	***H***	***N***	***P***
Phlyctinus callosus	Bunches	31.43	474	<0.01
	Trunk bands	21.35	297	0.01
	Vine head	32.21	3960	<0.01
	Vine base	100.93	3960	<0.01
Dysdercus fasciatus	Bunches	39.47	474	<0.01
	Trunk bands	12.85	297	0.12
	Cover crop	23.74	424	<0.01
	Vine trunks	271.15	3960	<0.01
Gonocephalum simplex	Bunches	6.74	474	0.56
	Trunk bands	9.53	297	0.30
	Vine trunks	17.53	3960	0.04
Gryllus bimaculatus	Trunk bands	24.45	297	<0.01

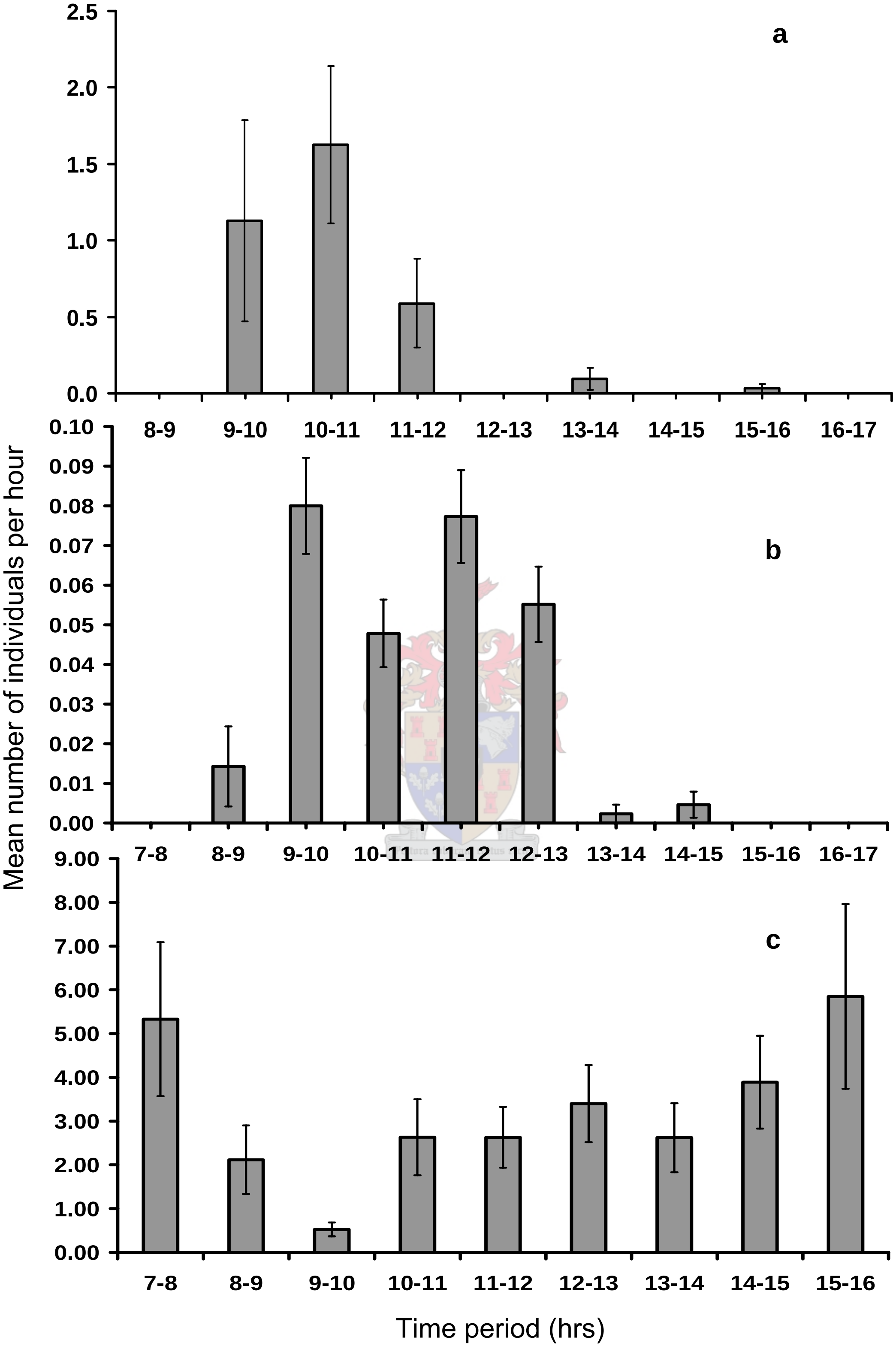

Figure 4.16 Mean number of *Phlyctinus callosus* and *Gryllus bimaculatus* during the day. **a** *P. callosus* in the bunches **b** *P. callosus* at the base of vines and **c** *G. bimaculatus* found under trunk bands. Mean (± 1 SE).

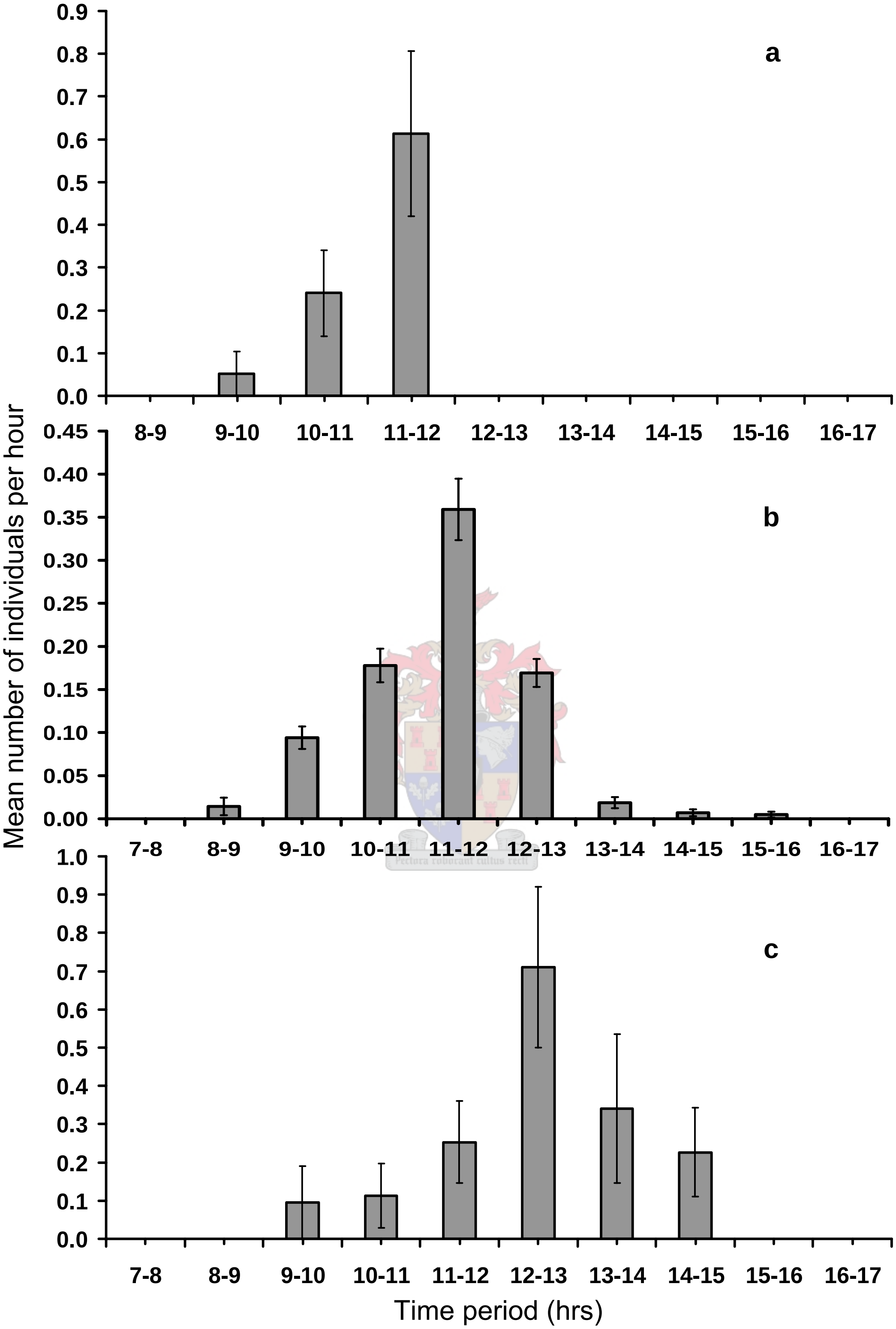

Figure 4.17 Mean number of *Dysdercus fasciatus* during the day. **a** In the bunches **b** *D. fasciatus* on the trunk of the vines and **c** in the cover crop. Mean (± 1 SE).

4.3.7 Differences between farms

Table 4.6 Results of Kruskal-Wallis tests for four phytosanitary pests at various locations on the vines per farm. *H* = Kruskal-Wallis coefficient, *N* = sample size, *P* = probability.

Species	**Location on the vines**	***H***	***N***	***P***
Phlyctinus callosus	Bunches	169.24	474	<0.01
	Trunk bands	925.58	2970	<0.01
	Vine head	448.90	3960	<0.01
	Vine base	134.18	3960	<0.01
Dysdercus fasciatus	Bunches	128.81	474	<0.01
	Trunk bands	102.12	2970	<0.01
	Undergrowth	43.20	436	<0.01
	Vine trunks	931.24	3960	<0.01
Gonocephalum simplex	Bunches	16.80	474	0.05
	Trunk bands	24.29	2970	<0.01
	Vine trunks	25.97	3960	<0.01
Gryllus bimaculatus	Trunk bands	410.39	2970	<0.01

There were differences in *P. callosus* numbers between farms at all locations on the vines (table 4.6). Abundance of *P. callosus* in bunches, under trunk bands and at the head of the vines were significantly higher on Moreson (figure 4.18 (a)) than on all the other farms. On De Hoop there were significantly more *P. callosus* at the base of the vines then all farms except Moreson ($H = 4.51$; $P < 0.01$).

The abundance of *D. fasciatus* at all locations on the vines was highly significant (table 4.6). Moreson had the highest number of *D. fasciatus* in the bunches and under trunk bands. Moreson and De Hoop had a significantly more *D. fasciatus* on the trunks of the vines than the other farms (Moreson: $H = 9.91$; $P < 0.01$; De Hoop: $H = 7.79$; $P < 0.01$) (figure 4.19 (a)). De Hoop had the highest number of *D. fasciatus* in the cover crop for all the farms (figure 4.19 (b)).

The mean number of *G. simplex* in bunches was only significant to the 5% level in the bunches, while the other locations were significant to 1% level (table 4.6). Moreson had the highest number of *G. simplex* found in the bunches and under trunk bands. *G. simplex* was recorded on the vine trunks on only three farms. They were recorded on Bella Vista (4) and Somerlus (4) followed by Moreson (3).

G. bimaculatus showed a highly significant relationship to the farms they were found on (table 4.6). Protea had a significantly higher average, with Cairngorm, Kanetvlei and Tesame showing a significant difference to the remaining farms (figure 4.18 (b)).

There were differences in numbers of *E. acerbella* caught in pheromone traps between farms (*F* = 3.64, *df* = 57, *P* < 0.01). Tesame had the highest mean number of *E. acerbella* per trap and was significantly different from other farms (*F* = 3.09; *P* < 0.01) (figure 4.19 (c)).

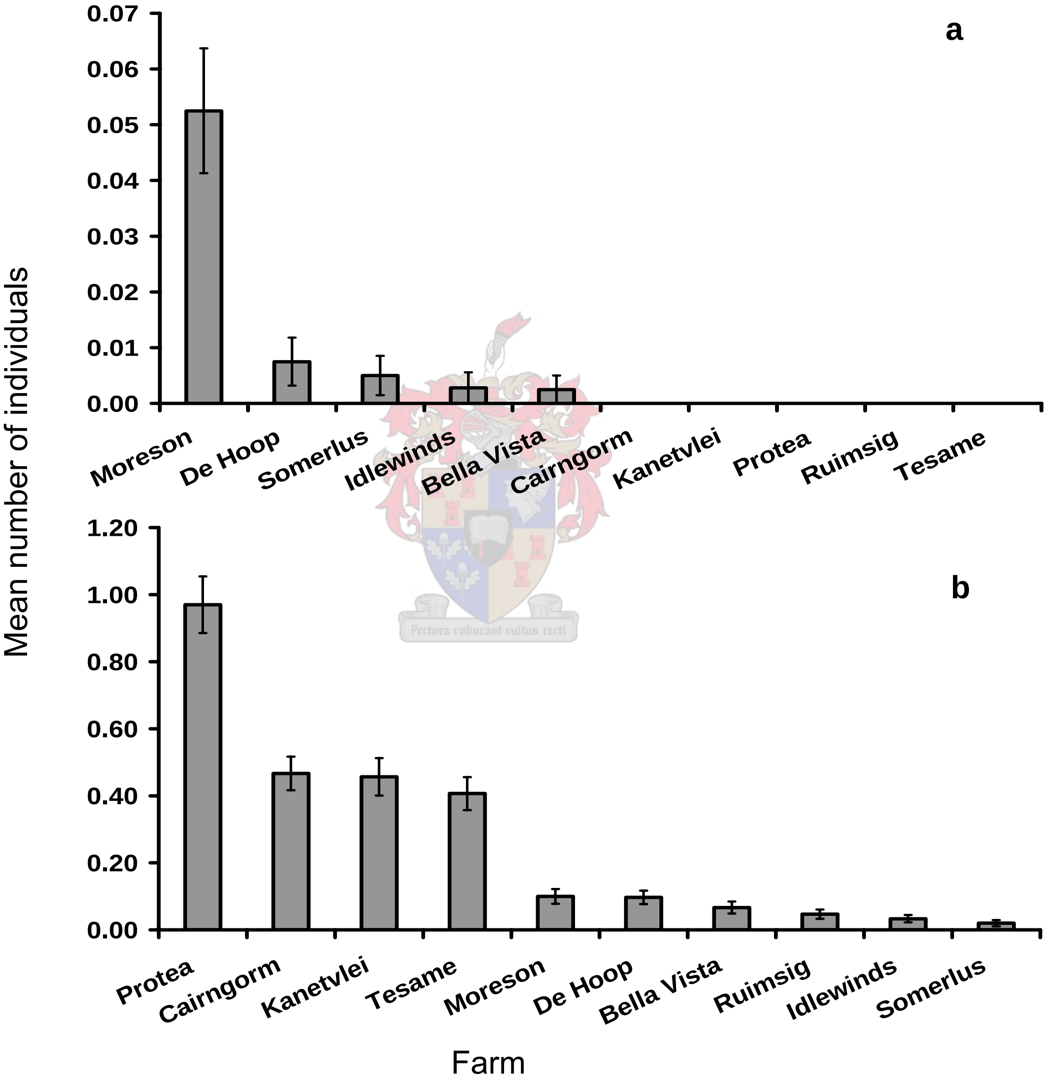

Figure 4.18 Mean number of *Phlyctinus callosus* and *Gryllus bimaculatus* per farm. **a** *P. callosus* at the base of the vine trunks, and **b** *G. bimaculatus* under trunk bands. Mean (± 1 SE).

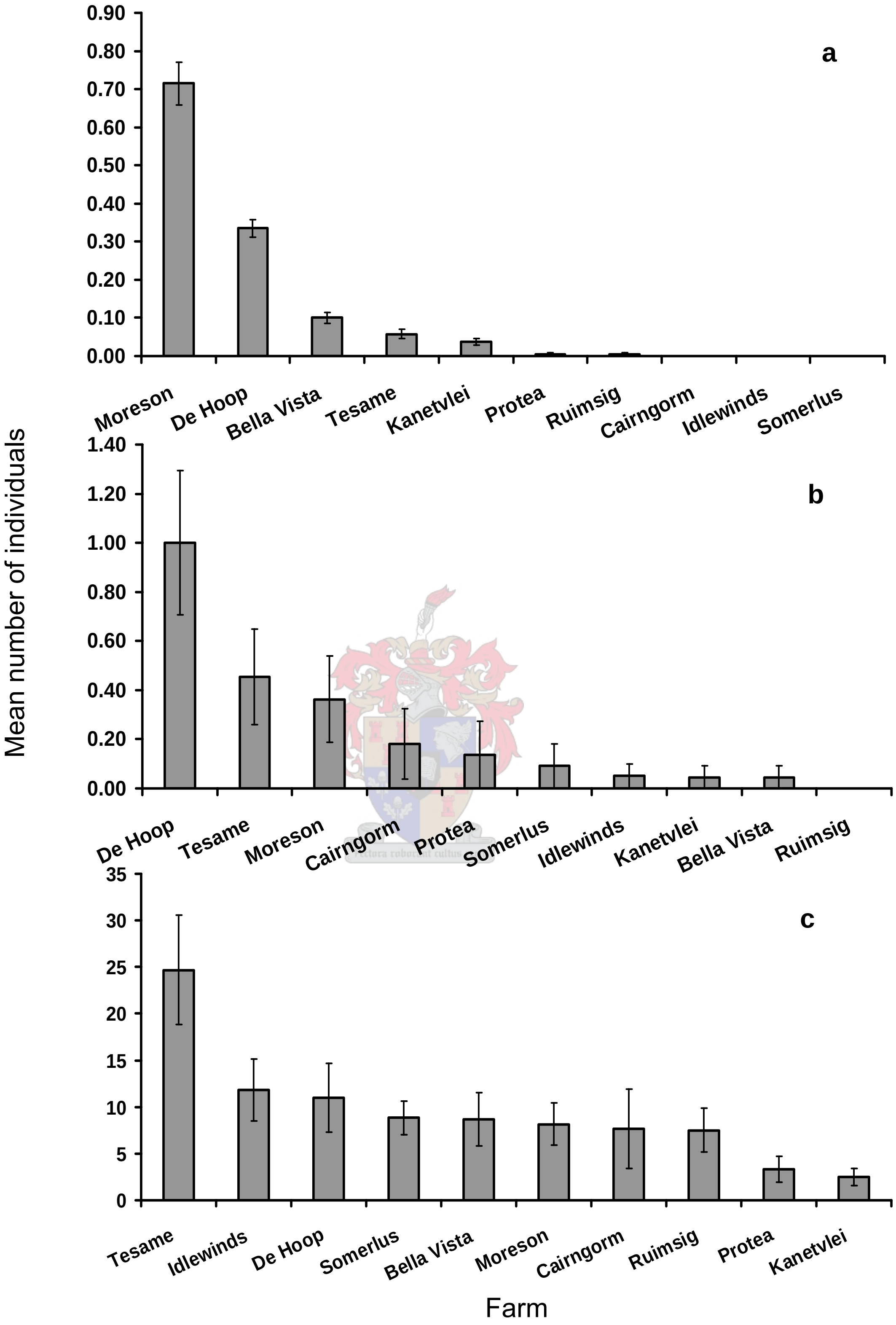

Figure 4.19 Mean number of *Dysdercus fasciatus* and *Epichoristodes acerbella* per farm. **a** *D. fasciatus* on the vine trunkss, **b** *D. fasciatus* in the cover crop, and **c** *E. acerbella* in pheromone traps. Mean (± 1 SE).

4.4 Discussion

4.4.1 Abundance of phytosanitary pests during the picking period

P. callosus did not vary much in abundance over the picking period, although numbers declined on all locations on the vine after the 11th week. There appeared to be more *P. callosus* later in the season higher in the vines (bunches and head of the vines). Due to the high abundance of *P. callosus* in bunches late in the season, care should be taken with the harvesting of late cultivars.

E. acerbella populations only decreased at the end of the picking period, generally too late to be at benefit from the phytosanitary point of view. Abundance of *D. fasciatus* increased during the season with most being found during the 13th to 15th weeks. *G. simplex* and *G. bimaculatus* were only a phytosanitary threat to late cultivars.

4.4.2 Current insecticide practices

The fact that there was no correlation between the overall IFP scores and the insecticide only IFP scores simply means that there was no relationship between the number of insecticide and total pesticides applications. Thus, high IFP scores did not necessarily mean that a large number of insecticide applications were used. In only two species was there a relationship between insect numbers and the number of insecticide or pesticide applications. There was a positive correlation between *P. callosus* numbers and the number of insecticide applications and *G. bimaculatus* numbers and the number of pesticide application. If producers see high numbers of *P. callosus*, they may spray more insecticides, although insecticides are normally applied before the emergence of *P. callosus* to avoid damage to the fruit. There also may be resistance to the insecticides. Local populations could become resistant to these insecticides on farms that have historically sprayed large amounts of insecticides. Although *P. callosus* is not a particularly mobile insect, it is unlikely to achieve the isolation required for resistance to develop in individual vineyards. This also does not explain why the significant correlation is only for *P. callosus* found high on the head of the vines and in the bunches. The answer may lie with the fact that some producers use Plantex® and so choose not to spray as much insecticide on their vineyards. Thus, this result could simply be due to Plantex® being more effective at preventing *P. callosus* getting to the head of the vines and into the bunches than insecticide.

The application of omethoate on the farm Moreson block 14 against *P. callosus* (figure 4.8) was not very effective. There appeared to be no difference between the number of *P. callosus* found under the trunk bands, with the spray also having been appliedtoo early to have any effect on those found in the bunches. *P. callosus* numbers on the vines appeared to be immediately reduced, but after a period of about six weeks the numbers on the vines were significantly higher than before the spray (figure 4.8). The population recovered before harvesting, so despite the spray, *P. callosus* would still be a major phytosanitary threat in this vineyard.

G. bimaculatus is not considered a major pest or phytosanitary pest and so it is unlikely that it is being targeted with insecticidal sprays. Vineyards that received a large number of pesticide applications had a higher abundance of *G. bimaculatus.* This was probably because it was highly tolerant to chemical sprays, while its natural enemies and competitors were not.

Of the 14 blocks for which pesticide spray records were obtained, 12 were treated with endosulfan and 10 with chlorpyrifos. All of them were treated either with endosulfan or chlorpyrifos or both. Using the AgChem Committee for Integrated Production of Fruit and Wine's (IFP) scoring system a score of over 140 constitutes a disqualification. Using this system only one vineyard would be considered medium risk (99), five vineyards medium-high risk (101, 107, 116, 117 and 117), two vineyards high risk (both 122) and six vineyards would have been disqualified (141, 152, 158, 176, 207, 221). Two vineyards scored over 200, with the highest score being 221. Thus there is a need to reduce the amount of pesticides currently used by the producers of the Hex River Valley, not only due to the health hazard and environmental risk (London *et al.* 2000) or to prevent the loss of beneficial insects and mites (Schwartz 1990; Walton & Pringle 1999), but producers may not be able to export their produce with increasing aversion to pesticide use by consumers.

4.4.3 Current and potential cultural control

The Plantex® band was highly successful at preventing *P. callosus* from entering the upper parts of vines. Therefore, this material can greatly reduce the phytosanitary importance of *P. callosus*. These are very similar results to those of Barnes *et al.* (1994), who showed that sticky bands were effective in controlling *P. callosus* in apple orchards. The only problem is that there appeared to be a reduction in effectiveness right at the end of the picking period. This may have been caused by the Plantex® becoming clogged with dust, leaves and other debris.

The fact that *C. capitata* has only been responsible for 3.84% of the phytosanitary rejections over the last two years (chapter 3), further emphasises Barnes's (2000b) claim that the current sterile release of fruit fly over the Hex River Valley is effective in controlling this pest.

There are other potential cultural practices that still need to be examined. The use of pheromones to disrupt mating has potential, although Barnes & Blomefield (2004) showed that the use of *E. acerbella* pheromones was less successful in controlling *E. acerbella* compared to other control means such as weed control and attract and kill.

Other potential physical control methods would include limb or bunch jarring and the construction of trenches, which are effective against non-flying pests (Oseto 2000; Vincent *et al.* 2003). Jarring of bunches before picking them, would have similar effects to the sampling technique used in this project, with insects falling out as they are disturbed. This would be based on Southwood's (1978) observations on Curculionidae behaviour of falling off plants when disturbed. This jarring could be done just before, or even while picking, provided containers are not placed under bunches being jarred. Trenches described by Boiteau *et al.*(1994) in which V-shaped trenches lined with plastic and filled with soapy water were dug around potato fields and were able to capture 95% of *Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae). This form of trapping would possibly be effective against pests like *P. callosus* that walks rather than flies (Vincent *et al.* 2003).

4.4.4 Current and potential biological control

Results from this study suggest that the application of *B. thuringiensis* is effective in controlling *E. acerbella*. Tabashnik (1994) cautions that the overuse of *B. thuringiensis* results in resistance within the Lepidoptera. So although wider application of *B. thuringiensis* would result in less *E. acerbella*, excessive use may ultimately cause it to be come ineffective.

Barnes (1987) mentioned an ant species *Dorylus helvolus* (Linnaeus) (Hymenoptera: Formicidae), Hymenopteran parasitoids from the family Mymaridae, also mites from the families Erythraeidae and Trombidiidae and a nematode from the genus *Mermithidae* have all been reported on or attacking *P. callosus*. Barnes (1987) also raised the possibility of the helmeted guineafowl *Numida meleagris* Linnaeus as a biocontrol agent.

The predators and parasitoids of *P. callosus* that Barnes (1987) reported on were all, when acting together, potential biocontrol agents. The ant species *D. helvolus* is a carnivorous army ant belonging to the subfamily Dorylinae, whose members influence arthropod communities (Berghoff *et al.* 2003b). This species has already been shown to reduce populations of the stemborers *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in maize crops in Lesotho (Ebenebe *et al.* 2001). *D. helvolus* was present but not dominant in the Hex River Valley (Addison & Samways 2000) This species should be encouraged in the vineyards either by modifying the cover crop or by reducing the amount of pesticides used. The *Dorylus* species are hypogaetic (Berghoff *et al.* 2002; 2003a; 2003b). Therefore, their subterranean lifestyle should prevent them from protecting the Psedococcidae as so they should not interfere with biological control of *P. ficus*.

The *Eucalyptus* snout beetle *Gonipterus scutellatus* Gyllenhal (Coleoptera: Curculionidae) is parasitized by the Mymaridae wasp *Anaphes nitens* (Girault) (Rivera *et al.* 1999). So the use of a Mymaridae wasp to control *P. callosus* is conceivable, especially the species mentioned by Barnes (1987), although further research on the topic is still required. The other organisms mentioned by Barnes (1987) could be used for the biological control of *P. callosus*, although these were found infrequently.

The helmeted guineafowl *N. meleagris* was shown by Barnes (1987) to have little effect on the populations of *P. callosus.* He also raised concern to potential damage these gunieafowl may cause, as fruit was found in their crops. Witt *et al.* (1995) in a similar study, found that guineafowl in fact consume the most abundant arthropod fauna present, and so do not significantly reduce the *P. callosus* population. The number of *P. callosus* found in the crops of guineafowl increased during summer (Little *et al.* 1995), the period when bunches are being harvested and when it needs to be controlled the most. None of these studies have confirmed whether guineafowl damage fruit or if the fruit found in their crops was from fruit fallen to the ground. In addition Little *et al.* (1997) reported high levels of endosulfan and chloropyriofos in the livers of guineafowl on deciduous fruit farms. Guineafowl may not be able to control *P. callosus*, but they potentially could help to prevent outbreaks, although a reduction in pesticides use may be required to successfully integrate them into the system.

No reports of the natural enemies of *E. acerbella* could be located.

4.4.5 Current and potential use of the cover crop to control phytosanitary pests

Only one of the phytosanitary species was recorded in the cover crop more than six times throughout this entire study. This particular species (*D. fasciatus*) appeared not to be affected by either the cover crop type or height. This suggested that manipulation of the cover crop would not encourage phytosanitary pest infestations, especially during the harvesting period. *D. fasciatus* was found to favour higher vegetation. This trend was not significant and numbers of *D. fasciatus* dropped in very tall vegetation, thus cover crop type did not affect numbers of *D. fasciatus* found. This suggested that *D. fasciatus* would be found in the vegetation no matter what the vegetation type or height was, so the control of the cover crop would not necessarily control *D. fasciatus*. Addison (2004) also reported that cover crops did not reduce pest ant populations.

P. callosus is associated with 17 weeds or grasses, 15 in their adult stage and two as larvae (Barnes 1987). These plants offer adult *P. callosus* either shelter, food or oviposition sites, while providing a food source for the developing larvae. *E. acerbella* has been reported to feed on two weeds during winter, namely the yellow sorrel and the small mallow (Blomefield & du Plessis 2000). There was no other information for other phytosanitary pests in relation to the weeds and grasses on which they feed. Fourie *et al.* (2001) identified seven grasses and sixteen nitrogen fixing broadleaf species that do not compete with grapevines. The use of these non-competitive weeds and grasses that do not harbour any of the phytosanitary pests yet encourage natural enemies is certainly viable.

There may be a need to keep the cover crop away from the vines to prevent the pests from climbing up the grass or weeds and directly onto the vine. In addition, cutting the cover crop before picking would prevent easy access of the phytosanitary insects to the picking crates left in the vineyard.

4.4.6 Current and potential use of the surrounding habitats to control phytosanitary pests

Only two *D. fasciatus* were found in the surrounding habitats. These two individuals were also found less than five meters from vineyards and so may have originated from the vineyards. The two pheromone traps in the surrounding fynbos did not catch any *E. acerbella*. There were too few traps in the fynbos to conclude whether *E. acerbella* was present in the surrounding fynbos or not. Sampling of the surrounding habitat did not capture any of phytosanitary pests during the picking period, although the scope of this study did not allow us to determine if this was also true during the winter months.

When the abundance of the phytosanitary pests was compared to the number of surrounding vineyards the results suggested that the pests entered the vineyards from other vineyards. The vineyards which had higher numbers of surrounding vineyards tended to have more phytosanitary pests in them. This could be important considering that much of the Hex River Valley consists of vineyards separated from each other by only roads and fences, with no other vegetation in between. The establishment of 'island' habitats to manipulate the populations of the natural enemies suggested by Thomas *et al.*(1991; 1992) could help in allowing natural enemies to enter the vineyards. In the Hex River Valley system, it may be more beneficial to have this as a vegetation barrier between vineyards as opposed to an island in the middle of the vineyard, thus creating a buffer zone between the vineyards to help prevent movement between vineyards. Care would also need to be taken in establishing these inter-vineyard strips as the plants associated with *P. callosus* (Barnes 1987) and *E. acerbella* (Blomefield & du Plessis 2000) would have to be removed from the strips. Pesticide spray drift onto the strip, or accidental spraying of the strip may result in conditions that favour pests, as their competitors and predators could be removed, especially if the pests have some degree of resistance to these pesticides.

4.4.7 Effect of the weather on the phytosanitary pest populations

Temperature has the stronger relationship than rainfall to *P. callosus* abundance at all sampling locations in the vineyards with the exception of those found under the trunk bands where both temperature and rainfall appeared to play a role. The results suggest that during warm periods, *P. callosus* may shelter under the bark of the vines and trunk bands. During periods of cooler weather, there is a higher likelihood of finding them in bunches. *P. callosus* is nocturnal and may prefer to feed during periods of cooler weather and so during cool weather are found feeding in the canopy and in bunches. In hotter conditions, *P. callosus* rests on or under the vines or in the trunk bands. The lower numbers of *P. callosus* found under trunk bands after periods of rainfall are probably a reduction in effectiveness of the bands (Barnes 1982; 1987) rather than a real reduction of the actual population.

There was no relationship between *D. fasciatus* and temperature at any of the sampled locations in the vineyards. Rainfall appeared to affect the distribution of *D. fasciatus* on the vines. *D. fasciatus* was found more often under the trunk bands after periods of rainfall, possibly sheltering from the rain under the bands. *D. fasciatus* may be adversely affected by rain and so during rainy periods finds shelter within the vineyard. This is obscured by irrigation in the cover crop and at the base of the vines as there is far more precipitation due to irrigation than rainfall during the summer months in the Hex River Valley (Weaver 1993).

It was unclear whether those *G. simplex* found under the trunk bands was a result of them sheltering due to cool weather or an increase in rainfall, but most likely both. *G. bimaculatus* numbers had no apparent relationship to either temperature or rainfall.

As the season drew to an end and the rainfall increased so the number of *E. acerbella* decreased, although these results were more likely due to other factors such as photoperiod.

4.4.8 Effect of the time of day on the number of phytosanitary pests encountered

Why a nocturnal insect like *P. callosus* is affected by the time of day sampled remains unclear. All the sampling occurred during the day. Therefore, one would expect that there would be no change in the abundance of *P. callosus* found throughout the day, especially as all the positions on the vines at which they were found could also be resting places. As the Curculionidae have been reported to fall when disturbed from vegetation by Southwood (1978), the longer *P. callosus* is resting in a position on the vines that are easily disturbed, such as in the bunches, the higher the likelihood that they will fall to the ground. Bunches are the locations which are most likely to be disturbed and had the shorter time period during which *P. callosus* were found, while the base of the vines are the least disturbed area and *P. callosus* was found at this location for the longer period. This would also explain why most *P. callosus* were caught during the morning. Another reason maybe that the order in which sampling on farms was done to reduce travelling time and this may have resulted in certain farms regularly been sampled at the same time of day. Thus, these results could be due to differences on the farms and not differences in the time of day. The starting times for the sampling days differed and farms were often sampled at different times, with the order occasionally changing. This does not explain why there were virtually no *P. callosus* found in bunches after 12h00, as all farms were sampled at some time after 12h00. Furthermore, if this was the case then it would be expected that there would be similar results for other nocturnal insects like *G. simplex*, but there was no trend in the number of *G. simplex* found at any location on vines with the time of day.

The time of sampling would explain why very few *P. callosus* were found in the cover crop as this was only sampled during the day and the adults that had emerged from the soil would presumably move into the vines during the active period at night.

D. fasciatus, as would be expected for a diurnal species, was found mostly during the midday period (11h00 to 13h00) except under the trunk bands. *D. fasciatus* is a highly mobile insect and is likely to either be feeding or moving to a feeding area when caught at these locations on the vine. Less *D. fasciatus* were found under the trunk bands around midday, which could possibly be due to *D. fasciatus* using trunk bands as shelter during the evenings.

G. bimaculatus showed a preference for the trunk bands during the earlier and later time periods, probably as a result of them also using the bands as shelter.

4.4.9 Effect of the different farms on the phytosanitary pests

There were significant differences in numbers of all phytosanitary pests had significant differences at each of the positions on the vines between the different farms. This was probably due to different management practices. There were many other variables related to individual farms which would affect the abundance of phytosanitary pests which were beyond the scope of this study. Cultivar, age of the vineyards, historical pest management tactics, the abundance of natural enemies and other factors such as soil type and irrigation regimes (Trichilo *et al.* 1990) could affect the abundance. Pest abundances during the years preceding the study were not known. Population levels of the pests' natural enemies were also not monitored during the present study. The abundance of these competitors or predators could have had an important influence on the pest populations.

4.4.10 Current management techniques with recommendations

The phytosanitary control of *P. callosus* appeared to be far more effective with the use of Plantex® than pesticides. Therefore, producers should use Plantex® in preference to insecticides for the control of this pest. Knowledge of when *P. callosus* emerges in the Hex River Valley would also help as this would allow producers to apply the Plantex® as late as possible, specifically to control the late infestation of bunches.

Weather conditions appeared to affect the abundance of *P. callosus*, especially warm weather, thus extra care should be taken during and after periods of elevated temperatures. In vineyards that have heavy infestations, picking later in the day would also help limit the number of *P. callosus* in bunches. If practical, bunches should be shaken before harvesting to further reduce the possibility of collecting *P. callosus* with the bunches.

P. callosus infestation appeared to come from neighbouring vineyards. Creation of barriers to prevent this pest from moving, in particular on farms in the middle of the valley or those in which there is poor control in surrounding blocks. These barriers could take two forms, either strips of natural vegetation to encourage natural enemies or the use of the trench reported by Boiteau *et al.* (1994) to catch this flightless pest.

Numbers of *E. acerbella* in vineyards sprayed with DiPel® appeared to be less than those blocks that were not sprayed, and so the use of DiPel® is strongly recommended. DiPel® does not offer complete *E. acerbella* although a synchronised spraying throughout the valley may increase the effectiveness of this control measure. At present the spatially erratic applications of DiPel® could result in *E. acerbella* re-infesting vineyards that have been sprayed, as DiPel® has only a short period of activity. The use of *E. acerbella* pheromones for mating disruption does not appear to be a commercially viable option (Barnes & Blomefield 2004).

C. capitata appeared to be successfully controlled using the sterile release program, as there were few rejections for this pest. The phytosanitary threat of *C. capitata* can be further reduced using cold sterilisation of the fruit as this appeared to be a successful postharvest quarantine treatment (Conlong 1998). Thus, *C. capitata* should no longer be a major phytosanitary pest of the Hex River Valley if these two measures are widely adopted.

Currently *G. simplex* is not a major phytosanitary pest as it resulted in few rejections. However, no specific control measures or management tactics against *G. simplex* are in place and none have emerged from this project. It is still unclear from where infestations originate as it was found in both the field and in the packhouses (chapter 3). *G. simplex* abundance may be related to wet weather. This was probably the reason why it was not a major threat as the Hex River Valley is in a very arid rainfall area, although it could become a greater phytosanitary threat during wetter years.

D. fasciatus is a conspicuous and mobile insect, which due to its feeding habitat, was not often recorded on bunches of grapes. The presence of this species in the grapes was possibly accidental. Care should be taken while picking, and if particular vineyards are heavily infested, picking during the early and late parts of the day when this species is less active, is recommended. *D. fasciatus* is not a major phytosanitary threat and due to its conspicuous nature it is seen in packhouses and so is unlikely to become a major phytosanitary threat.

G. bimaculatus, although not reported as a reason for rejections of table grapes for the past two years, is an actionable species that is present in large numbers in the Hex River Valley. The large size of this insect along with its tendency to jump away when disturbed probably prevents it from getting into bunches and into the packhouses. There was a strong correlation between increasing quantities of pesticides and higher abundances of *G. bimaculatus*. The presence of *G. bimaculatus* in fact, appeared to be an indicator of the overuse of pesticides.

4.5 References

ADAMS, R. G. & LOS, L. M. 1989. Use of sticky traps and limb jarring to aid in pest management decisions for summer populations of the pear psylla (Homoptera: Psyllidae) in Connecticut. *Journal of Economic Entomology* 82: 1448-1454.

ADDANTE, R. & MOLEAS, T. 1996. Effectiveness of mating disruption method against *Lobesia botrana* (Den. et Schiff.) (Lepidoptera - Tortricidae) in Apulian vineyards. *Bulletin Oilb* 19: 247-251.

ADDISON, P. & SAMWAYS, M. J. 2000. A survey of ants (Hymenoptera: Formicidae) that forage in vineyards in the Western Cape Province, South Africa. *African Entomology* 8: 251-260.

ADDISON, P. 2004. *Ant Management in Western Cape Vineyards.* University of KwaZulu-Natal (PhD Thesis), Pietermaritzburg.

ALTIERI, M. 1994. *Biodiversity and Pest Management in Agroecosystems.* Food Products Press, New York.

ANDOW, D. 1991. Vegetational diversity and arthropod population response. *Annual Review of Entomology* 36: 561-586.

BARNES, B. N. 1982. Snoutbeetles - Guidelines for optimal use of cardboard trunk bands in apple orchards. *Deciduous Fruit Grower* 32: 363-366.

BARNES, B. N. 1987. *Bionomics, Behaviour and Monitoring of the Vine Snoutbeetle,* Phlyctinus callosus *Boh., in Deciduous Fruit Orchards, With Proposals for an Improved Control Strategy.* University of Stellenbosch (PhD Thesis)., Stellenbosch.

BARNES, B. N. 1991. Evaluation of techniques for monitoring emergence of the banded fruit weevil, *Phlyctinus callosus*, in deciduous fruit orchards. *Entomologia Experimentalis et Applicata* 60: 7-11.

BARNES, B. N. 2000a. Fruit flies of economic importance in South Africa: an overview. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 101-107. Indian Ocean Commission, Flic en Flac, Mauritius.

BARNES, B. N. 2000b. Monitoring and control of fruit flies in South African fruit orchards. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 147-152. Indian Ocean Commission, Flic en Flac, Mauritius.

BARNES, B. N. & BLOMEFIELD, T. 2004. *Integrated phytosanitary management of pear leafroller on table grapes*. Final Report 2300/45. Deciduous Fruit Producers Trust, Paarl.

BARNES, B. N. & CAPATOS, D. 1989. Evidence for an aggregation pheromone in adult frass of banded fruit weevil, *Phlyctinus callosus* (Schoenherr) (Col., Coleoptera). *Journal of Applied Entomology* 108: 512-518.

BARNES, B. N. & EYLES, D. 2000. Feasibility of eradicating *Ceratitis* spp. fruit flies from the Western Cape of South Africa by the sterile insect technique. In: *Area-Wide Control of Fruit Flies and Other Insect Pests. Joint Proceedings of the International Conference on Area-Wide Control of Insect Pests, 28 May-2 June, 1998 and the Fifth International Symposium on Fruit Flies of Economic Importance, Penang, Malaysia.* 449-455.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1994. Trunk barriers provide effective control of banded fruit-weevil on apples and nectarines. *Deciduous Fruit Grower* 44: 327-332.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1995. Effective weevil control on apple trees with batting trunk barriers. *Deciduous Fruit Grower* 45: 376-378.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1996. Latest results with trunk exclusion barriers for weevil control on apples. *Deciduous Fruit Grower* 46: 284-287.

BEGON, M., HARPER, J. L., & TOWNSEND, C. R. 1996. *Ecology.* Blackwell Science Ltd, Oxford.

BENBROOK, C., MELLINGER, C., FRANTZ, G., SEXSON, D., STEVENSON, W., & WYMAN, J. 2003. Use of "resistance risk profiles" to guide resistance management planning. *Pesticide Outlook* 14: 107-110.

BERGHOFF, S., GADAU, J., WINTER, T., LINSENMAIR, K., & MASCHWITZ, U. 2003a. Sociobiology of hypogaeic army ants: characterization of two sympatric *Dorylus* species on Borneo and their colony conflicts. *Insectes Sociaux* 50: 139-147.

BERGHOFF, S., MASCHWITZ, U., & LINSENMAIR, K. 2003b. Influence of the hypogaeic army ant *Dorylus (Dichthadia) laevigatus* on tropical arthropod communities. *Oecologia* 135: 149-157.

BERGHOFF, S., WEISSFLOG, A., LINSENMAIR, K., MOHAMED, M., & MASCHWITZ, U. 2002. Nesting habits and colony composition of the hypogaeic army ant *Dorylus (Dichthadia) laevigatus* Fr. Smith. *Insectes Sociaux* 49: 380-387.

BLOMEFIELD, T. & DU PLESSIS, N. 2000. Pear leafroller: a simple matter of weed control? *Deciduous Fruit Grower* 50: 12-13.

BOITEAU, G., PELLETIER, Y., MISENER, G., & BERNARD, G. 1994. Development and evaluation of a plastic trench barrier for protection of potato from walking adult Colorado potato beetles (Coleoptera: Chrysomelidae). *Journal of Economic Entomology* 87: 1325-1331.

BOTERO-GARCES, N. & ISAACS, R. 2003. Distribution of grape berry moth, *Endopiza viteana* (Lepidoptera: Tortricidae), in natural and cultivated habitats. *Environmental Entomology* 32: 1187-1195.

BUGG, R. & WADDINGTON, C. 1994. Using cover crops to manage arthropod pests of orchards: a review. *Agriculture, Ecosystems & Environment* 50: 11-28.

CHAPMAN, R. F. 1998. *The Insects Structure and Function.* Cambridge University Press, Cambridge.

CONLONG, D. E. 1998. *Mediterranean fruit fly (Ceritltis capitata) rearing and cold sterilisation procedures in grape varieties.* Report to the SASA Experiment Station (Novermber 1998). SASA Experiment Station, Mount Edgecombe.

CORBETT, A. & ROSENHEIM, J. A. 1996. Impact of a natural enemy overwintering refuge and its interaction with the surrounding landscapes. *Ecological Entomology* 21: 155-164.

COSTELLO, M. J. & DAANE, K. 1995. Spider (Araneae) species composition and seasonal abundance in San Joaquin Valley grape vineyards. *Environmental Entomology* 24: 823-831.

COSTELLO, M. J. & DAANE, K. M. 1998. Influence of ground cover on spider populations in a table grape vineyard. *Ecological Entomology* 23: 33-40.

COSTELLO, M. J. & DAANE, K. M. 2003. Spider and leafhopper (*Erythroneura* spp.) response to vineyard ground cover. *Environmental Entomology* 32: 1085-1098.

DALVIE, M.A., CAIRNCROSS, E., SOLOMON, A., & LONDON, L. 2003. Contamination of rural surface and groundwater by endosulfan in farming areas of the Western Cape, South Africa. *Environmental Heath: A Global Access Science Source* 2.

DANTHANARAYANA, W., GU, H., & ASHLY, S. 1995. Population growth potential of *Epiphyas postvittana*, the lightbrown apple moth (Lepidoptera: Tortricidae) in relation to diet, temperature and climate. *Australian Journal of Zoology* 43: 381-394.

DIXON, B., PROKOPY, R., & SCHULTZ, B. 1999. Influence of weather and time of day on plum curculio (Coleoptera: Curculionidae) tree canopy entry behaviours and evaluation of traps for predicting fruit injury. *Journal of Entomological Science* 34: 191-202.

DUELLI, P., STUDER, M., MARCHAND, I., & JAKOB, S. 1990. Population movements of arthropods between natural and cultivated areas. *Biological Conservation* 54: 193-207.

EBENEBE, A., BERG, J., & LINDE, T. 2001. The incidence of *Dorylus helvolus* (Linnaeus) (Hymenoptera: Formicidae) and parasitoids (Hymenoptera: Braconidae) as mortality factors of *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in Lesotho. *African Entomology* 9: 77-84.

ENGLISH-LOEB, G., RHAINDS, M., MARTINSON, T., & UGINE, T. 2003. Influence of flowering cover crops on *Anagrus* parasitoids (Hymenoptera: Mymaridae) and

Erythroneura leafhoppers (Homoptera: Cicadellidae) in New York vineyards. *Agricultural and Forest Entomology* 5: 173-181.

FOURIE, J., LOUW, P., & AGENBAG, G. 2001. Effect of seeding date on the performance of grasses and broadleaf species evaluated for cover crop management in two wine grape regions of South Africa. *South African Journal of Plant and Soil* 18: 118-127.

GEERTSEMA, H. 1973. *Studies on the Biology, Ecology and Control of the Pine Tree Emperor Moth,* Nudaurelia cyherea cytherea *(Fabr.) (Lepidoptera: Saturniidae).* University of Stellenbosch (PhD Thesis), Stellenbosch.

GOLD, C., BAGABE, M., I, & SENDEGE, R. 1999. Banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae): tests for suspected resistance to carbofuran and dieldrin in the Masaka District, Uganda. *African Entomology* 7: 189-196.

HANNA, R., ZALOM, F., & ROLTSCH, W. 2003. Relative impact of spider predation and cover crop on population dynamics of *Erythroneura variabilis* in a raisin grape vineyard. *Entomologia Experimentalis et Applicata* 107: 177-191.

HARRIS, R. E. 1986. Cover crops for Western Cape orchards. *Deciduous Fruit Grower* 36: 359-362.

HOFFMAN, C., DENNEHY, J., & NYROP, J. 1992. Phenology, monitoring, and control decision components of the grape berry moth (Lepidoptera: Tortricidae) risk assessment program in New York. *Journal of Economic Entomology* 85: 2218-2227.

HOFFMAN, C. & DENNEHY, T. 1989. Phenology, movement, and within-field distribution of the grape berry moth, *Endopiza viteana* (Clemens) (Lepidoptera: Tortricidae), in New York vineyards. *Canadian Entomologist* 121: 325-335.

IFOULIS, A. & SAVOPOULOU-SOULTANI, M. 2004. Biological control of *Lobesia botrana* (Lepidoptera: Tortricidae) larvae by using different formulations of *Bacillus thuringiensis* in 11 vine cultivars under field conditions. *Journal of Economic Entomology* 97: 340-343.

JOUBERT, P. H. & LABUSCHAGNE, T. I. 1995. Alternative measures for controlling mango seed weevil, *Sternochetus mangiferae* (F.). *Yearbook - South African Mango Growers' Association* 15: 69-71.

KANGA, L., PREE, D., LIER, J., & WALKER, G. 1999. Monitoring for resistance to organophosphorus, carbamate, and pyrethroid insecticides in the oriental fruit moth (Lepidoptera: Tortricidae). *Canadian Entomologist* 131: 441-450.

KINGSOVER, J. G. 1986. Weather and the population dynamics of insects: integrating physiological and population ecology. *Physiological Zoology* 62: 314-334.

LALANNE-CASSOU, B. & FRÉROT, B. 1980. Analysis of pheromonal secretion of South African carnation tortrix, *Epichoristodes acerbella* (Walk.) (Lepidoptera: Tortricidae). *Comptes-rendus Hebdomadaires des Seances de l'Académie des Sciences de Paris.D* 291: 845-848.

LANDIS, D. A., WRATTEN, S. D., & GURR, G. M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* 45: 175-201.

LAPOINTE, S. 2000. Thermal requirements for development of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). *Environmental Entomology* 29: 150-156.

LIANG, W. & HUANG, M. 1994. Influence of citrus orchard ground cover plants on arthropod communities in China: a review. *Agriculture, Ecosystems & Environment* 50: 29-37.

LITTLE, R., CROWE, T., & PEALL, S. 1997. Pesticide residues in helmeted guineafowl *Numida meleagris* livers collected on deciduous fruit farms in the Western Cape province, South Africa. *South African Journal of Wildlife Research* 27: 1-4.

LITTLE, R., PERRINGS, J., CROWE, T., & WITT, A. 1995. Notes on the diet of helmeted guineafowl *Numida meleagris* on deciduous fruit farms in the Western Cape Province, South Africa. *South African Journal of Wildlife Research* 25: 144-146.

LONDON, L., DALVIE, M.A., CAIRNCROSS, E., & SOLOMON, A. 2000. *The quality of surface and groundwater in the rural western cape with regard to pesticides.* WRC Report No. 795/1/00. Water Research Commission, Pretoria.

MASSÉ, A., VAN FRANKENHUYZEN, K., & DEDES, J. 2000. Susceptibility and vulnerability of third-instar larvae of the spruce budworm (Lepidoptera: Tortricidae) to *Bacillus thuringiensis* subsp. *kurstaki*. *Canadian Entomologist* 132: 573-580.

MATTHEWS, G. A. 1997. Techniques to evaluate insecticide efficacy. In: Dent, D.R. & Walton, M.P. (Ed.) *Methods in Ecological and Agricultural Entomology.* 234-269. CAB International, Wallingford.

MOSCHOS, T., SOULIOTIS, C., BROUMAS, T., & KAPOTHANASSI, V. 2004. Control of the European grapevine moth *Lobesia botrana* in Greece by the mating disruption technique: a three-year survey. *Phytoparasitica* 32: 83-96.

MULLINS, M., BOUQUET, A., & WILLIAMS, L. 1992. *Biology of the Grapevine.* Cambridge University Press, Cambridge.

NICHOLLS, C. I., PARRELLA, M., & ALTIERI, M. 2000. Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops. *Agricultural and Forest Entomology* 2: 107-113.

ORR, D., LANDIS, D., MUTCH, D., MANLEY, G., V, STUBY, S., & KING, R. 1997. Ground cover influence on microclimate and *Trichogramma* (Hymenoptera: Trichogrammatidae) augmentation in seed corn production. *Environmental Entomology* 26: 433-438.

OSETO, C. Y. 2000. Physical Control of Insects. In: Rechcigl, J.E. & Rechcigl, N.A. (Ed.) *Insect Pest Management: Techniques for Environmental Protection.* 25-100. CRC Press, Boca Raton, Florida.

PHILLIPS, P. 1989. Simple monitoring of black vine weevil in vineyards. *California Agriculture* 43: 12-13.

PITCAIRN, M., ZALOM, F., & BENTLEY, W. 1990. Weather factors influencing capture of *Cydia pomonella* (Lepidoptera: Tortricidae) in pheromone traps during overwintering flight in California. *Environmental Entomology* 19: 1253-1258.

PPIS 2004. *Bilateral Quarantine Agreement between the Plant Protection and Inspection Services of Israel (PPIS) and the National Department of Agriculture Directorate: Plant Health and Quality of the Republic of South Africa (DPHQ) Regarding the Conditions for the Importation of Fresh Grapes (*Vitis vinifera*) From the Republic of South Africa into Israel.* State of Israel, Ministry of Agriculture and Rural Development, Plant Protection and Inspection Services, Bet-Dagan, Israel.

RIEUX, R., SIMON, S., & DEFRANCE, H. 1999. Role of hedgerows and ground cover management on arthropod populations in pear orchards. *Agriculture Ecosystems & Environment* 73: 119-127.

RIVERA, A., CARBONE, S., & ANDRES, J. 1999. Life cycle and biological control of the *Eucalyptus* snout beetle (Coleoptera, Curculionidae) by *Anaphes nitens* (Hymenoptera, Mymaridae) in north-west Spain. *Agricultural and Forest Entomology* 1: 103-109.

ROEHRICH, R. & BOLLER, E. 1991. Tortricids in Vineyards. In: van der Geest, L.P.S. & Evenhuis, H.H. (Ed.) *World Crop Pests: Tortricid Pests, Their Biology, Natural Enemies and Control.* 507-514. Elsevier, Amsterdam.

SAUPHANOR, B., BOUVIER, J., & BROSSE, V. 1998. Spectrum of insecticide resistance in *Cydia pomonella* (Lepidoptera: Tortricidae) in southeastern France. *Journal of Economic Entomology* 91: 1225-1231.

SCHMIDT-NIELSEN, K. 1979. *Animal Physiology Adaptation and Environment.* Cambridge University Press, Cambridge.

SCHWARTZ, A. 1988. Efficacy of trunk barriers for the control of key pests on trellised grapevines. *South African Journal for Enology and Viticulture* 9: 16-18.

SCHWARTZ, A. 1990. Pesticide effect on populations of *Tetranychus urticae* Koch (Acari: Tetranychidae) and a predaceous mite on table grapes in the Hex River Valley. *South African Journal of Enology and Viticulture* 11: 33-37.

SEXTON, J. M. & SCHOWALTER, T. D. 1991. Physical barriers to reduce damage by *Lepesoma lecontei* (Coleoptera: Curculionidae) to conelets in a Douglas-fir seed orchard in western Oregon. *Journal of Economic Entomology* 84: 212-214.

SHESKIN, D. J. 2000. *Handbook of Parametric and Nonparametric Statistical Procedures.* Chapman and Hall, Boca Raton, Florida.

SHOREY, H., SISK, C., & GERBER, R. 1995. Disruption of pheromone communication in *Platynota stultana* (Lepidoptera: Tortricidae) in grape vineyards. *Environmental Entomology* 24: 1270-1274.

SKROCH, W. A. & SHRIBBS, J. M. 1986. Orchard floor management: an overview. *HortScience* 21: 390-392.

SOUTHWOOD, T. R. E. 1978. *Ecological Methods With Particular Reference to the Study of Insect Populations.* Chapman and Hall, London.

STEEL, R. G. D. & TORRIE, J. H. 1980. *Principles and Procedures of Statistics.* McGraw-Hill Kogakusha., Toyko.

TABASHNIK, B. 1994. Evolution of resistance to *Bacillus thuringiensis*. *Annual Review of Entomology* 39: 47-79.

THOMAS, M., WRATTEN, S., & SOTHERTON, N. 1991. Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. *Journal of Applied Ecology* 28: 906-917.

THOMAS, M., WRATTEN, S., & SOTHERTON, N. 1992. Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and species composition. *Journal of Applied Ecology* 29: 524-531.

TRICHILO, P., WILSON, L., & GRIMES, D. 1990. Influence of irrigation management on the abundance of leafhoppers (Homoptera: Cicadellidae) on grapes. *Environmental Entomology* 19: 1803-1809.

UNDERWOOD, A. J. 1997. *Experiments in Ecology, Their Logical Design and Interpretation Using Analysis of Variance.* Cambridge University Press, Cambridge.

USDA-APHIS & SAAFQIS 2004. *Preclearance Inspection and Cold Treatment of South African Deciduous Fruit Designated for Export to the United States of America.* South African Department of Agriculture, Directorates Plant Health, Pretoria.

VAN FRANKENHUYZEN, K., NYSTROM, C., DEDES, J., & SELIGY, V. 2000. Mortality, feeding inhibition, and recovery of spruce budworm (Lepidoptera: Tortricidae) larvae following aerial application of a high-potency formulation of *Bacillus thuringiensis* subsp. *kurstaki*. *Canadian Entomologist* 132: 505-518.

VINCENT, C., HALLMAN, G., PANNETON, B., & FLEURAT-LESSARD, F. 2003. Management of agricultural insects with physical control methods. *Annual Review of Entomology* 48: 261-281.

WALDSTEIN, D., REISSIG, W., SCOTT, J., & STRAUB, R. 1999. Susceptibility of obliquebanded leafroller (Lepidoptera: Tortricidae) populations from commercial apple orchards and an unsprayed habitat in New York to tebufenozide. *Journal of Economic Entomology* 92: 1251-1255.

WALTON, V. M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa.* University of Stellenbosch (PhD Thesis), Stellenbosch.

WALTON, V. M. & PRINGLE, K. L. 1999. Effects of pesticides used on table grapes on the mealybug parasitoid *Coccidoxenoides peregrinus* (Timberlake) (Hymenoptera: Encyrtidae). *South African Journal for Enology and Viticulture* 20: 31-34.

WEAVER, J. M. C. 1993. *A preliminary survey of pesticide levels in groundwater from a selected area on intensive agriculture in the Western Cape*. WRC Report No. 286/1/93. Water Research Commission, Pretoria.

WITT, A. B. R., LITTLE, R., & CROWE, T. 1995. The effectiveness of helmeted guineafowl *Numida meleagris* (Linnaeus 1766) in controlling the banded fruit weevil *Phlyctinus callosus* (Schonherr 1826), and their impact on other invertebrates in apple orchards in the Western Cape Province, South Africa. *Agriculture, Ecosystems & Environment* 55: 169-179.

WRATTEN, S. D. 1987. The effectiveness of native natural enemies. In: Burns, A.J., Coaker, T.H., & Jepson, P.C. (Ed.) *Integrated Pest Management.* 89-112. Academic Press Limited, London.

Chapter 5

POSTHARVEST QUARANTINE TREATMENTS FOR THE DECIDUOUS AND CITRUS FRUITS OF THE WESTERN CAPE:

A DATABASE ANALYSIS

Development of postharvest quarantine treatments for export fruits in the Western Cape Province, South Africa, would help to reduce the quantity of export produce being rejected due to the presence of phytosanitary insects. These treatments must successfully control the pest species yet not damage the commodity. There is normally only a small zone of opportunity between controlling the insects and damaging the commodity. Owing to the ozone-depleting properties of methyl bromide, a widely used product in mitigation treatments, it is scheduled to be withdrawn in many countries in 2005. The main alternatives are irradiation, extreme temperatures, forced air, vapour-heat treatments and the use of controlled atmospheres. A literature survey was used to identify postharvest treatments which should have the highest likelihood of success. Data from 282 scientific articles relating to postharvest quarantine treatments were entered into a database (PQUAD). Queries were run to determine the most intensively studied commodities and pests. The tolerances of the commodities were compared to the tolerances of the pests at family level. Where minimum pest intolerance levels were lower than the maximum commodity tolerance, the treatment was regarded as a possible postharvest treatment for that particular commodity against that particular insect family. Methyl bromide, controlled atmospheres and irradiation were the most widely used identified treatments in PQUAD. Apples and nectarines were the most studied commodities, followed by oranges, grapes, grapefruits pears and mandarins. Tephritidae and Tortricidae were the two most studied insect families followed by Pseudococcidae and Curculionidae. Irradiation appeared to control the pests at doses that did not damage the fruit. Controlled atmospheres also had a high probability of success. Low temperature is relatively cheap as much of the export produce already undergoes cold storage. It appeared to control Pseudococcidae and Tephritidae, although more work is required for the other pest families. Phytosanitary pests of citrus could potentially be controlled using heat treatments.

5.1 Introduction

Postharvest quarantine treatments are carried out on produce after harvesting to control insect infestations (Paull & Armstrong 1994; Fields & White 2002). If accepted postharvest treatments control pest insects, the treated commodities are not liable for phytosanitary rejections (Paull & Armstrong 1994). These treatments need to successfully control the pest species without damaging the commodity. There is normally only a small zone of opportunity between controlling the insects and damaging the commodity (figure 5.1). If successful postharvest treatments can be developed for export fruit from the Western Cape, local pest insects would no longer be of phytosanitary importance.

Methyl bromide is a colourless, odourless, non-flammable, non-corrosive gas (Stark 1994). It is widely used for postharvest treatments as it is inexpensive, has a low residue, many fruits and vegetables are tolerant of it at insecticidal concentrations, it is effective at low temperatures, and is easy to use (Forney & Houck 1994; Stark 1994). Insects, mites, rodents, fungi, bacteria and viruses can be controlled by methyl bromide (Brunch 1961; Richardson & Monro 1962; Monro 1974; Price 1985; Stark 1994). It has been used since the 1930's to fumigate commodities against insects (Fields & White 2002). However, owing to its ozone depleting properties, it is due to be deregistered in developed countries in 2005 and developing countries in 2015 (Hough 1998), meaning that alternative postharvest quarantine treatments must be found. The main alternatives are irradiation, temperature (high or low), forced air, vapour heat treatments, and controlled atmospheres.

The use of irradiation to control insects involves the use of microwaves to transfer energy efficiently into the body of the insect pest raising its body temperature to a lethal level (van Pelletier & Colpitts 2001). At sublethal doses, irradiation can also cause sterilization or prevent adult emergence. Thus lethal doses are not necessarily needed to achieve the required level of protection (Nation & Burditt 1994; Morris & Jessup 1994; Hallman 2000). Irradiation at high doses can damage commodities (Burditt 1982), although it has been shown to extend the shelf life of some fresh commodities through induced effects on the fruit's physiology, biochemistry and populations of micro-organisms (Morris & Jessup 1994; Young 2003). Irradiation is currently being used to as a quarantine treatment against several Tephritidae species like: *Bactrocera dorsalis* (Hendel), *B. cucurbitae* Coquillett, *Ceratitis capitata* (Wiedemann) and *Anastrepha suspensa* (Loew) (Mitchell & Saul 1990; Nation & Burditt 1994; Hallman 1999).

Temperature manipulation is a logical method for the control of insects as they are susceptible to extreme temperatures (Schmidt-Nielsen 1979). It has been used for many years to control insects (Fields 2001). Temperature treatments were used before the extensive use of methyl bromide (Armstrong 1994; Neven 2003). The biggest problem with temperature treatments is damage to commodities. As a result, most research has been done on a fruit-by-fruit basis, depending on the pest species (Armstrong 1994). This study examines four different temperature treatments: low temperature, high temperature, vapour heat and forced air treatments.

Low temperature treatments are relatively simple and inexpensive, provided the commodity is placed in cold storage for quality reasons. Temperate fruits, such as those produced in the Western Cape, are the most tolerant commodities to low temperature treatments (Armstrong 1994; Neven 2003). Low temperatures affect insects by reducing metabolism and respiration, causing a loss of adenosine 5-triphosphate (ATP), while also inhibiting the insect's development and neural functions (Neven 2003). This leads to irreversible chill shock, oxidative stress, cellular and membrane dysfunction, reduced fertility and after prolonged exposure, mortality (Neven 2003). Low temperature treatment can be complicated by the diapausing nature of some species (Chapman 1998), especially within the Tortricidae (Brown 1991).

Heat treatments are generally conducted in one of two mediums, air or water (Lurie 1998b). Although there has been considerable success with heat treatments on tropical commodities, temperate commodities have shown low levels of tolerance (Couey 1989; Paull & McDonald 1994; Meheriuk & Gaunce 1994). High temperatures affect insects' metabolism, respiration, neural function and endocrine system leading to mortality from prolonged exposure if temperatures are elevated beyond the insect's critical thermal limit (Neven 2000; 2003).

Both vapour heat and forced air treatments are essentially heat treatments that deliver the heat in different ways. Vapour heat treatments involve the use of saturated hot air to heat the commodities. Heat is transferred from the condensation of water vapour on the fruit surface, thereby heating up the commodity more rapidly than unsaturated air (Lurie 1998a; Lurie 1998b; Oseto 2000). Forced air is the continuous flow of heated air into a chamber where the speed of air circulation is precisely controlled (Lurie 1998a; Lurie 1998b; Oseto 2000).

Controlled atmosphere treatments involve altering the normal atmospheric gas composition to one that will kill insects (Hallman 1994; Neven 2003). Controlled atmospheres generally involve lowering O_2 levels, increasing CO_2 levels and modifying the temperature. Initially controlled atmospheres were studied for preserving the quality of commodities. Their insecticidal properties have only more recently been explored (Kader & Ke 1994; Hallman 1994). Controlled atmospheres can cause fruit commodities to undergo anaerobic respiration, reducing the quality of the fruit (Kader & Ke 1994). Therefore, care needs to be taken when selecting the correct treatments. Mortality of insects in controlled atmospheres is normally associated with asphyxiation or a build up of carbonic acid (Neven 2003). Higher insect mortality in controlled atmospheres is more often achieved at higher temperatures as there is a greater metabolic demand for O_2 (Neven 2003).

To begin the task of developing postharvest treatments against the insect pests of the Western Cape, researchers need to know which treatments are most likely to succeed. The aim of this study was to determine which of the postharvest quarantine treatments are most likely to be successful in the Western Cape. To achieve this, a database was developed to allow comparisons to be made between the tolerance of insects and commodities.

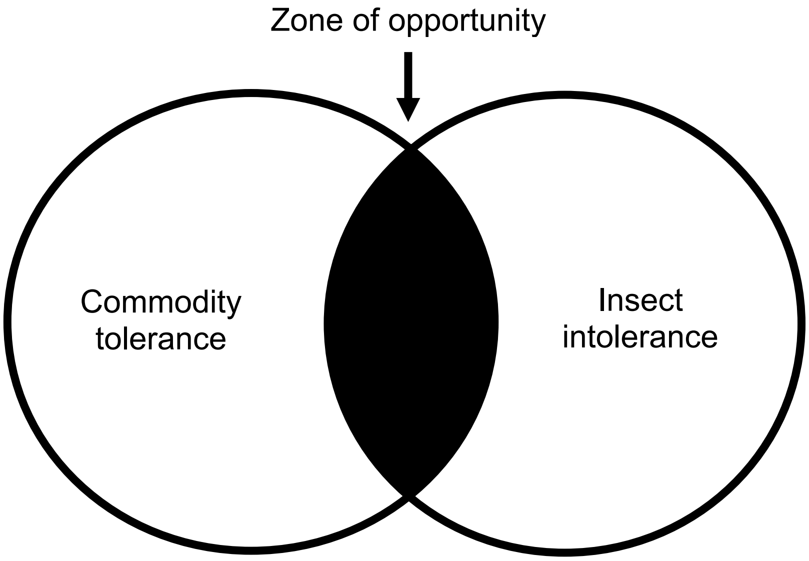

Figure 5.1 Goal of the development of postharvest quarantine treatments. (From Neven 2003).

5.2 Methods

CAB abstracts in the ISI web of knowledge were searched for literature relating to postharvest quarantine treatments for both pests and commodities. CAB abstracts include papers published between 1990 and 2004. Relevant articles were obtained and their reference lists were searched for further literature. This published information formed the basis for the postharvest quarantine treatment database (PQUAD) for the Western Cape. The relevant data were entered into PQUAD in Microsoft® Access 2002. Information from 282 papers was used in PQUAD.

PQUAD consists of 19 tables. There is an overall pest table and an overall commodity table. For each treatment these is both a pest and a commodity table, with a further table for all the references. The tables' fields can be linked to access information from multiple tables when queries are run (Dowling 1998). Table structure and a brief explanation of the field contents are given in table 5.1. A copy of PQUAD is given in Appendix II.

Once PQUAD was complete, queries were run to determine what the most studied commodities and insect families were for each treatment. Further queries were run to determine the most studied pest species and the historical change in treatments studied. The tolerances of the commodities were compared to the tolerances of the pest families for all treatments. The tolerances of the commodities were determined by finding the maximum level of tolerance for each cultivar and the differences between the cultivars were regarded as the range for the maximum tolerance, this is referred to as cultivar rang. Tolerance for the pest families was determined by initially determining the most tolerant life stage of the particular species to a treatment, then finding the minimum treatment required to effectively achieve 100% mortality for each species for the most tolerant life stages. Differences between species of the same family were regarded as the range of minimum intolerance for that family and this is referred to as species range henceforth. The results for commodity tolerance and the range were then compared with there for insect intolerance and their range. Where the minimum pest intolerance levels were lower than the maximum commodity tolerance, the treatment was regarded as a possible postharvest treatment for that particular commodity against that particular family of insect. Confidence levels could not be calculated due to the lack of replicated studies.

Table 5.1 PQUAD tables and their fields names and descriptions

Fields	Description
General tables	
Overall commodity table	
Commodity	commodity the study was conducted on
Cultivar	cultivar the study was conducted on
Treatment	treatment tested
Overall pest table	
Family	taxonomic family of insect pest
Genus	taxonomic genus of insect pest
Species	taxonomic species of insect pest
Commodity	commodity on which study was conducted
Cultivar	cultivar on which study was conducted
Treatment	treatment tested
Reference table	
Authors	author(s) of the article
Reference number	unique number for the particular article
Year	year the article was published
Title	title of article
Source	source of the article
Fields common to all commodity/treatment tables	
Commodity	commodity the study was conducted on
Cultivar	cultivar the study was conducted on
Temperature (ºC)	temperature used
Effect on the commodity	effect of the treatment on the commodity
Reference number	unique number for the particular article
Reference	reference for the article
Fields common to all pest/treatments tables	
Genus	taxonomic genus of insect pest
Species	taxonomic species of insect pest
Life stage	life stage of insect tested
Commodity	commodity the study was conducted on
Cultivar	cultivar the study was conducted on
Effect on the pest	effect of the treatment on the pest
Temperature (ºC)	temperature used
Reference number	unique number for the particular article
Reference	reference for the article

Table 5.1 continued

Fields	Description
Fields not common to all commodity / treatment or pest / treatment tables	
Controlled atmosphere commodity table	
O_2 composition (kPa)	O_2 levels of the treatment
CO_2 composition (kPa)	CO_2 levels of the treatment
Duration (h)	duration of treatment
Forced air commodities table	
Flow rate (m^3/s)	flow rate of the air
Duration (h)	duration of treatment
High temperature commodities table	
Duration (h)	duration of treatment
Medium	medium the treatment was conducted in
Irradiation commodities table	
Dose (Gy)	Irradiation dose used
Low temperature commodities table	
Duration (h)	duration of treatment
Methyl bromide commodities table	
Dose (g/m^3)	dose of methyl bromide
Medium	medium the treatment was conducted in
Vapour-heat commodities table	
Duration (h)	duration of treatment
Controlled atmosphere pests	
O_2 composition (kPa)	O_2 levels of the treatment
CO_2 composition (kPa)	CO_2 levels of the treatment
Duration (h)	duration of treatment
Forced air pests	
Flow rate (m^3/s)	flow rate of the air
Duration (h)	duration of treatment
High temperature pests	
Duration (h)	duration of treatment
Medium	medium the treatment was conducted in
Irradiation pests	
Dose (Gy)	Irradiation dose used
Low temperature pests	
Duration (h)	duration of treatment
Methyl bromide pests	
Dose (g/m^3)	dose of methyl bromide used
Medium	medium the treatment was conducted in
Vapour-heat pests table	
Duration (h)	duration of treatment

5.3 Results and discussion

5.3.1 PQUAD summary

The effect of quarantine treatments on commodities using methyl bromide and controlled atmosphere each account for 27.7% of all the studies, while in only 2.1% of the investigations were forced air treatments used (table 5.2). Similarly, in 27.8% of the investigations on the effects on insects, methyl bromide was used, while only 4.7% of the studies included vapour heat (table 5.3). Therefore, methyl bromide was the most studied treatment for both the commodities and the pests. This was because due it is being the oldest and most widely used postharvest treatments. Controlled atmosphere and irradiation were also included in a large number of studies (tables 5.2 & 5.3). From the small number of authors who published on controlled atmosphere and irradiation these studies it is assumed that they were conducted by specialist working groups. Few studies on high and low temperature treatments were encountered, as was the case with forced air and vapour heat (tables 5.2 & 5.3). This was probably because these treatments were normally restricted to tropical fruits.

Studies involving high temperature, irradiation and methyl bromide treatments have been conducted in equal proportions on both commodities and pests, suggesting an equal interest in their effects on both commodities and the pests (tables 5.2 & 5.3). There have been more studies on the effects of controlled atmospheres on commodities than on the pests, probably because they are also used to improve the quality and shelf-life of fruits. There were only a few studies on commodities at low temperatures (tables 5.2 & 5.3). This was probably because fruits are stored at low temperatures to preserve them before there were phytosanitary concerns. Thus the effect of cold storage on fruit is well known, while the effect of low temperature on the insect pests still needs to be studied. The reason for the disproportionately high number of studies on the effect of vapour heat and forced air treatments on pests relative to commodities is probably because these treatments are predominantly used on tropical commodities, while the pest families are cosmopolitan.

Table 5.2 Number of studies per commodity for the various postharvest treatments. Con. atmos. = Controlled atmosphere, temp. = temperature, Irradi. = Irradiation.

Commodity	Con. atmos.	Forced air	High temp.	Irradi.	Low temp.	Methyl bromide	Vapour heat	Total
Apple	25	0	9	7	1	13	0	55
Grape	6	0	0	8	0	4	1	19
Grapefruit	1	1	2	4	2	6	2	18
Lemon	0	0	0	1	2	0	0	3
Mandarin	0	0	0	7	0	5	0	12
Nectarine	15	1	9	0	4	14	0	43
Orange	1	2	6	8	0	5	1	23
Pear	6	0	2	2	0	4	0	14
Persimmon	0	0	1	1	0	2	0	4
Tangerine	0	0	0	2	0	1	1	4
Total	54	4	29	40	9	54	5	195

Table 5.3 Number of studies per insect family for the various postharvest treatments. Con. atmos. = Controlled atmosphere, temp. = temperature, Irradi. = Irradiation.

Pests (family)	Con. atmos.	Forced air	High temp.	Irradi.	Low temp.	Methyl bromide	Vapour heat	Total
Bostrychidae	0	0	0	0	0	1	0	1
Curculionidae	1	0	0	6	0	4	0	11
Diaspididae	0	0	0	1	0	0	0	1
Pseudococcidae	2	0	4	2	4	2	0	14
Tenebrionidae	0	0	1	0	0	0	0	1
Tephritidae	6	11	17	24	14	21	9	102
Tortricidae	24	0	13	6	7	31	1	82
Total	33	11	35	39	25	59	10	212

Apples and nectarines were the commodities most studied, followed by oranges, grapes, grapefruits, pears and mandarins. These represent the most important fruits globally exported, especially from developed countries that can afford research on postharvest quarantine treatments (Goletti 2003). Persimmons, tangerines and lemons were included in only a few studies (table 5.2).

Tephritidae and Tortricidae were the two most frequently studied families (table 5.3). They also represent the two most important families in terms of insect pest risk globally (van der Geest & Evenhuis 1991; Hallman 1999). The nine most frequently studied species were either Tortricidae or Tephritidae, and in the sixteen most frequently studied species, five and seven species belonged to these families, respectively (table 5.4). Pseudococcidae and Curculionidae were also relatively well studied, with Tenebrionidae, Diaspididae and Bostrychidae represented by one study each (table 5.3).

Methyl bromide during the late 1970's was the most frequently studied of the postharvest treatments, giving way to other treatments during the 1980's and early 1990's (figure 5.2). The decline after 1991 in the number of studies involving methyl bromide was not unexpected because in the 1987 Montreal Protocol it was agreed that developed countries should eliminate the use of methyl bromide by 2005 (Hough 1998; Fields & White 2002). The increase in methyl bromide studies after 1997 is difficult to explain, except that this may represent developing countries attempting to access the world markets by using methyl bromide as a fumigant. It is an attractive treatment as there is a lot of information and it is inexpensive.

The number of studies on all the other treatments increased after 1982, probably as a resulted the realization that an alternative to methyl bromide was needed. This may have been especially relevant after the 1985 Vienna Convention for the Protection of the Ozone Layer in which many developed countries agreed to phase out the use of chemicals that cause depletion to the ozone layer (Hough 1998). The large peak in the number of investigations using temperature was probably a result of the success of the initial studies and the ease with which these experiments can be done. Irradiation and controlled atmospheres require specialised equipment and facilities, hence the slow increase in number of studies using these treatments.

Table 5.4 Most common species of insects tested in postharvest treatments within PQUAD. Tort. = Tortricidae, Teph. = Tephritidae, Pseudo. = Pseudococcidae, Curc. = Curculionidae.

Species	**Family**	**Common Name**	**No. of Studies**
Cydia pomonella (Linnaeus)	Tort.	Codling moth	33
Anastrepha suspensa (Loew)	Teph.	Caribbean fruit fly	30
Ceratitis capitata (Wiedemann)	Teph.	Mediterranean fruit fly	23
Epiphyas postvittana (Walker)	Tort.	Light brown apple moth	17
Anastrepha ludens (Loew)	Teph.	Mexican fruit fly	14
Ctenopseustis obliquana (Walker)	Tort.	Brownheaded leafroller	11
Grapholita molesta Busck	Tort.	Oriental fruit moth	7
Planotortrix octo Dugdale	Tort.	Greenheaded leafroller	7
Bactrocera tryoni (Froggatt)	Teph.	Queensland fruit fly	6
Pseudococcus longispinus (Targioni)	Pseudo.	Long tailed mealybug	6
Anastrepha obliqua (Macquart)	Teph.	West Indian fruit fly	5
Cylas formicarius (Fabricius)	Curc.	Sweet potato weevil	4
Bactrocera dorsalis (Hendel)	Teph.	Oriental fruit fly	3
Pseudococcus viburni Maskell	Pseudo.	Obscure mealybug	3
Rhagoletis pomonella (Walsh)	Teph.	Apple maggot fly	3
Sitophilus granarius (Linnaeus)	Curc.	Grain weevil	3

Top 16 Species, further 29 not included

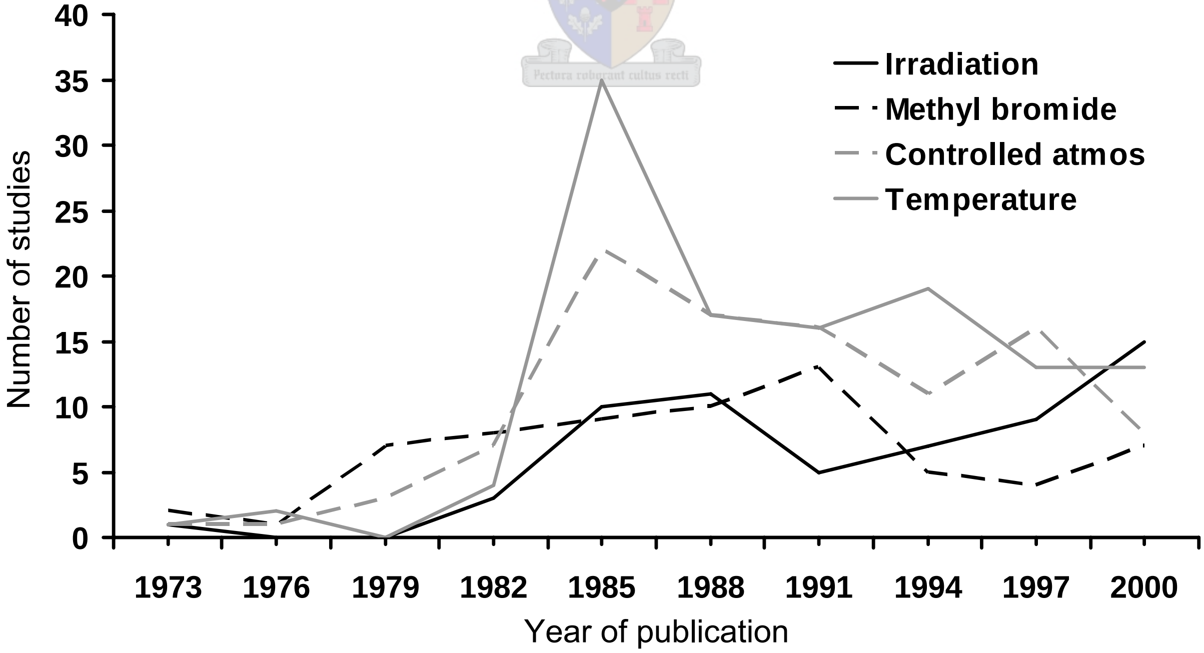

Figure 5.2 Number of studies per year of publication on four postharvest treatments.

5.3.2 Methyl bromide

Methyl bromide did not appear to be a successful quarantine treatment for two Coleoptera families (Curculionidae and Bostrychidae) as they were able to survive doses that would damage all commodities included in PQUAD (figure 5.3). Pseudococcidae would only be controlled on certain apple, grape and nectarine cultivars. The maximum tolerance of these commodities is very similar to the minimum dose that would be required to ensure 100% mortality for Pseudococcidae. Problems could arise from either damage to some of the fruit or a small number of insects surviving. Some Tortricidae and Tephritidae could be controlled on all the fruits (figure 5.3), although again the tolerances of both the commodity and the pests are very similar. Research into methyl bromide for the phytosanitary control of pests in the Western Cape would not be profitable as the produce is likely to be damaged at an insecticidal dose.

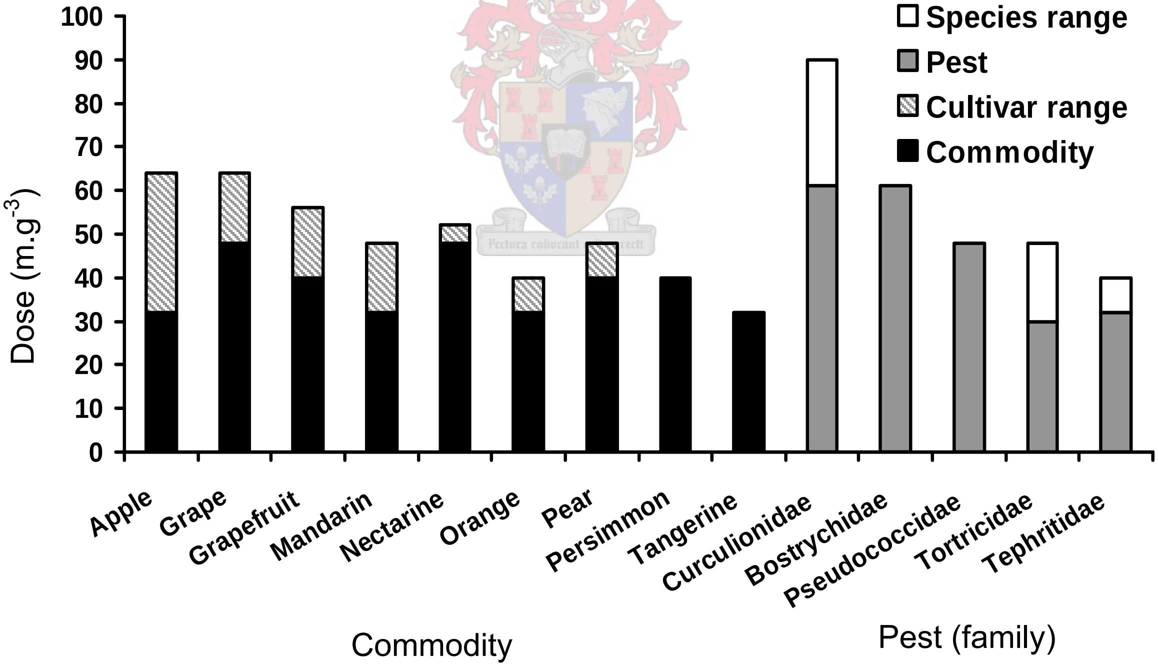

Figure 5.3 Maximum doses of methyl bromide that did not cause damage to commodities and the minimum doses that were required to control all pests during a two-hour fumigation period.

5.3.3 Irradiation

Tortricidae, Curculionidae, Tephritidae and Pseudococcidae infesting the three deciduous fruits included in figure 5.4 appeared to be controlled by irradiation. Doses of 250 - 600 Gy appeared to successfully control (either by sterilization or by killing) the pests while not affecting the quality of the fruit. The two citrus commodities included in figure 5.4 tolerate irradiation doses of 150 Gy and this may control Curculionidae, Tephritidae and Pseudococcidae. However, these commodities and the pests appeared to have similar tolerances. Research into the use of irradiation for postharvest quarantine treatments has great potential for deciduous fruits, as it appeared to control pests while not damaging these fruits at insecticidal doses.

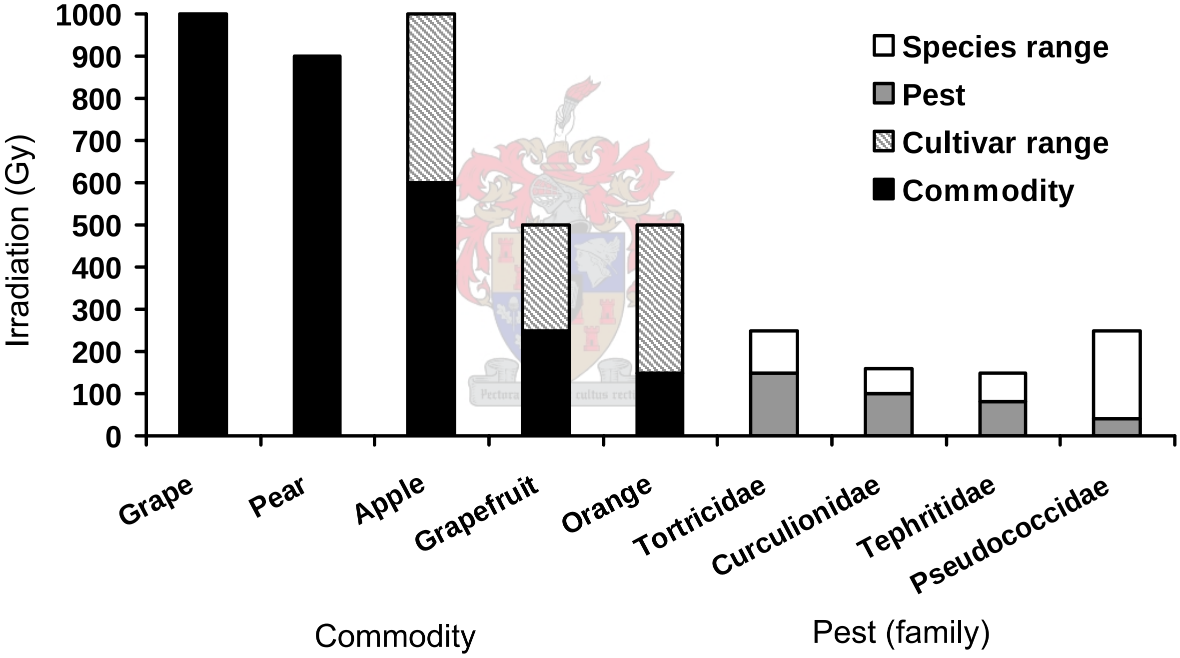

Figure 5.4 Maximum irradiation doses that do not cause damage to commodities and the minimum doses that are required to control pests.

5.3.4 Low temperature

Low temperature treatments would appear to control both Pseudococcidae and Tephritidae under the cold storage conditions currently used for deciduous fruits prior to or during export (figure 5.5). Low temperature also appeared to effectively control these pests in grapefruit (figure 5.5). However, it is unclear as to whether or not this treatment would effectively control Tortricidae. Many Tortricidae (e.g. codling moth) diapause in the larval stage and are able to tolerate low temperature (Brown 1991; Chapman 1998). Thus, research into cold storage would be recommended, especially for the Pseudococcidae and Tephritidae. Cold storage is already used as a quarantine treatment against the Tephritidae in the Western Cape for both grapes and apples. This is a relatively simple and inexpensive postharvest treatment. Therefore, research into using this method for controlling other phytosanitary pest families of Western Cape fruit, particularly Curculionidae and Lygaeidae and even lesser phytosanitary pest families such as Pyrrhocoridae and Tenebrionidae, is recommended.

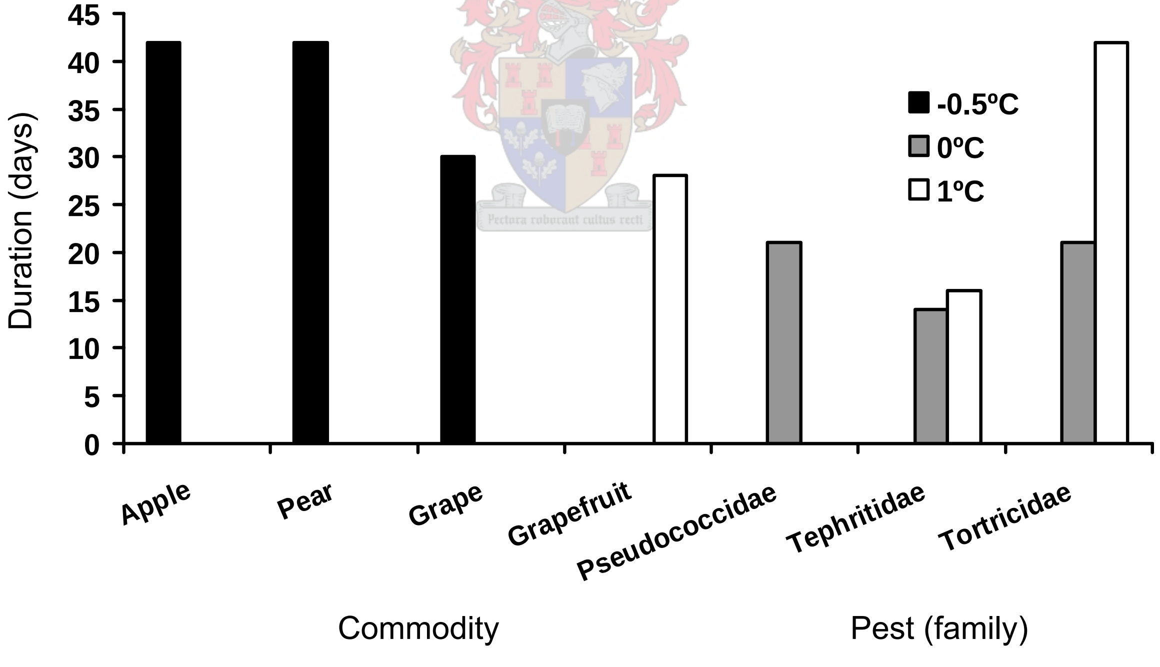

Figure 5.5 Current cold storage for export commodities, (grapefruit represents a duration that has been shown not to damage the commodity). Minimum time required to control the pests.

5.3.5 Heat treatments

Heat treatments appeared to be ineffective, as commodities were damaged long before treatments effectively controlled the pests (figure 5.6). Hot water treatments were more successful then hot air treatments. Grapefruit and persimmons were tolerant of treatments that achieved 100% mortality of all the pests included in figure 5.7. Apples and oranges suffered too much damage for this treatment to be considered for use on these commodities. Research on the effects of hot water treatment on other commodities and pests is required in order to obtain a clearer understanding of whether or not this is a viable quarantine treatment for Western Cape fruits.

5.3.6 Vapour heat and forced air treatments

Vapour heat treatments were unsuccessful for controlling Tephritidae in grapes. Vapour heat treatments at 44 or 46 ºC for 3.5 hours controlled Tortricidae, while not damaging grapefruit, oranges or tangerines. This treatment could be successful for citrus contaminated with tortricid moths, although it is unclear how other fruits or pest families would be affected.

The only forced air treatment studies found were against the Tephritidae in citrus fruits. Treatments of 43 ºC with a flow rate of 0.4 m^3/s for 2 hours effectively controlled all Tephritidae in grapefruits without damaging the fruit (Mangan *et al*. 1998, while in another study oranges tolerated treatments of 48 ºC with flow rates of 0.75 m^3/s for 2 hours (Shellie & Mangan 1994). This treatment appeares promising for citrus. However, few studies have been done, making it difficult to determine whether this form of quarantine treatment would be successful for other fruits or pests.

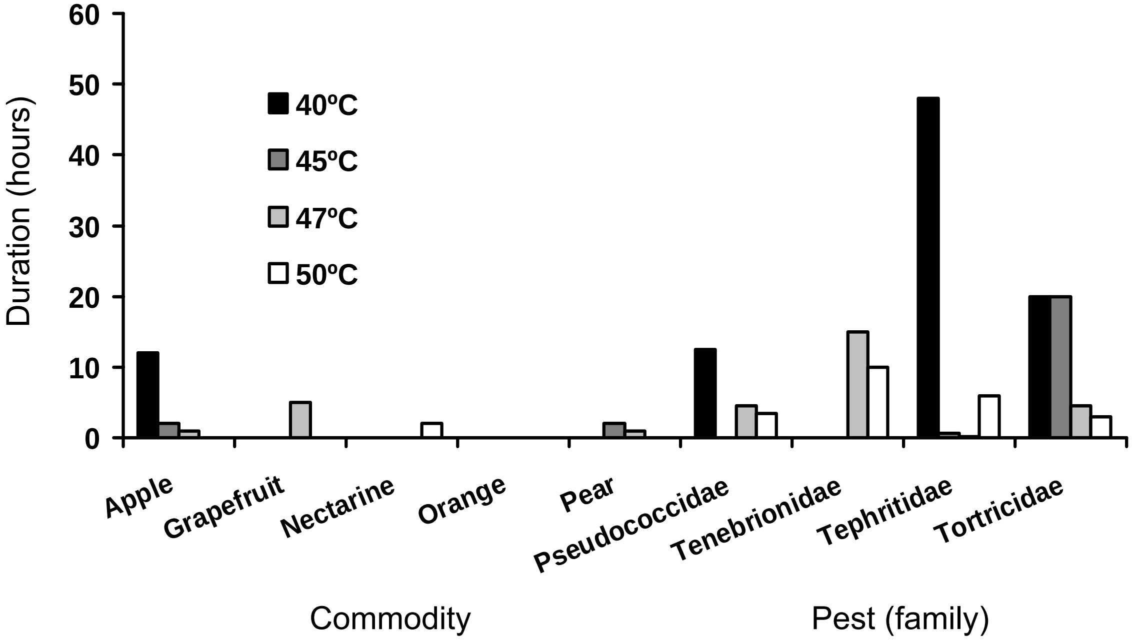

Figure 5.6 Maximum time that commodities are able to tolerate heated air treatments and the minimum time required to control pests.

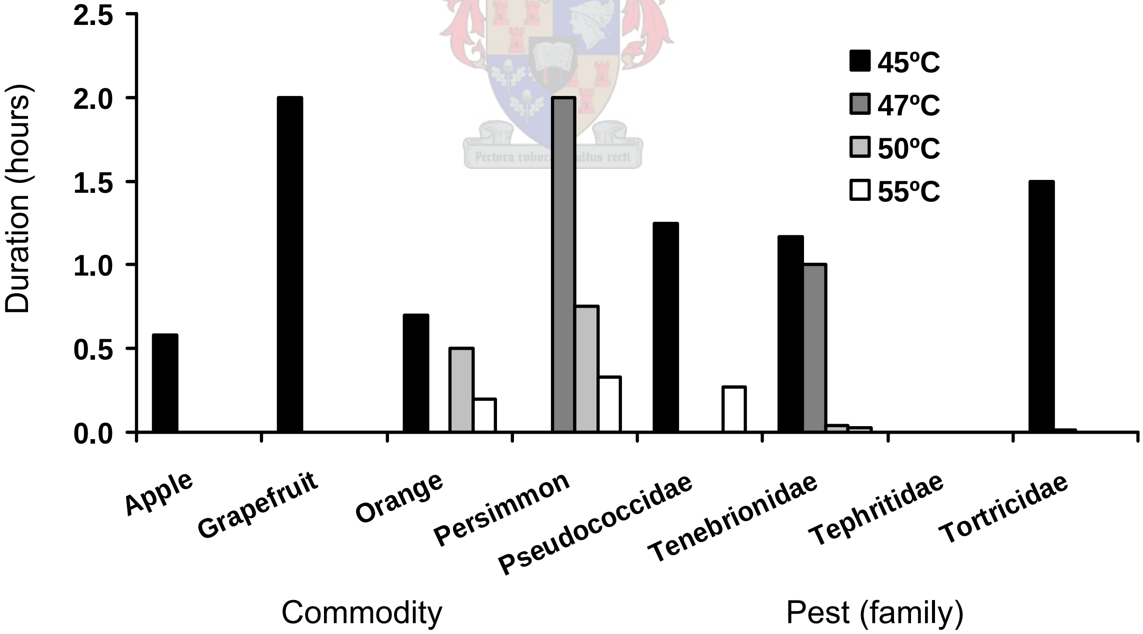

Figure 5.7 Maximum time that commodities were able to tolerate for hot water treatments and the minimum time required to control pests.

5.3.7 Controlled atmospheres

No studies directly comparing commodities and pests were evaluated. However, there was a trend suggesting that increasing temperature and CO_2 levels and decreasing O_2 levels resulted in quicker damage to the commodities as well as quicker lethal effects on the pests. Importantly, the rate of increased damage to the commodity and the lethal effects to the pests were not equal. Therefore, a considerable amount of experimentation is still required to determine treatments that do not damage the commodities while effectively controlling the pests. It appeared that high temperature controlled atmosphere treatments were more successful in controlling pests than low temperature treatments, probably due to the increased metabolic rates of the insects, resulting in higher demands for O_2 (Schmidt-Nielsen 1979; Neven 2003).

Table 5.5 summarises the results of controlled atmosphere studies in PQUAD. Low temperature controlled atmosphere data were omitted from table 5.5 for apples and pears as there where no corresponding studies on pests. Studies in PQUAD using low temperature on apples had a temperature range between -0.5 ºC to 5 ºC, O_2 levels between 0 to 3 kPa and CO_2 levels of 0 to 45 kPa. Low temperature controlled atmosphere studies for pears had a temperature range of between 0 ºC to 5 ºC, O_2 levels between 0.02 to 8.4 kPa and CO_2 levels between 0 to 99 kPa. It appeared that a controlled atmosphere treatment of 40 ºC and an O_2 level of 4 kPa for 6 hours controlled Curculionidae and would have no effect on pears and probably not on apples although this is unclear (table 5.5). A treatment of 40 ºC and an O_2 level of 0.4 kPa for 10 min would control Pseudococcidae, while not causing damage to apples or pears (table 5.5). No comparable high temperature controlled atmosphere studies on grapes were found.

With regards to citrus, there was only one successful experiment in which oranges were at 0.5 ºC and an O_2 level of 0.02 kPa for 120 hours. There were no corresponding experiments for pests because of the large number of possible combinations of factors.

Controlled atmospheres are the most complex of the treatments to analyse. This form of treatment does seem to control the pests with little damage to the commodities. However, much research into this treatment is still required.

Table 5.5. Maximum control atmosphere limits for three commodities and the minimum required to control three families of pests. Temp. = Temperature

Commodity	**Temp. (ºC)**	**O_2 (kPa)**	**CO_2 (kPa)**	**Duration (hours)**
Apple	22		90	24
	28	0.02		72
	28	1.7	1.1	72
	40	1	3	6
	44	1	15	6
	46	1	15	3
Grape	0	5	3	912
	0	5	25	2016
	1	3	10	5490
	5	0.02	55	144
Pear	20	0.25		3
	25	0.02		120
	28	0.5		72
	44	1	15	6
	46	1	15	3
Family				
Curculionidae	25	4		96
	30	4		192
Pseudococcidae	20	2	30	168
	35	0.4		0.33
	35	5		3.33
	40	0.4		0.17
	40	5		0.83
	45	5		0.17
Tortricidae	0	0.3	4.6	720
	0	0.4	5	2160
	0	1.5	3	672
	20	1	15	336
	20	2		360
	27	0.4	5	48
	28	1	15	72
	30	0	5	30
	30	0.3	4.6	96
	30	1	15	30
	40	1	1	9
	40	1.2	5	3.5
	40	2	5	5
	40	4.2	5	4.5
	45	1	15	1.17
	47	1	15	0.83

5.3.8 Other postharvest treatments

References to other postharvest treatments were found in the literature, although none were sufficiently numerous to be included in the PQUAD analysis. Sulphur dioxide has been repeatedly shown to prevent fungal decay (Thomas *et al.* 1995; Berry & Aked 1997; Al Bachir 1998), while Yokoyama *et al.* (2001) showed that *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), *Platynota stultana* Walshingham (Lepidoptera: Tortricidae) and *Tetranychus urticae* Koch (Acari: Tetranychidae) were successfully controlled using a combination of slow releasing sulphur dioxide pads and cold storage. High pressure washing treatments have been shown to reduce the number of *Pseudococcus viburni* (Signoret) (Hemiptera: Pseudococcidae) and *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) found on apples (Whiting *et al.* 1998). Initially ultrasound was studied as a means to determine whether or not consignments were infested with *Cylas formicarius* (Fabricius) (Coleoptera: Curculionidae) (Hansen *et al.* 1992), while recently it has been shown to cause mortality in *F. occidentalis* and *T. urticae* (Hansen 2001).

5.3.9 Conclusions

PQUAD attempts to outline the postharvest quarantine treatments that are most likely to be successful against phytosanitary insect pests found in consignments of the fruit commodities of the Western Cape. It can be used as an initial starting point for planning research into quarantine treatments. Unfortunately PQUAD is not sufficiently complete to provide anything but broad indications regarding research direction. The gaps in the data may represent areas which have been explored without being published due to the negative results. Thus, PQUAD needs to be extended to include preliminary and unpublished results to get a clearer indication of which treatments would be successful. Furthermore, family level was used, so the pest species themselves would need to be tested to verify the results from PQUAD.

The main phytosanitary pests of deciduous fruits of the Western Cape are species in the families Curculionidae, Pseudococcidae, Tephritidae, Tortricidae, Lygaeidae and Pyrrhocoridae. Lygaeidae and Pyrrhocoridae are not represented in PQUAD. Insects from all the other families were controlled by irradiation at doses that the fruit tolerate. Controlled atmospheres also could also have a high probability of success using treatments that control pests while not damaging fruits. Low temperature on the other hand is relatively cheap as exported fruit already undergoes cold storage. It appears that Pseudococcidae and Tephritidae are controlled by current cold storage regime, but the control of Tortricidae is complicated by their diapausing habit. The thermal limits of Curculionidae, Lygaeidae and Pyrrhocoridae still need to be determined.

Heat treatments against phytosanitary citrus pests seem promising, especially hot water treatments. In addition, controlled atmosphere and low temperature appear to be potential quarantine treatments for these fruits.

The other possibility is to combine treatments that showed a high degree of efficacy to maximise the security levels. Combinations of treatments would also need to be fully reviewed.

5.4 References

AL BACHIR, M. 1998. Use of gamma-irradiation and sulphur dioxide to improve storability of two Syrian grape cultivars (*Vitis vinifera*). *International Journal of Food Science and Technology* 33: 521-526.

ARMSTRONG, J. W. 1994. Heat and cold treatments. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 103-119. CAB International, Wallingford, UK.

BERRY, G. & AKED, J. 1997. Controlled atmosphere alternatives to the post-harvest use of sulphur dioxide to inhibit the development of *Botrytis cinerea* in table grapes. *Postharvest Horticulture Series - Department of Pomology, University of California* 160-164.

BROWN, J. J. 1991. Diapause. In: van der Geest, L.P.S. & Evenhuis, H.H. (Ed.) *World Crop Pests: Tortricid Pests, Their Biology, Natural Enemies and Control.* 175-186. Elsevier, Amsterdam.

BRUNCH, C. W. 1961. Gaseous sterilization. *Annual Review of Microbiology* 15: 245-262.

BURDITT, A. K. 1982. Food irradiation as a quarantine treatment of fruits. *Food Technology* 36: 51-62.

CHAPMAN, R. F. 1998. *The Insects Structure and Function.* Cambridge University Press, Cambridge.

COUEY, H. M. 1989. Heat treatment for control of postharvest diseases and insect pests of fruits. *Hortscience* 24: 198-202.

DOWLING, N. 1998. *Database Design and Management.* Continuum, New York.

FIELDS, P. G. 2001. Control of insects in post-harvest: low temperature. In: Vincent, C., Panneton, B., & Fleurat-Lessard, F. (Ed.) *Physical Control Methods in Plant Protection.* 95-107. Springer-Verlag, Berlin.

FIELDS, P. G. & WHITE, N. D. G. 2002. Alternatives to methyl bromide treatments for stored-product and quarantine insects. *Annual Review of Entomology* 47: 331-359.

FORNEY, C. F. & HOUCK, L. G. 1994. Chemical treatments. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 139-162. CAB International, Wallingford, UK.

GOLETTI, F. 2003. Current status and future challenges for the postharvest sector in developing countries. *Acta Horticulturae* 41-47.

HALLMAN, G. J. 1994. Controlled atmospheres. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 121-136. CAB International, Wallingford, UK.

HALLMAN, G. J. 1999. Ionizing radiation quarantine treatment against tephritid fruit flies. *Postharvest Biology and Technology* 16: 93-106.

HALLMAN, G. J. 2000. Expanding radiation quarantine treatments beyond fruit flies. *Agricultural and Forest Entomology* 2: 85-95.

HANSEN, J. D. 2001. Ultrasound treatments to control surface pests of fruit. *Horttechnology* 11: 186-188.

HANSEN, J. D., EMERSON, C., & SIGNOROTTI, D. 1992. Visual detection of sweetpotato weevil by non-invasive methods. *Florida Entomologist* 75: 369-375.

HOUGH, P. 1998. *The Global Politics of Pesticides: Forging Consensus From Conflicting Interests.* Earthscan Publications, London.

KADER, A. A. & KE, D. 1994. Controlled atmospheres. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 223-236. CAB International, Wallingford, UK.

LURIE, S. 1998a. Postharvest heat treatments. *Postharvest Biology and Technology* 14: 257-269.

LURIE, S. 1998b. Postharvest heat treatments of horticultural crops. *Horticultural Reviews* 22: 91-121.

MANGAN, R. L., SHELLIE, K. C., INGLE, S. J. & FIRKO, M. J. 1998. High temperature forced-air treatments with fixed time and temperature for 'Dancy' tangerines, 'Valencia' oranges, and 'Rio Star' grapefruit. *Journal of Economic Entomology* 91: 933-939.

MEHERIUK, M. & GAUNCE, A. P. 1994. Temperate fruits. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 291-307. CAB International, Wallingford, UK.

MITCHELL, W. & SAUL, S. 1990. Current control methods for the Mediterranean fruit fly, *Ceratitis capitata*, and their application in the USA. *Review of Agricultural Entomology* 78: 923-940.

MONRO, H. A. U. 1974. *Manual of Fumigation for Insect Control.* Food and Agriculture Organization of the United Nations, Rome.

MORRIS, S. C. & JESSUP, A. 1994. Irradiation. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 163-189. CAB International, Wallingford, UK.

NATION, J. L. & BURDITT, A. K. 1994. Irradiation. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 85-102. CAB International, Wallingford, UK.

NEVEN, L. G. 2000. Physiological responses of insects to heat. *Postharvest Biology and Technology* 21: 103-111.

NEVEN, L. G. 2003. Physiological effects of physical postharvest treatments on insects. *Horttechnology* 13: 272-275.

OSETO, C. Y. 2000. Physical control of insects. In: Rechcigl, J.E. & Rechcigl, N.A. (Ed.) *Insect Pest Management: Techniques for Environmental Protection.* 25-100. CRC Press, Boca Raton, Florida.

PAULL, R. E. & MCDONALD, R. 1994. Heat and cold treatments. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 191-222. CAB International, Wallingford, UK.

PAULL, R. E. & ARMSTRONG, J. W. 1994. Introduction. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 1-33. CAB International, Wallingford, UK.

PRICE, N. R. 1985. The mode of action of fumigants. *Journal of Stored Products Research* 21: 157-164.

RICHARDSON, L. T. & MONRO, H. A. U. 1962. Fumigation of jute bags with ethylene oxide and methyl bromide to eradicate potato ring rot bacteria. *Applied Microbiology* 10: 448-451.

SCHMIDT-NIELSEN, K. 1979. *Animal Physiology Adaptation and Environment.* Cambridge University Press, Cambridge.

SHELLIE, K. C., & MANGAN R. L. 1994. Postharvest quality of 'Valencia' orange after exposure to hot, moist, forced air for fruit fly disinfestation. *Hortscience* 29:1524-1527

STARK, J. D. 1994. Chemical fumigants. In: Paull, R.E. & Armstrong, J.W. (Ed.) *Insect Pests and Fresh Horticultural Products: Treatments and Responses.* 69-84. CAB International, Wallingford, UK.

THOMAS, P., BHUSHAN, B., & JOSHI, M. R. 1995. Comparison of the effect of gamma irradiation, heat-radiation combination, and sulphur dioxide generating pads on decay and quality of grapes. *Journal of Food Science and Technology (Mysore)* 32: 477-481.

VAN DER GEEST, L. P. S. & EVENHUIS, H. H. 1991. *World Crop Pests: Tortricid Pests, Their Biology, Natural Enemies and Control.* Elsevier, Amsterdam.

VAN PELLETIER, Y. & COLPITTS, B. G. 2001. The use of microwaves for insect control. In: Vincent, C., Panneton, B., & Fleurat-Lessard, F. (Ed.) *Physical Control Methods in Plant Protection.* 125-133. Springer-Verlag, Berlin.

WHITING, D. C., HOY, L. E., MAINDONALD, J. H., CONNOLLY, P. G., & MCDONALD, R. E. 1998. High-pressure washing treatments to remove obscure mealybug (Homoptera: Pseudococcidae) and lightbrown apple moth (Lepidoptera: Tortricidae) from harvested apples. *Journal of Economic Entomology* 91: 1458-1463.

YOKOYAMA, V. Y., MILLER, G. T., & CRISOSTO, C. H. 2001. Pest response in packed table grapes to low temperature storage combined with slow-release sulfur dioxide pads in basic and large-scale tests. *Journal of Economic Entomology* 94: 984-988.

YOUNG, A. 2003. Food irradiation. After 35 years, have we made progress: a government perspective. *Environmental Science and Pollution Research* 10: 82-88.

Chapter 6

GENERAL DISCUSSION

This study was prompted by the number of table grape consignments from the Hex River Valley being rejected by importing nations, particularly the USA, for phytosanitary reasons. The study has attempted to find means to reduce these rejections. The first step was to determine the most important phytosanitary pests, the second step involved the determination of the factors that affect the abundance and possible infestation routes of these pests, while the third step was to look into possible phytosanitary quarantine treatments as a means to further reduce rejections.

The two most important phytosanitary pests are *Phlyctinus callosus* (Schonherr) (Coleoptera: Curculionidae) and *Epichoristodes acerbella* Walker (Lepidoptera: Tortricidae) as they together were responsible for 74.3% of all the rejections for the 2002 and 2003 seasons in the Hex River Valley. *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), *Gonocephalum simplex* Fabricius (Coleoptera: Tenebrionidae), *Dysdercus fasciatus* Signoret (Hemiptera: Pyrrhocoridae) and *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) collectively caused 13.0% while a further 12.7% where from unidentified species. 33% of the rejections were misidentified, while the insects responsible 16% of the rejections were only identified to order or family level, which makes it impossible to attempt to solve the phytosanitary problem. The establishment of a central collection of all individual insects that cause rejections would help to solve these problems. *Gryllus bimaculatus* (De Geer) (Orthoptera: Gryllidae) was also included in this study, as it is found in high abundances in the Hex River Valley and is an actionable species for both the USA and Israeli markets (PPIS 2004; USDA-APHIS & SAAFQIS 2004).

Colour of the harvesting crates was shown to have no effect on the number of phytosanitary pests collected. In fact, fewer insects were attracted to colours that are used in the Hex River Valley (red and yellow) than any of the colours tested (blue, while or green).

P. callosus was effectively controlled using Plantex® barriers applied to the stems of vines, supporting the results of Schwartz (1988) and Barnes *et al.* (1994; 1996). This means of control was far more efficient than the use of insecticides. Thus, it is recommended that producers use Plantex® instead of insecticides to control this pest. Knowledge of when *P. callosus* emerges in the Hex River Valley would also help to allow producers to apply Plantex® as late as possible, and therefore derive maximum efficacy.

Weather conditions appeared to affect the abundance of *P. callosus*, especially warm weather. Thus extra care should be taken during and after periods of elevated temperatures. For vineyards that have heavy infestations, picking later in the day would appear to help limit the number of *P. callosus* collected in the bunches, along with shaking bunches before harvesting to further reduce the possibility of collecting *P. callosus* with bunches.

Irradiation may control *P. callosus* in grapes, as the grapes are able to tolerate doses of irradiation that would control curculionid beetles. High temperature controlled atmospheres have not been tested on grapes, although Curculionidae would appear to be controlled with these treatments. Temperature treatments against Curculionidae have not been undertaken, and so still needs to be explored.

DiPel® appears to at least reduce the population of *E. acerbella* in the Hex River Valley, and so its use is strongly recommended. DiPel® does not completely control *E. acerbella* although a synchronised spraying throughout the valley may control this pest with more successfully.

Possible postharvest quarantine treatments for *E. acerbella* include the development of irradiation and controlled atmospheres. High temperature treatments, although successful for killing species of Tortricidae, are unlikely to be tolerated by grapes at the required temperatures for durations required.

Control of *P. ficus* has been investigated by Walton (2003) and is listed as a non-actionable species for exports to the USA (USDA-APHIS & SAAFQIS 2004), and is not listed as a phytosanitary threat for Israel (PPIS 2004). The cold storage that table grapes currently undergo for the control of *C. capitata* and for quality reasons should control Pseudococcidae.

C. capitata, while causing rejections during the 2002 and 2003 seasons, is no longer a phytosanitary threat because grapes undergo a postharvest cold sterilization procedure, which provides the required security for this pest (Conlong 1998). There is also a sterile release program being run in the Hex River Valley against this pest (Barnes & Eyles 2000; Barnes 2000).

Currently, *G. simplex* is not a major phytosanitary pest as it is only caused a few rejections. No formal control measures against for *G. simplex* are in place. This project has not identified any management or control measures that can be used against this species. It is still unclear where infestation of the grapes takes place as it is found in both the field and packhouses, although the use of light traps in packhouses is recommended as they are effective in capturing this pest. *G. simplex* abundance may be reduced by wet weather. Only one postharvest quarantine treatment was identified for use against the Tenebrionidae. That was a hot water treatment that would probably damage the grapes. A great deal of work is required on the postharvest treatments against this pest.

D. fasciatus is a highly conspicuous and mobile insect which, due to its feeding habitat, was not found often on bunches of grapes. The presence of this species in the grapes is possibly a result of accidental occurrence. Care should be taken while picking, and if particular vineyards are heavily infested, picking during the early and late parts of the day, when this species is less active, is recommended. No information could be located on the tolerance to postharvest treatments in the Pyrrhocoridae.

G. bimaculatus, although not reported as a reason for rejections of table grapes during 2002 or 2003 years, is an actionable species that is present in large numbers in the Hex River Valley. The large size of this insect along with its tendency to jump away when disturbed probably prevents it from remaining in bunches and getting through the packhouses. There is a strong correlation between increasing amounts of pesticide applications and higher abundances of *G. bimaculatus*. The presence of *G. bimaculatus* in fact appears to be an indicator of the overuse of pesticides, possibly resulting from mortality of its natural enemies.

Pesticides are becoming less effective and more problematic, furthermore high levels of pesticides in the water of the Hex River Valley have been reported (London *et* *al.* 2000; Dalvie *et al.* 2003). Alternative means of controlling the pests need to be researched to reduce the pesticide levels in the Hex River Valley.

Results of this study show that infestation of the phytosanitary pests originate from neighbouring vineyards. Creating barriers to prevent the pests' movement, particularly on farms in the middle of the valley and those surrounded by blocks in which these pests are poorly controlled, is a possible method of reducing or preventing infestations. This project showed the vineyards' surrounding habitats do not appear to harbour any phytosanitary pests during the harvesting season. Thus, strips of natural vegetation could be used to encourage natural enemies and prevent pest movement between vineyards. Alternatively, the use of trenches, as described by Vincent *et al.* (2003), to prevent pest movement between the vineyards, particularly flightless pests like *P. callosus*, is recommended.

Although this study asks more questions than it answers, it does show that the control of phytosanitary pests can be achieved. A great deal of research is still required and many research possibilities have been identified in this study. It is hoped that this study has contributed to the understanding of the phytosanitary problem and will generate interest in solving this difficult and relatively unexplored aspect of fruit production.

References

BARNES, B. N. 2000. Monitoring and control of fruit flies in South African fruit orchards. In: Price, N.S. & Seewooruthun, I. (Ed.) *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium, Mauritius, 5-9 June 2000.* 147-152. Indian Ocean Commission, Flic en Flac, Mauritius.

BARNES, B. N. & EYLES, D. 2000. Feasibility of eradicating *Ceratitis* spp. fruit flies from the Western Cape of South Africa by the sterile insect technique. In: *Area-Wide Control of Fruit Flies and Other Insect Pests. Joint Proceedings of the International Conference on Area-Wide Control of Insect Pests, 28 May-2 June, 1998 and the Fifth International Symposium on Fruit Flies of Economic Importance, Penang, Mala.* 449-455.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1994. Trunk barriers provide effective control of banded fruit-weevil on apples and nectarines. *Deciduous Fruit Grower* 44: 327-332.

BARNES, B. N., KNIPE, M. C., & CALITZ, F. J. 1996. Latest results with trunk exclusion barriers for weevil control on apples. *Deciduous Fruit Grower* 46: 284-287.

CONLONG, D. E. 1998. *Mediterranean fruit fly (Ceratitis capitata) rearing and cold sterilisation procedures in grape varieties.* Report to the SASA Experiment Station (November 1998). SASA Experiment Station, Mount Edgecombe.

DALVIE, M.A., CAIRNCROSS, E., SOLOMON, A., & LONDON, L. 2003. Contamination of rural surface and groundwater by endosulfan in farming areas of the Western Cape, South Africa. *Environmental Heath: A Global Access Science Source* 2.

LONDON, L., DALVIE, M.A., CAIRNCROSS, E., & SOLOMON, A. 2000. *The quality of surface and groundwater in the rural Western Cape with regard to pesticides.* WRC Report No. 795/1/00. Water Research Commission, Pretoria.

PPIS 2004. *Bilateral Quarantine Agreement between the Plant Protection and Inspection Services of Israel (PPIS) and the National Department of Agriculture Directorate: Plant Health and Quality of the Republic of South Africa (DPHQ) Regarding the Conditions for the Importation of Fresh Grapes* (Vitis vinifera) *From the Republic of South Africa into Israel.* State of Israel, Ministry of Agriculture and Rural Development, Plant Protection and Inspection Services, Bet-Dagan, Israel.

SCHWARTZ, A. 1988. Efficacy of trunk barriers for the control of key pests on trellised grapevines. *South African Journal for Enology and Viticulture* 9: 16-18.

USDA-APHIS & SAAFQIS 2004. *Preclearance Inspection and Cold Treatment of South African Deciduous Fruit Designated for Export to the United States of*

America. South African Department of Agriculture, Directorates Plant Health, Pretoria.

VINCENT, C., HALLMAN, G., PANNETON, B., & FLEURAT-LESSARD, F. 2003. Management of agricultural insects with physical control methods. *Annual Review of Entomology* 48: 261-281.

WALTON, V. M. 2003. *Development of an Integrated Pest Management System for Vine Mealybug,* Planococcus ficus *(Signoret), in Vineyards in the Western Cape Province, South Africa.* University of Stellenbosch (PhD Thesis), Stellenbosch.

Appendix I

ACTIONABLE PEST INSECT SPECIES FOR THE USA AND ISRAELI MARKETS

USA market from USDA-APHIS & SAAFQIS (2004)

Actionable species for grapes:

Acia lineatifrons (Cicadellidae)

Altica indigacea (Chrysomelidae)

Agonoscelis puberula (Pentatomidae)

Bagrada hilaris (Pentatomidae)

Calpe emarginata (Noctuidae)

Calpe provocans (Noctuidae)

Carbula marginella (Pentatomidae)

Carbula litigatrix (Pentatomidae)

Cenaeus carnifex. (Pyrrhocoridae)

Cerbula marginella (Pentatomidae)

Cirphis leucosticha (Noctuidae)

Cletus caffer (Coreidae)

Coenomorpha atelocera (Acanthosomatidae)

Crematogaster peringueyi (Formicidae) (no action required if worker only)

Cryptolarynx vitis (Curculionidae)

Cryptophlebia leucotreta (Tortricidae)

Delottococcus elizabethae (Pseudococcidae)

Dischista cincta (Scarabeidae)

Dugaria scandulata (Noctuidae)

Dysdercus fasciatus (Pyrrhocoridae)

Ectomyelois ceratoniae (Pyralidae)

Eotochia pulla (Tenebrionidae)

Epichoristodes acerbella (Tortricidae)

Eremnus atratus (Curculionidae)

Eremnus cerealis (Curculionidae)
Eremnus setulosus (Curculionidae)
Gonocephalum simplex (Tenebrionidae)
Gonipterus scutellatus (Curculionidae)
Gryllotalpa africana (Gryllotalpidae)
Gryllus bimaculatus (Gryllidae)
Gymnelema plebigena (Psychidae)
Helicoverpa armigera (Noctuidae)
Heliothrips sylvanus (Thysanoptera)
Hippotion celerio (Sphingidae)
Lema erythrodera (Chrysomelidae)
Lygus nisius (Lygaeidae)
Lymantria monacha (Lymantridae)
Macchiademus diplopterus (Lygaeidae)
Nipaecoccus vastator (Pseudococcidae)
Oxycarenus hyalinipennis (Lygaeidae)
Pachnoda sinuata (Scarabaeidae)
Pantomorus cervinus (Curculionidae)
Paraccocus burnerae (Pseudococcidae)
Periapion antiquum (Curculionidae)
Periapion untiyruium (Curculionidae)
Phlyctinus callosus (Curculionidae)
Plangia graminea (Tettigonidae)
Raglius apicalis (Lygaeidae)
Saissetia oleae (Coccidae)
Scirtothrips aurantii (Thripidae)
Serrodes partita (Noctuidae)
Sitona discoides (Curculionidae)
Spilostethus pandurus (Lygaeidae)
Spodoptera littoralis (Noctuidae)
Stephanitis pyri (Tingidae)

Tanyrrhynchus carinatus (Curculionidae)
Theretra capensis (Sphingidae)
Thrips tabaci (Thysanoptera)
Xiphistes furcicornis (Membracidae)

Cold storage required:
Ceratitis capitata (Tephritidae)
Ceratitis rosa (Tephritidae)

Pest species with no action required:
Bustomus setulosus (Curculionidae)
Daktulosphaira vitifoliae (Phylloxeridae)
Erisoma lanigerum (Aphididae)
Hemiberlesia rapax (Diaspididae)
Iridomyrmex humilis (Formicidae)
Nezara viridula (Pentatomidae)
Oxycarenus exitiosus (Lygaeidae)
Parlatoria cinerea (Diaspididae)
Planococcus citri (Pseudococcidae)
Planococcus ficus (Pseudococcidae)
Pseudococcus calceolariae (Pseudococcidae)
Pseudococcus longispinus (Pseudococcidae)
Pseudococcus viburni (Pseudococcidae)
Quadraspidiotus perniciosus (Diaspididae)

Other actionable deciduous phytosanitary pests:
Antestia variegata (Pentatomidae)
Antestiopsis orbitalis (Pentatomidae)
Aphis pomi (Aphididae)
Cydia pomonella (Tortricidae)
Diaspidiotus africanus (Diaspididae)

Macchiademus capensis (Lygaeidae)
Monosteira unicostata (Tingeidae)
Tortrix capensana (Tortricidae)

Israeli market: from PPIS (2004)
Acia lineatifrons (Cicadellidae)
Aleurocanthus spiniferus (Aleyrodidae)
Aleurocanthus woglumi (Aleyrodidae)
Ceratitis rosa (Tephritidae)
Cryptolarynx vitis (Curculionidae)
Cryptophlebia leucotreta (Tortricidae)
Eremnus spp. (Curculionidae)
Gryllus bimaculatus (Gryllidae)
Helioththrips sylvanus (Thysanoptera)
Phlyctinus callosus (Curculionidae)
Pseudococcus calceolariae (Pseudococcidae)
Quadraspidiotus perniciosus (Diaspididae)

References

PPIS 2004. *Bilateral Quarantine Agreement between the Plant Protection and Inspection Services of Israel (PPIS) and the National Department of Agriculture Directorate: Plant Health and Quality of the Republic of South Africa (DPHQ) Regarding the Conditions for the Importation of Fresh Grapes (*Vitis vinifera*) From the Republic of South Africa into Israel.* State of Israel, Ministry of Agriculture and Rural Development, Plant Protection and Inspection Services, Bet-Dagan, Israel.

USDA-APHIS & SAAFQIS 2004. *Preclearance Inspection and Cold Treatment of South African Deciduous Fruit Designated for Export to the United States of America.* South African Department of Agriculture, Directorates Plant Health, Pretoria.

Appendix II

ELECTRONIC COPY OF THE PHYTOSANITARY DATABASE (PQUAD)

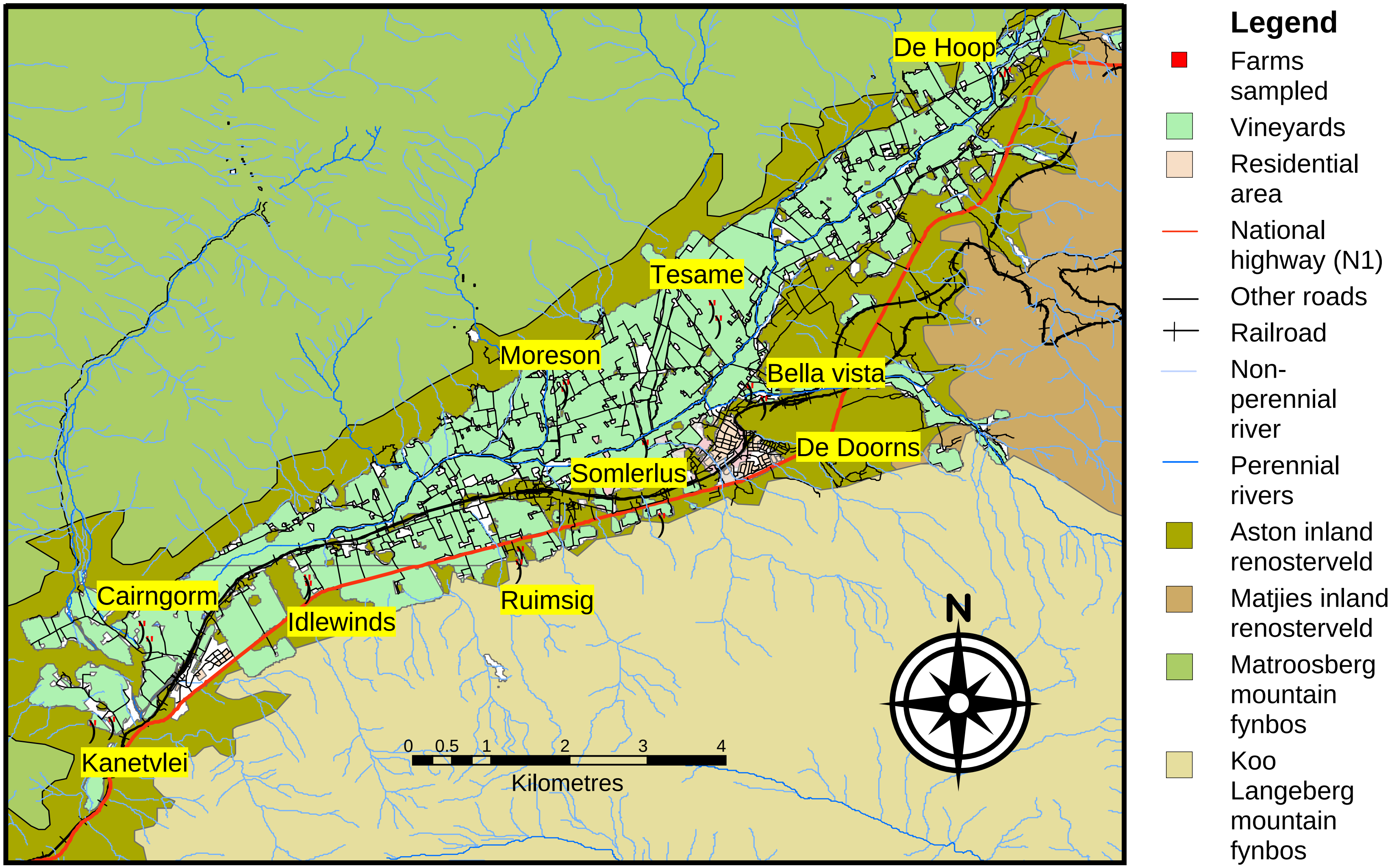

Figure 2.1 Map of the Hex River Valley, showing all the farms sampled in this study, with the exception of Protea, which is 8.2 km SW of the valley, along with the surrounding natural vegetation.

Figure 3.2 Crates placed in a vineyard to test the attractiveness of different colour crates to phytosanitary insects

Figure 3.3 Commercial light traps found in packhouses within the Hex River Valley

No statistical analysis could be performed on the number of phytosanitary pests found in the surrounding habitats as only two individual phytosanitary pests were recorded.

Figure 4.1 Youngest age of bunches inspected for pests

Figure 4.2 Cloth sheet used to collect pests shaken loose from the bunches.

Figure 4.3 A Plantex® ring (above) and a trunk band (below).

Figure 4.4 Cover crop of a vineyard.

Figure 4.5 Pheromone trap within a vineyard.

Figure 4.6. Vineyard surrounded by the indigenous vegetation.