FARMER MANAGEMENT PRACTICES OF STINK BUG (*Bathycoelia distincta*) AND ITS OCCURRENCE IN SELECTED MACADAMIA GROWING AREAS IN KENYA

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

I dedicate this thesis to my husband, William Wasonga Omole and my children; Mark Romeal, Charlotte Nita and Ivanna Princess for their unwavering moral support, love and prayers throughout my study period and my life. I feel honoured for having you all in my life.

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LIST OF ABBREVIATIONS AND ACRONYMS

CABI	**Centre for Agriculture and Bioscience International**
GDP	**Gross Domestic Product**
GOK	**Government of Kenya**
GPS	**Global Positioning System**
HCDA	**Horticultural Crops development Authority**
KALRO	**Kenya Agricultural and Livestock Research Organization**
KARI	**Kenya Agricultural Research Institute**
KEFRI	**Kenya Forestry Research Institute**
KEPHIS	**Kenya Plant Health Inspectorate Services**
NSRC	**National Sericulture Research Centre**
PTC	**Practical Training Centre**
U.S.A	**United States of America**

Abstract

Macadamia F. Muell. (Proteaceae) a nut bearing medium sized tree is steadily gaining global popularity because of its high nutritional value nut being used as a supreme dessert. Hence there is expansion in acreage to provide the raw material needed. Intensification comes with challenges and one of these are pests such as the Stink bug (*Bathycoelia distincta* Distincta***)*** an important pest of macadamia. Stinkbug feeding action results in kernel damage that contributes 55-70% nut losses. The study was undertaken to contribute to the management of pests and diseases limiting macadamia production to improve nut quality from Kenya. The objectives of the study were i) to determine the farmer knowledge and management practices of macadamia stinkbug in selected macadamia growing Counties; and ii) to assess the damage levels of nuts by stink bug and occurrence of the egg parasitoid in macadamia orchards in Murang'a County. Farmer knowledge on stinkbug and its management was collated and assessed using a structured questionnaire administered to 384 randomly selected macadamia farmers in Kiambu, Embu, Nyeri, Meru and Murang'a counties. The study utilized probability sampling technique entailing cluster sampling and simple random sampling procedure from which sub counties were selected as clusters and simple random sampling within the sub counties for the respondents. The sample size was calculated using the Krejcie & Morgan (1970) table and the farmer respondents drawn from a sampling frame (a list of macadamia growers) from each of the selected counties. Half of the respondents were male and the rest female. Slightly above 50% of the respondents were 50 years old and above while only 8% were youth. Greater than 50% of respondents had basic level of education. 80% were aware of the pests that affect macadamia and macadamia nut. Three quarters reported that stinkbug was the most difficult to manage causing losses in terms of yield and quality of the nuts. Other pests of importance after stinkbug were nut borer, mealybugs and thrips. Significantly ($p < 0.05$) over 80% respondents in UM1 and UM3 used various strategies to manage stinkbugs and they used cultural approach to manage stinkbug. That is weeding, pruning and burning of trash under the trees. Very few (negligible) farmers used pesticides to manage the stinkbug and other pests infesting macadamia. None reported using indigenous knowledge or biological control methods but over 84% of respondents across gender were willing to adopt biocontrol agents for management of macadamia stinkbug.

Experiments were conducted in three agro-ecological zones; (UM1), (UM2) and (UM3) to measure the damage levels and losses. Bi-weekly monitoring for presence of the pest, pest eggs and nuts damaged by the pest was done. Thirty trees were randomly selected per zone for the study. Another experiment was undertaken to collect and rear an egg parasitoid (*Trissolcus basalis)* within the macadamia orchards. *Trissolcus basalis* was reared in 85-ml glass tubes (30 mm diameter × 150 mm length) and incubated at (25 ± 1°C, 80 ± 5% RH, 15L: 9D photoperiod) in the laboratory on *Nezara* egg masses.

The populations of stinkbug significantly ($P<0.05$) differed across zones with lower altitude zones UM2 and UM3 recording higher populations of stinkbugs compared to UM1. No differences were observed in pest incidence and egg masses collected between UM2 and UM3.*Trissolcus basalis* parasitization was detected in orchards. The egg parasitoid were reared in the laboratory on *Nezara* eggs which varied in sizes from 44 to 131 (n = 143). Parasitoid discovery efficiency, was not influenced by the size of the egg masses ($F > 2.34$, df = 2, $P > 0.05$) indicating the ability to detect and locate the egg masses. However, with the increasing egg numbers per egg mass, there was a significant decline in parasitism efficiency ($F = 3.23$, df = 2, $P < 0.05$) with 40-70 eggs having 96% parasitism while 100 eggs and above had only 30% parasitism. This relationship was described by the regression equation: $y = 99.88 - 0.34x$, with an R2 value of 0.42 ($P < 0.05$) describing an inverse relationship between parasitism efficiency and size of egg mass exposed. *Trissolcus basalis* females showed a high (90%) efficiency in parasitizing *Nezara* eggs and the females of the parasitoid parasitized 59.7% of exposed egg masses. A strong parasitic affinity between *T. basalis* and *N. viridula* eggs was demonstrated. The presence of *T. basalis* avails a potential biological tool for controlling *Bathycoelia distincta* and there is significant potential for laboratory rearing of *T. basalis.*

CHAPTER1:

INTRODUCTION

1.1 Background Information

Macadamia F. Muell. (Proteaceae) is a nut bearing medium sized tree (20 m tall and 13 m wide) and produces nuts that are dicotyledonous (2002; Gitonga *et al.*, 2017). Two of the nine species of macadamia have edible nuts: *M. tetraphylla* and *M. integrifolia* as mentioned by Abubaker *et al.*,(2018).*M. integrifolia* exhibits leaves with an entire margin and minimal spines, with three leaves typically found at each node. Additionally, the nuts of *M. integrifolia* are smooth-shelled, as noted by Alam *et al.* (2018), while *M. tetraphylla* is characterized by its spiny leaves and four whorled nearly sessile leaves and a rough nut shell (Alam *et al.*, 2018).

1.1.1 Production state and economic worth of macadamia

Due to its high nutritional value, macadamia is steadily gaining global popularity as supreme dessert (Rahman *et al.*, 2021). Due to its significant economic value, it has proved to be a highly incentive crop causing countries like South Africa to establish in excess of 600,000 trees annually with Macadamia yield of China expected to grow threefold by the year 2022 (Parshotam, 2018; Quiroz *et al.*, 2019). Macadamia accounts for a hundredth of nut trees produced globally whereas Kenya accounts for 13% of total global production of macadamia. (Quiroz *et al.*, 2019). Bob Harries introduced macadamia to Kenya in 1946 (Murioga *et al.*, 2016). Original seed material of macadamia planted in Kenya was *Macadamia tetraphylla* and *Macadamia integrifolia* (Kiuru *et al.*, 2004).

Macadamia farming in Kenya is a lucrative business where the commodity has unprecedented local market demand, resulting in increased cultivation by smallholder farmers. Kenya is among the top global producers of macadamia at 16% of total nut yield worldwide(Hardner *et al.*, 2019). In the year 2008, the area under macadamia production in Kenya was above 2000havalued at Ksh.350 million from production of 13,510Mt (Muthoka *et al.*, 2008). Australia, South Africa, China, Kenya, U.S.A, Guatemala, Vietnam, and Malawi are the main growers of Macadamia globally in order of level of production (Figure 1.1) (INC, 2021).

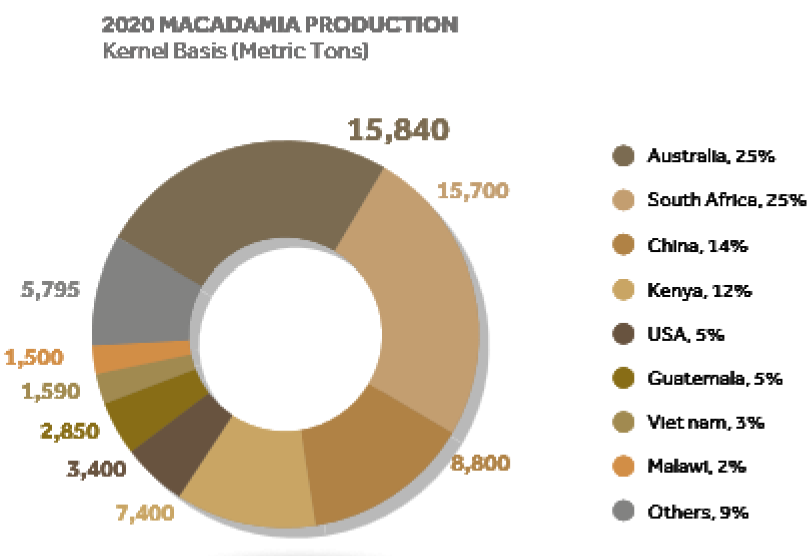

Figure 1.1Global macadamia production (Tonnes, Kernel basis) in leading countries in the year 2020

Source: International Nut & Dried Fruit (2021), Nuts & Dried Fruits Statistical Yearbook 2020/2021, p. 29.

Other countries like New Zealand, Tanzania, México, Venezuela, Fiji, Jamaica and Argentina cultivate the crop on a small scale (Ondabu *et al.*, 2007).

Macadamia nuts thrive in tropical regions, primarily cultivated at altitudes of 1500 to 1850 meters above sea level. In Kenya, the two dominant varieties of macadamia grown are *Macadamia integrifolia* and *Macadamia tetraphylla*.

At present, the macadamia industry stands as the fastest-growing agro-processing sector, strategically focusing on profitable niche markets in the Orient and Europe(Rotich, 2004). The cultivation area dedicated to macadamia trees in Kenya has experienced substantial growth, expanding to estimated 8000 ha in 2003 from 469 ha in 1989 to (Kiuru *et al.,* 2004).With a production of nearly 10,000 metric tons per year, macadamia is considered Kenya's most important nut crop. This crop has become a crucial source of income and sustenance for over 100,000 small-scale farmers, who are attracted to macadamia cultivation due to its low-input nature (Waithaka, 2001).There are over 100,000 small scale growers of macadamia as a cash crop in Kenya (Onsongo, 2003).Macadamia, currently cultivated by around200,000 small-holder growers in Kenya is rated as the second most lucrative cash crop after tea (Quiroz *et al.,* 2019).

Macadamia cultivation often involves intercropping with various cash and food crops.(Quiroz *et al.,* 2019).According to Ministry of Agriculture in Kenya (2016) survey, macadamia nut accounts for 47% of total nut value produced in Kenya, making it economically important in the nut industry in Kenya. According to (Murioga *et al.,* 2016), in the year 2016, the yield from macadamia nut stood at 113,498 metric tonnes with a cash value of KES. 3.75 billion. Macadamia production in Kenya is constrained by many challenges including diseases, lack of planting material, high price of planting material, lack of variants suited to different agro-ecological zones, and insect pest problems which affect nuts and lower the post-harvest quality (Gitonga *et al.,* 2009). Several insects are of major economic importance because they cause considerable nut yield loss and nut quality reduction in macadamia. Macadamia stinkbug *Bathycoelia distincta* Distant contributes to 55-70% nut losses (Muthoka *et al.*, 2008). The feeding action of stinkbugs on macadamia nuts results in kernel damage characterised by stained unsightly pits on the kernel surface, occasioning immature nuts to be harvested from the ground(Wallner *et al.,* 2014).Kernel damage is accumulative and tends to be witnessed throughout the year (Ikuma *et al.*, 2002; Kawate & Tarutani, 2006).

Puncture wounds caused probing action during feeding by stink bugs act as entry points for fungi which infect nuts resulting into moldy kernels (Jones & Caprio, 1990).There is general need to control the pest in order to ensure high quality and quantity of harvested nuts.

1.2Statement of the problem

Although the two spotted stinkbug has been recorded on crops such as avocados (Van den Berg Steyn, WP & Greenland, J, 1999), it is only a pest of tangible economic value in macadamias. Stink bug causes premature nut fall and kernel damage (Center *et al.*, 2004).

Chemical treatments of stinkbugs are usually not common in macadamia due to the morphology and feeding habits of the stink bug as well as the growth habit of the ever tall macadamia tree. Most chemicals available for management of stink bugs enhance fluctuations of populations of natural enemies complexes that has not been a desirable outcome to most farmers (Center *et al.*, 2004).Previous trials on biocontrol using parasitoids have yielded better response in management of the pest in other countries like Hawaii and Australia (Wright & Diez, 2011) and a research on its efficiency in Kenya would be considered a worthy course.

1.3Justification

In Kenya, there has been no documented biological control work on macadamia stinkbugs recorded so far, yet the pest continues to cause serious damages to macadamia resulting to serious losses, hence the effectiveness of biological control using parasitoids on the control of the macadamia stinkbugs in Kenya is not yet known.

The study seeks to gather empirical evidence regarding the economic losses incurred at the farm level due to stinkbug infestation in macadamia orchards. Accurate data on yield losses is essential in effectively managing stinkbug infestation and assessing effectiveness of current control practices employed for this pest. The findings from this study will play a crucial role in several aspects. Firstly, they will be vital for informing production policies and making economic decisions, as the yield losses experienced in macadamia due to stinkbug infestation can directly impact the export market prices that the country's commodity fetches. Moreover, these findings will serve as valuable information for both public and private agricultural stakeholders, highlighting the necessity to allocate funding and research capacity towards addressing the impact of stinkbugs on macadamia farming. In addition to economic implications, the study also addresses the lack of sufficient information regarding farmers' perceptions of control practices for managing stinkbugs, which is a significant constraint for macadamia producers across Kenya. By filling this knowledge gap, the study will add s to the growing works on sustainable agricultural technologies and aid in the design and formulation of an effective stinkbug biocontrol strategy. This pest poses a risk to sustainability of production of macadamia, which is classified as a principal cash crop in Kenya. Therefore, the findings from this study hold great significance in ensuring the long-term viability of the macadamia industry.

1.4Objectives

To contribute to the management of macadamia stink bug (*Bathycoelia distincta*) and the improvement of the quality of macadamia nut produced in Kenya.

1.4.1 Specific Objectives

1. To determine farmer knowledge on macadamia stink bug and its management in Kenya

2. To determine the occurrence, activity density of macadamia stink bug and laboratory rearing of its natural egg parasitoid in Murang'a County.

1.4.2Hypothesis

This research will be out to prove the following hypothesis:

1. Farmer awareness of macadamia insect pests and the management practices are not effective for stinkbug control.
2. There is high infestation of stinkbugs in macadamia and the presence of natural egg parasitoid of the pest in orchards in the lowland areas

CHAPTER 2:

LITERATURE REVIEW

2.1Contribution of macadamia nuts to GDP

To Australia, macadamia is a native crop (Srichamnong, 2012) and a vital source of food.(Carr, 2013). Small macadamia orchards were initially planted in Australia following European settlement in the early 1800s, later, the crop has since principally been adopted as a cash crop in Hawaii (Hardner *et al.,* 2019). Commercial production of macadamia in USA started around 1930-1940 (Barrueto *et al.,* 2018; Shigeura & Ooka, 1983). Selection of superior germplasm has led to development of new macadamia varieties(Hardner *et al.,* 2019). According to Langdon *et al.* (2020), there are desirable agronomical characteristics in these varieties including resistance to pest and disease as well as exceptional tolerance for different environmental condition.

Macadamia represents approximately 3% of global nut trade, as stated by Langdon *et al.* (2020). Cultivation of macadamia is widespread in various countries, including Kenya, USA (Hawaii), South Africa, Indonesia, Guatemala, Brazil, Costa Rica, Malawi, Uganda, Zambia, Vietnam, Zimbabwe, Vietnam, and China (Srichamnong, 2012). Global major macadamia producers in the year 2017were Hawaii (10%), Kenya (16%), Australia (23%) and South Africa leading at (24%),(Hadebe *et al.,* 20189).

Worldwide macadamia production has experienced a remarkable and unparalleled growth rate compared to other tree nut crops in the last ten years (Quiroz *et al.,* 2019). This surge in popularity has resulted in a continuous demand that surpasses the global production (Augstburger *et al.,* 2002). The quality of nuts in macadamia is assessed on the basis of oil content and their physical appearance. A significant constituent in macadamia nuts is palmitoleic oil, which possesses various health benefits and serves as a valuable asset in different markets (Phatanayindee *et al.,* 2012). Within the macadamia kernel, there are notable proportions of oleic acid (approximately 60%) and palmitoleic acid (approximately 20%) both of which contribute to human health advantages (Aquino-Bolaños *et al.,* 2017). Furthermore, macadamia nut shell can be utilized as a valuable resource for tar oil while macadamia oil is a possible source for biodiesel production (Azad *et al.,* 2017).

2.2 Macadamia industry in Kenya

Agriculture contributes to livelihood source for 75% of the Kenyan population (Murioga *et al.,* 2016). In spite of all that, in Kenya, only 26% of GDP comes from agriculture (Murioga *et al.,* 2016). Kenya exports Macadamia. It is a major horticultural crop with 99% nuts produced being for the export market. This contributes to 10% of the global macadamia production (Mbora *et al.,* 2008). Initially, the introduction of macadamia aimed to diversify the income of farmers in coffee-growing regions. Farmers have since embraced the crop for various purposes, including delineating boundaries and providing shade around their homesteads. According to independent studies carried out by Murioga (2018) and Röckle *et al.* (2019), the introduction of macadamia farming created another source of income for growers when global coffee market prices declined worldwide (Murioga, 2018; Röckle *et al.,* 2019). Farmers that took up macadamia growing considered it a reliable prime income source for their households (Murioga, 2018). Smallholder farmers in Kenya predominantly engage in macadamia cultivation, as stated by Murioga *et al.* (2016). Central and Eastern Kenya have most of macadamia farmers, specifically in the counties of Kirinyaga, Embu, Murang'a, Kiambu, Nyeri, and Embu. Some parts of western region do have macadamia farmers.

Kenya has a high degree of dependency on small farmers for its production, compared with the rest of the macadamia producing countries (Africa Research Bulletin, 2019). A total of 70% of Kenyan macadamia nut production is attributed to small scale farmers while 30% of the production comes from around 500 large scale farmers who have a minimum of 1000 trees each (Muhara, 2004). According to Muthoka *et al.* (2008), most of the farmers raise below 100 macadamia trees in mixed cultures with coffee or other food crops.

Farmers in Central Kenya were incentivized to explore macadamia farming with the expectation that macadamia yields would generate income that would be at par with, or even surpass, that of tea and coffee: the primary export crops during that period (Mbora *et al.*, 2008).

Improved agronomic practices in macadamia production led to an upsurge in macadamia nut yield in Kenya from 3170 Metric tons in 1996 to 10753 in 2001 (Waithaka, 2001). The propagation of macadamia variants adaptable for various Agro Ecological Zones by some macadamia producing states in America such as California (McHargue, 1996)and their introduction to Kenya has given rise to a higher gene base in the country. According to (Murioga *et al.*, 2016), macadamia nut accounts for 47% of total nut value produced in Kenya, making it economically important in the nut industry in Kenya. In the year 2016, the yield from macadamia nut stood at 113,498 metric tonnes with a cash value of KES. 3.75 billion giving a great boost to the GDP of Kenya (Murioga *et al.*, 2016).The growing economic significance of macadamia nuts was evident in the data provided by the Kenya National Bureau of Statistics for 2009. According to this report, the horticulture sector generated KES. 73.7 billion in revenue for the country, while macadamia nuts alone accounted for over KES. 0.5 Billion during the same year (KEBS, 2009). In 2011 the Ministry of Agriculture carried out a survey and found that there were over 100,000 employees in the macadamia nut industry. In 2013, macadamia generated a revenue of KES 7.4 billion accounting for 5% of total value of the horticultural industry in Kenya (HCDA, 2013). However, there has been a general slow growth rate in Kenya's macadamia sub-sector leading to loss of its market shares to competing countries such as South Africa (CABI, 2005).

2.3Constraints to macadamia production

Macadamia growing is gaining global popularity, however, limitations associated with cultivation history and industry size has seen macadamia farming experience a lot of constraints towards its sustained productivity and profitability (Hardner *et al.,* 2019).

Nut quality is widely recognized as the primary factor when selecting improved macadamia cultivars for nut processing, as emphasized by Muthoka *et al.* (2008). However, despite its significant potential for reducing poverty, the macadamia subsector in Kenya faces numerous challenges, including insect pest issues that adversely impact the nuts and diminish the post-harvest quality(Gitonga *et al.,* 2009), diseases such as anthracnose and husk spots (Drenth *et al.,* 2009), absence of suitably adapted varieties to various agro ecological zones, inadequacy of quality planting material as well as high price of good quality plant materials currently available (Gitonga *et al.,* 2017). Producers, researchers and other related industries are, however, addressing these challenges for sustainable macadamia production (Azad *et al.,* 2017).

Pest infestation has been a major contributing factor towards the macadamia sub-sector operating below its expected production potential in Kenya(Gitonga *et al.,* 2009). Insect pests are the main cause of reduced nut quality and quantity in macadamia (Wrona *et al.,* 2020). A number of insects stand to be of major economic importance because they cause considerable nut yield loss and nut quality reduction in macadamia(Muthoka *et al.,* 2008).

2.3.1 Insect pests of macadamia

Insect pests pose a significant constraint to macadamia production on a global scale(Schoeman, 2013). Up to 60 species of insect pests affect macadamia plantations in South Africa, with 40 being heteropteran (Schoeman & Millar, 2018).

Main pests of macadamia in Africa are two-spotted stinkbug, coconut bug (Schoeman, 2013), macadamia felted coccid(Schoeman & Millar, 2018), false codling moth, macadamia nut borer(Van der Merwe, 2018) and citrus thrips (Thackeray *et al.*, 2015).

Apart from macadamia felted coccid, a native of Australia and introduced into South Africa by chance, the other species are endemic to Africa (Schoeman & Millar, 2018). *Bathycoelia distincta* (Hemiptera: Pentatomidae) is monophagous and a known major pests of macadamias across plantations in South Africa (Schoeman & Mohlala, 2012).Stinkbugs are considered one of the chief causes of nut damage in macadamia nuts (Jones & Caprio, 1994). Stinkbugs are responsible for losses in the macadamia industry running into millions of shillings (Schoeman, 2009). Detailed studies indicate macadamia stink bug *Bathycoelia distincta* Distant and nut borer *Ephestia sp*. and *Cryptophlebia leucotreta* Meyr as major pests of macadamia in Kenya (Muthoka *et al.*, 2008). The stinkbug was observed to cause 55-70% of nut losses in areas lower than 1,600 (Muthoka *et al.*, 2008). It's feeding action on nuts results in stinkbug feeding lesions inside the husk and premature nut fall (Schoeman, 2013). It has been shown that early nut fall is due to the effect of this insect's feeding (Jones & Caprio, 1994), which encourages immature nuts to be harvested from the ground. Puncture wounds caused by the probing action during feeding by stinkbugs act as entry points of fungi which infect nuts resulting into moldy kernels (Jones & Caprio, 1990).

Based on preliminary research work carried out at KARI/Thika, parasitoid wasps e.g. *Trissolcus spp.*,*Tetractrichus spp. and Anastatus spp.* have potential to manage the Macadamia stinkbug, *B. distincta* with up to 55% success (Peres & Corrêa-Ferreira, 2004).

2.4The two-spotted stinkbug

2.4.1 History, description and occurrence of two-spotted stinkbug

The native*B.distincta,* which used to be known by the name *Bathycoelia natalicola* was first observed on macadamia trees in Levubu, South Africa's Limpopo province, in 1984, as reported by Bruwer (1992) and Schoeman (2014). *B. distinct* has light green adults with distinctive white dots on the upper corners of the scutellum (Figure 2.1) (Van den Berg Steyn, WP & Greenland, J, 1999).*Bathycoelia distincta* is a migratory pest that needs to be monitored annually for its wide range of host plants(Schoeman, 2014a).

Figure 2.1Morphological features of *B. distincta* showing colour and distinctive white spot
Source:(Schoeman, 2009)

Bathycoelia distincta has been reported in all major macadamia growing zones of South Africa (Bruwer *et al.*, 2021). The pest is also common in Kenya (Muthoka *et al.*, 2008).

2.4.2 Life stages

2.4.2.1 Eggs

The pentatomid insects, including *Bathycoelia distincta*, lay barrel-shaped eggs. These eggs are typically found in clusters and are covered by an operculum. Surrounding the operculum is a ring of aero-micropylar processes, which serve as openings for air exchange. During hatching, the operculum lifts off, allowing the nymphs to emerge (Matesco *et al.*, 2009). For *Bathycoelia distincta*, the females lay 14 clustered eggs tightly stuck in rows (Figure 2.2a) and firmly attached on a substrate (Figure 2.2b).

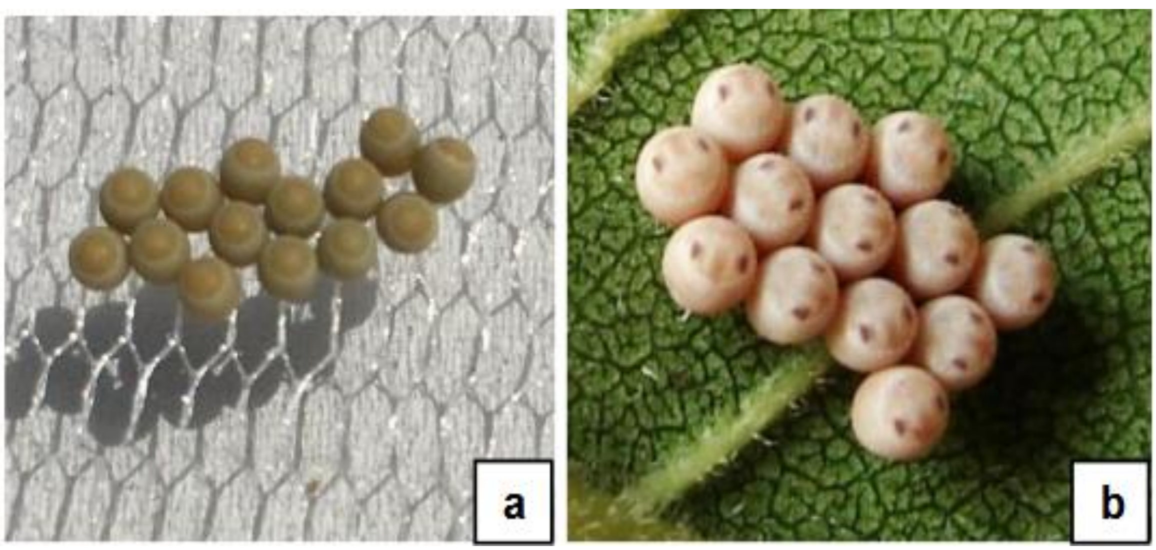

Figure 2.2a) *B. distincta* eggs glued together in rows (b) *B. distincta* eggs firmly attached on leaf surface *Source:(Schoeman, 2009)*

During their entire adult stage, female *Bathycoelia distincta* stink bugs are capable of laying eggs. Although small in size, these eggs can be observed with the naked eye and have an approximate diameter of ±2.5 mm, (Bruwer, 1992). Initially, eggs that are freshly laid exhibit a light green color, which gradually transitions to cream or pink as they develop. Before hatching, two prominent red spots can be observed on the eggs (Bruwer, 1992) (Figure 2.2b).In optimal conditions, the eggs hatch within six to seven days.. *Bathycoelia distincta* lays eggs on various parts of host plant including main stem, leaves, branches, fruit, and stalks (Bruwer, 1992).

2.4.2.2 Nymphs

Bathycoelia distincta undergoes five instar stages of development after egg hatching as depicted in Figure 2.3a-e. The nymphs are oval-shaped and predominantly black in colour with noticeable red and yellow markings on the first three nymphal instars (Figures 2.3a-c).

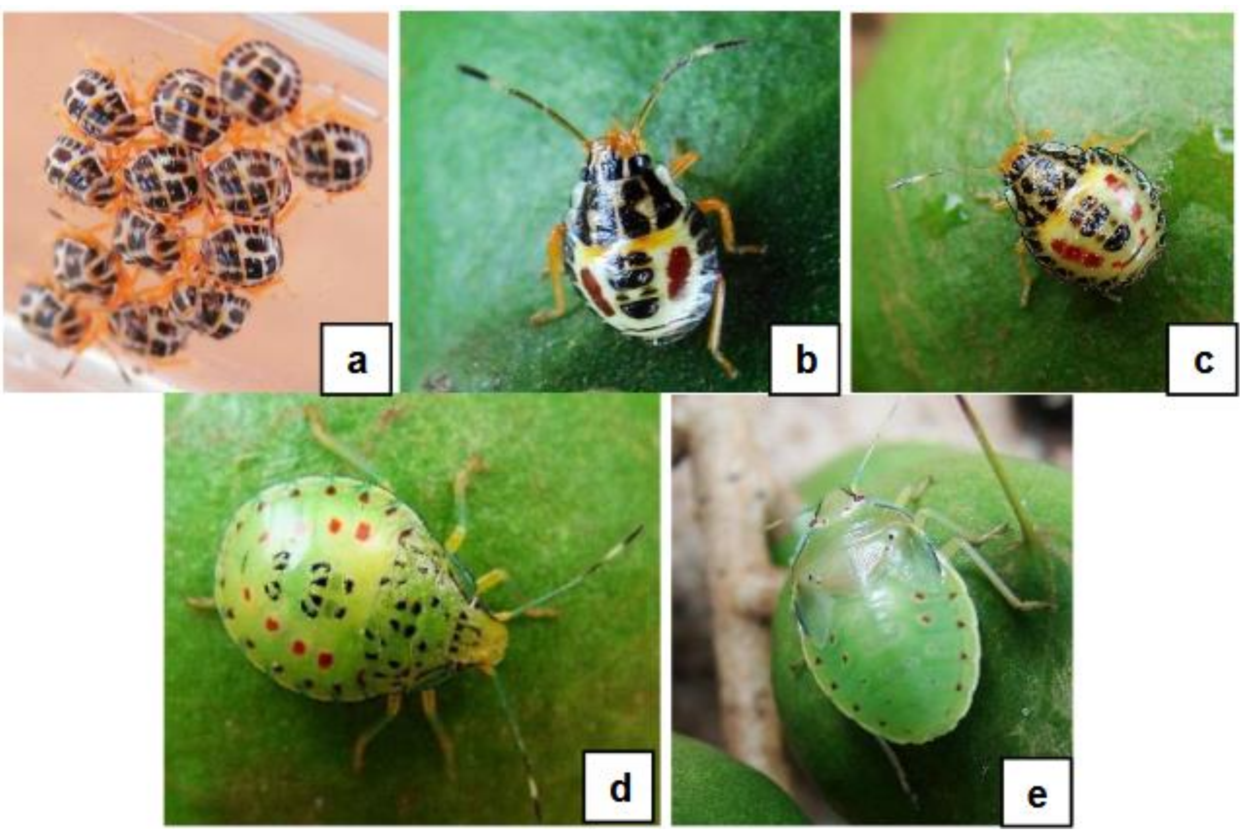

Figure 2.3*Bathycoelia distinct* different nymphal stages (instar 1-5) represented by letters a-e respectively *Source:(Schoeman, 2009)*

During the fourth and fifth nymphal instars, the two-spotted stink bug exhibits a lime-colored appearance (Figures 2.3d-e). For the purpose of obtaining beneficial microbial symbionts, neonate nymphs have a special behavior of aggregation on or close to blank eggshells, rather than feeding (Oishi *et al.*, 2019). These symbionts play a vital role in providing essential amino acids, vitamins necessary for nymphal development, enhancing resistance to natural enemies, and aiding in the effective breakdown of toxic substances (Oishi *et al.,* 2019; C. M. Taylor *et al.,* 2014). Normal development of the first instar nymphs may be impaired if they cannot acquire these microbial symbionts, thus causing a high mortality rate(C. M. Taylor *et al.,* 2014). First instar nymphs move away from the eggshells at four to five days after hatching, but continue to exhibit aggregation tendencies up to that time (Bruwer, 1992). The gregarious behavior of the nymphs plays a significant role in providing mutual protection and physical defense, ultimately reducing mortality rates and expediting their development. (Bruwer, 1992; Panizzi & Slansky, 1991). The gregarious behavior maintained through the first three instars completely disappears at the fourth instar (Panizzi & Slansky, 1991).

2.4.2.3 Adults

To complete *B. distincta*'s development from egg to adult when reared on green bean pod in the optimum constant conditions of temperature at 25 ± 2 C and humidity 75 ± 5 %, it will take about 43 to 58 days(Bruwer, 1992). Females are larger (18mm long) than males, that are around11-14mm long (Bruwer, 1992) (Figure 2.4).

Figure 2.4Copulating *Bathycoelia distincta* adults *Source: (Linda, 2021)*

Observations of ventral region at the abdominal tip may distinguish between female and male stink bugs, with males having a distinctive forked shape created by presence of claspers on the last abdominal segment(Jones, 2002) (Figure 2.5).

Figure 2.5 Ventral side of the abdomen of *Bathycoelia distincta* showing last abdominal segment a) claspers absent in female b) claspers present in males

Source:(Jones, 2002)

2.4.3 Economic importance

The two-spotted stink bug contributes to 55-70% nut losses in Kenya (Muthoka *et al.*, 2008). The pest is destructive on macadamia nuts from the second instar nymphs to adults. They havepiercing-sucking mouthparts that they use to extract fluids from nuts (Da Silva & Daane, 2014). Their feeding action introduces moulds and fungi into the kernel, causing crop loss due to premature nut abortion and formation of lesions on mature nuts (Jones, 2002; Schoeman, 2009)(Figure 2.6).

Figure 2.6Feeding lesions showing *B. distincta* damage to husks
Source:(Schoeman, 2009)

Suitability of sale of macadamia nut is lowered due to damage on nut caused by the feeding action of *Bathycoelia distincta* results in low-quality defective nuts(Golden *et al.,* 2006; Schoeman, 2009) (Figure 2.7).

Figure 2.7 Defective nuts showing *B. distincta* damage to kernels
Source:(Schoeman, 2009)

Revenue losses associated with the insect pest damage on nuts necessitates advancement of strategies to protect macadamia against this pest.

2.4.4 Mechanisms for control of *Bathycoelia distincta*

Bathycoelia distincta is highly mobile, which inhibits effective monitoring and scouting for the pest in macadamia orchards (Da Silva & Daane, 2014; Krupke & Brunner, 2003). To mitigate stink bug populations in macadamia orchards, several primary strategies are employed, namely, the utilization of biological control approach, trap crops and insecticides use(Schoeman, 2014b).

Lack of monitoring techniques and very high level of mobility of the pest has made it very challenging to deal with and control stink bugs (Krupke & Brunner, 2003). The objective of monitoring lacks clarity and specificity in some cases and nut damage symptoms contributing to different economic injury levels are not known. In most instances, it is difficult to put into practical context the count of bugs obtained through monitoring (Da Silva & Daane, 2014). Other than just measuring pest abundance, a monitoring program should possess the capability to consistently employ the designated sampling method and effectively detect even smallest bugs numbers as soon as they arrive(Da Silva & Daane, 2014).In macadamia orchards,(P. J. Taylor *et al.,* 2011)proposed the following monitoring techniques for hemipteran pests: i) To pick and identify the bugs that fall to the ground by **shaking branches**; ii) **Knocking down** stink bugs using dichlorovos; iii) **Scouting** for stinkbug egg clusters on the main tree trunk; and iv) **Dissecting** prematurely fallen nuts and examining kernels and husks and for stink bug feeding lesions.

Biological control encompasses use of living organisms in effectively reducing population densities of targeted pests, thereby minimizing the damage caused by these pests (Augustyniuk-Kram & Kram, 2012). Various natural enemies, such as entomopathogenic fungi (EPF) (de Faria & Wraight, 2007), nematomorphs (horsehair worms), as well as wasps and flies (Schoeman, 2009), can be employed in the management of insect pests. *Trissolcus basalis* is an egg parasitoid of both *Bathycoelia distincta* and *Nezara viridula* that is black in colour and relatively small in size with the females having club-shaped antennae.

The populations of egg parasitoids in normal environs are fairly low, therefore, in order to increase their ability to invade and successfully suppress pest populations, there's need for release of mass-reared natural enemies into the farms (Harris *et al.,* 1991). For effective biocontrol, *Trissolcus basalis* recognises the eggs of the stink bug by presence of secretions on the egg chorion, a mechanism that enhances the kairomonal relationship between the two organisms (Dauphin *et al.,* 2009).

CHAPTER 3:

FARMER KNOWLEDGE AND PRACTICES OF MACADAMIA STINKBUG (*Bathycoelia distincta* Distant) MANAGEMENT IN KENYA

Abstract

Macadamia production in Kenya is fast gaining popularity and being adopted in most counties as a reliable source of income to farmers. However, this popularity is also accompanied by an increasing threat to production of quality nuts by the macadamia stinkbug (*Bathycoelia distincta* Distant). Macadamia tree, which grows to more than three metres height, and more than 5 meters canopy, has minimal available methods of control for such a nut attacking pest. This study evaluated farmer knowledge of macadamia insect pests and the management practices applied to control stinkbug. Farmer knowledge on stinkbug and its management was collated and assessed using a structured questionnaire administered to 384 randomly selected macadamia farmers in Kiambu, Embu, Nyeri, Meru and Murang'a counties. The study utilized probability sampling technique entailing cluster sampling and simple random sampling procedure from which sub counties were selected as clusters and simple random sampling within the sub counties for the respondents. The sample size was calculated using the Krejcie & Morgan (1970) table and the farmer respondents drawn from a sampling frame (a list of macadamia growers) from each of the selected counties. Half of the respondents were male and the rest female. Slightly above 50% of the respondents were 50 years old and above while only 8% were youth. Greater than 50% of respondents had basic level of education. 80% were aware of the pests that affect macadamia and macadamia nut. Three quarters reported that stinkbug was the most difficult to manage causing losses in terms of yield and quality of the nuts. Other pests of importance after stinkbug were nut borer, mealybugs and thrips. Significantly ($p < 0.05$) over 80% respondents in UM1 and UM3 used various strategies to manage stinkbugs and they used cultural approach to manage stinkbug. That is weeding, pruning and burning of trash under the trees. Very few (negligible) farmers used pesticides to manage the stinkbug and other pests infesting macadamia. None reported using indigenous knowledge or biological control methods but over 84% of respondents across gender were willing to adopt biocontrol agents for management of macadamia stinkbug. Parasitoids offer excellent opportunity because they can be easily deployed and are able to search for the host. As such, they provide a key control measure against this pest.

3.1 Introduction

Macadamia production in Kenya is currently the greatest agro-industrial sector targeting lucrative distinct markets in the Orient and Europe (Rotich, 2004). Kenya is among the top global producers of macadamia at 16% of total nut yield worldwide (Hardner *et al.,* 2019). According to Ministry of Agriculture in Kenya (Murioga *et al.,* 2016) survey, macadamia nuts account for 47% of total value of nuts produced in Kenya, making it economically important in the nut industry in Kenya. From 469 ha in 1989 to almost 8,000 ha in 2003, the area covered by macadamia trees increased(Kiuru *et al.,* 2004; Onsongo, 2003). According to (Murioga *et al.,* 2016) the macadamia nut yield stood at 113,498 metric tonnes with a cash value of KES. 3.75 billion. Macadamia is the second most valuable cash crop after tea in Kenya, with more than 200,000 small-holder farmers producing it(Quiroz *et al.,* 2019).

The first measure for selecting quality macadamia cultivars in the nut processing sector is universally agreed on as 'quality of nuts'(Muthoka *et al.,* 2008). Several insects are of major economic importance because they cause considerable nut yield loss and nut quality reduction in macadamia(Linden *et al.,* 2019). The two spotted stinkbug is a pest of tangible commercial value in macadamia(Pal *et al.,* 2022). It is a major destructive pest causing premature nut fall and development of lesions on mature kernels of macadamia(Sonnekus *et al.,* 2022).The pest's feeding action on nuts results to feeding lesions inside the husk and premature nut fall (Bruwer *et al.,* 2021). It has been correctly reported that the puncture wounds caused by the probing action during feeding by stink bugs becomes the key entry points of infectious fungi which cause moldy kernels (Golden *et al.,* 2006). In South Africa, *Bathycoelia distincta* (Hemiptera: Pentatomidae) is a monophagous and known major pest of macadamia across plantations (Fourie *et al.,* 2022).

Pesticide use for the control of the two-spotted stink bugs usually not very effective due to high levels of resistance by the pest after repeated applications (Schoeman, 2017). Reportedly, pesticide use disrupts natural enemies population complexes, resulting to undesirable outcome to most farmers (Center *et al.*, 2004). However, according to Sonia (2017), the efficacy of synthetic pesticides to sufficiently manage the pest is not guaranteed due to their short residual effect on the plant, therefore the crop is always vulnerable to re-infestation from the surrounding areas. Previous trials on bio-control using parasitoids have yielded better response in the controlling *B. distincta* in Hawaii and Australia (Wright & Diez, 2011)and a research on its efficiency in Kenya would be considered a worthy course.

In Kenya, there is little evidence available on parasitoid use for management of this stinkbug. This survey was carried out to establish among others age, gender, level of education of farmer, number of trees in a farm, variety of macadamia planted, farmer knowledge on stinkbug and willingness of Kenyan macadamia farmers to adopt parasitoid use in biological control for stink bugs.

3.2 Materials and methods

3.2.1 Description of study sites

These studies were carried out in Meru, Kiambu, Embu, Murang'a and Nyeri, counties in Kenya (Figure 3.1).

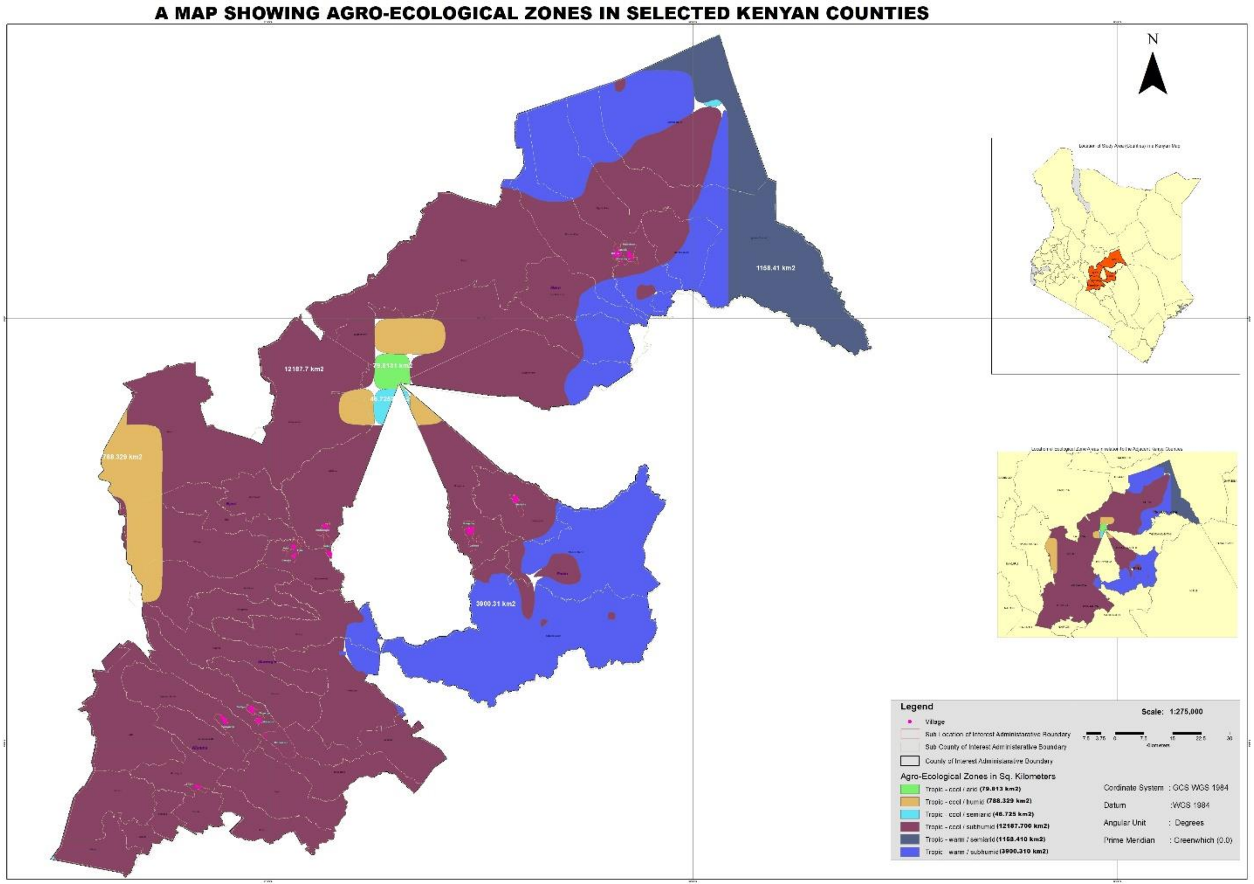

Figure 3.1Agro ecological zones of major macadamia growing counties in Kenya

Based on the similarity of the tropic cool and sub-humid agroecological characteristics, these five counties were selected. The five counties were selected based on their similarity in tropic cool/sub-humid agro ecological characteristics. These are among the leading macadamia growing zones in the country with an altitude range of between 1,500-1,850m and temperature of 16-23℃. The average rainfall is between 1,100-1,500mm annually with deep well drained fertile soils of pH 5.6.The study area was clustered into five agricultural ecological zones as Upper Midland 1(UM1), Upper Midland 2 (UM2), Upper midland 3 (UM3), Upper Highland 1 (UH1) and Lower Highland 1 (LH1) as shown in Table 3.1 below.

Table 3.1Sub counties, villages and sub agricultural ecological zones of major macadamia growing counties in Kenya

County	Sub county	Village	Sub agricultural ecological zone
Meru	Tigania West	Mucuune, Kitheo	UM2
	Tigania East	Kiguchwa, Abodii	UM3
Embu	Runyenjes	Gichicho	UM2
	Manyata	Kangima, Gatituri	UM1
Nyeri	Mathira	Karindundu, Gakuyo	UM1
	Mukurwe-ini	Muyu, Gaturia, Thiha	UM2
Murang'a	Gatanga	Mabanda, Gatiiguru, Gatambara, Kagongo	UH1
Kiambu	Githunguri	Lioki	LH1
	Gatundu North	Kamwangi	UM3

The study focused on farmers across the five counties who have mature macadamia trees that have had at least one fruiting season during their macadamia production cycle. Respondents were randomly selected from two sub counties in each of these Counties. Three hundred and eighty four (384) respondents were sampled from a population of 76000 using the Krejcie &

Morgan (1970) table of sampling which says that the sample size for a study population of above 75000 is 384. The study utilized probability sampling technique entailing cluster sampling and simple random sampling procedure. The cluster sampling technique was used hence two sub counties were selected per county to form the clusters where macadamia farming occurs. A simple random sampling was then applied within the sub county to randomly pick the respondents for administration of the questionnaires.

3.2.2 Data collection

A survey was conducted using an open-ended questionnaire to achieve the objective of this study. The questionnaire was first tested on a few respondents (Birmingham & Wilkinson, 2003) to check on its viability and reliability threshold. The pre-test involved administration of the questionnaire to 39 (10%) of the total sample size with homogenous characteristics within Murang'a county (Mugenda, 2003). The 39 respondents were not included in the sample size. The information obtained from the pilot helped in checking the consistency and validity of the research tool.

The ODK tool kit allowed for collection of data using android mobile devices and submission of data to an online server.

3.2.3 Data analysis

Data was retrieved from the server, cleaned, and analyzed using SPSS version 25 to obtain means, percentages, chi-square statistics and standard deviations.

3.3 Results

3.3.1 Demographics of interviewed respondents

In total, 49.4 % of the 384 participants who participated in the survey were male (Table 3.2).40.67% of all respondents across the agro ecological zones were above 60 years old, with 24.13% being within the age bracket of 50-60 years and 9.96% being below 35 years of age (Table 3.3).

Table 3.2 The percentage of respondents by gender in the agro-ecological zones

	Gender %	
Zone	Female	Male
UM1	50.7	49.3
UM2	47.3	52.7
UM3	49.3	50.7
UH1	50.0	50.0
LH1	55.9	44.1
Average	50.6	49.4
SD	3.10	
chi-square	0.79	
p-value	0.94	

Table 3.3The percentage of respondents by age in the agro-ecological zones

	Percentage within age bracket in years			
Zone	**>60**	**50-60**	**35-49**	**<35**
UM1	38.73	15.49	31.69	14.08
UM2	46.15	20.88	28.57	4.40
UM3	37.31	26.87	22.39	13.43
UH1	40.00	28.00	20.00	12.00
LH1	41.18	29.41	23.53	5.88
Average	40.67	24.13	25.24	9.96
SD	14.01			
Chi-square	15.25			
P-value	0.23			

Less than 50% of all respondents across the agro ecological zones had attained secondary education and above with only 9.04% having gone beyond secondary education (Table 3.4).

Table 3.4 The percentage of respondents by education level in the agro-ecological zones

	Level of education %		
Zone	**Post-secondary**	**Secondary**	**Primary**
UM1	13.38	36.62	50.00
UM2	9.89	26.37	63.74
UM3	2.99	40.30	56.72
UH1	16.00	40.00	44.00
LH1	2.94	41.18	55.88
Average	9.04	36.89	54.07
SD	20.67		
Chi-square	14.52		
P-value	0.07		

3.3.2 The characteristics of macadamia farms in the agro-ecological zones

On average, UM1 had the highest number of macadamia trees in a farm (Mean 45.60; SD=55.35), followed by UM3 (Mean 39.24; SD 46.23) and the lowest was UH1 (Mean 12.00; SD=16.97). About 75% of trees across the agro ecological zones ranged between 11-30 years of age (Table 3.5).

Table 3.5 Distribution of number of trees and age of macadamia trees across agro ecological zones

	Number of trees			**Average age of trees**				
Zone	Valid N	Means	Sd	<10	11-20	21-30	31-40	>40
UM1	142	45.60	55.35	9.86	28.17	45.07	13.38	3.52
UM2	91	26.40	39.78	13.19	42.86	34.07	7.69	2.20
UM3	67	39.24	46.28	8.96	49.25	28.36	10.45	2.99
UH1	50	12.00	16.97	22.00	30.00	36.00	10.00	2.00
LH1	34	34.24	36.48	8.82	52.94	32.35	5.88	0.00
	Average			12.55	40.64	35.17	9.48	2.14

Murang'a 20 is grown in large numbers across the agro ecological zones. Non-hybrid varieties are concentrated in UM1 and Um2. Kiambu 3 variety is found in relatively moderate proportions in UM1,UM3, UH1 and LH1. Embu variety is found only in UM zonesand in low numbers (Figure3.2).

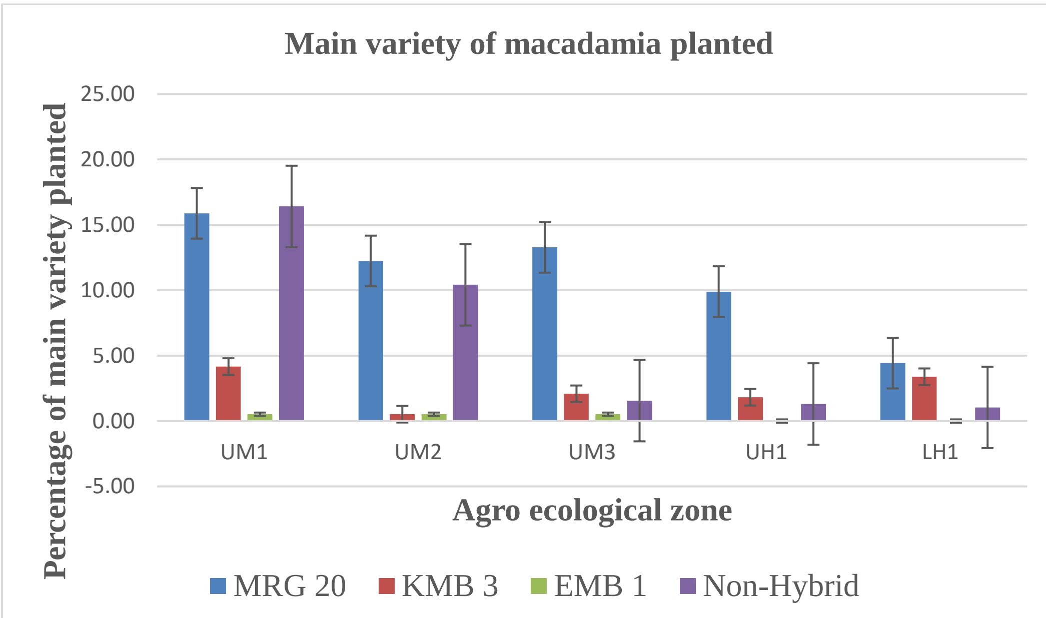

Figure 3.2Main variety of macadamia planted across agro ecological zones in percentage

Macadamia yield record was highest in LH1 at 87.95kg per tree per year, followed by UM1 (77.23Kg), UM3 (70.46), UM2 (60.40) and UH1 (58.30) (Figure 3.3).

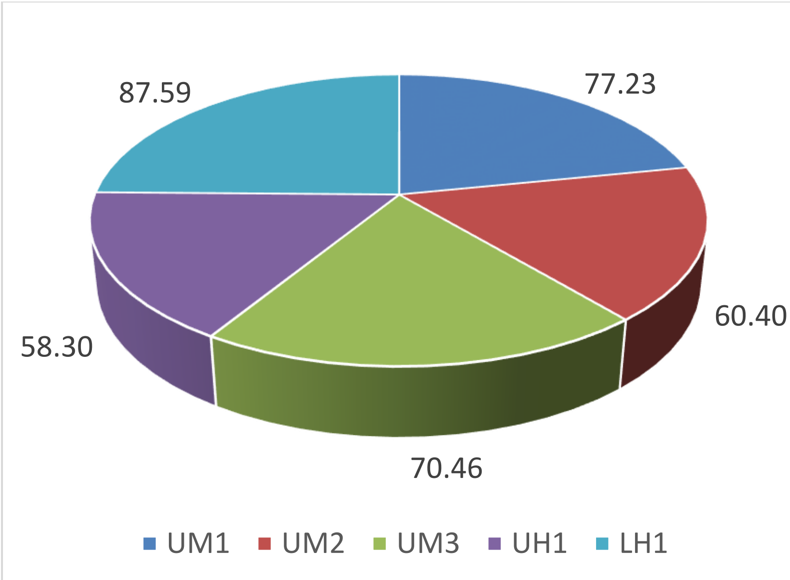

Figure 3.3Mean yield per tree per year (in Kg) across agro ecological zones

3.3.3 Insect pest constraints to macadamia production

Over 97% of the respondents across the agro ecological zones highlighted insect pest and their control as the major constraints towards production of high quality macadamia nuts. This was followed closely by fluctuations in market prices as reported by the respondents (81%) (Table 3.6).

Theft by humans and Climate change effects are some constraints that featured in the respondents' conversation. The two were highly ranked at position 4 and 5, respectively. From figure 3.4, farmers were aware of the pests affecting macadamia and over 80% of the respondents across the agro ecological zones had encountered stink bugs at least once in the production cycle (Table 3.7).

Table 3.6 Percentage respondents on major limiting factors of macadamia production across the agro ecological zones

	Agro ecological zone					
	UM1	**UM2**	**UM3**	**LH1**	**UH1**	**Average**
Type of constraints	%	%	%	%	%	%
Insect pests and their control	97.2	98.9	98.8	96.4	95.9	97.7
Fluctuation on market prices	84.0	85.4	76.2	85.7	73.5	81.5
Diseases and their control	25.5	40.4	41.7	46.4	26.5	35.7
Theft of produce in the farm	25.5	19.1	40.5	33.9	14.3	27.1
Climate change affecting fruiting	10.4	1.1	8.3	48.2	18.4	14.3
Limitation of manure /fertilizer application	3.8	0.0	9.5	0.0	0.0	3.1
Lack of suitable cultivars to various growing zones	0.9	0.0	10.7	0.0	0.0	2.6
High cost of good quality planting materials	0.9	0.0	1.2	0.0	0.0	0.5
Other (specify)	0.0	0.0	1.2	0.0	2.0	0.5
Inadequacy of high quality planting material	0.0	0.0	1.2	0.0	0.0	0.3
Total	100	100	100	100	100	100

Over 80% of respondents know about pests infesting macadamia through the growing cycle (Figure 3.4).

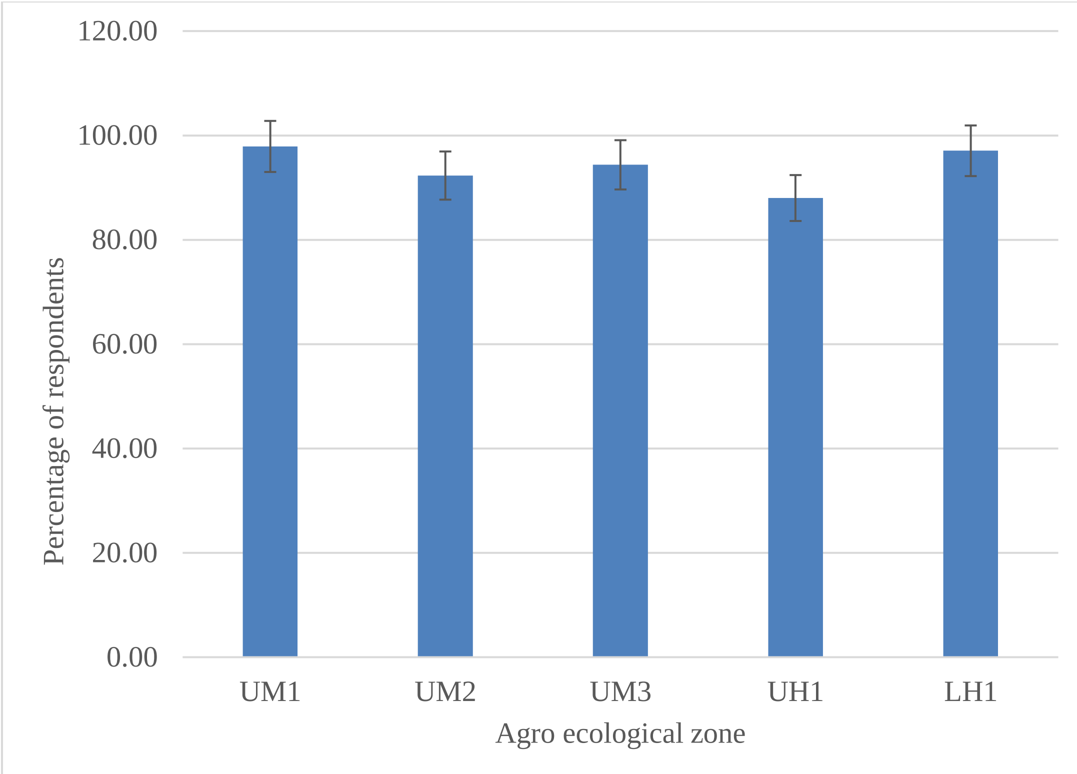

Figure 3.4 Farmer awareness across agro ecological zones on pests affecting macadamia

Table 3.7 Incidence of stink bugs on macadamia production cycle as a percentage across agro ecological zones according to the respondents

Agro ecological zone					
	UM1	**UM2**	**UM3**	**UH1**	**LH1**
Yes	85.8	98.9	91.7	89.3	81.6
No	6.7	1.1	8.3	5.4	6.1
n/a	7.5	0.0	0.0	5.3	12.3
Total	100.0	100.0	100.0	100.0	100.0

Up to 75% of respondents across the agro ecological zones considered stink bugs as the most problematic pest of macadamia with UM3 citing the highest percentage at 88.8% and UH1 having 67.0%. Apart from the stink bugs, Nut borers were another pest reported as being important by about a fifth of the respondents, followed by mealybugs and thrips reported by a few respondents less than 5%. (Table 3.8). Stink bugs are difficult to control as highlighted by 81.1% of respondents across the agro ecological zones. An additional 53.8% of all the respondents cited high level of nut damage and in particular, over 80% farmers in the UM2 zone reported that the stink bug destroyed the nuts. Only 0.5% held onto high cost of pesticides as the main reason why stink bugs are considered most problematic pest of macadamia. (Table 3.9).

Table 3.8Most problematic pest of macadamia as a percentage across agricultural ecological zones

	Agro-ecological zones					
	UM1	**UM2**	**UM3**	**UH1**	**LH1**	**Average**
Stink bugs	72.6	82.1	88.8	67.0	69.4	75.98
Nut borers	17.9	12.5	4.5	32.9	20.2	17.6
Mealy bugs	6.0	0.0	5.6	1.9	8.2	4.34
Thrips	3.6	0.0	1.1	5.7	0.0	2.08

Table 3.9Why stink bugs were considered the most problematic pest of macadamia as a percentage across agro-ecological zones according to the respondents

	Agro-ecological zone					
	UM1	**UM2**	**UM3**	**UH1**	**LH1**	**Average**
Difficult to control	79.6	80.9	72.6	88.7	83.7	81.1
Causes high levels of nut damage	48.0	82.0	38.1	56.6	44.2	53.8
High costs of pesticides	0.0	0.0	2.4	0.0	0.0	0.5

An average of 63% of respondents across the agro ecological zones had applied measures to try and manage stink bugs in macadamia. Over 80% of respondents in UM1 and UM3 had attempted management of stinkbugs with UM2 and UH1 having over 50% using various strategies to manage the pest. Only LH1 had the least respondents (<50%) attempting to manage stinkbugs using various strategies (Figure 3.5).

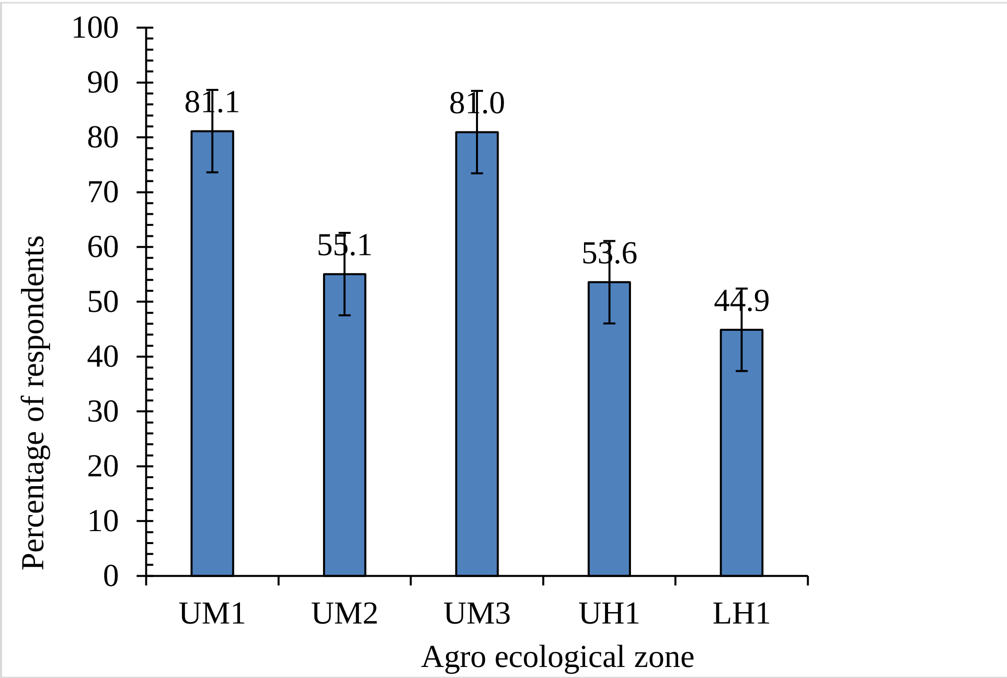

Figure 3.5 Percentage of farmers across agro ecological zones applying various strategies towards management of stink bugs in macadamia

According to the respondents, cultural approach only showed effectiveness at the initial stages of use. There is general use of cultural approach towards management of stinkbugs in macadamia through pruning, weed clearing and burning trash across the agro ecological zones studied. Pesticide use was not popular in the management of this pest due to associated costs. LH1 recorded the highest percentage of agrochemical use at 18.2%, UM1 (10.5%), UM2 (10.2%), UM3 (5.9%) and UH1 (0.0%) (Figure3.6).

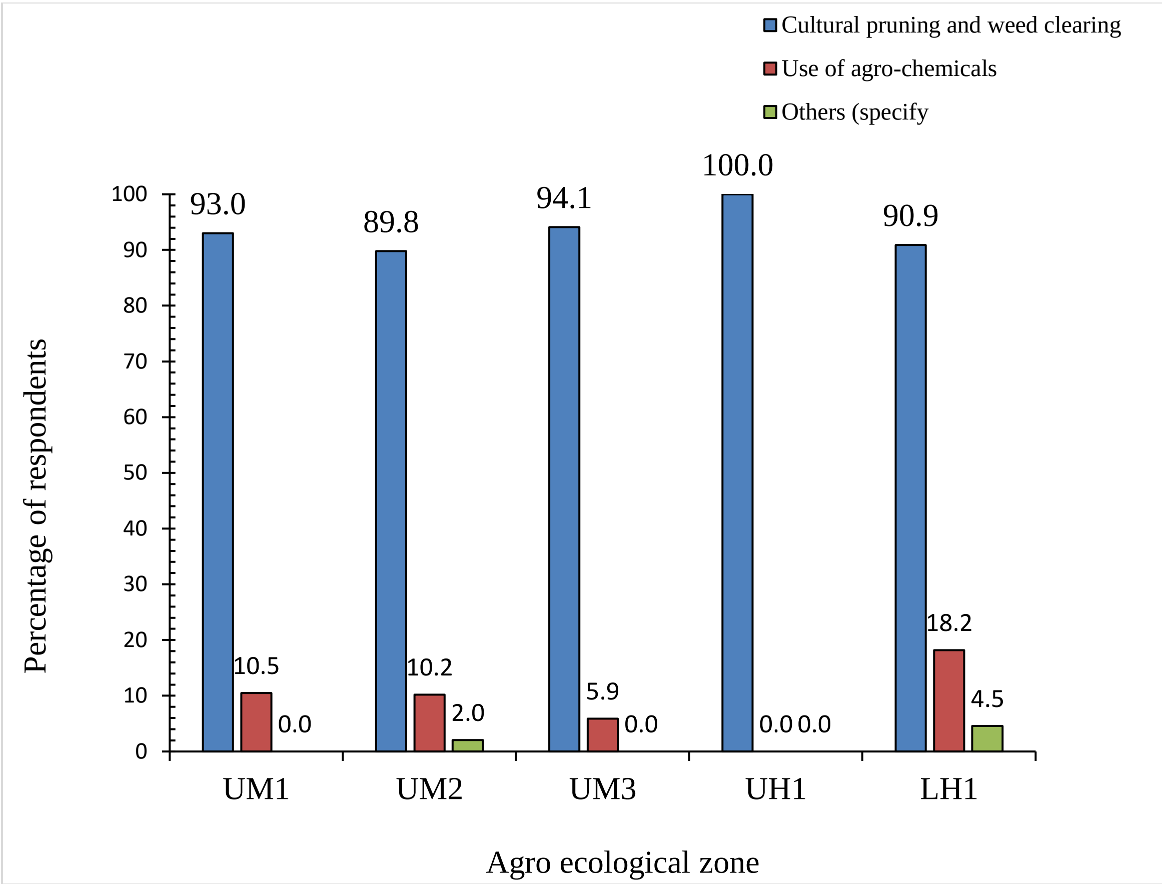

Figure 3.6Strategies for management of stink bugs in macadamia as a percentage by respondents across agro ecological zones

3.3.4 The willingness of farmers in macadamia growing areas to use parasitoid for the control of stink bugs.

Based on the short comings associated with existing cultural approach and use of agro chemicals towards management of stink bugs in macadamia across agro ecological zones in Kenya, farmers in the main macadamia growing zones are willing to use egg parasitoid for management of the pest. This is irrespective of the level of education (Table 3.10) and gender (Table 3.11) according to the survey. Over 84% of the total number of respondents across gender were willing to adopt the bio-control agent for management of macadamia stinkbug.

When asked about their preferred mode of acquisition of the bio-control agent, most farmers cited the Augmentative method as summarized in Figure 3.7.

Table 3.10 Chi-square values on relationship between level of education and willingness to adopt parasitoid.

	Value	df	p-value	
Pearson Chi-Square	1.749	4	0.782	ns
N of Valid Cases	384			

Table 3.11 Willingness to adopt egg parasitoid for management of macadamia stink bug across gender

		Female %	**Male %**	**Average %**
Willingness to adopt egg parasitoid	n/a	11.5	16.7	14.1
	No	1.6	1.0	1.3
	Yes	87.0	82.3	84.6

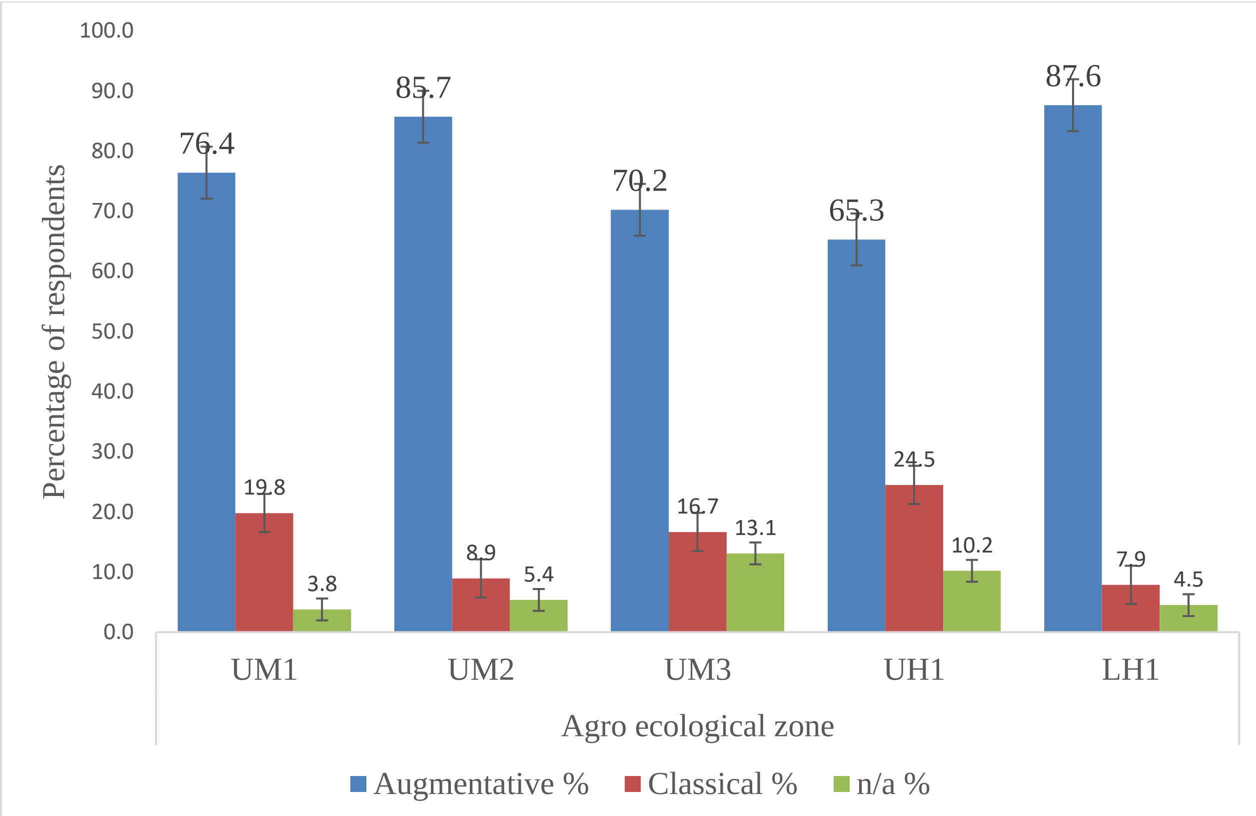

Figure 3.7 Preferred way for respondents in the agricultural ecological zones to acquire egg parasitoid

3.4 Discussion

The results showed 49.4% of the survey respondents were male, suggesting a 50: 50 involvement of men and women in macadamia production. These results align with previous studies conducted by (Manfre *et al.*, 2013) which also highlighted the active involvement of females in farming.

High numbers of macadamia farmers (over 64%) are within the productive age bracket of ≥ 50 years endowed with vast skills and experience in macadamia production. Youth participation is minimal in macadamia production at 9.96%.Significant initial capital requirements as well as an extended waiting period before farmers can start to harvest macadamia nuts are the reasons why there has been a low level of participation by young people in Macadamia farming.. There may be low motivation of youths to venture into macadamia farming due to limitation of capital for input acquisition, long wait before they can realize the fruit of the labour and fluctuation of market prices. Similar findings were documented by the World Bank's report, highlighting that a significant number of youths are not actively engaged in agricultural activities due to challenges related to limited access to financial services and difficulties in accessing stable markets(Brooks *et al.,* 2013). According to the study, 54% of macadamia growers achieved at least primary level of education. In the opinion of (Muema *et al.,* 2018), 87% of Kenyans have been to school and this population fits in this bracket. Education is one of the ways of enhancing agricultural productivity and breaking poverty chains as is believed by the society. Lower Highland 1 zone had the highest mean yield of macadamia. This is probably due to the fact that over 75% of the orchards in LH1 are under the high yielding Kiambu 3 and Murang'a 20 varieties of macadamia, coupled with good agronomic practices and high rainfall. This agrees with previous studies by (Trueman, 2013) who reported that flowering and fruit setting in macadamia is highly dependent on the cultivars planted and the agronomic maintenance on the orchards.

As corroborated by earlier studies done by (Mbaka *et al.,* 2009) that showed burning of organic waste (smoking) at the base of macadamia trees repelled the stink bugs, most macadamia growers are currently using cultural methods to manage stink bugs. Although a lot of previous research has been done globally on growers' adoption of IPM (Feder & Savastano, 2006; Peshin *et al.,* 2009), In particular, factors that affect the growers' choice of bio-control techniques have been focused on in only a few studies.(Perkins & Garcia, 1999). Different factors, e.g. age, risk assessment, education, acceptability of new technology, income, impacts on personal life and operation size may influence the adoption of biocontrol methods.(Perkins & Garcia, 1999). Farmers' views, outlooks, and production objectives play a critical role in farm management decision-making (Brodt *et al.,* 2004, 2006). In line with the earlier study carried out in Kenya by Muthoka *et al.,* (2008), the majority of trees perform below the expected yields of 85 kg per tree per year which would have a great influence on the willingness to adopt the use of egg parasitoid in the management of macadamia stinkbugs; based on the economies of scale in the cost of production and anticipated income growth based on nuts quantity and quality at harvest (Cock *et al.,* 2010). The challenge of insect pest damage on nuts is possibly contributing to fluctuations on market prices of nuts and ban on importation since pest damage results in lowered nut quality. Farmer knowledge on pest and willingness to adopt parasitoid was found to be dependent on level of education and gender. Most macadamia farmers across the country are willing to use egg parasitoid for management of stinkbugs irrespective of their level of education and gender.

CHAPTER 4:

OCCURRENCE, ACTIVITY DENSITY OF MACADAMIA STINK BUG (*Bathycoelia distincta* Distant) AND LABORATORY REARING OF ITS EGG PARASITOID (*Trissolcus basalis*)

Abstract

An upsurge of *Bathycoelia distincta* is causing severe damage to macadamia nuts in Kenya. 30 macadamia trees in each of the three agro-ecological zones of UM1, UM2 and UM3 in Kandara were randomly selected for the study. Branches of the macadamia trees were shaken and fallen bugs collected, identified, and recorded on scouting sheets. Aborted nuts were handpicked from base of the trees, dissected, kernels and husks inspected for stink bug probing marks and data tallied. The bottom 3 m of each sampled tree's main stem were examined and number of eggs recorded. Data was analyzed for means and ANOVA using Genstat software vs 15. The populations of stinkbug significantly ($P<0.05$) differed across zones with lower altitude zones UM2 and UM3 recording higher populations of stinkbugs compared to UM1. No differences were observed in pest incidence and egg masses collected between UM2 and UM3.*Trissolcus basalis* parasitization was detected in orchards. The egg parasitoid were reared in the laboratory on *Nezara* eggs which varied in sizes from 44 to 131 (n = 143). Parasitoid discovery efficiency, was not influenced by the size of the egg masses ($F > 2.34$, df = 2, $P > 0.05$) indicating the ability to detect and locate the egg masses. However, with the increasing egg numbers per egg mass, there was a significant decline in parasitism efficiency ($F = 3.23$, df = 2, $P < 0.05$) with 40-70 eggs having 96% parasitism while 100 eggs and above had only 30% parasitism. This relationship was described by the regression equation: $y = 99.88 - 0.34x$, with an R2 value of 0.42 ($P < 0.05$) describing an inverse relationship between parasitism efficiency and size of egg mass exposed. *Trissolcus basalis* females showed a high (90%) efficiency in parasitizing *Nezara* eggs and the females of the parasitoid parasitized 59.7% of exposed egg masses. A strong parasitic affinity between *T. basalis* and *N. viridula* eggs was demonstrated. The presence of *T. basalis* avails a potential biological tool for controlling *Bathycoelia distincta* and there is significant potential for laboratory rearing of *T. basalis*

4.1 Introduction

4.1.1 Macadamia

Increased global demand for macadamia nuts has made the crop to gain popularity worldwide (Yan *et al.,* 2018). According to (Quiroz *et al.*, 2019), it is projected that global macadamia nut-in-shell yields will reach 700,000 tonnes by the year 2025. Worldwide production of macadamia increased to 59,300 tonnes from 28,000 tonnes between the year 2007 and 2018 (Nuts, 2018). In Kenya, macadamia has great prospects asan export crop and foreign exchange source.(Gitonga *et al.,* 2017). After tea, it's regarded as the biggest cash crop in Kenya. (Quiroz *et al.,* 2019). Most Kenyan macadamia farmers are smallholders (Quiroz *et al.,* 2019). In particular, macadamia is grown predominantly in mixed crop with coffee and other agricultural products by more than 200,000 small farmers. (Quiroz *et al.,* 2019). Macadamia, which yields up to 10 000 tons per year, is Kenya's largest nut crop (Waithaka, 2001). However, the macadamia sub sector in Kenya shows a low growth rate compared with competing countries of Africa like South Africa because of various production constraints such as insect pests(Muthoka *et al.,* 2008).

Kenya is among the top global producers of macadamia at 16% of total nut yield worldwide (Hardner *et al.,* 2019). According to (Murioga *et al.,* 2016) Ministry of Agriculture survey, macadamia nut accounts for 47% of total value of nuts produced in Kenya, making it economically important in the nut industry in Kenya. The yield from macadamia nut stood at 113,498 metric tonnes with a cash value of KES. 3.75 billion in the year 2016 (Murioga *et al.,* 2016). There are a lot of challenges in macadamia growing in Kenya like insect pests which affect nuts and lower the post-harvest quality (Gitonga *et al.*, 2009).

4.1.2 *Bathycoelia distincta* damage on macadamia nuts and its biological control

Several constraints including insect pests affect nuts and lower post-harvest nut quality in macadamia(Schoeman, 2020). Significant loss in nut yields and reduction in nut quality in macadamia occurs due to macadamia stink bug (*Bathycoelia distincta*)(Pal *et al.,* 2022). Stink bug causes premature nut fall and development of lesions on mature kernels of macadamia(Bouarakia *et al.,* 2023). The pest's feeding action on nuts results to feeding lesions inside the husk and premature nut fall (Linden, 2019), often leading to undeveloped nuts dropping off. Probing action during feeding by stink bugs leads to puncture wounds on nuts that act as entry points for infectious fungi leading to moldy kernels(Mitchell *et al.,* 2018). In the plantations in South Africa, the monophagous *Bathycoelia distincta* (Hemiptera: Pentatomidae) is a significant macadamia nut pest. (Fourie *et al.,* 2022). Pesticide use results in undesirable outcome to most farmers due to disruption in the natural enemies population complexes(Altieri & Nicholls, 2020). Repeated use of pesticides for control of *B. distincta* has resulted in high resistance levels of the pest(Schoeman, 2017). Several attempts to introduce and establish parasitoids into new infested areas in Australia and Hawaii have been successfully accomplished due to the immigrant nature of stink bugs(Conti *et al.,* 2021).In order to achieve effective reduction in population densities of the target pest, which results in significantly reduced damages resulting from these pests, biocontrol involves use of naturally occurring living organisms(Wang *et al.,* 2019). Management of insect pests can be achieved through use of natural enemies such as wasps (Schoeman, 2009). *Trissolcus basalis* is an egg parasitoid of both *Bathycoelia distincta* and *Nezara viridula* that is black in colour and relatively small in size with the females having club-shaped antennae. It is one of the most common egg parasitoids in North America(Moraglio *et al.,* 2021).

The populations of egg parasitoids in normal environs are fairly low. It is therefore necessary to increase their ability to invade and successfully suppress pest populations by mass rearing and releasing natural enemies into agricultural holdings (Harris *et al.,* 1991). Chemical signals are known to influence the feeding behaviour of female parasitoids, impacting on the success of any biological control program. *Trissolcus* recognises stinkbug's eggs by presence of secretions on the egg chorion, a mechanism that enhances the kairomonal relationship between the two organisms for effective biocontrol(Colazza & Wajnberg, 1998). Previous laboratory studies on *T. basalis* revealed that it is highly efficient in host finding. It has been shown to effectively utilize volatile compounds released by the host's oviposition-induced synomones, as well as volatile and contact kairomones emitted by adult bugs. (Cusumano *et al.,* 2016). From the study, presence, infestation density and activity of macadamia stinkbugs across the three coffee growing agro ecological zones in Kandara, Murang'a County was determined. This data is crucial for understanding the pest crop phenology, which is essential in devising effective management strategies to control macadamia stink bugs.

4.2 Materials and methods

4.2.1 Description of Study area

The study on occurrence and activity density of macadamia stink bugs was done within Kandara in Murang'a. The area was originally characterized as main coffee growing region. It lies within 0°53'59.99" N 37°00'0.00" E and characterized by a warm and temperate climate of 18.9°C and 1231mm of rainfall annually. The study was limited to the coffee growing zones of upper midland 1 (UM1- humid, 1570-1810m a.s.l.), upper midland 2 (UM2- sub humid, 1395-1675m a.s.l.) and upper midland 3 (UM3- semi humid, zone 1330-1560m a.s.l.) (Mugo *et al.*, 2012).The study was conducted in UM1, UM2 and UM3 of Kandara, Murang'a County.

4.2.2 Assessing occurrence and stink bug activity in macadamia orchards

In order to determine occurrence and activity density of macadamia stink bugs, macadamia farm orchards with mature unsprayed macadamia trees that had produced fruits at least once were selected for the study. A single macadamia tree was considered as a study plot. In the study, 30 trees of macadamia were sampled per agro-ecological zone. Each study plot was established through random-systematic sampling in farmer orchards within the specific agro ecological zone. There was bi-weekly monitoring of the study sites (Linda, 2021; Wallner *et al.,* 2014) for occurrence and activity of macadamia stink bug in terms of egg populations, pest presence and nut damage in each of the agro ecological zones for comparative analysis.

Thirty trees were randomly selected in each of the three agricultural ecological zones in the study. Ten recently dropped nuts were picked underneath the each of the study plot during the study to determine pest activity on nuts. The nuts underwent dissection, where the soft developing shell was carefully removed, allowing for inspection of the interior of the husks to identify any stylet puncture marks. The assessment was done bi-weekly between June to November 2019. The dissections commenced when the nuts reached the size of peas and continued until the harvesting stage, at which point the interior of the husks had turned brown, making any puncture marks indistinguishable.Evaluation of the feeding activity and density of the pest on macadamia nutswas achieved through bi-weekly collection and monitoring of live samples of nuts for symptoms of infestation by the pest such as presence of feeding probes on nuts, premature nut fall, unsightly staining of kernels and moldy patches on kernels due to presence of secondary infection by pathogens (Schoeman, 2013). The observations were recorded in a tallying sheet. Nuts damaged by stinkbugs were handpicked from the base of the trees covered by the tree canopy at a specific GPS location and the data obtained from the nut on stinkbug damage was tallied on a pre-existing data collection sheet. Nut damage was classified into five different damage classes ranging from uninfested to completely destroyed.

In order to quantify pest density and estimate pest incidence, one at a time, four branches were shaken at the bottom 3 meters of randomly selected trees. Both adult and nymphal stages of the pest that fell were collected, counted and tabulated in pre-existing data sheets. In order to determine presence of stinkbug egg packets and number of eggs, the lowest 3 m on main trunk in every 90 sampled trees were examined. The data is reflective of level of stinkbug activity causing nut damage at a given GPS location of a tree/plot. This data was periodically captured and tallied in data entry sheets.

Laboratory rearing of the egg parasitoid *Trissolcus basalis* Wollanston

Laboratory rearing of the egg parasitoid was carried out at the KALRO, National Sericulture Research Centre (NSRC) in Murang'a which lies within coordinates $0^0$59' S, 37^0 04' E and 1548 metres above sea level. It was carried out from July 2021 to December 2021.

Cultures of *N. viridula* obtained from macadamia orchards at the KALRO Practical Training Centre (P.T.C) were used for laboratory rearing of the egg parasitoid, *Trissolcus basalis* (Askar & El-hussieni, 2006). In transparent plastic cages of measurement 300 × 195 × 125 mm with meshed holes measuring 5 cm in diameter, different stages of the pest were separately raised. The cages were kept at 14 light hours, 70 ± 10 % relative humidity and 25 ± 2 °C. A mixture of seed and vegetative components from their main source of nutrition was introduced for each phase of the pest to satisfy its dietary requirements. This was Soy beans and Ground nuts which were changed every 3 days. Ground nuts and soy bean at 50:50 ratio were used to feed *N. viridula* and were given fresh water put in wet cotton wool balls every week.

Presence of *Trissolcus* in the macadamia orchards at P.T.C was determined by searching for parasitized eggs of *Bathycoelia distincta*. In colour, fresh eggs are light green, turning cream to pink as they develop (Bruwer, 1992), while it turns black when parasitized and the larval stages of the parasitoid develop in the egg.

4.2.3 Biology of *Trissolcus basalis* Wollanston(Askar & El-hussieni, 2006)

Trissolcus basalis Wollaston is a scelionid egg parasitoid and a natural enemy of *Nezara viridula* (Colazza & Bin, 1995b; Colazza & Wajnberg, 1998; Kamal, 1937; Odermatt *et al.*, 2000). Previous works of general biological data of the pests exist globally (Askar & El-hussieni, 2006; Awadalla, 1996; Orr, 1988). Detailed description concerning the form and duration of the parasitoid egg as well as the three instar larvae, prepupal, and pupal stages has also been documented in recent literature (Askar & El-hussieni, 2006).

Trissolcus basalis eggs were inserted singly by the female ovipositor through the operculum to the inside yolk of *Nezara* eggs. The larval stage of *T. basalis* showed 3 larval instars (L1, L2 and L3) of the metapneustic apodous type. Due to the type of feeding on the food (yolk), the larvae had no mouth parts but only a mouth opening. The larval stage is characterized by increase in length involving transitions from L1 at 100µ, L2 at 350µ, L3at 600µ which takes 5-6 days. The larva turns itself with head upwards inside the egg shell at the end of L3. Thereafter, the hind gut opens to spill its meconium content signifying transition of L3 into the prepupal stage. Prepupal stage is oval to barrel in shape, cream in color and lasts for an average of 1 day. The free type pupa is white to white-creamy in color and lasts 1-2 days, after which it darkens black gradually within the host egg giving the characteristic black color of *N. viridula* parasitized eggs. Pupal period ranges from 5-6 then transition to adult. The adult cuts an emergence hole by chewing the operculum.

From July to December 2021, in the macadamia orchards at P.T.C, naturally oviposited *N. viridula* eggs were collected biweekly. The experimental sites being monitored were free from any form of insecticide treatment during the entire study period. Sampling of eggs involved visual examinations of leaf surfaces of macadamia plants for approximately 3 hours. All collected masses of eggs were marked and incubated for hatching into nymphal stages or parasitoid. The eggs that remained intact after being kept in the laboratory were carefully examined by dissection to determine their contents. For each collected egg mass, the following data were recorded: number of eggs present, hatched nymph numbers from the eggs, and numbers of eggs parasitized. *Trissolcus basalis* was collected from macadamia orchards at the P.T.C in Murang'a using *N. viridula* laboratory-laid eggs placed on macadamia trees for exposure. Parasitoids were incubated in 150 mm long glass tubing that had a diameter of 30mm at 15 light hours, 80 ± 5% relative humidity and 25 ± 1°C.Selected eggs were ≤ 72 hours old. A total of 143 freshly laid egg masses of Nezara during the rearing process in the laboratory were used in the study. Of the 143 egg masses, 18 had 40-70 eggs per mass, 84 had 71-100 eggs per mass and 41 had 101-135 eggs per mass . The grouping of egg masses into clusters was done in order to determine whether egg mass size would have an influence on the parasitism efficiency. After every three days, all egg masses were collected ≤ 72 hours were mounted, and taken for exposure to parasitism by *T. basalis* for 48 hours in the macadamia orchards at the P.T.C. The 48 hour exposure was to allow for complete parasitism. After this period, eggs were retrieved from the orchards, and incubated in a petri dish lined with damp filter paper at 65±10% relative humidity and 25±2°C until emergence. Emerged parasitoid wasps were kept in a petri dish for mass rearing on honey syrup soaked in cotton wool balls.

Adult wasps cultures were provided with a specific diet consisting of a solution containing water, 10% sugar, 10% benzoic acid, yeast and, 10% honey, as described by Safavi (1986). Prior to the start of the experiments, mated 2 to 5 day old female parasitoids were placed in 25 mm long glass vials with a diameter of 10 mm. A small drop of Safavi (1986) diet was placed in the vials before incubation. Freshly laid *N. viridula* eggs, ranging from 0 to 24 hours old, were exposed to the female parasitoids in the laboratory for a period of 48 hours to maximize parasitism. Parasitoids were then removed and eggs incubated. Emerged parasitoids were kept together to facilitate mating. Tally sheets of *Nezara* eggs laid, *Nezara* eggs exposed to parasitism, *Nezara* eggs parasitized and incubated and parasitoids emerged were recorded to track on parasitism and possibility for laboratory rearing of the egg parasitoid.

4.2.4 Data analysis

There was comparative analysis of data on the occurrence and activity of macadamia stink bugs through the three agricultural ecological zones in Kandara. Data was analyzed for means and ANOVA using Genstat. Turkey-Kramer's HSD comparison test was used to separate means that were significantly different $P \leq 0.05$. Data on parasitism and adult egg parasitoid emergence was subjected to analysis of variance. If the analysis of variance was significant at 95% confidence level, Turkey´s test was applied.

4.3 Results

Pest incidence was observed across transect in Kandara. Slightly higher populations of macadamia stinkbugs were recorded in UM2 and UM3 which were significantly ($P<0.05$) higher than the population recorded in UM1. The populations recorded in UM2 and UM3, were not different (Table 4.1).

Table 4.1The mean of macadamia stink bugs withinKandara's agricultural ecological zones

Agro-ecological zone	Means of pest
UM 1	11.50a
UM 2	12.17b
UM 3	12.40b
CV%	21.12
L.S.D	0.56
S.E.M	0.20

In the same column, (Mean± S.E.M) not having a common letter are significantly different ($P<0.05$).

Zone UM3 had the highest number of nuts damaged but the damage level compared to that recorded on UM2 and UM1 nuts (Table 4.2).

Table 4. 2The mean of damaged nuts within Kandara's agricultural ecological zones.

Agro-ecological zone	Mean of damaged nuts
UM 1	12.77a
UM 2	12.83a
UM 3	13.83a
CV%	17.30
L.S.D	2.75
S.E.M	0.98

In the same column, (Mean± S.E.M) not having a common letter are significantly different ($P<0.05$).

Upon dissection, most nuts were found to be mouldy with stained unsightly pits on the kernel surface which is characteristic of the feeding action of *B. distincta* (Bruwer *et al.*, 2021) see Figure 4.1.

Figure 4.1Mouldy kernels of macadamia due to *B. distinct* feeding action

There was no significant difference (P < 0.05) in the number of eggs collected across the three macadamia growing zones that were studied (Table 4.3).

Table 4. 3 The mean of eggs in Kandara's agricultural ecological zones

Agro-ecological zone	Mean of eggs
UM 1	15.58a
UM 2	40.33a
UM 3	40.83a
CV%	19.10
L.S.D	25.64
S.E.M	6.53

In the same column, (Mean± S.E.M) not having a common letter are significantly different (P<0.05).

For laboratory rearing of parasitoid, 143 *N. viridula* eggs masses were collected and used. These egg masses exhibited significant variation in size, ranging from 44 to 131 eggs per mass, with an average of 92.4 ± 21.62 eggs per mass (n = 143). At least one egg was found to have been parasitized by *T. basalis* in 129 eggs of these masses. It was found that the average efficiency of parasitism is 90.21 % (Table 4.4).

Eggs were divided into three groups on the basis of cluster size, with a view to examining whether egg masses have an effect on parasite efficiency: 18 egg masses had 40-70 eggs, 84 egg masses had 71-100 eggs and41 egg masses had 101-135 eggs (Table 4.5). It was observed that the discovery efficiency by the parasitoid was not influenced by the size of the egg masses ($F > 2.34$, $DF = 2$, $P > 0.05$) indicating the ability to detect and locate the egg masses. However, with the increasing egg numbers per egg mass, there was a marked decline in parasitism efficiency ($F = 3.23$, do = 2, $P < 0.05$). This relationship was described by the regression equation: $y = 99.88 - 0.34x$, with an R2 value of 0.42 ($P < 0.05$). Overall, there is an inverse relationship observed between parasitism efficiency and size of egg mass exposed.

Table 4. 4 Average efficiency of parasitism of *Trissolcus basalis* on exposed *Nezara* eggs

Range	No. of egg masses exposed	No. of egg masses parasitized	Discovery efficiency	Parasitism efficiency, Mean ± SD
40-70	18	17	38.61	96.89 ± 3.63a
71-100	84	77	43.23	81.63 ± 29.02ab
101-135	41	35	32.96	68.97 ± 30.76c
TOTAL	143	129		90.21%

In the same column, (Mean± S.E.M) not having a common letter are significantly different (P<0.05).

There was 90.21% (n=129) parasitism efficiency realized on the 143 exposed *N. viridula* masses of egg. *Trissolcus* females exhibited full parasitization in 59.7% of exposed egg masses. A further 24.8% of egg masses showed parasitization rate of between 50% and 100% with 15.5% of the egg masses parasitized below 50%. (Table 4.5).

Table 4. 5 *Trissolcus basalis* percent parasitism on *N. viridula* egg masses

Parasitism %	No. of eggs masses parasitized	% egg masses parasitized
100%	77	59.7
51% - 99%	32	24.8
< 50%	20	15.5
TOTAL	129	100.0

4.3 Discussion

This study established incidence of two-spotted stink bug populations and activity across macadamia farms in Kandara. There is high incidence of stink bug eggs, as well as adult pests that cause nut damage and relative yield loss during the production cycle of macadamia trees. Highest level of incidence and activity of the pest was determined in UM3 followed by UM2 and UM1 respectively. This corresponds with other studies (Bouarakia *et al.,* 2023; Muthoka *et al.,* 2008)indicating that stink bug causes 55-70% of nut losses in areas below 1,600m above sea level and that stinkbugs are responsible for major losses in the macadamia industry (Taylor *et al.,* 2018).

Collected macadamia nuts had stained unsightly pits on kernels as a result of the pest extracting fluids from the kernel during its feeding. The puncture wounds that act as entry points for fungi results in the moulds forming on kernels as supported by previous studies (Jones & Caprio, 1994; Wallner *et al.,* 2014). This pest has a very strong potential to result in significant yield losses during future production seasons, according to current populations of adult pests, nymphs and eggs.

Nezara viridula egg masses (129) parasitized out of the 143 egg masses exposed amounted to a parasitism efficiency of 90.21% that is in line with results from the laboratory study conducted by Correa-Ferreira (1994) where *Nezara* eggs exposed to *Trissolcus* showed 99.7% parasitism efficiency. The introduction of new phytophages such as *N. viridula* that have appeared in greenhouses requires the application of biocontrol measures (Canton-Ramos & Callejón-Ferre, 2010). Luckily Laumann *et al.(* 2008) shows that the presence of *T. basalis* confers a potential biological tool for controlling *Bathycoelia distincta*. The egg masses of *N. viridula* showed a large variation in size from 44 to 131 eggs with an average value of 92.4 ± 21.62 eggs per egg mass (n = 143) that is in line with results from a prior study by Colazza and Bin (1995) who reported that the size of the *N. viridula* eggs varied from 44 to 134 eggs and a total of 260 masses of eggs studied showed an average of 91 ± 16.53 eggs per mass.

Trissolcus basalis, similar with other scelionid species, is known to be proovigenic, meaning that it possesses a pre-determined number of eggs upon maturation. The egg potential fecundity of *T. basalis* is estimated to be around 61 eggs (Mattiacci *et al.*, 1991; Orr, 1988). This characteristic helps explain the observed inverse relationship between size of mass of eggs exposed and efficiency to parasitism. *Trissolcus basalis* females exhibited a high level of efficiency in parasitizing *Nezara* eggs. For this study, *Trissolcus* females exhibited full parasitization in 59.7% of exposed egg masses. A further 24.8% of egg masses showed parasitization rate of between 50% and 100% with 15.5% of the egg masses parasitized below 50%. These findings closely align with the results obtained in a similar study conducted by Colazza and Bin (Colazza & Bin, 1995a), where *Trissolcus* females were reported to exhibit full parasitization in 60% of exposed egg masses. A further 25% of egg masses showed parasitization rate of between 50% and 100% with 15% of the egg masses parasitized below 50%. The results indicate strong parasitic affinity between T basalis and *N. viridula* eggs, as previously demonstrated in earlier studies by Dauphin *et al.* (2009). In addition, the feasibility of rearing *T. basalis* in laboratory conditions for future release into commercial greenhouses is shown by our findings. The study supports previous works by Greathead & Greathead (1992), Cook & Baker (1983), DeBach (1964), Greathead (1986) and Laing & Hamai (1976) indicating biocontrol of insect pests on crops as economically feasible, although there are no prior works in Kenya concerning successful biocontrol of *Bathycoelia distincta*.

CHAPTER 5:

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Farmer knowledge on macadamia stinkbug (*Bathycoelia distincta* Distant) and its management in Kenya was documented in this study. This was done through a survey across the five major macadamia growing zones in Kenya: Meru, Embu, Kiambu, Nyeri and Murang'a. The survey generated evidence that stinkbug is present in different agroecological zones and that it causing nut losses in macadamia growing areas. Most macadamia farmers in Kenya use cultural methods such as burning of trash to manage stinkbugs agreeing with prior work by Mbaka *et al.*,(2009) who established that burning of organic waste (smoking) at the base of macadamia trees repelled the stink bugs. However, the practice is not effective. The use of chemicals in managing stinkbugs is uncommon with macadamia growers in Kenya. Hence, the growers were willing to adopt parasitoid use to control stinkbugs in macadamia since there was no effective way of managing the pest.

Looking at occurrence and activity of macadamia stinkbug (*B. distincta*) in Murang'a County, Kenya, biweekly monitoring across the agro ecological zones revealed a great deal of activity of stinkbug in the area. Macadamia stinkbug egg pockets, stinkbug damaged nuts and live samples of stinkbugs were found across UM1, UM2 and UM3 zones studied in Kandara. The need for use of biocontrol is necessitated by the emergence of new phytophage pests (Catalán & Verdú, 2005) appearing in greenhouses (Canton-Ramos & Callejón-Ferre, 2010). Fortunately, Laumann *et al.* (2008) demonstrated the potential for biological control of *Bathycoelia distincta* using *T. basalis*.

As the final part of the study, laboratory rearing of *Trissolcus* for biological control of *Bathycoelia* was done using Nezara eggs. Laboratory set up was preferred since it allowed for modification of the environment during incubation of the parasitized host (*Nezara viridula*) eggs for maximum emergence of parasitoids after incubation. The laboratory experiment realized a parasitism efficiency of 90.21% which corroborates with a parasitism efficiency of 99.7% by Correa-Ferreira, (1994) and 92.6% by Colazza & Bin (1995b). This is the first study to report presence of *T. basalis* in macadamia orchards, the parasitoid can be reared and there is need to optimize its rearing under laboratory conditions in Kenya.

5.2 Conclusions

- Farmer management practices of macadamia insect pests include mainly pruning, weeding and burning trash which is not effective in controlling stinkbug and pesticide use is uncommon.
- Stinkbug occurs *(Bathycoelia distincta)* in macadamia orchards with populations observed to be higher in lower altitude zones (UM2 and UM3) compared to higher altitude zone such as UM1.
- The natural egg parasitoid *(Trissolcus basalis)* of stinkbug occurred in macadamia orchards and demonstrated a high affinity for *Nezara* eggs showing high parasitism efficiency (90%) and parasitization of about 60% under laboratory conditions.

5.3 Recommendations

- Optimize mass rearing of egg parasitoid *(Trissolcus basalis)* in the laboratory for the management of stinkbug in macadamia in Kenya
- Undertake further research on the use of frozen *Nezara viridula* eggs for mass rearing of parasitoid to ensure all year round supply to the farmers.
- Test the efficacy of using *Trissolcus basalis* in the management of stinkbug in the orchards to offer an alternative technology for managing stink bug on macadamia.

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APPENDIX I

Questionnaire

NAME: ALOSA NOREEN AKOTH ODUOR

COURSE: MSc CROP PROTECTION

TITLE OF THE STUDY: **Macadamia stink bug (*Bathycoelia distincta*); occurrence, activity and biological control in Murang'a County, Kenya**

The information given will be treated with utmost confidentiality and will purposely be used for academics only.

General Information

Questionnaire No: …………Date of interview (*dd/mm/yy*)……/…….. /…..……..

Name of the enumerator (*Full Name*)…………………………………………………..…

Name of respondent (*Full Name*)…………………………………………………….……….

Respondent`s mobile number…………….……………………………………………………..

County….…………………….…..…. Sub-County…..……………………………………

Location……..……………..….Sub-Location………………………Village………………...

GPS Coordinates; Longitude: …..……………………..…….. Latitude:

……..…………………….   Altitude: …………………………..

START TIME: …………………………

SECTION A: <u>Demographic features of the FARMER</u>

1. Please provide the following demographic information

Relationship with the head of the household (***see code A)***	**Year** of birth of the respondent ***(indicate below)***	What is the **gender** of the respondent? ***1=male 2=female***	What is the **highest** level of education attained ***(in year)***

<u>Codes A (relationship with household head):</u> 1=head; 2=spouse; 3=own child; 4=step child; 5=parent; 6=brother/sister; 7=nephew/niece; 8=grandchild; 9=worker; 10=other relative (specify)………….:

2. Provide information on macadamia production and marketing features.

Number of trees *(indicate below)*	**Average age***(year)* of the trees in your farm *(see code A)*	Main **varieties** planted. *(see code B)*	**Yield** per tree per year *(in Kg)* *(indicate below)*	Main **Buyers** *(see code C)*	Mode of delivery *(see code D)*	Terms of sales *(see code E)*
[]	**[]**	**[] []** **[] []**	**[]**	**[]**	**[]**	**[] []**

Code A (average age of the trees)	Code B (main varieties planted)	Code C (main buyers)	Code D (mode of delivery)	Code E (term of sale)
1=Below 10 2=11-20 3=21-30 4=31-40 5=40 and above	1=MRG 20 2=KMB 3 3=KRG 15 4=EMB 1 5=Indigenous *(specify…………….)*	1=Brokers 2=Companies 3=Cooperatives 4=Others *(specify)* ……………….	1=Farm gate 2=Buying center 3=Far market 4=Others *(specify)* ……….	1=Cash on delivery 2=Credit 3=Loan 4=Contract selling

SECTION B: Farmer knowledge on macadamia pests and their control

3. Provide information on the type of constraints encountered in macadamia production

Constraint type (***tick*** *the type of macadamia constraint that you have encountered in the recent past.)**yes=1; no=0***	
1. Insect pest and their control [ ]	6. Theft of produce in the farm [ ]
2. diseases and their control [ ]	7. Climate change affecting fruiting [ ]
3. Lack of suitable cultivars adapted to various agro ecological zones [ ]	8. High cost of the available good quality planting materials [ ]
4. Limitation of manure/fertilizer application [ ]	9. Market prices and ban on exportation [ ]
5. Inadequacy of high quality planting material [ ]	10. Others *(specify)*…………………………….

4. Are you aware of any pests affecting macadamia nuts? **[]** (1=yes; 0=no

5. If **YES**, specify which ones **[] [] []**

1=Stink bugs

2=Nut borers

3=Mealy bugs

4=others *(specify)* …………...………………………………

6. Have you ever encountered macadamia stink bugs in your production cycle of macadamia nuts? **[]**

(1=yes; 0=no)

7. Are there any pest management control strategies you applied on the stink bugs? **[]**

(1=yes; 0=no)

8. If **YES**, specify which ones **[] []**

1= Use of agro-chemicals

2= Cultural pruning and weed clearing

3= others *(specify)* …………...………………………………

9. To what extent has the method of pest management you applied effective in reducing the effects of stink bugs on your total nut yield? **[]**

1= highly effective

2= moderately effective

3= Effective at initial use;

4= No effect at all

10. Would you be willing to test and adopt a biocontrol approach to management of the pest in your orchard? **[]**

(1=yes; 0=no)

11. If **YES,** how would you like to acquire the biocontrol agent for your farm? **[]**

1= Augmentative

2= Classical

3= others *(specify)* ……………………………………………

END TIME:

Thank you for the information. Have a blessed moment and God bless you.