ON FARM AND POST-HARVEST MANAGEMENT OF MANGO STONE WEEVIL

(*Sternochetus mangiferae* F.**)**

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DECLARATION

I hereby declare that this work is the result of my research and that this thesis has neither in whole nor part been presented anywhere for a degree. All authors whose work were cited have been duly acknowledged as reference.

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DEDICATION

This is work is dedicated to Jehovah God for keeping me alive. I also dedicate it to my mother Madam Lucy Dennis and my brother Mr Nathan Dennis for their remarkable financial and spiritual support throughout my studies. God bless you.

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ABSTRACT

A questionnaire composed of twenty-three (23) open and closed-ended questions was administered to thirty (30) mango farmers within the eastern mango enclave to investigate the level of mango stone weevil (MSW) infestation within the eastern mango enclave. Data obtained from the questionnaire was analysed using the SPSS version 25.0 and presented as tables in percentages. Chi-square was used to determine the association between selected parameters. The response from farmers revealed that 40.7% of farmers grow only one variety of mango and the common variety is Keitt which is cultivated by 33.7% of the farmers. About eighty-seven percent of the farmers admitted to the presence of the mango stone weevil on their farms. Fifty percent of the farmers were found to be relying on insecticides for controlling the MSW. About seventy-seven percent of the respondents viewed the mango stone weevil as a major pest because it is a pest of phytosanitary importance. The major mango season was considered to have the highest infestation as indicated by 90% of respondents. Responses from farmers revealed that 76.7% spend about GH¢2000:00 – 5000:00 per acre every season in controlling the mango stone weevil. A survey was conducted during the major and minor mango seasons immediately after the questionnaire administration. During the survey, thirty (30) farms were visited. On each farm, fifty (50) matured fruits were randomly picked and dissected to check whether the seeds are infested or free from weevils. The survey brought to light that, the MSW is at its highest level during the major season as compared to the minor season. Infestation levels on the average were 23.6% and 19.13% for the major and minor seasons respectively. To determine the effect of trunk banding using a sticky band, grease and insecticide in the control of MSW, the sticky band proved to be the most efficient method. The sticky band had lower fruit infestation levels (i.e., 11.5% for minor mango season and 10.5% for the major mango season) which were significantly different from the fruit infestation levels of the grease banding for both minor and major seasons. Although an X-ray imaging technique

could not capture the image of mango stone weevil within infested fruits, it was able to capture the image of damaged cotyledon which resulted from feeding by mango stone weevils. The findings of the research showed that the mango stone weevil is persistent in the study area, mango stone weevil infestation levels are high during the major mango season, the sticky band is more effective in controlling the mango stone weevil and lastly soft X-ray technique can be used to detect internal infestation of mango by the stone weevil. These findings would go a long way to address the menace of MSW infestation, the efficient and effective method of controlling mango stone weevil and a non-destructive method of detecting MSW infestations which would improve the fortunes of Ghana in the export of fresh mango fruits.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

List of Appendices

LIST OF ABBREVIATIONS

ACP-EU	Africa, Caribbean and Pacific – European Union
ANOVA	Analysis of Variance
CABI	Centre for Agriculture and Bioscience International
CCALS	Cornell College of Agriculture and Life Science
CORAF	Central African Council for Agricultural Research and Development
CRFG	California Rare Fruit Growers
DAF	Department of Agriculture and Fisheries
EFSA	European Food Safety Authority
EPPO	European and Mediterranean Plant Protection Organisation
EU	European Union
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
GEPA	Ghana Export Promotion Authority
GNA	Ghana News Agency
MOAP	Market Oriented Agriculture Programme
MoFA	Ministry of Food and Agriculture
MSW	Mango Stone Weevil
PVC	Polyvinyl Chloride
RDI	Reference Daily Intake
SPSS	Statistical Package for the Social Science
USAID	United States Agency for International Development
YKMFA	Yilo Krobo Mango Farmers Association

CHAPTER ONE

1.0 INTRODUCTION

Mango (*Mangifera indica* L.), is an important tree crop which is cultivated throughout the tropical and semi-tropical regions of the world. Mango also referred to as the "King of fruits" is a drupe or a stone fruit containing a large seed in the middle. According to Raman (2018), the fruit is a good source of dietary fibre, and vitamins and has antioxidant properties. Sambrani *et al*., (2015), also stated that the mango fruit is very nutritious and rich in carotenes.

The crop is cultivated in about ninety (90) countries worldwide with about 50.65 million metric tonnes produced in 2017 (Pariona, 2018). India accounts for approximately 38.5% as the leading producer of mango, followed by China and Thailand on the world table accounting for 9.5% and 7.5% respectively (FAO, 2019). It is estimated that the continent of Asia produces about 56.5% of the world's mango while Africa supplies only 10%.

Egypt is the largest mango-producing country in Africa followed by Nigeria and Sudan ranked eighth, tenth and twelfth in the world respectively (Pariona, 2018). West Africa produces about one point five (1.5) million metric tonnes of mangoes annually representing about four percent (4%) of the global production (CORAF, 2019).

Commercial cultivation of grafted mango varieties has been increasingly adopted by Ghanaian farmers since the late 1990s, mainly due to programmes on food security sponsored by the United States Agency for International Development (USAID) and efforts of the Ministry of Food and Agriculture (MOFA) (Van Melles and Buschmann, 2013).

Mango cultivation in Ghana occurs in two (2) zones namely, the southern and northern zones. The northern zone is composed of Upper East, Upper West, Northern, Brong Ahafo and Ashanti regions while the Central, Eastern, Greater Accra and Volta forms the southern zone

(Abu *et al*., 2011). This vast land area provides a great window for an increase in mango production.

The fresh fruit export market in Ghana is a profitable business, earning the nation millions of dollars in foreign exchange (Akotsen-Mensah *et al*., 2017; Abdulahi *et al*., 2011). It is projected that Ghana has more than 12,000 ha of land under mango cultivation and most of the fruits produced are exported to Europe and the Middle East. According to the Ghana Export Promotion Authority's report on potential markets of mango (2017), Ghana was the third-largest supplier to the United Kingdom in 2016, after Brazil and Peru. The growing interest in the export of fresh mango has therefore made mango production one of the fast-developing sectors of Ghana's agriculture and it has been the strategy of the government to make mango the leading non-traditional cash crop expected to contribute to the highest foreign exchange for the country thus exceeding cocoa (GEPA, 2009). Abu *et al*., (2011) equally, stated that the crop has great potential to become a major foreign exchange earner. In terms of export earnings, the current yield per acre of cocoa stood over GH¢1000; citrus was GH¢1500 – 2500 but mango ranged between GH¢2500 – 4000 (Zakari, 2012).

The government of Ghana and the private sector have realised this comparative advantage and are doing everything to promote mango production to meet the high export and local market demands for fresh fruits, and processed products including mango jams, dried fruits, flavours and juice. Mango is seen as one of the finest fruits and an important tree crop in tropical and subtropical regions of the world (Krishnan, *et al*., 2009). Van Melle and Buschmann (2013), in their research on the comparative analysis of the mango value chain models in Benin, Burkina Faso and Ghana, stated that Ghana has a comparative advantage over her next-door countries largely because it has double harvesting seasons in the south (i.e., major and minor).

Mango cultivation is one of the paramount farming activities in the Yilo Krobo Municipality of Ghana. Following the economic prospects and potentials presented by the cultivation of the crop, there have been both private and public sector interventions to enable the country to obtain optimum benefits from mango production. In Ghana, the Yilo Krobo Municipality is the only area in the country credited with a bimodal production system (MoFA, 2013) and almost forms the entire coastal savanna zone.

Crop production in the tropics is however stifled by several factors such as high cost of inputs including fertilizers, poor quality of planting materials, insufficient and expensive labour costs for harvesting and other farming practices, post-harvest losses due to poor handling and marketing channels, inadequate processing machinery, pests and diseases infestation, etc. and mango cultivation is not an exception. Okorley *et al*., (2014) also established that pests and diseases, as well as the unstable market price of fresh fruit and inadequate funding were some of the major problems confronting most mango farmers in the Dangme West District of Ghana., Abu *et al*. (2011), in addition, said a substantial waste of fruits during harvesting, especially of exotic mango types, is a key constraint in mango production. With the above-listed constraints, the most devastating is the damages caused by pests and diseases. This is because if insect pests and diseases are not controlled, they can destroy an entire mango plantation, leaving the farmer with no income. (Akotsen-Mensah *et al*., 2017).

Every crop plant has a good number of insect pests attack during its lifecycle and the mango tree is not exempted. Fruit flies, mango mealy bugs, thrips, aphids, scale insects, tree borers, mango stone weevils and mango hoppers are a few examples. However, the key pests of mango include the fruit flies, mango stone weevil, tree borers and mango hopper (Obeng-Ofori, 2007; Pena and Mohyuddin, 2000).

The mango stone weevil also known as the seed weevil is a monophagous insect pest of mango. According to CABI (2015), the complete development of mango stone weevil is only achieved on mangoes. It is a major problem in mango production all over the world. It occurs in India, throughout south-east Asia, parts of Australia, Africa, and the Americas.

Follett (2002) and Verghese *et al*., (2005) stated that, controlling the mango stone weevil is important because it can increase fruit drops during early fruit development and may reduce germination capability of seeds. Peng and Christian (2007) also reported that the control of mango stone weevil is of great importance because adult oviposition activities lead to downgrading of fruit and as a result, the grower's profit decreases.

1.1 Problem Statement

The mango stone weevil (*Sternochetus mangiferae* F.) is a key and an important quarantine pest for commercial mango production. Because of its quarantine status, some large mango importing countries, including the United States, China, Japan, the European Union, and certain countries in the Arabian Gulf, place quarantine restrictions on mangoes imported from affected areas. (Peng and Christain, 2007).

According to CORAF (2019), the economies of mango-producing countries in West Africa (where Ghana is geographically located) and exporters have experienced substantial losses because of interceptions of mango export.

Furthermore, most mango pests and diseases are of worldwide quarantine concern, and their presence in the production chain is enough to cause mangoes to be rejected on the export market (Clarke et. al., 2005). There has been a threat of banning mangoes from Ghana by importing countries such as the United State of America and the European Union since 2012, due to the incidence of pests. When the United States banned the export of fruit from Ghana in 2013, the horticultural industry suffered a loss of over $10 million. (GEPA, 2014).

According to Quartey (2008), Ghana's comparative advantage in the production of fresh mangoes, particularly the grafted variety, has the potential to drastically turn around and transform the economy if more attention is redirected and focused on mass cultivation of the fruit. This enormous potential has yet to be realized and it is largely because of the mango stone weevil's presence in Ghana. There is a low motivation for farmers to control the mango stone weevil, since the fruit's eating quality is unaffected (CABI and EPPO, 2015).

The easy detection of the pest without destroying the fruit is also another headache, since infested fruits cannot be practically distinguished from uninfected fruits unless they are cut open because infested fruits are often not visibly damaged (Woodruff and Fasulo, 2006). There is a risk of the nation being banned because of infestation which cannot be easily detected.

Farmers have been using insecticides to control the mango stone weevil, but the problem persists. This is partially due to the high cost of inputs and the difficulty of obtaining them (Micah and Inkoom, 2016). The insecticides also have the disadvantage of killing beneficial insects which helps in pollinating flowers leading to fruit sets since most of them are broad-spectrum insecticides. Some insecticides are very effective in controlling the mango stone weevils but affect the quality of fruits due to the residual effects. Farmers do not also apply the insecticides at the right time. Time of application is very critical in the control of insect pests. The main approach in using these chemicals is to employ trunk application and foliar spray at the period of oviposition to target diapausing adults (EFSA, 2018).

Good farm sanitation is another efficient method of reducing adult population. During and immediately after harvesting, all fallen fruit and fruits with seed damage must be destroyed (Peng and Christian, 2004). Although this cultural method is effective, it is practically difficult to carry out on large plantations since this practice cannot be mechanised and should be done manually.

The weaver ant (*Oecophylla smaragdina*) is reported to be the mango stone weevil's most efficient biocontrol agent (Peng and Christian, 2005). However, the mass rearing and release of the weaver ant requires much time and resources. The entomopathogenic fungus (specifically *Beauveria bassiana*) is also reported to control the mango stone weevil (Peng and Christian, 2007).

Physical barriers such as the sticky band and grease have also produced good results (Muriuki *et al*., 2011). These are applied at the ends of tree trunks just at the time of flowering to prevent migrating of weevils to branches for egg-laying.

Although researchers have conducted numerous investigations into the control and management of the mango stone weevil (*Sternochetus mangiferae*), the pest persists in the country (EFSA, 2018). Farmers and exporters therefore, have challenges in exporting their mango fruits due to quarantine restriction of which the mango stone weevil infestation is a factor (Zakari, 2012).

1.2 Justification

Crop production in Ghana is faced with numerous problems and mango production is not an exception. Amongst the problems confronting agriculture in Ghana is pest management which has tremendous impact on crop yield due the militating effect of crop pest.

Identification and implementation of measures to eliminate the bottlenecks in mango production would open a new window to foster rapid growth and development of the agricultural sector. The cultivation of mango offers employment to people, generates income for the farmer and has the potential to generate extra foreign exchange for the nation (MoFA, 1998)

To propel agriculture to play its role in economic development especially in developing countries such as Ghana, studies must be carried out to find out some of the major constraints limiting growth in the agricultural sector and how to curtail them.

This research aims at finding the most effective management measures for controlling the mango stone weevil within the eastern mango enclave. The outcome of this work would provide an idea of the infestation levels of the mango stone weevil and the right measures to adopt in the management of the MWS to help bring the MWS attacks to tolerable levels to ensure the availability of high-quality mango fruits for both the local and international market.

1.3 General Objective

The study aims at reducing infestation and phytosanitary risk resulting from mango stone weevil (*Sternochetus mangiferae* F.) infestation.

1.4. Specific Objectives

- To assess the knowledge, attitude and practice of mango farmers towards the mango stone weevil.
- To determine the levels of mango stone weevil infestation and distribution in the eastern mango enclave of Ghana.
- To investigate the effect of insecticide application and trunk banding on infestation of mango stone weevil.
- Assessment of mango stone weevil in harvested fruits using soft X-ray technique.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The mango crop

Mango (*Mangifera indica* L.) is a tree crop thought to have originated in Southeast Asia and over thousand (1000) varieties have been discovered around the world (Rymbai *et al*., 2014). Yadav and Singh (2017), also stated in their work on the origin and distribution of mango that, mango originated from the Southern Asia's foothills of the Himalayas (eastern India, Burma, and the Andaman Islands) surrounding the Bay of Bengal, where it still grows wild in the hills of Assam and surrounding regions, dating back to 4000 BC.

According to Singh *et al*., (2016), an extensive comparison of the anatomy and morphology of several modern-day species of the genus *Mangifera* with fossil samples supported the view that the mango genus originates from North-East India, where it spread into surrounding areas of South-East Asia. Today, the genus *Mangifera* has 72 species, the majority of which may be found in the rain forests of Malaysia and Indonesia.

Mehta (2017) also added that scientific evidence suggests that the mango first appeared 25 to 30 million years ago in North-East India, Myanmar, and Bangladesh, from which it spread south to Southern India. Wild mango species are also found in India, Sri Lanka, Bangladesh, Myanmar, Thailand, Kampuchea, Vietnam, Laos, Southern China, Singapore, Brunei, the Philippines, Papua New Guinea and the Solomon and Caroline Islands (Kole, 2011; Litz, 2009).

Mango seeds were imported into America from the West Indies, India and Cuba during the second half of the 19th century. In the 1830s, cultivars arrived in Florida. Most of the famous mango types grown throughout the world today are derived from the Florida mango (Yadav and Singh, 2017). Presently mango is said to be one of the most adaptable and widely grown fruit crops of tropical and subtropical regions (Vasugi *et al*., 2012; Neguse *et al*., 2019).

2.1.1 Botany

The crop belongs to the family *Anacardiaceae* (the cashew family), order *Sapindales*, class *Magnoliopside* and the division *Tracheophyta* (the vascular plants) (Singh *et al*., 2016). Mango is a delicious stone fruit (drupe) produced by a variety of tropical tree species that belong to the flowering plant genus *Mangifera*, cultivated primarily for its edible fruit.

Mango trees reach a height of 35–40 meters and have a crown radius of about 10 meters. The trees have a lengthy lifespan, with some specimens still bearing fruit after 300 years (CRFG, 2015). It has a taproot which could descend to a depth of about 6m. The leaves are evergreen, alternating and simple. Young leaves are orange-pink, but as they grow, they turn a dark, glossy red and finally dark green.

Flowers are generated toward the end of panicles of about 1040cm long; each flower is small and white with five petals of about 5–10mm long, with a mild and sweet fragrance (Morton, 1987). There are over five hundred (500) known varieties of mangoes, many of which ripen in summer, while some produce a double harvest (Toptropicals, 2014). The fruit takes about four to five months from blossoming to ripening.

The size, shape, colour, sweetness, and eating quality of ripened mango fruits varies depending on the cultivar. Fruits might be yellow, orange, red, or green, depending on the cultivar. The fruit has a single flat, oblong pit on the surface that might be fibrous or hairy and does not easily detach from the pulp. The fruits can be round, oval, or kidney-shaped, with lengths varying from 5–25 cm and weights ranging from 140 grams to 2 kilograms per fruit. When fully ripe, the skin is leather-like, waxy, silky, and aromatic, ranging in colour from green to yellow, yellow-orange, yellow-red, or flushed with various shades of red, purple, pink, or yellow. (Morton, 1987).

Morton (1987) further stated that, mangoes have a particular aromatic and sweet scent. A thin coating of 1–2 mm thick covers a solitary seed 4–7 cm long inside the pit. Mango has a tough seed that does not like to be frozen or dried (Marcos-Filho, 2014). Mango trees are easy to establish from seed, with good germination success when received from mature mangoes.

2.2 Mango varieties

Rymbai *et al*. (2014), in their research stated that, there are over thousand varieties of mangoes identified around the world. Seedling populations and grafted variations are both available. In certain cases, the same mango variety is given several names depending on where it is grown. (Ravishanker and Misra, 2010). Although there are hundreds of mango varieties being cultivated around the world, the varieties of mango currently grown in Ghana include Keitt, Kent, Haden, Palmer, Eldon, Tommy Atkins, Zill, Amelie (Amini), Irwin, Julie (Saint Julian), Jaffna, Njala 5, Springfels (Springfield) and Sunset (Abu *et.al*., 2011).

Akotsen-Mensah *et al*., (2017), in their work on pest management knowledge and practices of mango farmers in southeastern Ghana, said the mango types that are commonly produced in the study area covering Yilo Krobo (Somanya), Manya Krobo (Kpong), and Shai Osudoku (Ayikuma) included Keitt, Kent, Palmer, and Haden.

Agyapong (2013) stated that, the common varieties of mango were Keitt, Kent, Palmer, Erwing (Irwin) and Haden. Frimpong (2013), also articulated that, mango varieties cultivated in Ghana are Keitt, Kent, Francine, Tommy Atkins, Palmer, Haden and Irvin (Irwin).

Okorley *et al.* (2012), reported that about 68.9% of farmers grow two or more varieties with Kent, Keitt and Palmer as the most popular varieties in descending order. Zakari (2012), in his work titled “National Mango Survey”, stated that, Ghana grows a variety of mangoes, however Keitt is the most common (approximately 80%), Kent (10%) and other fourteen varieties (Palmer, Tommy Atkins, Zill, etc.) recording very little quantities. Akurugu (2011), on the contrary stated that, the most popular variety is Kent (32.89%), Amelie (29.53%), Keitt (28.19%) and others sharing a smaller percentage of (9.39%). Fordjour (2014) also stated that, Ghanaian farmers grow Keitt 48%, Kent 25.6%, Palmer 10.4%, Haden 6.4% and the others totalling about 9.4%.

This puts Keitt, Kent, Palmer, Irwin (Irvin or Erwing), Haden and Tommy Atkins as the common varieties. Because of their low fibre content and high demand in international markets, Kent and Keitt mangoes have received a lot of attention among the Ghanaian mango varieties. (Amos, 2014).

2.2.1 Haden

The Haden mango variety is a mid-season crop that originated from Florida, United States. The fruit is ovate-shaped with a rounded apex (Fruitrop.com, 2019). The skin is golden-yellow and crimson red blush when matured and can weigh about 350-650g. It has medium to low fibre with a rich and sweet, slightly turpentine flavour near the skin. It is monoembryonic (DAF, 2014).

Figure 2.1: Fruit of the Haden variety of mango.
Source: https://en.wikipedia.org/wiki/File:Haden_mango.jpg

2.2.2 Keitt

Keitt is a mango cultivar that blooms late in the season known to be a progeny of Brooks and originates from South Florida. The fruit is relatively large, with some reaching over 500g in weight. They have a rounded apex and no beak. The skin is usually green with a little red blush. It is fibreless, acidic and sweet, and a monoembryonic seed characterize the meat. It is one of the highly prized late-season types due to its high disease resistance (Campbell, 1992).

Figure 2.2: Fruit of the Keitt variety of mango.
Source: https://en.wikipedia.org/wiki/File:Mango_KEITT_Asit.jpg

2.2.3 Kent

Kent originates from Florida and is believed to be an offspring between Brooks and Haden Campbell, 1992). The fruit is oval, measures 570–740g, and has a sweet, rich flavour. As it matures, it normally turns greenish-yellow colour with a red flush. The seed is monoembryonic, and if left on the tree for too long, it will sprout in the fruit.

Figure 2.3: Fruit of the Kent variety of mango.
Source: https://en.wikipedia.org/wiki/File:Mango_Kent_Asit_fs8.jpg

2.2.4 Palmer

The palmer variety of mango which is believed to be a progeny of Haden and originates from Florida. The fruit is huge, with some weighing over 600 grams. When ripe, the fruit is yellow with a crimson blush; nevertheless, the fruit becomes purple long before it fully matures. The flesh is orange-yellow in colour and has a moderate, aromatic flavour. It has a monoembryonic seed and is low in fibre. It is a late-season cultivar. It is a late-season cultivar (Campbell, 1992).

Figure 2.4: Fruit of the Palmer variety of mango.
Source: https://en.wikipedia.org/wiki/File:Mango_Palmer_Asit_fs8.jpg

2.2.5 Tommy Atkins

The Tommy Atkins variety of mango is a seedling of Haden. fruits are a medium to large sized mango variety with an oval or oblong shape, averagely weighing up to 450-710g (CRFG, 2015). The skin has a dark red blush with green and yellow highlights that covers much of the fruit and its thick. This variety is valued for its long shelf life and resistance to bruising and deterioration during handling and shipping.

Figure 2.5: Fruit of the Tommy Atkins variety of mango.
Source: https://en.wikipedia.org/wiki/File:Mango_TommyAtkins03_Asit.jpg

2.3 Mango production in the world

Mango is cultivated on approximately 3.7 million hectares worldwide and places second out of the tropical fruit crops (Jahurul *et al.*, 2015). Despite being classified as a tropical crop, mangos are increasingly grown in subtropical climates in eighty-nine nations of the world. The major mango growing countries are India, Pakistan, Bangladesh, Myanmar, Sri Lanka, Florida and Hawaii of USA, Australia, Brazil, Thailand, the Philippines, Malaysia, Vietnam, Indonesia, Fiji Islands, Egypt, Israel, South Africa, Sudan, Somalia, Kenya, Uganda, Tanzania, Niger, Nigeria, D. R. Congo, West Indies Islands, Cambodia, etc. (Yadav and Singh, 2017).

According to the FAO (2019), estimated that, the global production volume of mango was about 48.36 million metric tonnes in 2017. Asian countries accounted for about 74.69%, Africa 14.9% and the rest of the world produced about 10.41%. Below is a table showing the world's top ten mango producers with their respective output for the year 2017.

Table 2.1. Top ten mango producing countries in the world for year 2017.

Rank	Country	Production (Tonnes)	Percentage (%)
1	India	19,686,900	51.51
2	China	4,870,100	12.74
3	Thailand	3,838,600	10.04
4	Indonesia	2,239,300	5.86
5	Mexico	1,581,700	4.14
6	Pakistan	1,525,200	3.99
7	Egypt	1,397,000	3.65
8	Bangladesh	1,155,600	3.02
9	Kenya	1,024,500	2.68
10	Brazil	904,100	2.37
TOTAL		**38,223,000**	**100**

Source: FAO (2019). Major tropical fruits - Statistical compendium 2017.

2.3.1 Mango production and distribution in Ghana

According to Yadav and Singh (2017), Portuguese traders brought mango to West Africa in the 17th century. Abu *et al*., (2011), also argued that Ghanaian farmers have been cultivating mangoes since the 1920's. In Ghana, mango is produced in large quantities in Somanya in the Yilo Krobo District of Eastern Region. Because there is a guaranteed dual harvest in a year, both during the major and minor season.

In 2016, Ghana was said to have exported about 476,200 metric tonnes of mangoes (GEPA, 2017), which was about 16.78% higher than mango exports made in the year 2015. The main destination of mango produced in Ghana is the European market with the United Kingdom importing about 57.2% of Ghana's export according to GEPA (2017). Ghana can compete in the European markets with the Latin American suppliers since there is a guaranteed dual harvest in a year (Frimpong, 2013). The country's location geographically, gives her a greater advantage as its closer to Europe and the Middle East. However, exports to the Middle East countries such as Lebanon is dominated by Egypt (GEPA, 2017).

Grumiller *et al*. (2018), stated that, Ghana is battling to improve fresh produce exports but is specialized in the processed mangoes (mainly fresh sliced and dried fruits). Mango production is currently around 110,000 tonnes, accounting for 0.3 percent of agricultural GDP. With over 30% post-harvest losses (MOAP, 2016), the volumes accessible for processing are around 30,000 tonnes, whereas 40,000 tonnes are typically eaten locally as fresh fruits. In West Africa, Ghana is second to Burkina Faso, producing about 800-1,000 tonnes of dried mango for exports, whiles the latter exports about 2,000 tonnes per year Grumiller *et al*. (2018).

The Ghana News Agency (GNA, 2017) stated that, about 2,218 metric tonnes of fresh cut and dried mangoes were exported in 2015 to countries in Europe, South Africa, Israel, USA, China, Russia and Niger. The institution also revealed that, about seventy percent (70%) of all mangoes produced in the country is traded on the local market as fresh or processed, while 432 metric tonnes were imported to feed some local processing industries mainly in the off season, as well as 479 metric tonnes of mango juice were also imported.

Abu *et al*. (2011), stated that, mango producing areas in Ghana has been put into two zones, the Southern comprising parts of Central, Eastern, Greater Accra, and Volta Regions (now Oti and Volta regions) and the Northern zone made up of Ashanti, Brong Ahafo (now Bono East, Ahafo and Bono regions), Upper East, Northern (now Northeast, Northern and Savannah) and Upper West Regions. The Western Region (now Western and Western North Region) was the only region where mangoes are not commercially cultivated. The southern zone enjoys two seasons mainly because of the bimodal rainfall pattern whiles the Northern zone has one mango season presumably due to the unimodal raining season in the guinea savannah zone.

Ghana, according to agronomists, has a superior comparative advantage in Africa in terms of rainfall, soil, and proximity, and might become a major producer in a few years if the country invests in the sector (Quartey, 2008).

2.4 Economic importance of mango

Mango has numerous uses and due to that it has been given different names such as “Golden Tree”, “Next Cash Crop”, “Gold Mine”, “Ghana’s Future”, etc., (Avah, 2008). The mango fruit is used at all the stages of its development be it mature or not. Chutney, pickles, and juice are all made using the raw fruit. Aside being used as a desert, the ripe fruit is also used in preparing products such as squash, syrups, nectars, jam and jellies. The kernel also has 8-9 percent high-quality fat that can be utilized to make soap as well as a substitute for cocoa butter in confectionary (Agricoop.gov).

According to Timesofindia.com (2017), quercetin, fisetin, isoquercitrin, astragalin, gallic acid, and methyl gallate are antioxidants found in mangoes. Breast cancer, colon cancer, prostate cancer, and leukaemia are all prevented by above mentioned antioxidants found in mango. Mangoes are also abundant in vitamin C, fibre, and pectin, making them an excellent fruit for lowering cholesterol.

Mangoes are known to cleanse the skin from deep within the body when consumed. Mango leaves can equally be boiled or soaked overnight to treat diabetic patients. In addition, since mango has a low glycemic index, it will not raise blood sugar levels if consumed in moderation (Raman, 2018).

Mangoes are high in tartaric and malic acids, as well as traces of citric acid, which assist the body maintain its alkali reserve. The fruit is high in fibre which aids in normal digestion, preventing many stomach-related ailments, and burning unneeded calories from the body, assisting in weight loss. (Timesofindia, 2017).

The mango, often known as the 'king of fruits' and the 'love fruit,' has aphrodisiac properties that boost libido and stamina. The mango tree is regarded as a symbol of love, and people believe that it could grant desires. (Yadav and Singh, 2017).

The abundance of vitamin A in mangoes, makes t is an excellent fruit for improving vision. Mangoes also contain vitamins C and A, as well as a variety of carotenoids, all of which are vital and advantageous to maintaining a robust and healthy immune system (Raman, 2018). Individuals with difficulties in concentration and low memory, could gorge on mangoes. The high iron content in mango is a natural remedy for anaemic people (Timesofindia.com, 2017). Mangoes are not only delicious, but they also have a high nutritional value. According to Raman (2018), one cup (165g) of sliced mango provides the following nutrients as shown in the table 2.2. on page 22.

The mango tree aside providing us numerous nutritional benefits, is a major foreign exchange earner for the nation. According to SelinaWamucii.com, before 2019, a kilogram of mango was sold for US$6.34 in 2017, US$6.59 in 2018 and increased to US$7.26 in 2019. The total values in export for mangoes in Ghana were US$2,223,000, US$59,326,000, US$68,149,000 and US$68,322,000 for the years 2016, 2017, 2018 and 2019 respectively (Selinawamucii.com).

Table 2.2: Nutrient component of 165g of sliced mangoes

Nutrient	Component in grams (g)	Component in percentage (%)
Calories	99	
Proteins	1.4	
Carbohydrate	24.7	
Fat	0.6	
Dietary fibre	2.6	
Vitamin C		67% of reference daily intake (RDI)
Copper		20 RDI
Folate		18 RDI
Vitamin B_6		11.6 RDI
Vitamin A		10 RDI
Vitamin E		9.7 RDI
Vitamin B_5		6.5 RDI
Vitamin K		6 RDI
Niacin		7 RDI
Potassium		6 RDI
Riboflavin		5 RDI
Manganese		4.5 RDI
Thiamine		4 RDI
Magnesium		4 RDI

Source: https://www.healthline.com/nutrition/mango#nutrition

2.5. Constrains to mango production

The cultivation and management of mango just as any other crop is bedevilled with several constrains or challenges. According to Micah and Inkoom (2016), production constraints are factors that limit farmer's ability to achieve their production objective as best as possible Shinde and Sawant (2006), stated in their work that, the major constraints in mango production at Maharashtra in India were unavailability of inputs, quality of mango grafts, lack of knowledge regarding improved technology, poor rates offered by middlemen and lack of knowledge in exporting of fruits.

Micah and Inkoom (2016), in a research survey also stated that, the constraints faced by mango farmers in the Yilo Krobo Municipality included accessibility and high cost of inputs, access to credits and unavailability of skilled labour. Access to transportation systems, fluctuating market price for mango fruits, and access to export market were also captured as challenges. They further indicated that, land tenure systems, and access to government support are some of the factors limiting the production potentials of farmers. Pest and disease control, effective pruning, harvesting, and fruit drops were cited as some of the production activity related constraints limiting mango productivity in the Municipality.

According to Van Melle & Buschmann (2013), the major constraints facing mango farmers included quality issues, poor negotiation power, high transaction cost and lack of irrigation infrastructures. Okorley *et al*, (2014) added that, most mango producers in Ghana's Dangme West District faced a variety of challenges, including fluctuating market prices for fresh fruit, pests and diseases, and a lack of cash. In 2015, Abdul-Razak *et al*, also conducted a research in the Savelugu/Nanton Municipality in the Northern Region of Ghana and stated that, disease and pest attacks, low yields, bushfire outbreaks, lack of cash credit, inadequate inputs, lack of irrigation, no flexible contract terms and delayed payment were the significant obstacles facing mango farmers.

In addition, Abu *et al*, (2011) wrote that, the substantial waste of fruits during harvesting, particularly of exotic mango types, is a key restriction in mango production. Akurugu (2011), stated that, a substantial portion of mangoes harvested are wasted annually due to improper harvesting and post-harvest practices, diseases and lack of facility and technology to extend the storage life.

Agyapong (2013), disclosed that, harvesting labour is insufficient and untrained, heavy occurrence of diseases and pest, lack of cold storage facilities, mechanical accidents because of improper handling, a weak road network, insufficient transportation, and poor packing and fewer number of processing plants as the major problems faced by handlers of mango fruits. Micah and Inkoom (2016), also added that, productivity of farmers depends on several factors, such as quality of previous crop, weather and soil conditions, altitude, control of pest and diseases, fertilizer application and cultivar.

The common factor in most of the research findings relating to challenges or production constrains were pest and diseases, inadequate credit facilities, lack of technology to extend shelf-life and lack of irrigation. For the mango sector to explore its full potential as the nation's next "cash crop", Ghana's future or "gold mine", these constraints which serves as hindrances must be curtailed.

2.5.1 Pest and diseases

According to Ravishankar and Misra (2010), over 492 insect species attack mangoes around the world. Out of this number, 298 species of insects and mites both significant and minor, have been identified: fruit feeder (87), foliage feeder (127) and feeds on inflorescence (26), buds (33) and branches and trunk (25). In badly infested orchards, they inflict a 20 to 100 percent loss. Although mango is plagued by several insect pests, a few are particularly damaging to the industry and are responsible for significant losses in Ghanaian mango production.

Fruit flies, mango stone weevils, tree borers, and mango hoppers are the most common pests on mango trees. (Pena and Mohiuddin, 1997). Reddy *et al*. (2018), also stated that, over 400 insects and mites, are noted as pest of mangoes but, only a few are of economic importance. Out of the few insects of economic importance, fruit flies and the stone weevils are of quarantine importance and restrict international trade of mangoes (Reddy *et al.*, 2018).

Currently, the world's focus is on producing high-quality fruit for both domestic and international markets therefore, Insects that contaminate fruits by eating, scratching, or ovipositing in the pulp or seed can result in appreciable losses. (Aluja, 1994; Obeng-Ofori, 2007).

At every stage of its existence, mangoes suffer from a variety of diseases. Some of these diseases are economically significant because they cause significant losses in mango output. Reddy *et al*., (2018), further stated that, the major mango diseases of economic importance include powdery mildew, anthracnose, gummosis, dieback, sooty mould, stem end rot, scab and damping off.

Hoque (1985), also stated that, there are many diseases of mango caused by fungi, bacteria viruses, phanerogamic parasites and nutritional deficiencies, however, number and severity of diseases vary as to cultivars. The major diseases are mango malformation, anthracnose, bacterial leaf spot, scab, fruit rot, sooty-mould black mildew, collar rot, brown felt, thread blight, pink disease, shoestring root, leaf spots, blight, powdery mildew, and red rust. Stem end rot, black mould rot, soft rots, alternaria rot, dry rot, black spot, brown spot, phomispsis rot, bacterial soft rot and bacterial rot were also listed by Hoque (1985), as major diseases.

2.6 The mango stone weevil

2.6.1 Biology and ecology of the mango stone weevil

Adult mango stone weevils during March and April, eat mango leaves and delicate shoots. (Subramanyam, 1926; CABI and EPPO, 2015). They are nocturnal, readily fly, generally feed from late afternoon until dusk, mate and oviposit. Adults experience a diapause after emergence, which varies in length depending on the geographic range. Adults emerging in June in southern India and Hawaii, for example, enter a diapause from July until late February the following year (Shukla and Tandon, 1985; CABI and EPPO, 2015).

The mango stone weevils can withstand long and unfavourable conditions. During the non-fruiting period, weevils hibernate in crevices near mango trees or under loose bark on trunks and branch terminals. Only a few adults experience two seasons, with a diapause interval in between (Peng and Christian, 2004; CABI and EPPO, 2015).

Shukla and Tandon (1985), revealed that, females oviposit 3-4 days after mating. This occurs around mid-March and in the first week of April, it reaches its height. Peng and Christian (2004), also stated that, oviposition occurs around mid-August to early October in Australia and oviposition period varies from 3 weeks to 6 weeks. Females constantly oviposit on a variety of fruit sizes, ranging from marble-sized to full-sized unripe fruits. (Hansen *et al*., 1989; CABI and EPPO, 2015), and deposit eggs primarily on the fruit's sinuses, but sometimes on the stems (Shukla *et al*., 1985; Peng and Christian, 2004).

The female weevil often makes a boat-shaped cavity in the skin (*epicarp*), deposits its' eggs and covers each egg in a brown exudate with two small-angled tails on one end and cuts a crescent-shaped region in the fruit 0.25-0.50 mm. A sap flow is produced by the wound, which solidifies and coats the egg in a protective opaque layer. These oviposition marks are difficult to remove on the fruit packing line, resulting in fruits being devalued (Peng and Christian, 2007). In the laboratory, one female could lay roughly 15 eggs each day, with a maximum of over 300 throughout a three-month period (Balock and Kozuma, 1964; CABI and EPPO, 2015).

Incubation of eggs varies from 5-7 days, depending on the season and temperature (Balock and Kozuma, 1964; CABI and EPPO, 2015). The larva tunnels through the flesh of the apple into the seed after hatching. The tunnel and seed entry are entirely ceiled when the fruit and seed mature, such that in time, unless the fruits are sliced open, it is impossible to tell the difference between infested and non-infested ones.

The entire larval development, is common in the maturing seed, although it can also happen in the flesh on rare occasions (Follett and Gabbard, 2000). There are five or seven larval instars (Hansen *et al*., 1989). Pupation usually last about a week and mainly takes place within the seed. The pupal phase lasts approximately one week (Shukla and Tandon, 1985). However, Hansen *et al*. (1989) and CABI and EPPO (2015) reported that, pupae can be found from the end of May through the middle of July.

Generally, an adult will mature per seed, despite the fact that there have been as many as six reported (Follett, 2002). They carve their way out of the naked seed, usually through a small circular hole in the endocarp's concave edge, 4-8 weeks after the fruit falls and decays. In the Northern Territory of Australia, adults were found to be in seeds for 15-40 days from October to mid-November (Peng and Christian, 2004). Rather than flying, the weevils crawl out of the seeds and look for a hiding place.

There are varied reports as to the time at which the stone weevil population is high. Adults of the next generation appear in Bangalore, South India, in June (Shukla and Tandon, 1985; CABI and EPPO, 2015), but in the Northern Territory of Australia, late November to December is the time when new generations emerge. According to Peng and Christian (2004), it takes between 45-58 days for an egg to develop into adult. Adults typically stay around the parent tree until the following fruiting season (Jarvis, 1946; CAB and EPPO, 2015) and year after year, significant infestations are reported in some areas, whereas low infestations are reported in others nearby (Hansen *et al.*, 1989). This makes infestations localized, such that on one farm, the weevil may be on a section or a portion whiles the remaining section or portion would be free from the weevils.

2.6.2 Taxonomy, description and distribution of the mango stone weevil

The mango stone weevil, otherwise known as seed weevil, mango weevil and mango nut weevil, according to CABI and EPPO (2015), is an invasive and monophagous pest of mango belonging to the Kingdom: *Metazoa*, Phylum: *Arthropoda*, Class: *Insecta*, Order: *Coleoptera*, Family: *Curculionidae*, Genus: *Sternochetus* and Species: *Sternochetus mangiferae*. It was initially described in 1775 in the genus *Curculio*.

Freshly laid, the eggs of the weevil are creamy-white and ovate in shape (Woodruff and Fasulo, 2006). The larvae of the first instar are long, cylindrical, legless, and exceedingly slender. The head is black, while the body is white. The whitish and legless final instar larvae (4th or 5th instar) have a curled, classic curculionid shape. (Shukla and Tandon, 1985, CABI and EPPO, 2015).

Fig. 2.6: Close-up of an egg-laying mark of mango seed weevil.

Fig. 2.7: A larva of a mango stone weevil

Source: https://www.infonet-biovision.org

When the pupae are first produced, they are whitish, but shortly before ecdysis, they turn a very pale red colour. The adults have a compact body with black scales that are grey or yellowish in colour. Adults can fly, although they are not known to be powerful flyers, and they don't venture far from the fruit-bearing tree (Woodruff and Fasulo, 2006). However, there have been reports that they can fly further than previously imagined. They act as though they are dead when touched or disturbed (Infornet.biovision, 2019).

Fig. 2.8: Pupa of a mango seed weevil

Fig. 2.9: Adult mango seed weevil

Source of Fig. 2.8: A picture taken from an orchard at Somanya, Ghana
Source of Fig. 2.9: https://www.infonet-biovision.org

The mango stone weevil is a common pest that can be found all around the world. In Africa, the pest is said to be present in almost all mango growing countries. Countries that have reported the presence of the mango stone weevil are Central African Republic, Gabon, Ghana, Guinea, Kenya, Liberia, Madagascar, Malawi, Mauritius, Mozambique, Nigeria, Réunion, Seychelles, South Africa, Uganda, Zambia and Tanzania (EPPO, 2018). Below is the distribution map showing countries where the mango stone weevil persists in Africa.

Fig.2.10: Geographical Distribution of the Mango stone weevil in Africa (red marked)
Source: CABI Updated on 10 July, 2019

2.6.3 Importance of mango stone weevil on mango production and export in Ghana

One of the most critical quarantine pests for commercial mango production is the mango stone weevil. Because the mango seed weevil is a quarantine pest, certain significant mango-importing countries have implemented quarantine measures. USA, China, Japan and Arabian Gulf countries are examples of countries that have impose quarantine restrictions on the importation of fruits from infested areas (Peng and Christian, 2007). Braimah and van Emden (2010), stated that, the presence of the MSW in the mango production system is sufficient to justify the fruits' rejection in the export market.

The common reasons for rejection of fresh mangoes at the factory level includes mechanical abrasions, spoilage from fruit fly or stone weevil infestation (idhsustainabletrade, 2019). According to GEPA (2019), the European Union (EU) introduced new regulations governing the imports of mangos. These rules were made in response to high number of interceptions of mango imports due to the presence of fruit fly (non-European *Tephritidae*) which is one of the quarantine pests just as the MSW.

ACP-EU, Newsletter (2013), stated that, because of the presence of insects declared as quarantine pests, mangoes supplied to certain European nations were intercepted, confiscated, and destroyed. This resulted in great economic losses to exporters. In 2012, there were twenty-eight (28) interceptions of mangoes from Ghana and the cost per interception was US$39,348:00 (ECOWAS-TEN Newsletter, 2012). EUROPHYT (2017), reported that, one consignment was intercepted in Europe.

According to CABI and EPPO (2015), the greatest damage caused by MSW is to interfere with fruit export, because of quarantine restrictions. Mango stone weevil infestation can also enhance fruit drop throughout fruit development, and seed germination capacity can be reduced.

2.6.4 Management of Mango stone weevil

2.6.4.1 Chemical control

According to CABI and EPPO, (2015) and Villiers (1987), chemical control has had some success, and a variety of insecticides have been suggested. Spraying of the chemicals is targeted to diapausing adults by trunk application or foliar pesticide application during oviposition (EFSA, 2019).

The Department of Agriculture and Fisheries, Queensland Australia (DAF, 2017), stated that, chemical sprays used to control other mango pest can also be used to kill adult mango stone weevils using one or two targeted sprays at the start of egg-laying. Reddy *et al*. (2018), suggested, spraying with deltamethrin when fruit are at marble stage as a management measure and added that, during the off-season, other pesticides used to control other pests should be applied to the trunk to kill adult weevils.

Balock & Kozuma, (1964), added that, a number of pesticides have been tested for controlling adult mango stone weevils, particularly during the mango crop's flowering and fruiting periods. These insecticides, which includes Acephate, thiamethoxan, carbaryl, deltamethrin, dimethoate, endosulfan, ethofenprox, fenthion, fenvalerate, imidacloprid, monocrotophos and prothiofos have been effective in minimizing stone weevil populations and fruit infestations, and are all treated at least twice throughout flowering (Verghese *et al*., 2005b; Akotsen-Mensah *et al*., 2017).

Ravinshankar and Misra (2010), reported that, spraying of carbaryl (0.2%) or fenthion (0.1%) on the stem, branches and fallen leaves kills hibernating adults. They further recommended the spraying of fenthion (0.1%) or deltamethrin (0.0025%) at the time of egg laying when fruits are of marble size. Muriuki (2011), in his work on mango production practices and assessment of chemical and physical barriers in the management of MSW, concluded that, trunk painting using chlorpyrifos ones per month during the fruiting period is most effective treatment for controlling MSW. Aboagye *et al*. (2014), suggested that insecticides such as alpha cypermethrin, acetamiprid and fenithion plus fenvalerate at different doses are effective in controlling MSW.

2.6.4.2 Biological control method

Peng and Christian (2004), in their research on the integrated control of mango seed weevil using weaver ants (*Oecophylla smaragdina*) as a major component in the Northern Territory of Australia reported that, the weaver ant (*Oecophylla smaragdina*) is an effective biocontrol agent of the mango stone weevil adults. In 2007, Peng and Christian again, established that, the weaver ants worked as predators and deterrents, reducing mango stone weevil damage. Mango stone weevil are often caught by the weaver ants on tree trunks. On the contrary, Louw (2008), stated that, the mango stone weevil has no natural enemy.

Shukla *et al*. (1984), reported a baculovirus which attacks the larvae of MSW. Verghese *et al*. (2002), in their field survey, discovered a fungus-infected (*Beauveria bassiana)* dead weevil. In South Africa, strains of *Beauveria bassiana* have been tried on mango seed weevil adults. In a laboratory test, two strains caused 30% mortality within 14 days, none of the strains however, had an effect on the mango seed weevil in an orchard (Joubert and Labuschagne, 1995).

Pena *et al*, (1998) and Peng and Christian (2007), however, revealed that the mango stone weevil's effectiveness as a pest can be linked to the fact that it has no efficient natural enemies as they have not been capable of providing sufficient control.

2.6.4.3 Cultural control method

This is a crucial method that involves manipulating the weevil's habitat in order to reduce its chances of survival and as a result, enhance the mango plant's healthy growth. Although the existing research suggests that farm sanitation as a control measure is ineffectual and labour-intensive, it is valuable for its contribution to an integrated approach to the sustainable management of the mango stone weevil (Pena *et al*., 1998).

Monitoring for egg laying markings on young fruits can help detect stone weevil attacks (Infornet.biovision, 2019). Good sanitation by collection and destruction of all scattered fallen fruits can reduce insect population. Chopping them finely or burying them deeply (50cm deep) is advisable. To prevent adult weevils from hiding, orchards should be cleansed of fallen fruits, seeds, and plant debris (Peng and Christian, 2004). Stopping the movement of fruits from known infested areas to uninfected areas and young orchards free of the seed weevil will greatly reduce the chance of infestation.

Braimah *et al.*, (2009), further stated that, pruning allows adequate light and ventilation into the tree canopy, resulting in a less humid microclimate within the canopy, making weevil aestivation less suited. Refusing to remove tall weeds decreases air movement and makes a plantation's environment damp, favouring the weevil. However, Hansen and Amstrong (1990), reported that no significant reduction in weevil populations was recorded in Hawaii in research which employed the cultural control method.

2.6.4.4 Pest resistant varieties

According to Godse and Bhole (2003), out of ninty two (92) cultivars used in research in India, only ten (10) were noted to be free from *Sternochetus mangiferae* infestation. Grove *et al*. (2007), proposed that, cultivars that produce no seed, form seeds with a hard or insect-toxic shell early, or fruit off season are all potential mechanisms of host plant resistance. Obeng-Ofori (2007), also added that, mango cultivars that are resistant to the mango stone weevil and have favourable features such as seedless, early seed formation and fruiting out of season would be valuable.

Although most cultivars are susceptible to the stone weevil infestation (Hansen *et al*, 1989; Akotsen-Mensah *et al*., 2017), it is said that larval entry into Itamaraca seed is impossible (Balock and Kozuma, 1964; Akotsen-Mensah *et al*., 2017). In Ghana, the only variety that is near seedless, though it does not meet export requirements is Jacqueline. Braimah and Van Emden (2010), stated that, there are no cultivars in Ghana that bear fruit on a regular basis during the off-season.

2.6.4.5 Physical and Mechanical control

These are techniques that physically prevent pests from gaining access to their host. (Mahr, 2007). Mechanical control has relatively little impact on the beneficial natural enemies of pests and other non-target organisms (Mahr, 2007). Elshafie (2019), explained that mechanical and physical controls make the environment unsuitable for pests, by restricting them from obtaining their resources. Important biological aspects of pests, such as feeding, reproduction, dispersal, and survival, are also affected by these approaches.

Sticky band is an example of the barriers that are used in the control of insect pest. Deep Green Permaculture (2019) described the sticky band as an aggressive long-lasting adhesive in the form of a waterproof band covered in horticulture glue wrapped around the tree's trunk to produce a sticky barrier that keeps climbing insects out of the tree canopy where they can feed, mate, and lay eggs. According to Infornet.Biovision (2019), Sticky bands should be put to the upper end of the trunk before it branches to prevent weevils from traveling to the branches to lay eggs. CCALS (2020), added that, the sticky band act as both a monitoring and a management tool. Even though these weevils are not strong fliers, some reports claim that, they can fly, and even with the banding, they might infest the trees (Infornet.Biovision, 2019).

Research conducted on spotted lanternfly by the CCALS (2020), revealed that, sticky band cannot provide a sole source of management because once the sticky band is full, the remaining nymph are far less to become stuck. The researchers further stated that, sticky band are also less effective on fourth instar nymph and adults which are either strong enough to walk across band without getting stuck or avoid them by jumping or flying. Swackhamer (2018), reported that, one disadvantage of utilizing sticky bands is that it can capturing other creatures of which some could be beneficial.

Brigham and Smishek (1991) suggested that a substitute for the adhesive band (tangle trap) may be the automotive lubricating grease. The grease has a low cost, good water resistance, and excellent long-term adhesive capabilities. Horticultural glues should never be applied directly to a tree's bark, as trees with thin bark, particularly young trees, can be sensitive to such application. The tree will be ring-barked and die if the bark is injured all the way around its circumference (Deep Green Permaculture, 2019).

2.6.4.6 Quarantine and phytosanitary measures

Phytosanitary measures are quarantine and biosecurity measures which are used to safeguard the lives of humans, animals, and plants life from risk arising from the introduction, establishment and spread of pest and diseases arising resulting from food and feed additives, poisons and pollutants (Agriculture.gov 2020). According to FAO (2003), a quarantine pest is a pest that has the potential to be economically important to the area threatened by it but is not yet present or is present but not widely disseminated and is under official control.

Braimah and Van Emden (2010), stated that, phytosanitary measures aim at eliminating, regulating pests in exported fruits by sterilizing or killing them to prevent their introduction and establishment in new locations. The mango stone weevil is a major pest with a 1:40 rejection rate in international quarantine (Braimah *et al*, 2009).

CABI and EPPO (2015), reported that, fruits, mango seeds and plants provide a phytosanitary threat and as such mango-growing countries may exclude materials from countries where the pest is present. Fruits imported from countries where *Sternochetus mangiferae* is found may be quarantined.

Mango stone weevils are thought to spread into clean areas by the transit of contaminated fruit for propagation and consumption, according to available evidence. Even in seed weevil-infested locations, young orchards planted from weevil-free nursery stock have been demonstrated to be seed weevil-free for several years after planting. (DAF, 2017).

2.7 Detection of mango stone weevil within the fruit

The mango stone weevil spends a significant period of its life cycle in the mango fruit and has been described by several researchers as an insect pest that solely depends on mangoes for survival. Its attribute of growing mainly inside the fruit usually in the seed, makes it difficult to determine whether a fruit is free from the weevil or not. Farmers in Ghana most often than not turn to cut open sampled fruits to determine whether they are infested or not. According to Sambrani *et al*., (2015), mango varieties that have seed weevil or stone weevil infestation, are not visible externally in Indian mangoes.

Infornet.Biovision (2019), stated that, Fruit infestation at a later stage is difficult to identify because there is no visible evidence of infestation other than an inconspicuous egg laying scar, and subsequent feeding activity in the seed stays unnoticed. It is impossible to tell the difference between infected and uninfected seeds unless they are cut open. A seed splitting equipment is essential for detection because contaminated fruit is normally not visibly harmed (Woodruff and Fasulo, 2006). Thomas *et al*. (1995), also said that mango fruits infected with seed weevil have no evident outward signs of infestation but generate significant concerns.

In research to determine the presence of mango stone weevil in Thailand, Unahawutti *et al*. (2005), resorted to cutting sampled fruits longitudinally open to inspect seeds for presence of the mango weevils. Follet (2002), reported that, as the fruit and seed mature, the weevils' tunnels and stationary spots are completely healed. This makes distinguishing between infested and non-infested fruits impossible unless the fruits are disserted to expose the state of the internal structures. (Follet, 2002).

Peng and Christian, (2007), on the contrary, stated that, the hardened, amber-coloured secretion, which is sometimes sculptured with two angled tails at one end and remains attached to the site of oviposition, distinguishes afflicted fruits from uninfected ones. Maheswari and Purushottham (1999), stated that, the presence of reddish-brown patches and water-soaked areas in the pulp of immature mango fruits is a quick way to diagnose the presence of MSW in fruits.

Sambrani *et al*. (2015), reported that, an effective and accurate solution that can detect spongy tissue and seed weevil infested mangoes was by instrumental means and grading good quality mangoes for consumption and export. Sambrani *et al*. (2015), therefore proposed the use of a totally non-destructive indigenous technology which employs Digital X-ray imaging. The researchers added that, mangoes that have been scanned with a digital X-ray are safe to eat and pose no health risks.

According to Thomas *et al*, (1995), because of feeding by developing larvae, an X-ray radiograph of infested mangoes shows dark regions in the seed corresponding to distinct kernel tissues. Non infested mangoes on the other hand, display a light-grey region that represents a wholesome kernel. A high degree of agreement was detected between X-ray images of fruits exhibiting weevil infestation and physical examination of cut fruits, suggesting the technique's trustworthiness. As a quality control method, X-ray imaging has a lot of potential in the processing sector and the export trade (Thomas *et al*, 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Study Areas

The study was conducted in the eastern mango enclave of Ghana where mango is cultivated on a large scale for commercial purpose. The study was mainly concentrated in the Yilo Krobo Municipality in the South-Eastern part of Ghana. The municipality lies between latitude 60^{o} 00' south and 00^{o} 30' North and between longitude 00^{o} 30' east and 10^{o} 00' west. It covers an area of about 805km^{2} which forms about 4.2% of the total land area of the Eastern region (ERCC, 2016).

The Municipality shares border with Upper Manya Krobo on the north, Lower Manya Krobo to the east, Akwapim North Municipality and Shai-Osudoku District on the south, New Juabeng Municipal and East Akim Municipal on the west and Fanteakwa District on the north-west.

The rainfall pattern of the Municipality is bi-modal and reaches its maximum during the two peak periods of May – June and September – October. The annual rainfall ranges from 750 to 1600mm. Temperature ranges between 24.9^{o}C and 29.9^{o}C (ERCC, 2016).

The Yilo Krobo Municipal District lies within the semi-deciduous rain forest and the coastal savannah zone. Most common trees found in the municipality include oil palm, mango, nim, ceiba and acacia. And these factors underline the selection of the Yilo Krobo Municipal District as suitable place for carrying out this experiment. These attributes according to Aboagye (2009), makes the study area one of the few mango-growing areas assured of double harvest annually, with the major season falling between May-July and the minor harvest between October – November. Although the research was mainly conducted in the Yilo Krobo

Municipal District, the survey to investigate mango stone weevils took the researcher as far as Todekofe (Pricon Farms, N6°12'44.3484" E0°6'42.318") in the Asuogyaman District.

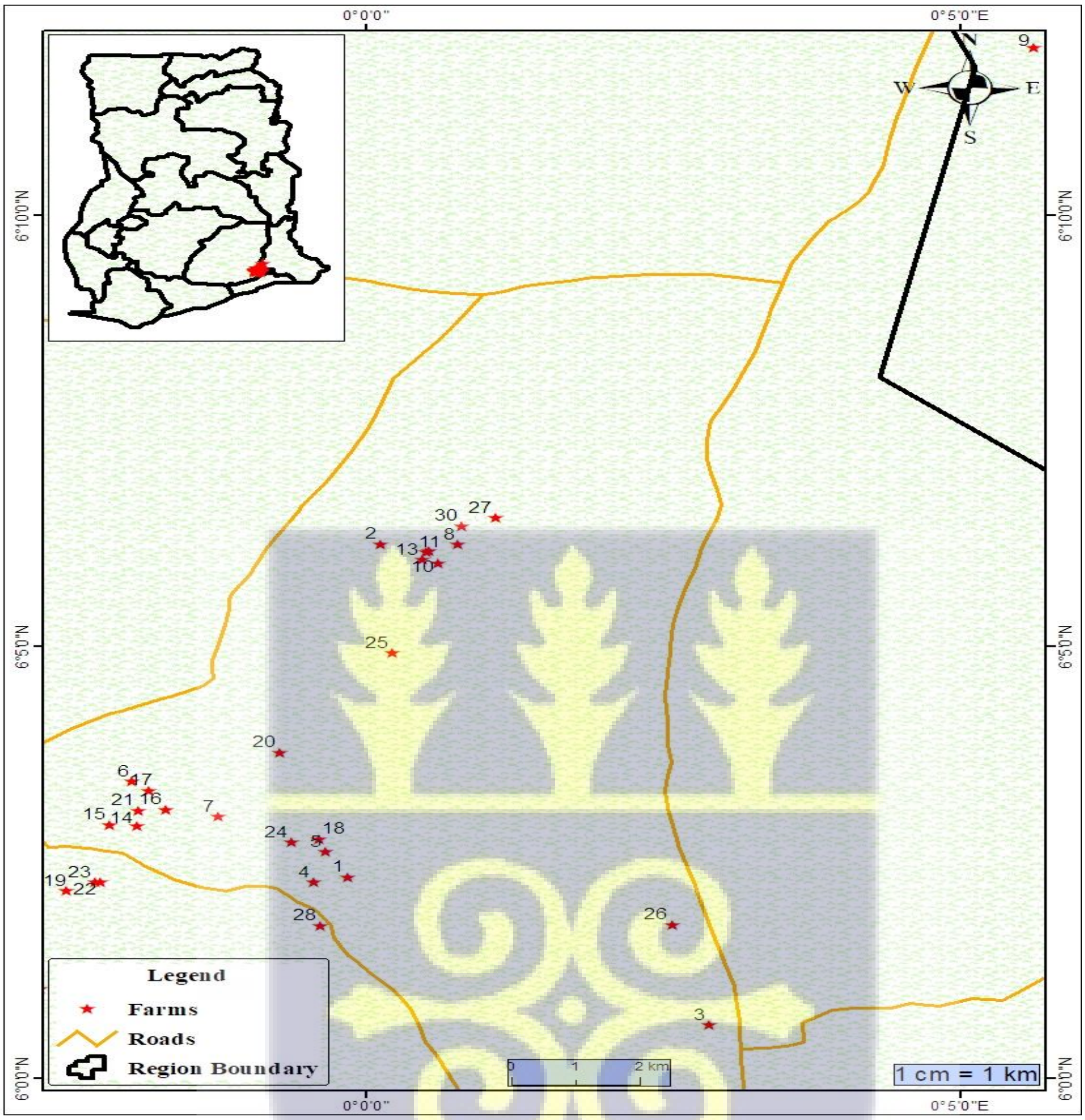

Figure 3.1: Map of the study area.

The research work had four components (i.e., administration of questionnaire to evaluate the knowledge, attitude and practice of farmers in the management of mango stone weevil, a field survey to investigate the level of mango stone weevil infestation, application of different treatments to control the mango stone weevil and a non-destructive detection of mango stone weevils in fruits).

3.2 Knowledge, attitude and practices of mango farmers towards mango stone weevil and its management.

Farmers from the Yilo Krobo Mango Farmers Association (YKMFA) were randomly selected for the study to answer questionnaires with the objective of investigating farmers' knowledge, attitude and practice on the mango stone weevil (MSW) and its level of infestation on the field. The questionnaire was made up of twenty-three (23) questions which boarded on the biodata of respondents, knowledge on MSW and their management, farmer's attitude towards MSW and their management and MSW management practices. The questions were made up of twenty-one (21) select type objectives of which respondents had alternative answers to choose from. Farmers offered their own replies to the remaining questions, which were of the supply type. The questionnaires were translated into Akan (Twi) and Dangme for farmers who were unable to read and write in English.

3.3 Survey of mango stone weevil infestation

To determine the extent of the mango stone weevil infestation, a survey was conducted within the Eastern Mango enclave of Ghana, thirty (30) mango orchards were visited during the minor and major season after interacting with farmers through questionnaire administration.

Farms visited were located at villages near Somanya such as Akode, Alorley, Akuse road, New Somanya, Akode, Agomada, Asesease and Todekofe near Juapong. A greater percentage of the farms were however, located in the Yilo Krobo municipality. Thirty (30) farmers were visited on their farms during the minor season between November, 2019 and January, 2020 when greater percentage of fruits were fully matured. On each selected farm, fifty (50) matured fruits that have dropped were picked at random and disserted using a cutlass to check mango MSW infestation. In instances where the mango stone weevil was present, record was taken on the developmental stage of the insect. Where fruits had exit holes but no insect present, they were considered as infested, and the stage of development recorded as adult.

The visits were repeated during the major season between May – July, 2020. These farmers were selected based on accessibility to their farms. Below is a table of farm sampled for the survey.

Table 3.1: List of communities captured during the survey

Town (community)	Number of farmers
Akorley	6
New Somonya	7
Akuse Road	8
Akode	6
Agomada	1
Asesease	1
Todekofe	1
Total	**30**

3.4 Evaluation of different management methods against the mango stone weevils

Treatments applied to manage (trap or kill) mango stone weevil included Sticky band, Grease, Chlorpyrifos (Dursban 4EC) and a control. The sticky band and chlorpyrifos were purchased from Agrimat at Firestone near Madina - Accra whiles the grease was obtained from Goil filling station, Aburi. The Modest Step Farm (N6^{o}2’19.644” W0^{o}0’9.67788”) at Akorley was selected for the evaluation of the different management methods due to the presence of the weevils on this farm and its accessibility. These treatments were applied on fifteen (15) trees in total (i.e., each treatment had five replications). Trees that received the treatments were sampled in a 'W' patterned transect.

After the application of treatments, ribbons were used to identify the mango trees on which treatments were applied and labelled. The orchard was visited every week until maturity and ten (10) dropped fruits from each selected tree were cut into two halves in a longitudinal cross-section. Any larvae, pupae or adult present were collected and preserved in a micro centrifuge tube containing 70% alcohol.

Data collection lasted eight (8) weeks from 30th November, 2019 to 18th January, 2020 and repeated on 6th May to 24th June, 2020 for the major season. The treatments were reapplied on different trees on the same farm during the major season between May – July 2020.

3.4.1 Sticky Band

The sticky band is made up of a PVC sheet of dimension of 26cm×40cm (0.104m^2) with tanglefoot (a sticky material) applied to both sides. It is sticky on both sides making it very efficient in trapping insect pest that land or crawl on the surface. A pair of scissors was used to cut the sticky band longitudinally to a dimension of 13cm×40cm (0.52m^2). The sticky band was cut to make it sizeable and to reduce wastage since the target insect (i.e., the adult mango stone weevil) is about 8mm long (Infornet.Biovision.com). It was then fastened around the trunks of selected mango trees about 1m above the ground using 1inch long nails and a hammer to cover the entire circumference of the trunk. Five trees received the treatment, and each tree represented a replicate. Monitoring was done for eight weeks and observations such as trapped insects and their status (i.e., harmful or beneficial were recorded).

Figure 3.2: A mango tree with sticky band

3.4.2 Chlorpyrifos (Dursban 4EC)

Dursban 4EC (chlorpyrifos), a broad spectrum organophophate insecticide was diluted with water at a concentration of 1.25ml/l and applied on the trunks of selected trees to form a 10cm band about 1m above the ground. Great caution was taken to cover the entire circumference of the trunk and for the insecticide to enter all cracks and crevices on the trunk.

Figure 3.3: The trunk of a mango tree treated with chlorpyrifos

3.4.3 Grease banding

An automobile lubricating grease which is usually used by mechanics in lubricating machines was used as the third treatment in this research. The grease was applied to the trunks of five (5) selected mango trees around the circumference using a home-made scraper. The treatment was applied such that it was about 0.5mm thick and 5cm wide. Five (5) other mango trees were selected as control plants on which no treatment was applied.

Figure 3.4: The trunk of a mango tree treated with grease

3.5 Non-Destructive Detection of Internal infestation of Mango Stone Weevil

The mango stone weevil spends greater part of its life cycle within the mango fruit, accounting for the difficulty in controlling it. Since it lives within the fruits, local farmers find it difficult to detect it unless they dissect sampled fruits. This further increases the post-harvest losses during the supply chain. As a result, a scanner using a soft X-ray was used to pick images of fruits that were harvested from mango trees.

Ten (10) fruits randomly picked from an infested farm and sent to the laboratory (in brown envelops). At the laboratory, the fruits were washed in salt solution (at a concentration of 500g/l), cleaned and place in new envelops and labelled. The fruits were then sent to the medical laboratory where X-ray images of the fruits were taken. The specification of the X-ray image was voltage = 50kv, current = 10mAs and exposure time = 4s. Just after the X-rays were taken the fruits were immediately dissected to enhance easy comparison of fruits (i.e., whether infested or uninfected) and the content thereof with the image captured.

3.6 Data Analysis

Qualitative and quantitative data collected through questionnaire administration and data collected during survey was analysed with descriptive statistics in frequencies and percentages using the statistical package for social science students (SPSS) statistics for window, version 25.0. Chi-square was used to determine the association between demographics of respondents and farm management practices.

Data collected in evaluating different management methods against the mango stone weevil was subjected to analysis of variance (ANOVA) test and treatment means were separated using LSD at 0.05%. Normality and Homogeneity of data was done using Shapiro-Wilk test for Normality and Bartlett's test for homogeneity of variances respectively, using GenStart software 12th edition. Microsoft excel spreadsheet was used in preparing the bar graphs and pie charts.

CHAPTER FOUR

RESULTS

4.1 Knowledge, attitude and practices of mango farmers towards mango stone weevils.

4.1.1 Demographic characteristics of mango farmers.

Respondents' demographic characteristics were very essential to the research because it could influence how respondent's mange the mango stone weevil, control other insect pest and the acreage they cultivate.

The result of socio-demographic characteristics of mango farmers interviewed on the field showed that, 90% of the respondents were male while the remaining 10% were females.

A greater number of respondents fell outside the youth bracket. Sixty percent of respondents were aged, 36.7% were adults and 3.3% of the respondents were youth.

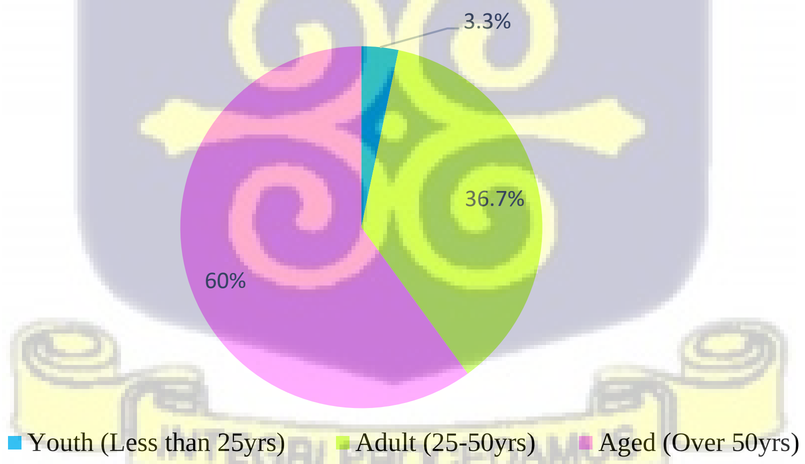

Figure 4.1. Age of respondents

Data obtained from the questionnaire showed that 30% of mango farmers had Basic Education. 40% have experienced secondary education (i.e., vocational school, technical school and secondary school), while the remaining 30% are products of tertiary institutions (i.e. College of Education, Nursing Training, Agricultural Colleges, Poly-techniques and Universities).

The finding from the Chi-Square analysis showed that, the educational background of the respondent is independent of the annual income from fruit sales. Meaning that farmer's level of education had no bearing with annual income from sales as a farmer.

A mean of 2.97 was recorded as the number of years a farmer has been involved in mango farming. Seventy percent of farmers had cultivated mangoes for 11-20years. Thirteen percent of respondents said they have 5-10years experience in mango farming. Ten percent of the farmers interviewed also said they have farmed mango for 21-30years. Three-point three percent of the respondents said they have cultivated mangoes for less than 5years and over 30years in each case.

The evidence obtained suggests that the respondent's farm size has nothing to do with the number of years he or she has been farming. It implied that, the number of years of farming has correlation with farm size.

Table 4.1. Number of years in mango farming

Years	Frequency	Percent
Less than 5yrs	1	3.3
5-10yrs	4	13.3
11-20yrs	21	70.0
21-30yrs	3	10.0
Over 30yrs	1	3.3
Total	**30**	**100.0**

4.1.2 Farm size and mango varieties on the farms captured in the survey

At the end of the survey, it was revealed that, 53.3% of the respondents were medium scale farmers, 33.3% were large scale farmers whiles the remaining 13.3% were small scale farmers.

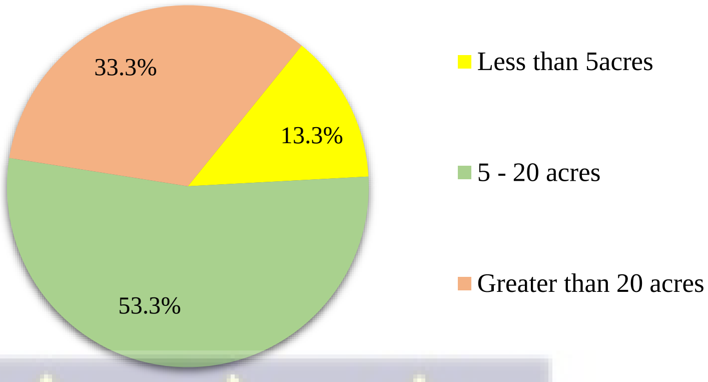

Figure 4.2: Farm size of respondents

The research brought to light that, 36.7% of the farmers interviewed, were in the cultivation of the Keitt variety. Thirty-three-point three percent were growing Keitt and Kent on their farms. Ten percent cultivated Keitt, Kent and Palmer. Six-point seven percent had Keitt, Kent, Haden, and Palmer. Three-point three percent of the farmers were found to be involved in the cultivation of Kent only, Keitt and Haden, Keitt, Kent, Haden and Springfels, and Keitt, Kent, Haden, Sunset, Palmer, Springfels and Amilie in each case.

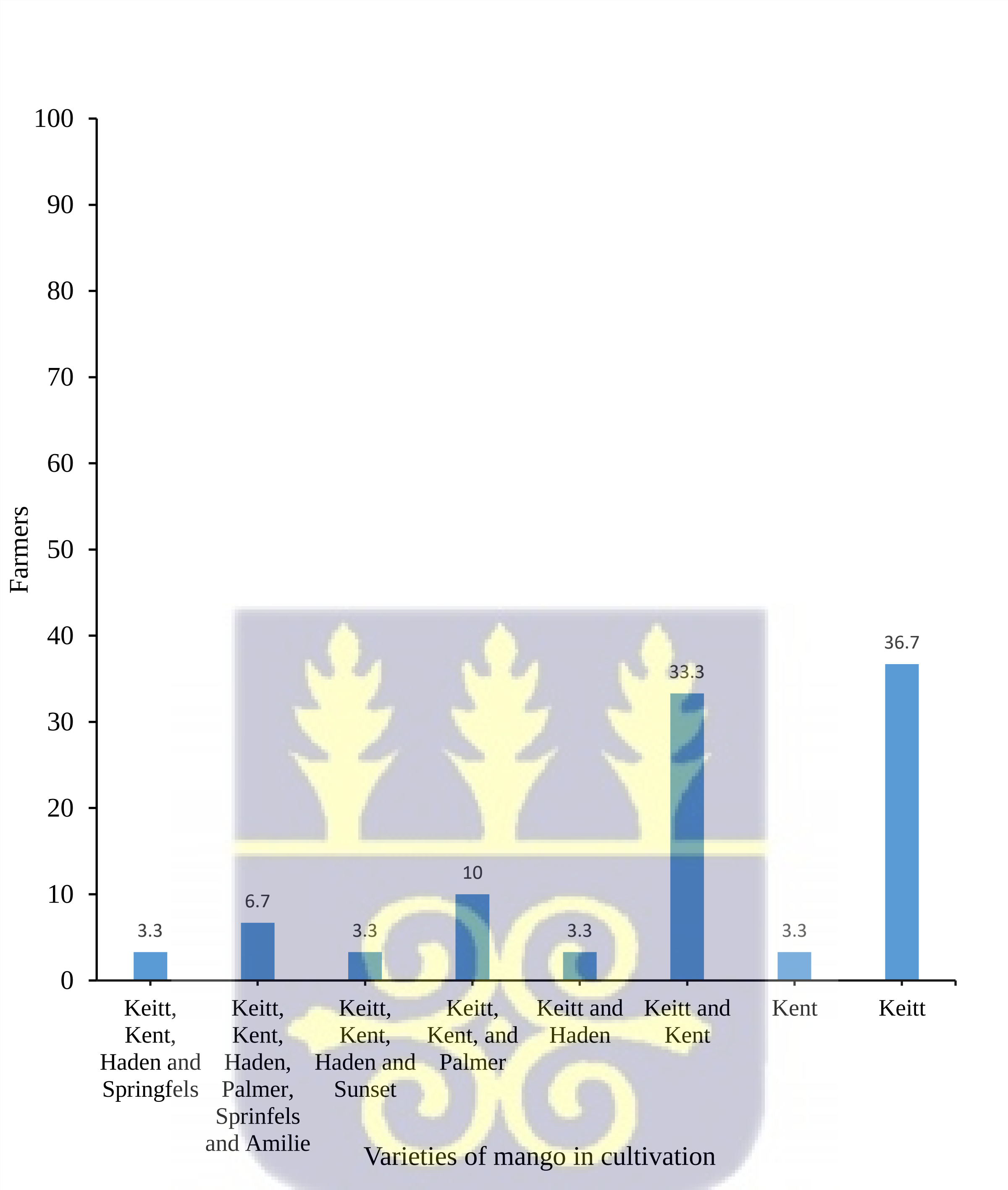

Figure 4.3: Mango varieties cultivated by farmer

Response from farmers showed that, 40% of farmers cultivated two varieties on their farm. Thirty-six-point seven percent of respondents planted only one variety. Thirteen-point three percent were manging more than three mango varieties. The remaining 10% of the respondents were growing three varieties of mango on the same farm.

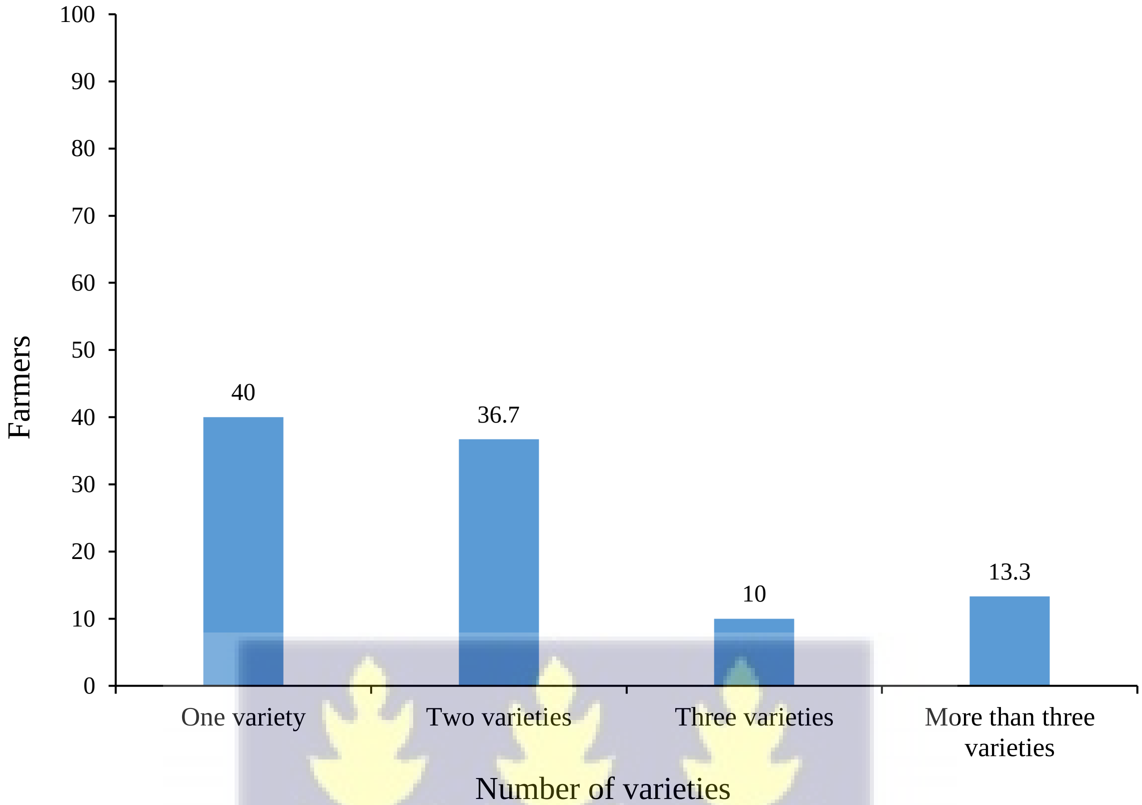

Figure 4.4: Number of mango varieties cultivated by farmers.

4.1.3. Farmers' knowledge on pest and pest control.

All the respondents (100%) interviewed in the research, stated that, they encounter pest on their respective farms.

Fruit flies and mango stone weevils were identified by 36.7% of the respondents as the main types of pests often encountered on mango farms. Sixteen-point seven percent of the farmers pointed fruit flies, mealy bug and mango stone weevil, and fruit flies and mealy bugs as the pest they often come across in each case. Six-point seven percent of the farmers said fruit flies only and mango stone weevil only in each case are the pest frequently encountered.

Table 4.2: Pests encountered by farmers

Pest	Frequency	Percent
Fruit flies	2	6.7
Fruit flies, MSW and Aphids	1	3.3
Fruit flies and Mealy bug	5	16.7
Mealy bug and Aphids	1	3.3
Fruit flies, Mealy bug and Aphids	1	3.3
MSW	2	6.7
Mealy bug	1	3.3
Fruit flies and MSW	11	36.7
Fruit flies, MSW and Mealy bug	5	16.7
Fruit flies, MSW, Mealy bug, Aphids and Coconut bug	1	3.3
Total	**30**	**100.0**

All the thirty farmers (100%) used in the survey, knew about the nuisance posed mango stone weevil as a pest of mango. Almost eighty-seven percent of the farmers stated that, the mango stone weevils were present on their respective mango farms. Thirteen-point three percent of the respondents however, stated the contrary.

Twenty farmers, representing 66.7% of the respondents said the mango stone weevil are still present on their individual farms. Twenty percent of respondents said, the mango stone weevils do not persist on their farms anymore.

In the control of the mango stone weevil, 50% of the respondents on whose farms the mango stone weevils were not persisting stated that, they used chemical method in controlling the mango stone weevil. Forty percent of respondents also said they used both chemical and cultural method. Ten percent on the other hand said, they used the integrated pest management method.

There is no significant association between how farmers control MSW and Annual expenditure on MSW control. Here, it can then be concluded that controlling MSW is not likely linked with annual expenditure on MSW control.

Table 4.3: Control measures employed by farmers in controlling MSW

Control measures	Frequency	Percent
Chemical Control	5	16.7
Integrated Pest Control Method	1	3.3
Chemical and Cultural Method	4	13.3
Total	20	33.3
Missing System	10	66.7
Total	**30**	**100**

4.1.4. Pest and pest management on mango farms in the study area.

Thirty-seven percent of the farmers stated, they apply control measures at the flowering stage and after harvesting of fruits. Sixteen-point seven percent of the respondents said they control the mango stone weevil at the flowering stage. Respondents that applied control measures after harvesting were also sixteen-point seven percent. Farmer that applied the control measure at the golf ball size stage were 10%. About seven percent of respondents applied control measure at flowering stage and golf ball size stage, and full maturity stage in each case. Three-point three percent of the farmers disclosed they controlled the pest at the tennis ball size stage, and the flowering stage, tennis ball size stage and the full maturity stage in each case.

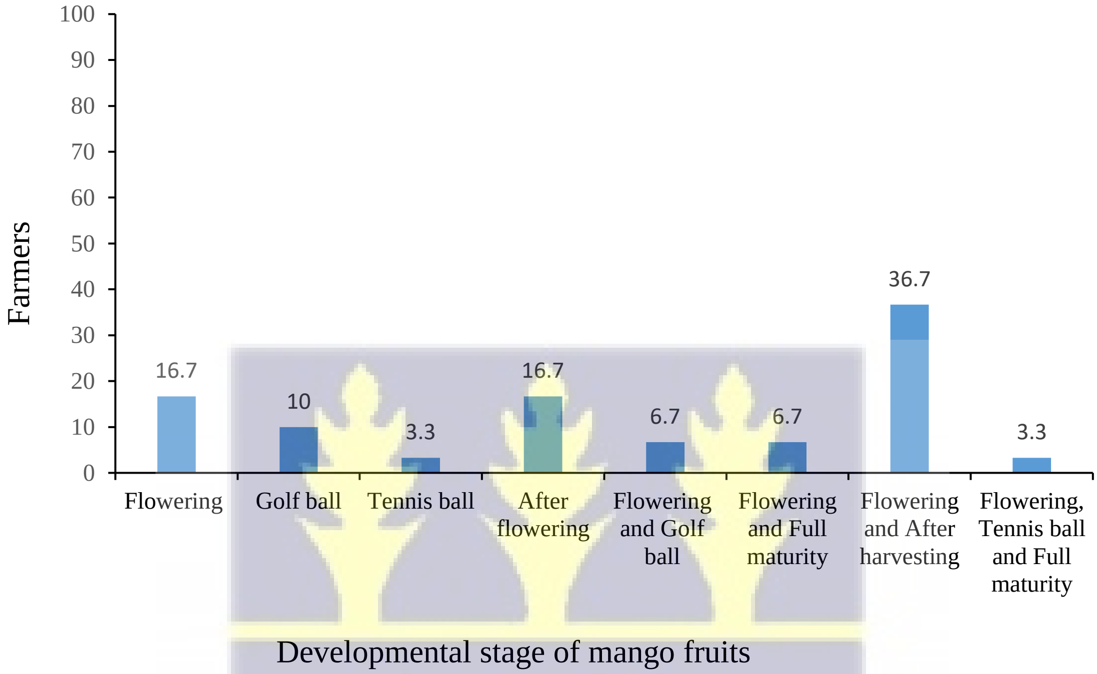

Figure: 4.5. Time farmers usually control MSW.

About fifty-three percent of the respondents had view that, the mango stone weevil attacks at the golf ball size stage. Thirteen-point three percent of the farmers also said the pest attacks at the flowering stage, and the flowering and golf ball size stages in each case. Ten percent of respondents indicated that, the mango stone weevil often attacks at the tennis ball size stage. Three-point three percent were of the view that, the pest in discussion attacks at full maturity, flowering stage and tennis ball size stage, and flowering stage, tennis ball size stage and full maturity in each case.

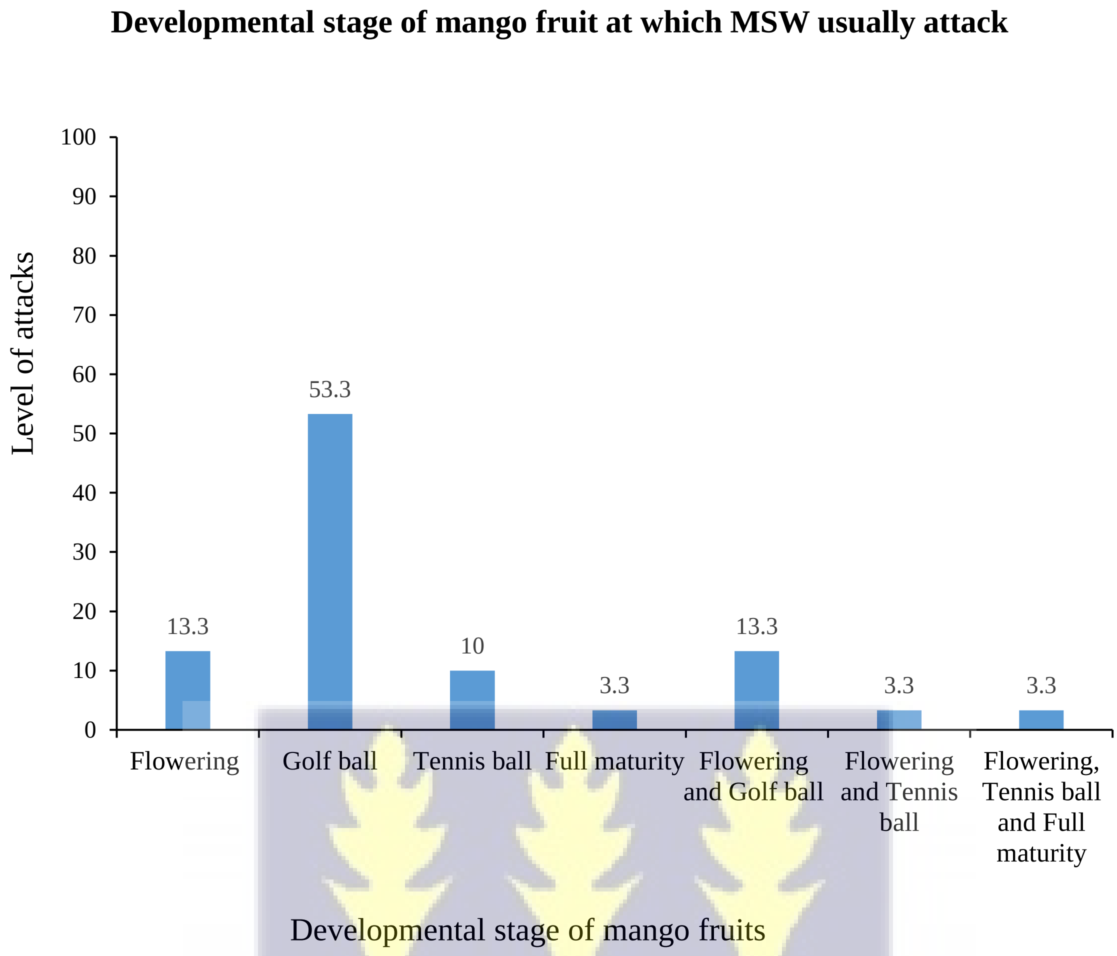

Figure 4.6: Developmental stage of mango fruit at which MSW usually attacks.

One hundred percent of the farmers interviewed said they sample some fruits from their farms and dissect to determine whether it is infested or not. The seeds of the dissected fruits were then inspected to see the presence of the weevil or otherwise.

In responds to the question as to whether the mango stone weevil is a major insect or not, 76.7% of the farmers described the mango stone weevil is a major pest. The remaining 23.3% said the mango stone weevil is not a major pest.

Thirty-seven percent of respondents said they see mango stone weevil as major pest because it's a quarantine pest. Thirteen-point three percent of the respondents said, the pest is a major pest in mango production because, it's difficult to detect, and difficult to control in each case.

Six-point seven percent of farmers said it's a major pest because it reduces fruit quality. Three-point three percent of the respondents said mango stone weevil is a quarantine pest and difficult to detect and reduces fruit quality and promotes premature fruit drops in each case. Farmers that took part in the study were all from the same agro-ecological region and therefore 100% of the farmers said they experience two fruiting seasons (i.e., major and minor seasons). Answering the question on which season has the highest infestation, 90% of the respondents indicated that, the major season has the highest mango stone weevil infestation. Six-point seven percent of respondents said infestation is high in both minor and major seasons. Three point three of the farmers however, opined that, the minor season has the highest infestation.

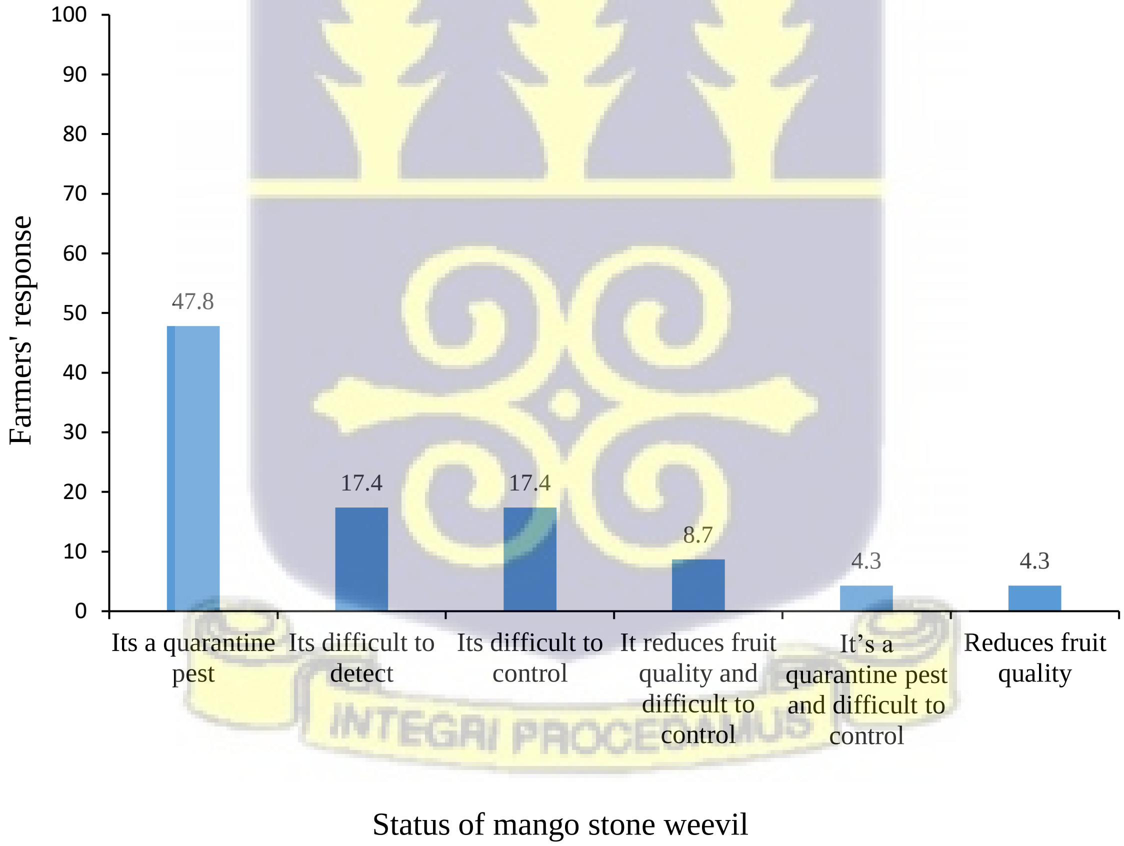

Figure 4.7: Status of the mango stone weevil as a pest of mango

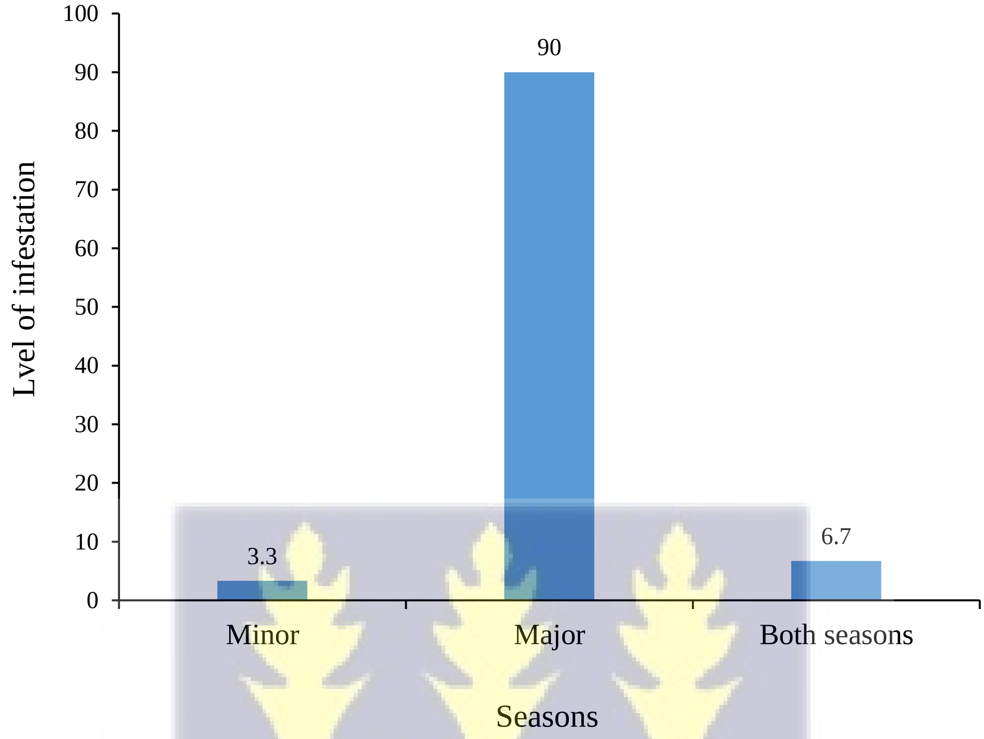

Figure 4.8: Season and infestation levels.

4.1.5. Finances of mango farms covered in the study area.

About forty-three percent of the farmers said they produce for export, processing companies and the local market. This means that any group of consumers that comes to the farm when fruits are available would be served. Thirty-three-point three percent of respondents indicated that their fruits are available for exporters and processing companies. Ten percent of the farmers said they produce for processing companies, and processing companies and the local market in each case. Thirty-point three percent of the respondents however, said the solely produce mangoes for the export market.

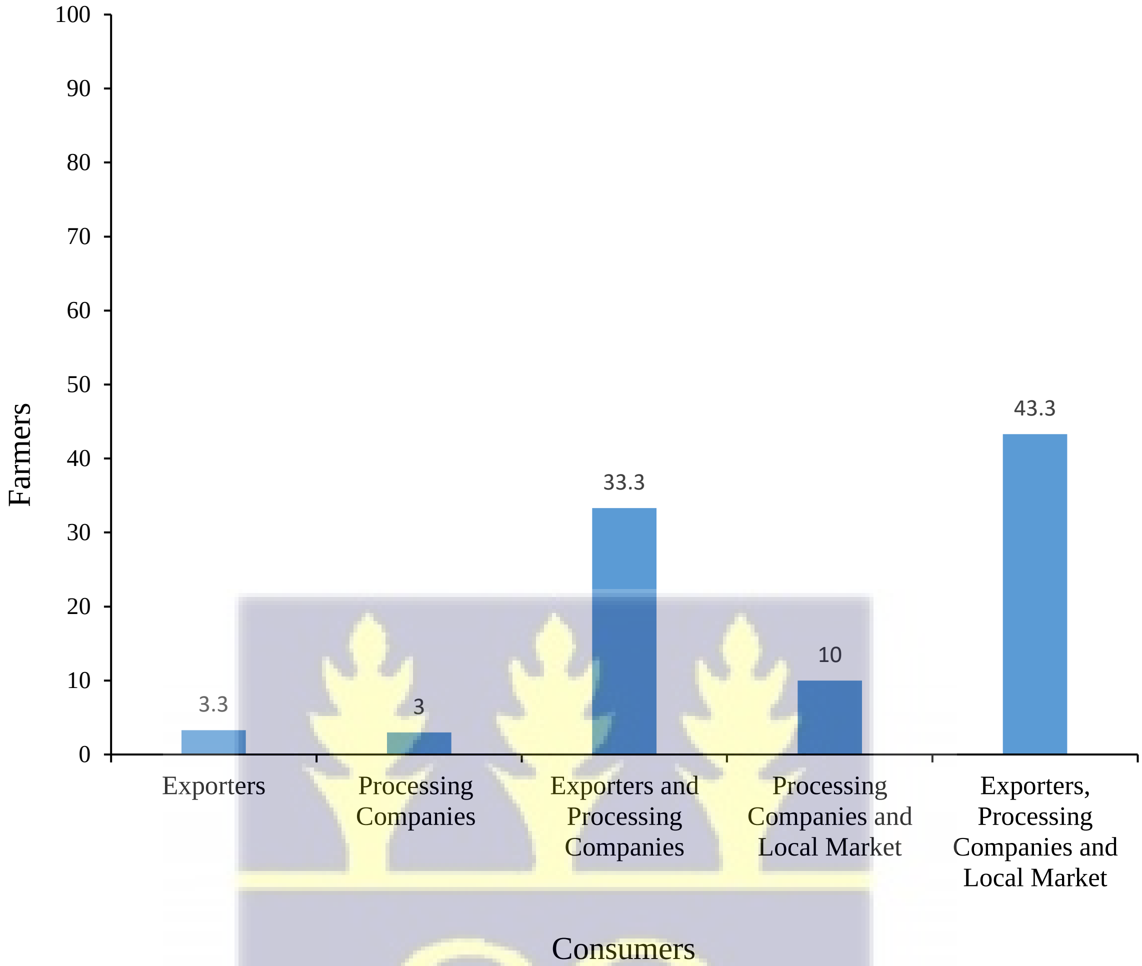

Figure 4.9: The targeted consumers of respondents

Thirty percent of the respondents interviewed in the survey said, they earn between GH¢15,000 – 20,000:00 annually from fruit sales. Twenty six percent of farmers also said they earn over GH¢25,000:00 annually. Twenty percent said they earn between GH¢5,000 – 10000:00 per annum. Thirteen point three of the farmers who were captured in the survey said, they earn between GH¢20,000 – 25,000:00. Six-point seven percent of respondents disclosed they earn between GH¢10,000 – 15,000:00. Three-point three percent representing one farmer stated he earns less than GH¢5000:00 annually.

Table 4.4: Annual income from fruit sales

Income	Frequency	Percent
Less than GH¢5,000	1	3.3
GH¢5,000 - 10,000	6	20.0
GH¢10,000 - 15,000	2	6.7
GH¢15,000 - 20,000	9	30.0
GH¢20,000 - 25,000	4	13.3
Greater than GH¢25,000	8	26.7
Total	**30**	**100.0**

Seventy-seven percent of respondents to the questionnaire stated that, they spend between GH¢2,000 – 5,000:00 on pest control. Thirteen-point three percent of the farmers said they spend less than GH¢2,000:00 in controlling pest. Ten percent however, said they spend between GH¢5,000:00 – 8,000:00 on pest management on their farms.

Table 4.5: Annual expenditure on pest control

Expenditure	Frequency	Percent
Less than GH¢2000	4	13.3
GH¢2000-5000	23	76.7
GH¢5000-8000	3	10.0
Total	**30**	**100**

Twenty-one farmers representing 70% of the respondents said they spend less than GH¢2000:00 in controlling the mango stone weevil. Twenty-six-point seven percent of the farmers also said they spend between GH¢2,000 – 5,000:00. The remaining 3.3% of the respondents, said they spend GH¢5,000 – 8,000:00 in controlling mango stone weevil.

Table 4.6. Annual expenditure on MSW control

Expenditure	Frequency	Percent
Less than 2000	21	70.0
2000-5000	8	26.7
5000-8000	1	3.3
Total	**30**	**100.0**

4.2. Level of MSW infestation and distribution within the eastern mango enclave.

In general, the survey revealed that mango stone weevil is persistent within the eastern mango enclave. About twenty-two (22) farms (i.e., 73.3%) out of the thirty (30) farms used for the study (as shown in table 4.1) recorded increase in the number of infested fruits during the major season (i.e., May - July). A total of hundred fruits were dissected for each season per farm.

Table 4.7: Mango stone weevil infestation within the eastern mango enclave.

			MINOR SEASON	MAJOR SEASON
S/N	**Farms**	**Farm's GPS Coordinates**	**Percentage Infestation**	**Percentage Infestation**
1	Modest Farm	N6°2'19.644" W0°0'9.67788"	56	46
2	Trinity Farm	N6°6'11.28708" E0°0'6.687"	18	0
3	Enyonam Farm	N5°53'45.2061" W0°4'54.1668"	0	0
4	Shottos Farm	N6°2'16.01988" W0°0'26.892"	44	50
5	Pristige Farm	N6°2'37.14612" W0°0'20.99052"	16	6
6	Joe Farm	N6°3'25.90812" W0°1'58.62612"	4	6
7	Matesco Farm	N6°3'1.50408" W0°1'15.13596"	6	14
8	Kofi Agbojilo	N6°6'10.86588" E0°0'46.32012"	44	4
9	Pricon Farm	N6°12'44.3484" E0°6'42.318"	18	30
10	Kwabena DVLA	N6°5'57.90588" E0°0'36.15012"	26	54
11	Opposite DVLA	N6°6'5.72652" E0°0'29.8278"	14	26
12	Block Factory	N6°6'6.30612" E0°0'31.49388"	28	38
13	Joseph Kabutey	N6°60.306" E0°028.12212"	22	6
14	Ethyln Joyce Farm	N6°2'54.942" W0°1'56.30412"	14	40

15	Tettmon Farm	N6°2'55.986" W0°2'10.16988"	16	22
16	Agbeko Farm	N6°3'6.38813" W0°1'64.125"	0	0
17	Adjecent Mama Zimbi	N6°3'19.854" W0°1'50.088"	20	28
18	Nagmor Farm	N6°2'45.94812" W0°0'23.95188"	16	30
19	Delali Farm	N6°2'9.70188" W0°2'32.01612"	12	18
20	Mama Zimbi	N6 °14'50.83332" E0°7'32.61432"	26	44
21	Oboadie Farm	N6°3'6.00048" W0°1'55.2378"	22	34
22	FN Korzey Farm	N6°2'15.97092" W0°2'14.68068"	14	14
23	Opposite Korzey Farm	N6°2'16.81548" W0°2'17.5254"	18	16
24	Awuye Farm	N6°2'43.66356" W0°0'38.2788"	28	16
25	Cover Farm	N6°5'31.26192" W0°1'6.14136"	14	20
26	Bokom Farm	N6°1'46.5096" E0°2'34.26612"	16	20
27	Pick Up Farm	N6°6'29.48328" E0°1'5.01708"	12	26
28	Jaho Farm	N6°1'45.768" W0°0'23.454"	22	46
29	Down Hill	N6°1'2.01" W0°2'45.28788"	16	34
30	Believe Farm	N6°6'23.684" E0°0'47.808"	12	20

Table 4.7: Continued

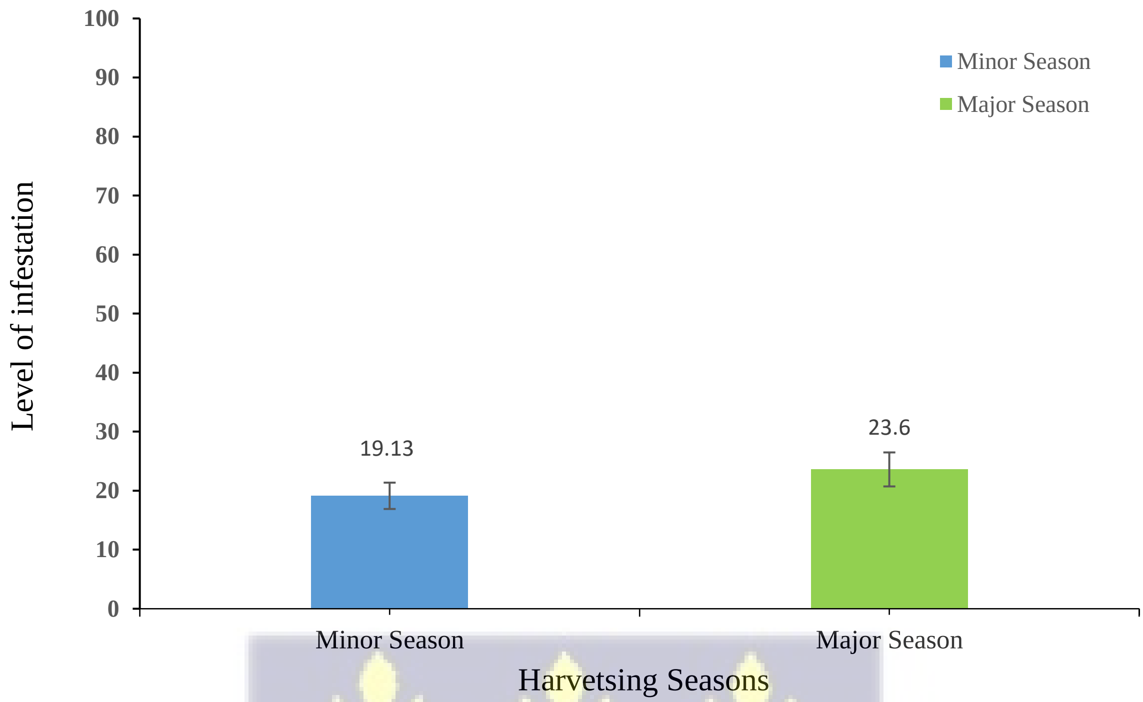

Figure 4.10: Average level of MSW infestation for minor and major seasons

4.3. Effect of different treatments in controlling the mango stone weevil.

Data collected on the effect of various treatments (Chlorpyrifos, Grease and Sticky band) applied to control mango stone weevil over the growth period for both major and minor seasons for eight weeks in both seasons, is shown in table 4.12 above. A significant difference exists between treatments. Sticky band had the lowest fruit infestation whiles the control had the greatest fruit infestation for both seasons. There was no significant difference ($p \leq 0.001$) between the control and grease during the major season, although the control had a greater mean than the grease. The fruit infestations recorded for the control and grease were greater in the major season than that recorded in the minor season. Chlorpyrifos and sticky band on the other hand, recorded smaller fruit infestations for the major season instead.

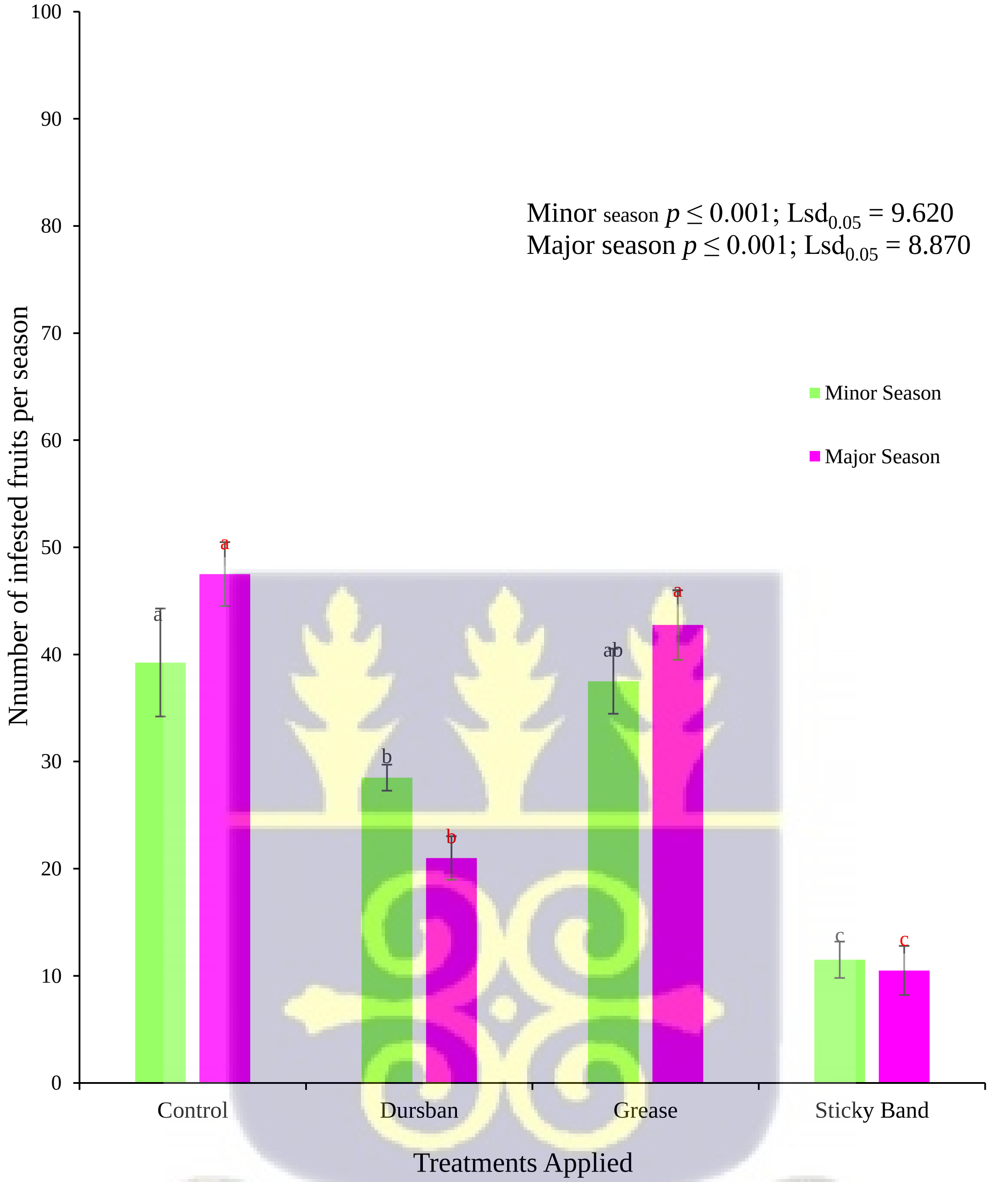

Figure 4.11. Total number of infested fruits during the major and minor season

4.4. The non-destructive method of detecting mango stone weevil using soft X-ray technology.

The images from the X-ray of uninfected and infested mango fruits are presented in figure 4.13 and figure 4.14 respectively below. The image of an uninfected fruit showing the image of the internal structure of the mango seed without any damage is displayed in figure 4.13. Although, the X-ray could not capture the image of the weevils, it captured the image of the damaged cotyledon and a spongy tissue as shown in figure 4.14.

Figure 4.12. The X-ray image of an uninfected mango fruit

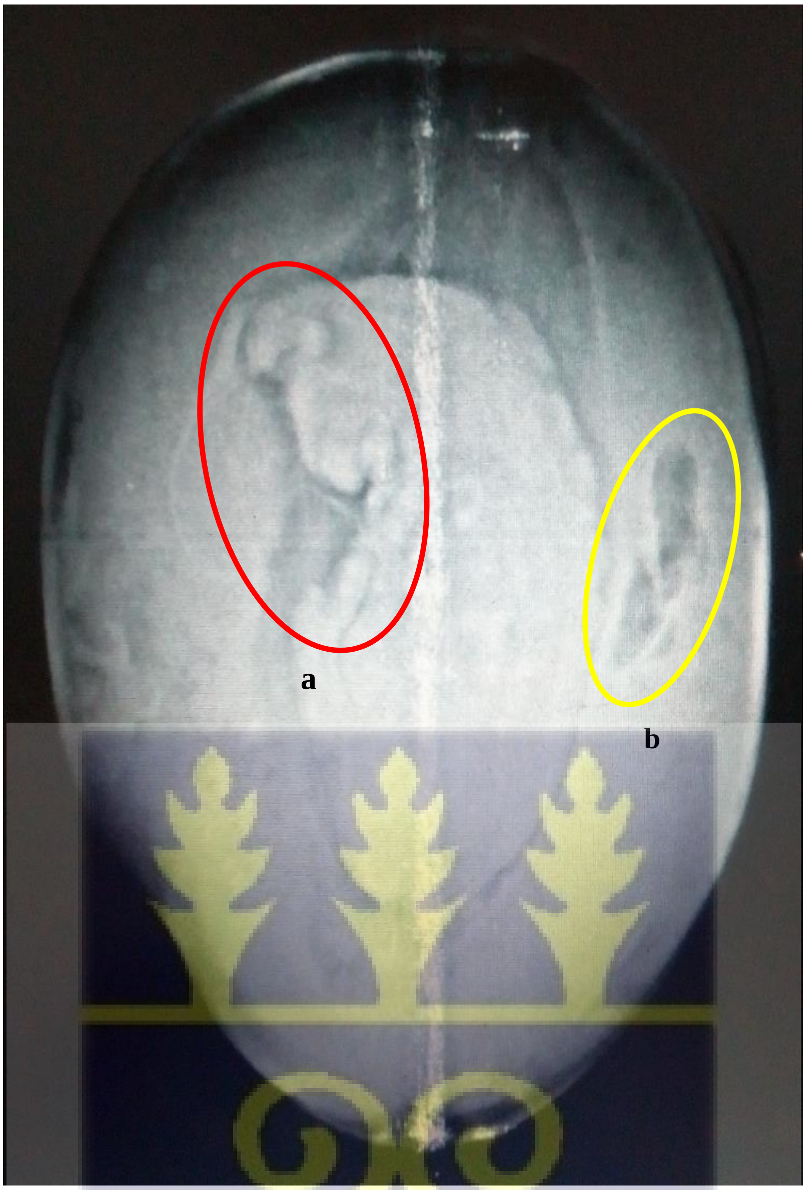

Figure 4.13. The X-ray image of an infested fruit with a damaged cotyledon (a) spongy tissue (b).

CHAPTER FIVE

DISCUSSION

5.1 Demographic characteristics of mango farmers in the study area

The research revealed that, mango cultivation in the study area is predominantly composed of males notwithstanding the fact that women play an important role in the distribution and marketing of mangoes. This confirms the work of Okorley *et al*. (2014), which stated that, 89% of mango farmers were men. Plantation crops such as mango, requires a large span of farmland, high initial capital and labour which Ghanaian generally lack (Okorley *et al*., 2014, Duncan and Brants, 2004).

Fordjour (2014) also acknowledged that, then mango cultivation in Ghana is male dominated and attributed it to the fact that farming as an enterprise is labour intensive and men traditionally control assets such land and tree crops. Micah and Inkoom (2016), in research to find the economic efficiency of mango production in the Yilo Krobo Municipality, acknowledged that, only 9.7% of the farmers are females with the rest being males. Agyapong (2017) and Akurugu (2011) also disclosed that majority of males engage in the growing of fruit crops.

The current study indicated that, a greater number of the farmers in the cultivation of mango were aged (over 50 years old). This can be attributed to the ability of the aged to acquire the needed financial resources to establish and manage mango farms. Additionally, the aged have an advantage of controlling family lands as compared to the youth and adults. This puts the future of mango farming in danger because the aged and illiterates may be among the people who find it difficult to adopt new and improved technologies (Berg, 2013 and Neguse, 2019).

The findings of this study contradict the work of Okorley *et al.* (2014), which disclosed that, 62.2% of mango farmers are adults (40-59yrs). It however, agrees with the work of Micah and Inkoom (2016), who stated that, the mean age of mango farmers is 56yrs.

The educational background of most of the farmers engaged in the survey was very encouraging. Forty percent (40%) of them had secondary education. It was however, noted that, thirty percent (30%) had tertiary education. All farmers captured in survey had experienced formal education. This disclosure is very essential, because it would enhance the easy adoption of new and improved farming methods which would intend reflect in productivity. This result is supported by Micah and Inkoom (2016), who remarked` that, 48.4% of mango farmers had tertiary education. Okorley *et al.* (2014), also reported that about 78% of mango farmers have a minimum of secondary school level education. Akurugu (2011), in contrast, declared that (47.65%) of farmers had no formal education as only 27.52% had basic education.

Most of the farmers (70%) captured during the research were found to have engaged in the mango business for 11-20yrs. This finding communicates that a significant number of mango farmers in the study area have obtained enough experience in the production of mangoes. This result is backed by Micah and Inkoom (2016), who recorded an average farming experience of 11.2yrs and stated that, experience turns to improve the way farmers conduct farm activities, which intends to improve their productivity over time.

Agyapong (2017), in comparing the level of experience of farmers to pest control methods, stated that, farmers with experience between 11-15yrs were more likely to use pest control measures which confirms the current findings which confirms the current results. Neguse *et al.*, (2019), in their quest to investigate mango production practices and challenges in

Ethiopia's mango growing regions, disclosed that 61.9% of respondents had more than 15-30yrs mango cultivation experience.

5.2 Farm size and mango varieties cultivated

A significant number (i.e., 53.3%) of farms captured in the survey were between 5-20acres (medium scale). This may be resulting from competition with estate developers for lands and lack of initial capital to acquire large farmlands.

According to Okorley *et al*., (2014), majority of mango farmers (44.5%) operate on small (<9.9acres) to medium (9.9-19.8acres) scale in the Dangme West District. Only a few farmers (22.2%) were growing the crop on large scale basis (>19.8acres) and this does not differ from the current findings. Akotsen-Mensah *et al*. (2017), also stated that, the average farm size in the Yilo Krobo Municipality, Manya Krobo and Shai Osudoku District was 16.5acres.

The current research brought to light that, 36.7% of farmers (which forms the majority) cultivate the Keitt variety of mango. Farmers' preference for this variety connected with its good traits such as disease resistance and late maturity (Campbell, 1992). Briamah *et al*, (2009), also revealed that, Keitt is the most widely cultivated exportable exotic variety. Micah and Inkoom (2016), disclosed that, farmers in the Yilo Krobo Municipality mainly grow Keitt or Kent or both. Fordjour (2014) added that 48% of farmers in the cultivation of mangoes are into the growing of Keitt whiles 25.6% grow the Kent variety of mango. Akotsen-Mensah *et al*, (2017) stated that out that, 46.7% of the farmers grow Keitt and Kent combined and 33.3% cultivate Keitt only. The present study, however, does not comprehend with Akurugu (2011), who stated that, 32.89% of mango farmers cultivate the Kent while 29.55% of them grow Amilie.

It however, came to light that, 40.7% of farmers in this research had two varieties of mango growing on their fields, 36.7% grew only one variety as the remaining percentage were into were managing three or more varieties.

5.3 Farmers' knowledge on pest and pest management

All the farmers interviewed during the survey conceded that, their farms were not free from pest. Fruit flies and mango stone weevils were listed as the major pest in mango production with about 36.7% of the respondents expressing that view. This disclosure validates the publication of Okorley *et al.*, (2014), which stated that, mango fruit fly is a major economic important pest. The presences of mango fruit fly are a bad quality feature (Akurugu, 2011, and Prinsley and Tucker, 1987). The current findings conform to the work of Reddy *et al.*, (2018) which concluded that, out of the few insects of economic importance, fruit flies and the stone weevils are of quarantine importance and restricts international trade of mangoes. Louw (2008), on the contrary wrote that, there is little evidence that mango stone weevil infestation impacts yield, even though some authors maintain that fruit drop may occur if the mango stone weevil develops in the seed.

The farmers' view of ranking fruit flies and mango stone weevil as the major pest of the mango fruit can be linked to the fact that, both pests are of quarantine importance and reduces the export potential of famers with infestation. The biology of these pest also makes it difficult to control since they spend part of their lifecycle in the mango fruit. In addition, infested fruits (especially with respect to the fruit flies) are of poor quality and low market value. The feeding of these pests also leads to premature fruit drops (Follet and Gabbard, 2000).

The research revealed that, farmers within the study area are aware of the presence of the mango stone weevil with about 86.7% of the farmers declaring that they have ever encountered the mango stone weevils on their farms. The presence of the weevils on most of the farms can be attributed to the unrestricted movement of mango fruits from an infested area to weevil free areas. This result agrees with EPPO (2018), publication that, the mango stone weevil is present in almost all mango growing areas.

Out of the 86.7% of the farmers that, stated the mango stone weevil were present on their field, 76.9% of them, said the pest (mango stone weevil) persist on their farms. This can be explained that farmers are not doing enough to control the pest or the mango stone weevils are very difficult to control based on their biology and ecology. Farmers who managed to control the mango stone weevils on their farms (i.e., 23% of those who use to have the mango stone weevils on their field) said the pest does not persist anymore. This gives an assurance that, when frantic efforts are made towards the control of the mango stone weevil, it would be successful.

The results showed that, chemical method of control was the tool deployed by 50% of the respondents who have effectively controlled the mango stone weevil on their farms. The use of chemical in controlling the pest is dominant among farmers because the chemical control method seems to be the simplest and easiest way of controlling pest of mango since it does not control only the stone weevils but other pests that might be on the farm. This is backed by the assertion made by Louw (2008), that sanitation practices are time consuming therefore chemical control techniques are used more frequently by mango farmers. Fordjour (2014) also opined that in the management of mango stone weevils, farmers' preference for the use of chemicals is high (60.8%).

According to Akotsen-Mensah *et al.*, (2017), about 66.7% of farmers use conventional insecticides in the management of pest on their orchards. Notwithstanding, the use of nonselective pesticides to combat pest outbreaks on a routine basis could have a direct impact on pest control through the occurrence of insecticide resistant strains, pest resurgence and secondary pest outbreaks (Akotsen ten-Mensah *et al*, 2017, Tiwari *et al.*, 2011 and Mckinney and Schoch, 2003). Surprisingly, there was no significant relation between how farmers control the mango stone weevil and annual expenditure on MSW control. The reason is that farmers don't really pay specific attention to the control of mango stone weevil, as the control of MSW is integrated into the general measures for controlling pest of mangoes.

5.4 Pest and pest management on mango farmers

The current studies indicated that, a significant number of farmers (36.7%) apply control measures at the flowering stage and after harvesting of fruits. Farmers that applied control measures at the flowering stage were 16.7% while another 16.7% controlled the stone weevils after harvesting of fruits. This means that, there is no coordination between farmers as to when to control the MSW, as one farmer is applying control measure, another farmer close by is not ready to apply any control and this has occasioned the high levels of infestation in the study area.

Response gathered from farmers (53.3% as shown in table 4.14) showed that, the mango stone weevil often attacks the fruit when it is at the golf ball size. This stage of growth seems to be the stage at which the larva (which is the most destructive stage) can easily eat into the seed because the seed coat is not fully formed to protect the cotyledon from being damaged. 13.3% of the farmers that the pest attacks at the flowering stage. This is however difficult to comprehend with, because at this stage, the fruit has not yet formed and therefore newly hatched larvae would have no fruits which serves as growth medium to survive on although the flowers attract the weevils as it appears, they feed on nectar and pollen (Fordjour, 2014).

Interestingly, a significant association was observed between the time farmers control MSW attack on mango fruits and the stage at which the MSW usually attack. This shows a strong relation between when control measures are applied and the time MSW often attack because when control measures are applied at the appropriate time (i.e., the time the stone weevils attack), the pest could be effectively controlled.

The study also revealed that most farmers sample their fruits from the trees and dissect them into two halves longitudinally to observe whether the weevils present or not. The reason farmers have to cut sampled fruit into two halves before they determine the presence of the weevil is because the weevils spend a significant period of its lifecycle in the fruit of the mango specifically in the seed coat feeding on the cotyledon. Follet (2002), stated that, Unless the fruits are disserted to expose the state of the interior structures, it is hard to separate between infested and non-infested fruits. This is supported by the argument made by Follett and Gabbard (2000) that, complete development of lava usually occurs within the maturing seed. Another reason is that there are no visual clues on fruits to tell whether it is infested or free from stone weevils. Sambrani *et al* (2015), reported that mango varieties that have seed weevils or stone weevil infestation, are not visible externally. Thomas *et al*. (1995), also said that mango fruits infected with seed weevil have no evident outward signs of infestation but generate significant worries. Peng and Christian, (2007), on the contrary, stated that, the hardened, amber-coloured secretion, which is sometimes sculptured with two angled tails at one end and remains attached to the site of oviposition, distinguishes afflicted fruits from uninfected ones.

A great number of farmers forming about 76.7% said the mango stone weevil is a major pest. The rest of the farmers (23.3%) said the mango stone weevil is not a major pest. The farmers who view the stone weevil as a major pest lamented that, farms with weevil infestation are not able to export their fruits and this affect their finances since production may exceed the quantities required by the local market and also fewer number of processing companies. This finding is in line with the view of Reddy *et al*., (2018), which mentioned that the stone weevil is of quarantine importance and restrict international trade of mangoes. Braimah *et al*., (2009) added that, the mango stone weevil is a major pest with a 1:40 rejection rate in international quarantine. The other group of farmers which did not see the stone weevil as a major pest were mainly those who sell their fruits on the local market mostly to women by the roadside where stone weevil infestation is not a headache because it does not affect the eating quality of the fruits.

An appreciable number of farmers (36.7%) explained that the mango stone weevil is a major pest because it's a quarantine pest. Thirteen-point three percent of them labelled the pest a major pest because it is difficult to detect. As stated by CABI and EPPO (2015), the greatest damage caused by the mango stone weevil is to interfere with fruit export, because of quarantine restrictions.

All the farmers interviewed during the survey said they experience two (i.e., major and minor season) harvesting seasons. This is responds is not surprising because all the farmers captured in the survey found in the same agro-ecological region. The above observation augments the work of Abu *et al*., (2011), which mention that mango producing areas in Ghana are categorized into the southern and northern zone. The southern zone is characterised by a major season and minor season probably because of its binomial rainfall pattern.

The research brought to light that the major season has the highest weevil infestation as 90% of the farmers professed as such. However, 6.7% of the farmers stated that, infestation is high in both seasons (i.e., major and minor seasons). This assertion by the farmers is not different from what was observed during the survey where the major season recorded a higher infestation level. This result may be due to the abundance of fruits during the major season (i.e., mid-April to mid-August) where there is more than enough food for the mango stone weevils to feed on. Peng and Christian (2004), indicated that oviposition occurs around mid-August to early

October in Australia and this is not contrary to the current results. Shukla and Tandon (1985) and CABI and EPPO (2015) reported that in India, oviposition occurs around mid-March and reaches a peak during the first week of April.

5.5 Finance of mango farms

A significant number of the farmers (i.e., 43.3%) encountered during the survey disclosed that, their mango fruits are available for exporters, processing companies and the local market. Thirty-three percent said they produce their mangoes for export and processing companies. The survey revealed that only about three percent of farmers solely produce mangoes for export. This means that, majority of farmers mainly do not solely produce for export due to high levels of stone weevil infestation within the study area as the stone weevil is a quarantine pest. This is backed by CABI and EPPO (2015) that, the greatest damage caused by the stone weevil is that, it hinders fruit export due to quarantine regulations. The view of Reddy *et al*., (2018) was that out of the few insects of economic importance, fruit flies and mango stone weevil are of quarantine importance and restrict international trade of mangoes. This results also explains why there is high infestation levels in the study area because famers sell their fruits to any entity that is ready to purchase the fruits especially the processing companies and local market as stone weevil attack does not cause any significant damage to the eating quality. The presence of stone weevils did not appear to have a negative impact mango development, but that the mere presence of stone weevils in fruits can lead to shipment being turned down for export (Louw, 2008 and Schotman, 1989). Braimah and van Emden (2010) also remarked that, the presence of the mango stone weevil in the mango production system provides sufficient grounds for the fruits being rejected for export.

The survey disclosed that, thirty percent of farmers in the locality earn between GH₵ 1500:00 – 20,000:00 yearly from fruit sales. Most of the farmers in this category were found to be managing medium scale farms. A significant number of farmers forming about 26% of the respondents stated they obtain over GH₵ 25,000:00 annually. This result is very encouraging because with the high level of infestation which reducing or restricting export of fruits to the international market could earn an amount over GH₵ 25,000:00 for a medium scale farmer, then when the right measures are put in place to control the menace of mango stone weevil, earning of farmers would increase tremendously. This finding sinks with the work of Zakaria (2012), who commented that, an exporter could fetch between €3 (GH₵ 6:45Gp) and €5.2 (GH₵ 11:18Gp) per 4kg crate at the wholesale level in 2011, where the final value is influenced by elements such as count, weight, size, aesthetic value and quality. At the farm gate, farmers were selling the first-grade fruits at three fruits for GH₵5:00 with an average of 2–3kg to middlemen (personal communication).

The research as expected to witness a great relation between who the targeted customers of the farmers are and the annual income from fruit sales, however, the results of the study proved otherwise. This was somewhat surprising because, the targeted customer (especially if it is for export) would have shown much influence with respect to the quality of fruits that are produced to avoid problems that would emanate from quarantine restrictions due to mango stone weevil infestations.

An appreciable number of the farmers representing 76.7% of respondents were found to be spending between GH₵2000 – 5000:00 in controlling pest on their orchards. 13.3% of the farmers were spending less than GH₵2000:00 for the same job of pest control. On the average farmers were spending about GH₵220:00 per acre of land on pest control (personal communication). This amount includes the cost of labour, water and chemical (pesticide). This tells that if the farmer applies the control measure for about three times, he/she would be spending about GH₵660:00 on the control of pest and most farmers were not prepared to part away with such money since it drains their financial resources. This seems to be the reason why stone weevil infestation levels are high in the study area.

In the quest to find the amount of money set aside in controlling the mango stone weevil, 70% of the respondents stated they spend less than GH₵2000:00. A significant 26.7% of the farmers were captured to be spending between GH₵2000 – 5000:00. This shows that majority of the farmers were not paying much attention or doing much in the control of the stone weevils because the cost of controlling stone weevils in most cases was the same as the total amount spent on general pest control. This revelation also means that, farmers do not keep proper records on the expenditure with respect to pest control. This is quite worrying because most of the farmers reached in the survey were educated and would not have many problems with respect to recording the expenditure of the farm.

5.6 Mango stone weevil infestation levels in the eastern mango enclave

The survey conducted to investigate the level of mango stone weevil infestation within the eastern mango enclave showed higher number of infestations during the major season. This can be attributed to the fact that, May-July falls within the major raining season in the southern part of Ghana, and during this period the weather becomes humid and conducive for the survival of the mango stone weevil. This finding agrees with the work of CBI and EPPO (2015), and Shukla and Tandon (1985), which disclosed that, adult mango stone weevils of new generations emerge during June in research conducted in Bangalore, South India.

According to Abu (2010), lower environmental temperatures, influences flowering leading to fruit set. This favourable conditions at this time of the year ensures enough feed for the mango stone weevils to feed on. Hansen *et al*., (1989) found that, adult mango stone weevils become reproductively active when mangos begin to bloom. Braimah (*et al.*, 2009), remarked that, adult mango stone weevils are attracted to flowers and turned to feed on nectar and pollen. The odour of the flowers provides the cues that direct the weevils to the host plant after hibernation and that while feeding, they mate and lay eggs.

There were however, six (6) farms (forming 20%) which recorded higher infestations during the minor season. The high infestation during the minor season was observed to be farms that were not properly managed. Farmers managing these farms would not visit the farms and carry out agronomic practices such as pruning on time, disease control and weeding during off season and hardly keep the farms clean. They however, pay attention or concentrate on the farm during the major season where there is greater probability of obtaining higher yield as compared to the minor season and work harder resulting in a relatively lower levels of infestation during the major season.

The remaining two (2) farms (i.e., 6.7%) were free from the mango stone weevils in both seasons. These two (2) farms were found to be managed by the owners themselves (i.e., they are not hired). Hence, farmers could have enough time to carry out cultural practices such pruning, weeding, fertilizer application, disease control on time and keep farm sanitation. This finding is in support of the assertion made by Hansen *et al*., (1989), that high infestations are reported year after year in some locations, whiles low infestations occur in other farms nearby. The uninfected farms were also relatively young depriving the dreaded mango stone weevil of crevices and loose barks which are hibernating place for the weevil. This does not differ from the assertion made by Braimah *et al*., (2009), that younger trees have rather smooth barks that cannot shield the weevils from the environment and natural enemies between fruiting seasons.

5.7 Evaluation of different management methods against the mango stone weevil

The sticky band proved to be the most effective treatment in controlling the mango stone weevil. Although no weevil was captured by sticky band, it was the treatment that recorded lesser number of infested fruits. This could be explained that the sticky band provided a physical barrier which made it hard for the stone weevils to access the fruits and lay their eggs. It however trapped other beneficial insects such as the *oecophylla* and honeybees. Elshafie (2019), explained that mechanical and physical controls prevent pest from accessing their resources by making the environment unsuitable for them. These measures also affect important biological parameters of pest such as feeding, reproduction, dispersal and survival and this reflected in the results recorded by the sticky band. Muriuki *et al*. (2011), communicated that, physical barriers such as the sticky bands applied at the ends of tree trunks just at the time of flowering prevents migrating of weevils to branches for egg laying.

The chlorpyrifos was the second-best treatment in the management of the stone weevils. Even though the chlorpyrifos was applied just ones, the results showed a significant difference ($p \leq 0.001$) between the grease and also the control plants for both major and minor seasons. The chlorpyrifos was applied just ones to ensure that, its residual effect might be reduced or broken down before the fruits reach maturity. It was also to reduce its impact on beneficial insect such as the pollinators. The results obtained from the chlorpyrifos treatment agrees with the work of Muriuki *et al*. (2011), who concluded that, trunk painting using chlorpyrifos ones per month during the fruiting period is most effective treatment for controlling mango seed weevil. Ravinshankar and Misra (2010), suggested the spraying of insecticides at the time of egg laying and when fruits are of marble size.

Out of the treatments applied, grease recorded the highest infestation levels. There was no significant difference ($p \leq 0.001$) between the grease treatment and the control plants. This result can be attributed to the fact that, the stickiness or adhesiveness of the grease reduced with time and therefore could not prevent adult mango stone weevils in accessing oviposition sites to mate and lay eggs. The results from the grease treatment is however, inconsistent to the view shared by Brigham and Smishek (1991) that, the lubricating grease is potentially low cost, effective water resistance and better retention of adhesion properties over a long period of time.

5.8 Non-destructive detection of mango stone weevil

The final phase of the research sort to find a non-destructive way of determining the presence of mango stone weevils in fruits. The research therefore employed the use of soft X-ray to capture the image of weevils in infested fruits. Although the X-ray imaging could not capture the weevils in this current study as the images shown in figure 4.3, it was able to capture damage cotyledons in the seed as well as spongy tissues.

The X-ray image of mango fruit showed an irregular shape of the cotyledon in the mango seed with dark outline. The irregular shape of the cotyledon may be a result of the feeding by the stone weevil. The spongy tissue also appeared as a dark area on the mesocarp (pulp). The healthy or uninfected fruit on the other hand had a grey bean shaped cotyledon with fine outline or edge.

The comparison between the two images obtained from the soft X-ray, gives great assurance that, infested fruits and healthy fruits can be sorted without splitting into two halves. The acceptance of X-ray imaging in the supply chain would go a long to reduce losses incurred by farmers through rejection of fruits by exporters and the risk of facing a ban from the international market and would go a long way to improve the nation's fortunes.

Sambrani *et al*. (2015), proposed that a non-destructive indigenous technology which employs X-ray imaging would be an effective and accurate solution to detect spongy tissue and seed weevil infested mangoes which would enhance grading of good quality mangoes for consumption and export. X-ray imaging has great potential for application in the processing industry and the export trade as a quality control measure (Thomas *et al*., 1995). Valente *et al*., (2013) also stated that, non-destructive and automated fruit grading system is seen as the solution for increased accuracy in quality control and lesser losses in production. These results would add-up to the technologies used in grading mango fruits before it is sent to the market and help improve the post-harvest handling of mango fruits.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The research revealed that, mango stone weevil remains a major constraint to mango production and marketing in the eastern mango enclave especially the Yilo Krobo Municipal District where the study was mainly concentrated. Out of the thirty farms captured for the research, only 6.67% and 10% were free from stone weevils during the major and minor seasons respectively. The major season recorded a higher infestation level with an average of 23.6% which is far above the international quarantine status of 2.5%. Mango farmers within the research area were very much aware of the status of mango stone weevil as a major pest due to its quarantine status.

Although about 60% of farmers cultivated more than one variety of mango and this contributed to the high infestations because all the varieties do not flower and set fruit at the same time. The Keitt variety, however, was recorded as the most cultivated variety of mango with 36.7%. All the respondents had experienced some form of formal education and 53.3% of them cultivated on farmlands ranging between 5–20 acres. However, a greater number of the farmers forming about 60% were aged and this is worrying.

Majority of farmers (36.7%) applied control measures at the flowering stage and after harvesting as 53.3% of these respondents held the view that the stone weevils mainly attack when the fruit is at the golf ball size stage. There was a strong association between the time weevils usually attack mango fruits and the time farmers usually apply control measures. This means that, if the right control measure is applied, the mango stone weevil can be managed to reduce infestation levels to meet the international quarantine threshold of 2.5%.

The sticky band proved to be an effective option for controlling the mango stone weevils. It gave the lowest infestation levels for both minor and major seasons which was significantly different ($p \leq 0.001$) from the other treatments (i.e., chlorpyrifos and grease). The grease recorded the highest level of infestation among the three treatments for both minor and major seasons though not significantly different from the control plant.

Respondents captured during the research held the view that, the only means by which fruits infested with weevils can be determined is dissecting fruits into two halves. The soft X-ray imaging technology which is a non-destructive means of determining internal infestation although was not able to capture the image of weevils (irrespective of their developmental stage), it was however able to capture damaged cotyledon of mango seed resulting from the feeding of the mango stone weevils. Spongy tissues formed within the pulp of the mango fruits was also captured Thus, soft X-ray imaging could be used to detect the damage caused by MSW and holds great potential for use in the trading of mango.

Implementing the findings of this study would reduce the field infestation and phytosanitary risk that the mango stone pose to the mango industry.

6.2 Recommendations

Based on the findings of the current research, the following recommendations can be made;

- ✓ To significantly reduce mango stone weevil infestation level as recorded on orchards, sticky bands should be adopted for field management of the mango stone weevil.
- ✓ Farmers and Agricultural Extension Officers should be trained on how to deploy the sticky band method for mango stone weevil management on orchards.
- ✓ The soft X-ray technology should be integrated into the mango fruit supply chain enhance the sorting of fruits for export. To this end, further work is required in collaboration with industry to develop soft X-ray imaging equipment for phytosanitary screening of mangoes at sea and land ports
- ✓ Further research on mango stone weevil infestation levels and detection of mango stone weevils in fruits on different orchards (farms) within the eastern mango enclave (especially in and around Kpeve in the Volta Region) would be very helpful to mango farmers.

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APPENDICES

Appendix 1:

Results of analysis from the questionnaire using SPSS.

Gender of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	27	90.0	90.0	90.0
	Female	3	10.0	10.0	100.0
	Total	30	100.0	100.0	

Age of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 25yrs / Youth	1	3.3	3.3	3.3
	25-50yrs / Adult	11	36.7	36.7	40.0
	Over 50yrs / Aged	18	60.0	60.0	100.0
	Total	30	100.0	100.0	

Educational Background of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Basic	9	30.0	30.0	30.0
	Secondary	12	40.0	40.0	70.0
	Tertiary	9	30.0	30.0	100.0
	Total	30	100.0	100.0	

Number of years of farming

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 5yrs	1	3.3	3.3	3.3
	5-10yrs	4	13.3	13.3	16.7
	11-20yrs	21	70.0	70.0	86.7
	21-30yrs	3	10.0	10.0	96.7
	Over 30yrs	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Farm size of respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 5acres	4	13.3	13.3	13.3
	5 - 20acres	16	53.3	53.3	66.7
	Greater than 20acres	10	33.3	33.3	100.0
	Total	30	100.0	100.0	

Varieties of mango cultivated by respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Keitt, Kent, Haden and Springfels	1	3.3	3.3	3.3
	Keitt, Kent, Haden and Palmer	2	6.7	6.7	10.0
	Keitt, Kent, Haden, Sunset, Palmer, Springfels and Amilie	1	3.3	3.3	13.3
	Keitt, Kent and Palmer	3	10.0	10.0	23.3
	Keitt and Haden	1	3.3	3.3	26.7
	Keitt	11	36.7	36.7	63.3
	Kent	1	3.3	3.3	66.7
	Keitt and Kent	10	33.3	33.3	100.0
	Total	30	100.0	100.0	

Varieties cultivated by respondent

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	One variety	11	36.7	36.7	36.7
	Two varieties	12	40.0	40.0	76.7
	Three varieties	3	10.0	10.0	86.7
	More than three varieties	4	13.3	13.3	100.0
	Total	30	100.0	100.0	

Whether farmer encountered pest on farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	30	100.0	100.0	100.0

Type of pest encountered

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fruit flies	2	6.7	6.7	6.7
	Fruit flies, MSW and Aphids	1	3.3	3.3	10.0
	Fruit flies and Mealy bug	5	16.7	16.7	26.7
	Mealy bug and Aphids	1	3.3	3.3	30.0
	Fruit flies, Mealy bug and Aphids	1	3.3	3.3	33.3
	MSW	2	6.7	6.7	40.0
	Mealy bug	1	3.3	3.3	43.3
	Fruit flies and MSW	11	36.7	36.7	80.0
	Fruit flies, MSW and Mealy bug	5	16.7	16.7	96.7
	Fruit flies, MSW, Mealy bug, Aphids and Coconut bug	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Whether farmer knows MSW

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	30	100.0	100.0	100.0

Whether farmer has MSW on farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	26	86.7	86.7	86.7
	No	4	13.3	13.3	100.0
	Total	30	100.0	100.0	

Whether MSW problem still persist

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	20	66.7	76.9	76.9
	No	6	20.0	23.1	100.0
	Total	26	86.7	100.0	
Missing	System	4	13.3		
Total		30	100.0		

How farmer controls MSW

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Chemical Control	5	16.7	50.0	50.0
	Integrated Pest Control Method	1	3.3	10.0	60.0
	Chemical and Cultural Method	4	13.3	40.0	100.0
	Total	10	33.3	100.0	
Missing	System	20	66.7		
Total		30	100.0		

Time farmer controls MSW attack

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flowering Stage	5	16.7	16.7	16.7
	Golf ball size	3	10.0	10.0	26.7
	Tennis ball size	1	3.3	3.3	30.0
	After harvesting	5	16.7	16.7	46.7
	Flowering stage and Golf ball size	2	6.7	6.7	53.3
	Flowering stage and Full maturity	2	6.7	6.7	60.0
	Flowering stage and After harvesting	11	36.7	36.7	96.7
	Flowering stage, Tennis ball size and Full maturity	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Stage MSW usually attack

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flowering stage	4	13.3	13.3	13.3
	Golf stage	16	53.3	53.3	66.7
	Tennis ball size	3	10.0	10.0	76.7
	Full maturity	1	3.3	3.3	80.0
	Flowering stage and Golf ball size	4	13.3	13.3	93.3
	Flowering stage and Tennis ball size	1	3.3	3.3	96.7
	Flowering stage, Tennis ball size and Full maturity	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

How do you determine the farm is free from MSW

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dissecting of sampled fruits	30	100.0	100.0	100.0

Whether MSW is a major or a minor pest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	23	76.7	76.7	76.7
	No	7	23.3	23.3	100.0
	Total	30	100.0	100.0	

Why is MSW a major pest

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Its a quarantine pest	11	36.7	47.8	47.8
	Its difficult to detect	4	13.3	17.4	65.2
	Its difficult to control	4	13.3	17.4	82.6
	It reduces fruit quality	2	6.7	8.7	91.3
	Its a quarantine pest and difficult to detect	1	3.3	4.3	95.7
	Reduce fruit quality and promotes premature fruit drops	1	3.3	4.3	100.0
	Total	23	76.7	100.0	
Missing	System	7	23.3		
Total		30	100.0		

Number of fruiting season

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Two Seasons	30	100.0	100.0	100.0

Season with high infestation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Minor Season	1	3.3	3.3	3.3
	Major Season	27	90.0	90.0	93.3
	Both Seasons	2	6.7	6.7	100.0
	Total	30	100.0	100.0	

Who are your targeted consumers

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Export	1	3.3	3.3	3.3
	Processing Company	3	10.0	10.0	13.3
	Export and Processing Company	10	33.3	33.3	46.7
	Processing Company and Local Market	3	10.0	10.0	56.7
	Export, Processing Company and Local Market	13	43.3	43.3	100.0
	Total	30	100.0	100.0	

Annual income from fruit sales

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 5000	1	3.3	3.3	3.3
	5000-10000	6	20.0	20.0	23.3
	10000-15000	2	6.7	6.7	30.0
	15000-20000	9	30.0	30.0	60.0
	20000-25000	4	13.3	13.3	73.3
	Greater than 25000	8	26.7	26.7	100.0
	Total	30	100.0	100.0	

Annual expenditure on pest control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 2000	4	13.3	13.3	13.3
	2000-5000	23	76.7	76.7	90.0
	5000-8000	3	10.0	10.0	100.0
	Total	30	100.0	100.0	

Annual expenditure on MSW control

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 2000	21	70.0	70.0	70.0
	2000-5000	8	26.7	26.7	96.7
	5000-8000	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Appendix 2.

Chi square analysis of selected parameters to determine association between the selected parameters.

Number of years of farming * Farm size of respondent Cross tabulation

Count

		Farm size of the respondent			Total
		Less than 5 acre or Small scale	5-20 acre / medium scale	Greater than 20 acres / Large scale	
Number of years of farming	Less than 5yrs	0	0	1	1
	5-10yrs	1	3	0	4
	11-20yrs	3	12	6	21
	21-30yrs	0	1	2	3
	Over 30yrs	0	0	1	1
Total		4	16	10	30

Number of years of farming * Farm size of respondent Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.933[a]	8	.440
Likelihood Ratio	9.750	8	.283
N of Valid Cases	30		

a. 13 cells (86.7%) have expected count less than 5. The minimum expected count is .13.

Educational Background of respondent * Annual income from fruit sales Cross tabulation

Count

		Annual income from fruit sales						Total
		Less than 5000	5000-10000	10000-15000	15000-20000	20000-25000	Greater than 25000	
Educational Background of respondent	Basic	0	2	1	3	0	3	9
	Secondary	0	2	0	5	3	2	12
	Tertiary	1	2	1	1	1	3	9
Total		1	6	2	9	4	8	30

Educational Background of respondent * Annual income from fruit sales Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.634[a]	10	.567
Likelihood Ratio	10.700	10	.381
N of Valid Cases	30		

a. 18 cells (100.0%) have expected count less than 5. The minimum expected count is .30.

How farmer controls MSW * Annual expenditure on MSW control Cross tabulation

Count

		Annual expenditure on MSW control			Total
		Less than 2000	2000-5000	5000-8000	
How farmer controls MSW	Chemical Control	4	0	1	5
	Integrated Pest Control Method	1	0	0	1
	Chemical and Cultural Method	2	1	0	3
Total		7	1	1	9

How farmer controls MSW * Annual expenditure on MSW control Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2.914[a]	4	.572
Likelihood Ratio	3.484	4	.480
Linear-by-Linear Association	.029	1	.864
N of Valid Cases	9		

a. 9 cells (100.0%) have expected count less than 5. The minimum expected count is .11.

Time farmer controls MSW attack * Stage MSW usually attack Cross tabulation

Count

		Stage MSW usually attack						Total
		Flowering stage	Golf stage	Tennis ball size	Full maturity	Flowering stage and Golf ball size	Flowering stage and Tennis ball size	
Time farmer controls MSW attack	Flowering Stage	0	5	0	1	0	0	6
	Golf Size	0	3	0	0	0	0	3
	Tennis Ball Size	0	0	1	0	0	0	1
	After Harvesting	2	1	0	0	2	0	5
	Flowering stage and Golf size	0	1	1	0	0	0	2
	flowering stage and Full maturity	1	0	0	0	0	1	2
	Flowering stage and After harvesting	2	6	1	0	2	0	11
Total		5	16	3	1	4	1	30

Time farmer controls MSW attack * Stage MSW usually attack Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	45.505[a]	30	.035
Likelihood Ratio	34.364	30	.267
Linear-by-Linear Association	.139	1	.710
N of Valid Cases	30		

a. 41 cells (97.6%) have expected count less than 5. The minimum expected count is .03.

Who are your targeted consumers * Annual income from fruit sales Cross tabulation

Count

		Annual income from fruit sales						Total
		Less than 5000	5000-10000	10000-15000	15000-20000	20000-25000	Greater than 25000	
Who are your targeted consumers	Export	0	0	0	1	0	0	1
	Processing Company	1	1	0	1	0	0	3
	Export and Processing Company	0	3	0	2	0	5	10
	Processing Company and Local Market	0	0	0	1	1	1	3
	Export, Processing Company and Local Market	0	2	2	4	3	2	13
Total		1	6	2	9	4	8	30

Who are your targeted consumers * Annual income from fruit sales Chi-Square Tests

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	22.783[a]	20	.300
Likelihood Ratio	21.421	20	.373
N of Valid Cases	30		

a. 30 cells (100.0%) have expected count less than 5. The minimum expected count is .03.

Appendix 3

ANOVA FOR TOTAL NUMBER OF INFESTED MANGO FRUITS OVER THE GROWING PERIOD FOR MAJOR SEASON

Bartlett's test for homogeneity of variances

Chi-square * on -1 degrees of freedom: probability < 0.001

Shapiro-Wilk test for Normality

Data variate: Percentage Number of Infested Mango Fruits

Test statistic W: 0.9281

Probability: 0.142

Analysis of variance

====================

Variate: Percentage Number of Infested Mango Fruits

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	4	79.38	19.84	0.48	
Treatment	3	4646.48	1548.83	37.41	<.001
Residual	12	496.88	41.41		
Total	19	5222.73			

Tables of means

===============

Grand mean 30.4

Treatment	CR	DR	GR	SR
	47.5	21.0	42.8	10.5

Standard errors of means

Table	Treatment
rep.	5
d.f.	12
e.s.e.	2.88

Standard errors of differences of means

Table	Treatment
rep.	5
d.f.	12
s.e.d.	4.07

Least significant differences of means (5% level)

Table	Treatment
rep.	5
d.f.	12
l.s.d.	8.87

Coefficients of variation

=========================

Cv% 21.1

Fisher's protected least significant difference test

==

Treatment

	Mean	
CR	47.50	a
GR	42.75	a
DR	21.00	b
SR	10.50	c

Appendix 4

ANOVA FOR TOTAL NUMBER OF INFESTED MANGO FRUITS OVER THE GROWING PERIOD FOR MINOR SEASON

Bartlett's test for homogeneity of variances

Chi-square * on -1 degrees of freedom: probability < 0.001

Shapiro-Wilk test for Normality

Data variate: Percentage Number of Infested Mango Fruits

Test statistic W: 0.9329

Probability: 0.176

Analysis of variance

====================

Variate: Percentage Number of Infested Mango Fruits

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	4	195.00	48.75	1.00	

Treatment	3	2418.36	806.12	16.55	<.001
Residual	12	584.38	48.70		
Total	19	3197.73			

Tables of means

===============

Grand mean 29.2

Treatment	CR	DR	GR	SR
	39.2	28.5	37.5	11.5

Standard errors of means

Table	Treatment
rep.	5
d.f.	12
e.s.e.	3.12

Standard errors of differences of means

Table	Treatment
rep.	5
d.f.	12
s.e.d.	4.41

```
Least significant differences of means (5% level)
---------------------------------------------------
Table              Treatment
rep.                       5
d.f.                      12
l.s.d.                  9.62


Coefficients of variation
=========================
Cv%     23.9


Fisher's protected least significant difference test
=====================================================
Treatment
---------
          Mean
CR       39.25 a
GR       37.50 ab
DR       28.50 b
SR       11.50 c
```

Appendix 5:

Questionnaire for mango farmers

QUESTIONNAIRE FOR MANGO FARMERS

INTRODUCTION

This study is being undertaken by a Radiation Entomology student of the School of Nuclear and Applied Sciences, University of Ghana, on On-farm and Post-Harvest Management of Mango Stone Weevil. This questionnaire is intended to assess the level of mango stone weevil infestation within the eastern mango enclave.

This questionnaire is for academic proposes only and any information provided by respondents would be kept confidential.

Thank you.

Contact Line **0242-889-670 / 0277-973-267 / 0508-555-667**

Please tick (√) the appropriate box and fill in the blank space where appropriate.

1. Gender
   (a) Male [ ]   (b) Female [ ]

2. Age
   (a) Youth [ ] (*Less than 25ys*)   (c) Adult [ ] (*25 – 50yrs*)   (c) Aged [ ] (*Over 50yrs*)

3. Educational background
   (a) Nil [ ]   (b) Basic [ ]
   (c) Secondary [ ]   (d) Tertiary [ ]

4. How many years have you been farming?
   (a) Less than 5yrs [ ]   (b) 5 – 10yrs [ ]   (c) 11 – 20yrs [ ]
   (d) 21 – 30yrs [ ]   (e) Over 30yrs [ ]

5. What is the acreage of your farm?
   (a) Small farm holder (*less than 5acres*) [ ]
   (b) Medium size plantation (*5-20 acres*) [ ]
   (c) Large plantation (*greater than 20acres*) [ ]

6. What variety do you grow?
   (a) Keitt [ ] (b) Kent [ ] (c) Palmer [ ] (d) Haden [ ]
   (e) Springfield [ ] (f) Sunset [ ] (g) Other(s) specify…………………
7. Do you encounter pest on your field?
   (a) Yes [ ] (b) No [ ]
8. If **Yes**, what pest do you often encounter?
   …………………………………………………………………………………………
   …………………………………………………………………………………………
9. Do you know about mango stone weevil?
   (a) Yes [ ] (b) No [ ]
10. If **Yes**, have you ever encountered mango stone weevil on your farm?
   (a) Yes [ ] (b) No [ ]
11. If **Yes**, does the mango stone weevil still persist on your farm?
   (a) Yes [ ] (b) No [ ]
12. If **No**, how did you to control the mango stone weevils?
   (a) Trunk banding (b) Biocontrol agents (c) Insecticide application
   (d) Farm hygiene (e) IPM (f) Other(s) specify ……………
13. At what time do you often apply control measure(s)?
   (a) Flowering stage (b) Golf ball size (c) Tennis ball size
   (d) Full maturity (e) After harvesting
14. How do you determine that your farm is free from mango stone weevil?
   …………………………………………………………………………………………
   …………………………………………………………………………………………
15. At what stage does the mango stone weevil usually attack?
   (a) Flowering stage (b) Golf ball size (c) Tennis ball size (d) Full maturity
16. Do you consider the mango stone weevil a major pest on your orchard?
   (a) Yes [ ] (b) No [ ]
17. If **Yes**, what makes the mango stone weevil an important pest?
   (a) It is a quarantine pest (b) Difficult to detect (c) Difficult to control
   (d) Reduces quality of fruit (e) Causes premature fruit drop
   (f) Other specify……………………………………………………………………

18. How many fruiting seasons do you have in your agro-ecological zone?
(a) One (major) (b) Two (major and minor)

19. Which of the seasons do you have more mango stone weevil infestation?
(a) Minor (b) Major

20. Who are your targeted consumers?
(a) Export market (b) Processing companies (c) Local market
(*Respondent can select more than one option*)

21. How much do you earn annually from sale of fruits?
(a) Less than GH₵5,000:00 (b) Above GH₵5,000 – 10,000:00
(c) From GH₵10,000 – 15,000:00 (d) AboveGH₵15,000 – 20,000:00
(e) Above GH₵20,000 – 25,000:00 (f) Over GH₵25,000:00

22. How much do you spend annually on pest control?
(a) Less than GH₵2000:00 (b) From GH₵2,000 – 5,000:00
(c) Above GH₵5,000 – 8,000:00 (d) Above GH₵8000 – 11,000:00
(e) Other specify……………………………………………………………………………………

23. How much do you spend annually on mango stone weevil control?
(a) Less than GH₵2000:00 (b) From GH₵2,000 – 5,000:00
(c) Above GH₵5,000 – 8,000:00 (d) Above GH₵8000 – 11,000:00
(e) Other(s) specify…………………………………………………………………………….