DECLARATION

I hereby declare that, this work is the result of my own original research and that this thesis has neither in whole nor part been presented anywhere for a degree except for the references cited in relation to other works.

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ABSTRACT

Studies were conducted on mango farmers' indigenous technical knowledge about the mango stone weevil (*Sternochetus mangiferae* L.) and the impact this knowledge have on the management of the weevil. Laboratory studies were also carried out on the bio-ecology of the weevil. For farmers' indigenous technical knowledge, the country was divided into three zones (Southern, Middle and Northern Zones) and structural questionnaire was administered to a total of 125 farmers chosen at random. Fruits were also collected from each zone and dissected to ascertain the levels of infestation. The results showed that awareness about pests among mango farmers was high (96.0%). About 34.4% and 35.2% of the respondents indicated the mango stone weevil and fruit flies, respectively, were the most important insect pests of the crop in Ghana. Only 40.8% of the respondents have adopted the use of garlic extract, pepper, neem seed extract, local soap (alata samina), wood ash and cow dung as part of the indigenous, non-synthetic materials for the management of insect pests on the crop. On the infestation of the mango fruits by the weevils, 15.6%, 38.1% and 46.1%, were recorded on mango collected from the Northern, Middle and Southern zones respectively. From bio-ecological studies, it was found that fresh mango flowers are the most attractive part to mango stone weevils (*S. mangiferae*). The study also revealed that black colour significantly ($P < 0.05$) attracts more weevils than the other colours. This has shown that visual stimuli such as shape and colour have an effect on the habitat behaviour of the weevil.

DEDICATION

This work is dedicated to my brother, Mr. Peter Ackon for his support and encouragement.

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I say God bless you all.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Mango (*Mangifera indica* L.) is the most widely cultivated fruit tree in the tropics (Deng and Janssen, 2004). The mango fruits are eaten raw and serve as an excellent source of dietary fiber, provitamin A and vitamin C (Evans, 2008).World production of mango in 2005 was estimated at 28.51 million tonnes (Evans, 2008). Of this, Africa produced only 2.5 million tonnes, accounting for about 10% of fresh fruits and 11% of processed mango. Ghana's production is reported to have increased from about 1,200 tonnes in 2007 to about 2,000 tonnes in 2008 (Quartey, 2008). It is targeted as the next non-traditional export crop expected to fetch the highest foreign exchange for the country replacing cocoa (Quartey, 2008). The export of 857.57 tonnes in 2008 was valued at US $521,820 (ISSER, 2009). This significant export volume of mango from Ghana to the European and Asian markets far exceeds the demand (Avah *et al.*, 2008). This shows clearly that there is a potential to increase production of mango in Ghana.

However, profitable mango production however, is hampered by several challenges, including inappropriate agronomic practices, lack of adequate true-to-type planting materials, inappropriate pest and disease management technologies, poor extension support systems, poor post-harvest handling technologies and poor marketing infrastructure as well as lack of appropriate credit support facilities (Braimah *et al.*, 2010). Currently, the key problem is in the area of insect pest management. Notable among these insect pests are mango mealybugs, the mango stone weevil, fruit flies, thrips and tip wilters.

The mango stone weevil (MSW), *Sternochetus mangiferae* L (Coleoptera: Curculionidae) is an important phytosanitary pest of the Ghana mango industry. The presence of mango stone weevils in mango seeds of any of the varieties being grown hinders the Ghana industry from gaining access to new foreign markets. Even in existing export countries such as the Netherlands and the rest of Europe, where phytosanitary restrictions are less strict, the presence of adult weevils in mango fruit contributed to a substantial percentage of export fruit rejections in the past (Joubert and Pasques, 1994; Schoeman, 1988).

In Ghana, the mango stone weevil causes losses varying from 5-80%, depending on the place and variety of mango (Verghese *et al*., 2005). The loss affects production and export to the international market because of quarantine restrictions imposed by importing countries and the market requirement for blemish-free fruit (Varela *et al*., 2006). The infestation behaviour of the mango stone weevil exacerbates the problem because, in many instances, weevil attack remains undetected in the field, and is first noticed in storage or in transit (Varela *et al*., 2006). All the evidence suggests that weevils spread into clean areas through the movement of infested fruits for propagation and consumption (Pinese and Holmes, 2005).

Proper management of the mango stone weevil is a prerequisite to meeting the quality demanded in the competitive export market (Braimah *et al*., 2010). The use of synthetic insecticides to manage insect pests has arguably been the mainstay of fruit crop production. However, the increasing demand for organically grown foods in the face of environmental and health concerns has downplayed reliance on synthetic pesticides to manage pests and the identification of eco-friendly and reliable alternatives would be an incentive to minimize reliance on synthetic insecticide use. Effective management of mango stone weevil using indigenous technical knowledge at the farm level will serve as an incentive to increase mango production for the local market and export (World Bank, 2011). But very limited research work has been conducted on this pest. Technology development relies on the understanding of knowledge gaps to guide the development of appropriate technologies to fill them. Braimah *et al.* (2009) conducted some preliminary work to understand the bio-ecology of the weevil and to determine the relationships between it and mango plant with very little work on the bio-ecology of the pest. It was against this backdrop that this study was to determine the indigenous technical knowledge of mango farmers about stone weevils (*Sternochetus mangiferae*) and current management practices and bio-ecology of the weevil was undertaken.

The specific objectives were to:

(i) assess the general perception and awareness level among mango farmers about the mango stone weevil

(ii) determine the indigenous management practices adopted by mango farmers in managing the stone weevil in Ghana

(iii) determine the impact of the mango stone weevil on the production and export of mango in Ghana

(iv) examine the influence of some environmental, especially habitat factors on the foraging behaviour of the mango stone weevil

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mango Tree

According to McGovern and LaWarre (2001), mango (*Mangifera indica* L.) belongs to the family Anacardiaceae. Mango is indigenous to India. Cultivated in many tropical and subtropical regions and distributed widely in the world, mango is one of the most extensively exploited fruit for food, juice, flavour, fragrance and colour. In several cultures, its fruit and leaves are ritually used as floral decorations at weddings, public celebrations and religious ceremonies (McGovern and LaWarre, 2001).

2.1.1 Botany

According to Kaur *et al*. (1980) the mango tree is believed to have evolved as a canopy layer in the tropical rainforest of Southeast Asia. Mature trees attain heights of up to 30 m, and can survive for more than 100 years. The tree is an arbore scent evergreen tree with alternate, oblong ovate leaves that are spirally arranged. Young leaves are characteristically pink to red in colour, but become dark green and leathery during development. Older leaves are 12 – 15 cm in length. The inflorescence is erect and widely branched with hundreds of small flowers. The flowers are pink to red in colour and 6 – 8 mm in diameter. Both female and male flowers are found within a single inflorescence. The pollination is done by insects, in particular insects (Singh *et al.*, 1962; Jiron and Hedström, 1985).

2.1.2 Cultivars

Knight and Schnell (1994) stated that some of the Florida cultivars of mango, notably, Haden, have been important in aiding the establishment of a modern mango industry in other parts of the world and that the phenomenon first observed in Florida is occurring elsewhere. According to them the mango industry is now presented with the prospect of the importation/exportation of cultivars of outstanding merit from their countries of origin to be grown; first experimentally and later commercially, in new regions. For this reason it is important to become familiar with the characteristics of a group of cultivars that currently are known in the commerce and/or horticulture of one or more countries and that may have potential for expanded culture or use in breeding (Knight and Schnell, 1994).

2.1.3 Mango Industry in Ghana

Mango is touted as the next big commodity in Ghana 'with the potential to replace cocoa as the nation's most valuable cash crop. Over the years there has been widespread interest in the cultivation of the crop not only by development agencies under various environmental protection and poverty reduction programmes, but also by private individuals and companies for export (Avah *et al.*, 2008). The Centre for the Promotion of Imports from Developing Countries Market Survey (CPIMS) (2008) reported that the mango fruit is one of the most highly esteemed fruits of the tropics. The importance of mango to many Ghanaians is epitomized in the description of the crop as 'Golden true, 'next cash crop, 'gold mine, 'Ghana's future, amongst others (Avah *et al.*, 2008). Mangoes account for approximately 50% of all tropical fruits produced worldwide (FAO, 2008).

According to the European Union Strategic Marketing Guide (EUSMG, 2001), favourable climatic conditions and low labour cost leading to the low production cost give the South American and African countries a strong position on the European markets. The report further stated that Ghana compared to some of the countries in the southern region is closer to Europe and thus gives it the urge in terms of market opportunities due to lower transportation cost and shorter delivery times. Irrespective of these opportunities, Ghana is unable to take advantage due to the uncompetitive state of the industry. For example, a report on a baseline study on the mango industry in Ghana indicated overwhelmingly among other challenges that mango farmers in Ghana have difficulty in determining when to harvest fruits for the export and local markets (Abu *et al*., 2011). Litz (2003) reported lack of simple and reliable methods for determining the stage of fruit maturity also affects quality. One of the major problems currently restricting international trade in mangoes is the variation in physiological maturity in a single consignment (Mitra, 1997).

2.2 Factors Hindering Mango Production and Export in Ghana

2.2.1 Pests and Diseases

Mango production in Ghana is threatened by the attack of many insect pests, including mango mealybug (*Rastrococcus invadens* William), mango stone weevil (*S. mangiferae*), fruit flies (*Bactrocera invadens* Drew, Tsuruta and White), thrips (*Selenothrips* spp.), and tip wilters (*Callimetropus* spp.) (Braimah *et al*., 2009). Fruit flies, especially *B. invadens*, described as the most devastating fruit fly pest in Africa (Ekesi and Billah, 2006; French, 2005) attack both ripe and unripe fruits by laying eggs under the skin of the fruit. The eggs hatch into larvae which feed on the fruit tissue resulting in the rotting of the fruit and premature fruit drop (Afreh-Nuamah, 2007). Yields are not significantly affected by the mango stone weevil, since the larvae usually feed entirely within the stone and very rarely in the pulp of the fruit. However, post-harvest damage to the pulp of late-maturing cultivars by emerging adults occurs in Africa, including Ghana (Kok, 1979). Kok (1979) further reported that the adults tunnel through the fruit, leaving scars on the outside which serve as sites for secondary fungal infection. Probably its greatest significance as a pest is to reduce the germination capacity of seeds greatly and to interfere with the export of fruit, because of quarantine restrictions imposed by importing countries (Bagle and Prasad, 1985).

According to Braimah *et al.* (2010), diseases including anthracnose, bacterial black spot, powdery mildew, scab, wilt and many other infect mangoes in the nursery, orchard or in storage or transit. These pests and diseases affect the quality of fruits.

2.3 Economic importance of Mango stone weevils

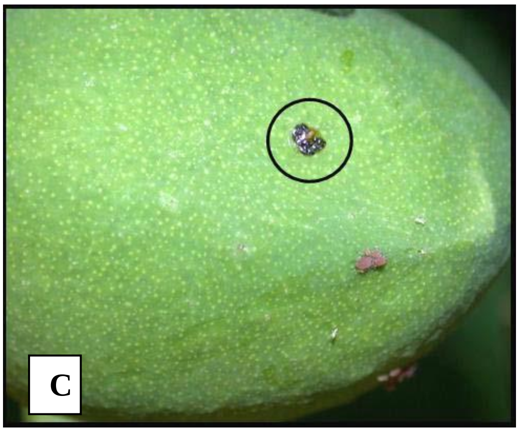
The mango stone weevil is an important phytosanitary pest for the mango industry. Mango weevil is considered an important pest of mango fruit worldwide (Peña *et al.,* 1998). It is considered as a serious pest because its development in the fruit causes damage to the pulp rendering it unmarketable, reduces the germination of seeds and causes premature fruit drop. Contrasting reports are found in literature regarding pulp feeding by the mango seed weevil; however, pulp feeding is considered to be rare (Follet and Gabbart, 2000; Hansen *et al.*, 1989). Pulp feeding was observed in South Africa, but the incidence was considered to be low in the cultivar 'Kent' but not in the early maturing cultivar 'Tommy Atkins'. Pulp feeding might have resulted from eggs laid late in the season when seed husks had already hardened and thus prevented penetration by larvae (Louw, 2006). Pulp damage is also caused when adult weevils emerge from the fruit on the trees in late season cultivars (Kok, 1979; Milne *et al.,* 1977).

Louw (2006) found emergence holes on the cultivar 'Kent' but the incidence was low. Exit holes were not present on the early maturing cultivar 'Tommy Atkins'. Studies conducted in Hawaii to assess the effect of mango weevil infestation on seed viability showed that mango seed can withstand substantial damage and still germinate successfully (Follett and Gabbard, 2000). Follett (2002) studied the effect of mango seed weevil infestation on premature fruit drop and reported that mango weevil infestation can increase fruit drop during early fruit development. When infestation by mango seed weevil was reduced by chemical sprays, fruit drop also decreased (Verghese *et al.*, 2005).

2.4 Biology and Ecology of Mango Stone Weevil

The Mango stone weevil is an insidious pest that spends most of its life cycle inside the mango seeds (Pena *et al.*, 1998). Adult female weevils oviposit into boat-shaped cavities on the fruit (Follet, 2002; Smith, 1996)

Plate 2.1. Mango stone weevil eggs laid (A) and Egg (B).
Pictures courtesy Louw. C. Estelle



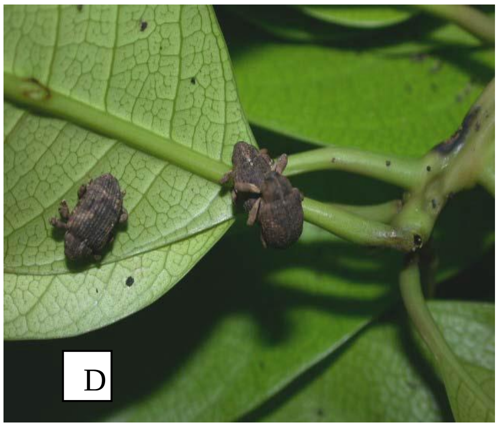


Plate 2.2. Mango stone weevil eggs (encircled) (C) and Mature stone weevil (D) Pictures courtesy Louw. C. Estelle

The larvae burrow through the pulp to the developing seed on hatching. The tunnel made by the larvae becomes undetectable after a short time (Woodruff and Fasulo, 2006; Joubert, 1998). The subsequent larval and pupal stages occur in the seed (Follet and Gabbard, 2000). The larvae feed on the seed and makes extensive tunnels on the seed surface. A copious amount of frass is deposited in these feeding tunnels. The strategy of feeding inside the seed capsule makes it difficult to control the pest by use of such conventional methods as a foliar application of chemical pesticides. Newly emerged grubs bore through the pulp, feed on seed coat and later cause damage to cotyledons. Pupation takes place inside the seed. Pulp is discoloured around the affected portion.

The adult weevils become reproductively active when mango flowers begin to bloom (Hansen *et al.*, 1989). Small or marble-size fruits are preferred, but nearly full-grown fruit may also be attacked. The female makes a boat shaped cavity in the skin (epicarp) in which an egg is deposited. She then covers each egg with a brown exudate and cuts a crescent-shaped area 0.25 - 0.50 mm in the fruit, near the posterior end of the egg. The wound creates a sap flow, which solidifies and covers the egg with a protective opaque coating (Hansen, 1993). One female may lay 15 eggs per day, with a maximum of almost 300 over a three-month period (Balock and Kozuma, 1964). The oviposition data suggested that the female weevils randomly select fruit for egg-laying and, hence, do not mark the oviposition site (Hansen *et al.,* 1989). Hansen *et al.* (1989) concluded that the mango seed itself must be a nutritious resource, considering that five or more individuals can successfully complete development within one seed. After hatching, the small larva burrows through the pulp to the young developing seed. Generally, only one larva develops into a seed, but as many as five have been found. Larval development usually occurs within the seed and only very rarely in the pulp (Hansen *et al.*, 1989). Hansen *et al.* (1989) believed that the larvae excavate cavities within the seed and pupate. Balock and Kozuma, (1964) calculated the larval period at 22 days. However, larval developmental period may be influenced by climate, location, host cultivar, and non-biotic site characteristics, for example, soil chemistry and humidity (Hansen *et al.,* 1989). The pupal stadium lasts for about a week (Balock and Kozuma, 1964).

Adults generally emerge from the seed about one or two months after the fruit has dropped and the fruit pulp has been consumed by various organisms (Balock and Kozuma, 1964). Upon maturation, the adults rapidly move out of the seed and find hiding places. The weevils hide under loose tree barks, in the crotches of trees, under loose material beneath the trees and are able to hibernate inside the seed of the mangoes. Schoeman (1987) found weevils in crotches of trees after harvest, whereas soil samples and samples of loose material under the trees produced no weevils. According to Griesbach (2003) once the mango stone weevils have left the fruit, they search for a hiding place such as beneath loose bark of trees or in waste material under the trees where they spend the time of the year that is unfavourable for them.

According to Balock and Kozuma (1964) the weevils remain in the sheltered locations until the fruiting season of the following year.

The factors which break diapause and motivate the weevils to seek oviposition sites are unknown (Hansen *et al.,* 1989). Balock and Kozuma (1964) suggested that the onset of diapause seems to be associated with long-day photoperiod, and the break with short-day photoperiod. Mango weevils possess well-developed wings, but are poor fliers and fly only 50 to 90 cm at a time (De Villiers, 1983; Kok, 1979). However, Schoeman (1987) observed the weevils fly from tree to tree with ease and quickly disappear into the foliage. In India the adult weevils were found to feed on the leaves and tender shoots of mango trees during March and April. They are nocturnal, fly readily and usually feed, mate and oviposit at dusk. After emergence, adults enter a diapause, which varies in duration according to the geographic area (Shukla and Tandon, 1985).

In a similar study in Ghana it was argued that the adult weevils fed on both honey and cotyledons of the mango seed in the laboratory and the adult weevils were attracted to mango flowers and appeared to feed on nectar and pollen. The attraction of mango stone weevils to flowers probably explains how it moves out of its hideout into flowering and fruiting mango trees and odours of flowers provide cues that direct the weevils to the host plant (Braimah *et al*., 2009).

2.4.1 Host Plant Search Process of an insect pest

Host plant's location is known to begin with some form of movement and orientation in space (Miller and Strickler, 1984). Insects may be in flight, walking in a random dispersal mode, or even moving in response to a particular stimulus when they come in contact with a stimulus that they follow to enter a host plant patch (Kennedy, 1978). Most insects which rely upon specific resources are challenged by habitat heterogeneity at several spatial scales. This is highly important for herbivorous insects which may depend on specific host plants for feeding and oviposition (Schoonhoven *et al.*, 2005). Insects that move in a landscape can detect and locate host plants that often occur in scattered patches which may differ in size, isolation and plant density (Tscharntke *et al.*, 2002). At smaller scales, when insects have entered patches, they also must be able to distinguish host plants among non-host plants (Hambäck *et al.*, 2003). The habitat heterogeneities have constraints on the host finding ability of insects, which has to rely upon different sensory cues in order to find patches and host plants (Schoonhoven *et al.*, 2005). Once within the boundaries of a habitat, direct or random oriented movements occur in response to visual, olfactory or other stimuli generated from either a host plant habitat or the host plant (Hsiao, 1985). The stimuli emanating from the resources are assessed in terms of quality, so that the foraging insect searches in the best habitat, patch or resources unit (Bell, 1990). The mango weevil occurs on mangoes only and no alternative host crops are known (Hansen *et al.*, 1989). Complete development was only achieved in mangoes. In the laboratory, oviposition was obtained on potatoes, peaches, litchi, plums, beans and several cultivars of apples, but larvae failed to reach maturity (Balock and Kozuma, 1964). In a study in the laboratory when feeding preferences between mango and other substances (protein, sugar, plant volatile) were compared, the adult weevils only visited mango (Louw, 2006). The weevils preferred to feed on very young and soft flush and did not feed on old leaves and stems. Portions of the lamina were consumed on soft flushes while in slightly older flushes feeding occurred along the veins or on stems. Weevils fed in large numbers on mango fruit, especially when it was cut in half. Weevils did not respond to mango juice (Bell, 1990).

2.4.1.1 Attractiveness of Mango Plant Parts to the Mango Stone Weevil

Schoeman (1987) found large numbers of adult seed weevils in tree crotches directly after harvest, although these numbers did not correlate to fruit infestation levels prior to harvest. During the course of the season he observed only a small number of adult weevils, either walking along tree branches within trees (Schoeman, 1987), or flying to adjacent trees where they landed with ease, disappearing into the foliage (Schoeman, 1987). He also collected soil and debris samples from beneath infested trees to investigate for the presence of mango seed weevils. These samples, however, yielded no adult weevils. The mango seed weevil (MSW) is a monophagous pest (Follett and Gabbard, 2000) with mango the only known host (Follet, 2002; Hansen and Armstrong, 1990).

2.4.1.2 Effect of Colour and Shape on weevils

Weevil response to silhouettes of different achromatic contrasts is influenced by the background colour; thus weevils use visual cues in locating their host plant in the field (Hausmann *et al.*, 2004). Visual cues are reported to be important for host plant location in insects (Prokopy and Owens, 1983). Colour background and some light spectra are known to influence the foraging activities of several insects (Braimah and van Emden, 1999) and for that matter the colour and shape preferences of the target insect are important considerations in the design and construction of insect traps (Braimah and van Emden, 1999).

2.5 Impact of Mango Stone Weevil on Mango Production and Export in Ghana

The mango stone weevil does not usually damage the fruit and consequently is not a serious pest as far as local consumption of the fruit is concerned. However, the pest hinders the development of a fresh fruit export market because the leading import countries in the Middle East and other places maintain strict quarantine regulations (Griesbach, 2003). The international quarantine infestation threshold of the mango weevil is 2.5 per cent (one out of 40 fruits) (Bagshaw *et al.,* 1989; Soe *et al.,* 1974). This rather low threshold requires that serious attention is paid to the problem posed by the mango weevil.

2.5.1 Management of Mango Stone Weevil

Recommended practices for management of the mango stone weevil include orchard hygiene, application of pesticides (such as Lebaycid, Azinphos, Endolsulfan, Malathion and Carbosulfan) adherence to quarantine regulations and planting resistant cultivars (Pinese and Holmes, 2005; Griesbach, 2003; Joubert, 1998; Smith, 1996; Hill, 1975). Pesticides are applied either as foliar sprays or as trunk paint bands (Griesbach, 2003). The reduction in infestation levels that results after using the recommended practices varies from one region to the other. Griesbach (2003) argued that most of these insecticides have been uneconomical and ineffective. He argued that the combination of sanitation of the orchard, treatment of the trunk and branches with insecticides and fruit treatment with pesticides usually reduces the weevil population in the orchard better than the application of single insecticides.

2.5.1.1 Effect of pesticide application

According to Ntow (2008), worldwide pesticide usage has increased tremendously since the 1960s. It has largely been responsible for the "green revolution", when there was massive increase in food production obtained from the same surface of the land with the help of mineral fertilisers (nitrogen, phosphorus, and potassium), more efficient machinery and intensive irrigation. The use of pesticides helped to significantly reduce crop losses and to improve the yield of crops such as corn, maize, vegetables, potatoes and cotton. Notwithstanding the beneficial effects of pesticides, their adverse effects on environmental quality and human health have been well documented worldwide and constitute a major issue that gives rise to concerns at local, regional, national and global scales (Cerejeira *et al*., 2003; Kidd *et al*., 2001; Ntow, 2001; Huber *et al*., 2000; Planas *et al*., 1997). Residues of pesticides contaminate soils and water, persist in the crops, enter the food chain, and finally are ingested by humans with foodstuffs and water. Furthermore, pesticides can be held responsible for contributing to biodiversity losses and deterioration of natural habitats (Sattler *et al*., 2006). There have been reported instances of pest resurgence, development of resistance to pesticides, secondary pest outbreaks and destruction of non-target species. Despite the fact that pesticides are also applied in other sectors, agriculture can undoubtedly be seen as the most important source of adverse effects (Sattler *et al*., 2006).

2.5.1.2 Pest Resistant Varieties

According to Braimah and van Emden (2010) varietal resistance is one of the foundation blocks of any sustainable pest management programme. Thus, the authors believe that would be the cheapest means of control as well as the best-suited for the mango industry in Ghana, considering the financial situation of the average farmer, the environmental friendliness of the approach and especially its compatibility with other pest management tactics and the required stringent market standards.

2.5.1.3 Local Technology and Government Intervention

Nzomoi *et al*. (2007) reported that numerous problems are associated with technologies that are not locally developed. Common difficulties include inappropriateness, lack of qualified personnel to implement them, and high costs associated with the acquisition and utilization of such technologies.

On the role of government in the horticultural industry, Nzomoi *et al*. (2007) observed that government plays a significant role that enables firms or farms to enhance their production and marketing strategies. For technologies to be utilized there is a need for government involvement in making it possible for the users to conveniently benefit from the availability of the new technology. Nzomoi *et al*. (2007) further stated that failure to utilize technologies by the various intended beneficiaries can be blamed on the government's inability or reluctance to facilitate same, and that government's role should be minimized since excessive government meddling can actually curtail productivity in the horticultural industry.

2.6 The Role of Indigenous Knowledge in Agriculture

Indigenous knowledge is the unique knowledge confined to a particular culture or society. It is also known as local knowledge, folk knowledge, people's knowledge, traditional wisdom or traditional science. This knowledge is generated shared and transmitted by communities, over time, in an effort to cope with their own agro-ecological and socioeconomic environments (Fernandez, 1994). Indigenous knowledge is passed from generation to generation, usually by word of mouth and cultural rituals. It is anchored in actions, experiences and values of a particular social group. Indigenous knowledge is not just a compilation of facts drawn from local and remote environment, but a complex and sophisticated system of knowledge drawn from centuries of experience, testing and wisdom of local people (World Bank, 1998).

Indigenous knowledge systems combine culture and religion, therefore making it compatible with indigenous environment and culture. Indigenous knowledge includes accumulated knowledge as well as the skills and technologies of the local people that are developed locally and handed down through the centuries (Khodamoradi and Abedi, 2011). Dewalt (1994) states that even farmers who are part of the modern agriculture have an indigenous knowledge system. African communities have a vast array of Indigenous knowledge in food technology that is favourable to the supply, quality and safety of food and hence has a direct contribution to food security (Aniang'o *et al.*, 2003). According to Khodamoradi and Abedi (2011), indigenous knowledge is accessible, useful and cheap. This makes it important in supporting the poor farmers in the marginal areas who have no physical and economic access to scientific technologies.

2.6.1 Indigenous Knowledge and Insect Pests Management Practices

There are several traditional pest management practices that risk being forgotten if they are abandoned for the sake of chemical pesticide usage. According to Morales (2002) such practices include site selection, soil management, timing of planting and harvesting, crop resistance, intercropping, weed management, harvest residue management, post-harvest management, management of natural, mechanical control and use of repellents and traps in the natural regulation of potential pests. This section discusses some of the practices and their application to mango production in Ghana.

In the face of this continuing failure to control pest losses in Sub-Saharan Africa with synthetic chemical insecticides, Grzywacz *et al*. (2013) proposed that there is a need to explore more vigorously alternative, more affordable, appropriate and sustainable solutions to the current pest control model that focuses exclusively on the use of imported synthetic chemicals as the primary option. This would not seek to replace current pest control systems where they are effective, nor impede attempts to develop or disseminate modern pest control to a wider constituency, but it could have a useful role in providing an alternative, cheaper, locally-accessible option for the poor subsistence farmers who cannot afford the more expensive synthetic pesticides or lack the resources to use them.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study was conducted from August 2013 to July 2014. The study consisted of two phases as outlined below.

PHASE I

Studies on Farmers Indigenous Technical Knowledge on mango stone weevil

3.1 Study Area

3.1.1 Study Zones and Communities

The study covered all mangoes producing areas in Ghana except, Upper East, Upper West, and Central Regions. For the purpose of this study, the country was divided into three main zones (Figure 3.1).

Figure 3.1. Map of Ghana showing the towns covered under the study

3.2 Pretesting Questionnaire

A pilot survey was conducted in three communities (Somanya, Kintampo and Tamale) which represented the Southern, Middle and Northern Zones, respectively. The pilot was conducted in October, 2013, one month before the actual field data collection. It was carried out to pre-test the research instruments (questionnaires, key informant interview guide and on-farm observation guide) and to work out the modalities for the identification of all stakeholders, especially those in mango production and export.

3.3 Sampling Procedure

The study employed a stratified random sampling procedure to ensure adequate representation of mango farmers in the three main zones identified. Within the zones, prominent mango producing communities/towns were selected. Since the total number of mango producing households in the country was not known, the snowball technique (Sarantakos, 1997) was employed to identify the unknown mango producing communities/towns and thus the mango farmers. The number of mango farmers interviewed in the three zones is presented in Table 3.1.

Table 3.1. Number of respondents interviewed in each of the three zones.

Zone	Number of Respondent Interviewed
Southern	37
Middle	55
Northern	33
Total	125

3.4 Data Collection

3.4.1 Primary Data

Primary data were collected using a structured questionnaire. A total of 125 mango producing households were randomly selected for the study. Additional information on the level of stone weevil infestation was also collected through the use of focus group discussions. At least one focus group discussion was organised in each of the three zones selected for the study. To complement the information gathered using the questionnaires, randomly selected key informants; including Agricultural extension agents were also consulted in the process to determine the relevance of information collected from the mango producing households.

In addition, 100 fruits were picked at random from each zone and dissected to ascertain the presence of the weevil. Fruits were collected mainly from mango trees growing in the wild (not managed).

3.5 Questionnaire Design

The questionnaire contained both open and closed ended questions. The questionnaire was divided into eight main parts, namely; socio-demographic characteristics of mango producing households, mango production data, cultural practices adopted by farmers, mango pests and diseases and marketing constraints of mango farmers, knowledge level of mango farmers about stone weevil, extension services mango farmers received on the menace of stone weevil and finally, government intervention to boost mango export in Ghana.

3.6 Data Analysis

Socio- economic data of the farmers which were collected using the questionnaire was analysed using Statistical Package for Social Sciences (SPSS) version 17 (2007).

PHASE II

3.7 Study of the foraging behaviour of the Mango stone weevil (MSW)

3.7.1 Laboratory Experiment Site

The study was conducted in the laboratories and insectary of the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR-CRI) at Kwadaso, Kumasi, Ghana.

3.8 Materials and Methods

3.8.1 The Foraging Arena

The foraging arena used was adapted from the one that was originally used by Moorhouse (1971) to study the behaviour of locusts. It was made of a wooden base with an internal diameter of about 400 mm (Plate 3.1). The sides were raised to a height of about 100 mm making it appear like a large open pan. For the purpose of these studies, it was provided with two glass lids (inner lid and outer lid). The inner lid covered up to about a height of 75 mm and had a diameter of 390 mm and the outer lid which covered the top had a diameter of 420 mm and this reduced loss of weevils and odour from the plant parts.

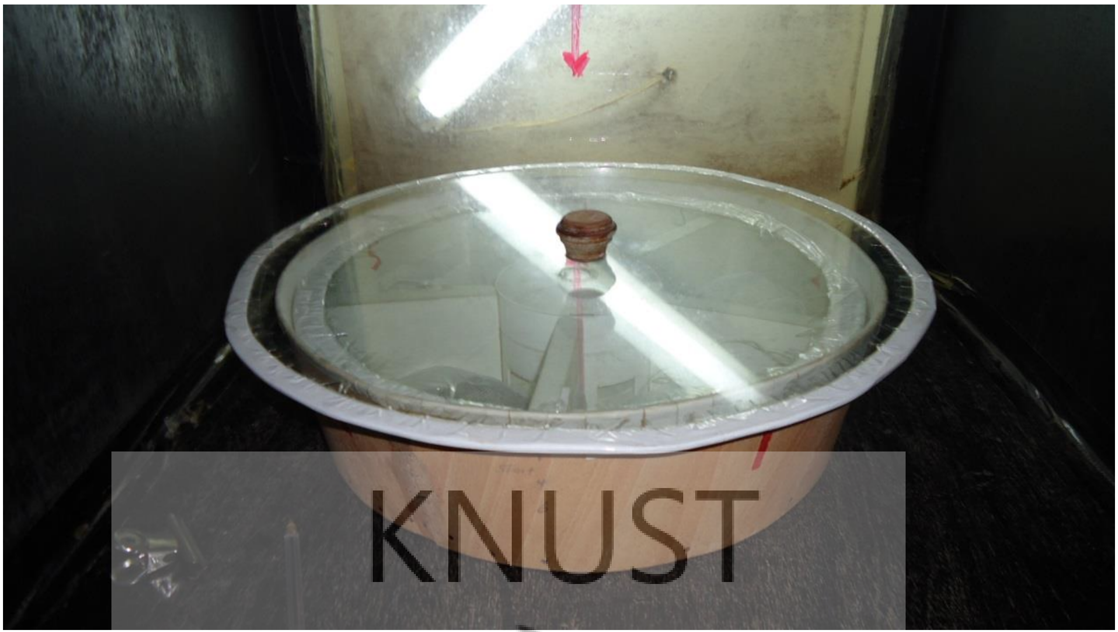


Plate 3.1. Foraging Arena. In use, it was lined with white paper in all the inner walls and bottom to facilitate viewing of the weevils.

3.8.2 Arena Divider

The foraging arena, where the weevils were tested, was divided into 4, 5 and 6 parts as required using polyvinyl chloride (PVC) ring and wooden partitions (Plate 3.2). The PVC ring was cut off at 4 inch diameter pipe. Depending on the number of test items rings were made with 4, 5, 6 grooves (outlets holes) on the edge. Each hole has grooves measuring 1.5 x 2 cm. The PVC ring held test weevils in the centre of the arena while the holes in its edge provided windows for odours of the test materials to diffuse into the ring and a means for the weevils to leave the ring and access the test materials. The holes on the edges of the ring provided windows for the weevils to leave the inner section and enter the compartment within the outer part which housed the chosen test material.

Plate 3.2. Showing 4 inches white PVC ring arena divider. Note the grooves cut out of the edge to act as doors for weevils

3.8.3 Nylon mesh bags

Nylon mesh bags of about 0.6 mm sewed in pocket sizes with nylon tread interwoven in it were used. The bagging of the plant parts was necessary to allow odours to diffuse out into test arena while preventing direct contact with weevils attracted (Plate 3.3).

Plate 3.3. Showing the nylon mesh net this was used as a container for the tested materials

3.8.4 Olfactometer

A linear, three-chambered olfactometer was used to assess the behavioural responses of starved weevils. The olfactometer is made up of three identical round perspex arenas each of about 900 mm internal diameter and about 500 mm high. Each arena is connected to the other by a narrow tube also made of perspex that allows for movement of the weevils between the arenas. The entire olfactometer was covered with black tape in order to create a dark environment for the weevils.

Plate 3.4. Showing a linear, three - chambered olfactometer with activated charcoal attachments

3.8.5 Wooden Black Box

A wooden black box with dimension of 95 cm x 70 cm x 68 cm was used to create a dark environment in which foraging arena and olfactometer experiment were conducted. The front of the box was also lined with a flap made of black polythene sheet. In use the olfactometer was placed in the dark box and the flap was lowered and held in place using cloth pegs. This was done to create an environment of total darkness and even distribution of light.

Plate 3.5. Showing the wooden black box with an olfactometer

3.8.6 Plant Parts

The plant parts used as test materials for this study were obtained from mature mango orchard belonging to CSIR-CRI at Kwadaso. The orchard consists of about 40 mango trees; palmar variety accounts for 60% of the trees. Other varieties are Keitt and Jaffina. The trees were planted in 1998. No synthetic or biological insecticides have been applied on the farm. Selection of the parts of the tree used for this study was based on the plant parts reviews by Louw and Mukhethoni (2006). The following mango plant parts were selected for the investigation; Fresh Mango Flowers, Cut And Dried Mango Back, Dead Mango Leaves, Dried Mango Twigs, Dead Mango back, Dead Mango Twigs (Taken from Tree), Dried Mango Leaves (Mature Leaves), Fresh Mango fruits (immature) and Empty (Control). All the parts that needed to be dried were dried under room temperature.

3.9 Mango Stone Weevils Cultures

3.9.1 Source of Insects

Mango stone weevils were obtained from Ejura in the Ashanti region of Ghana. Five hundred and seventy seeds were collected between December and January, 2013. A total of 510 weevils was obtained from the stones of the seeds collected. Only adult weevils were used in this study.

3.9.2 Culturing

The weevils were kept in insect laboratory. The weevils were cultured on whole mango stones. All materials were checked to ensure that there was no insect infestation, and then stored in the culture room in plastic boxes. Holes were created on the lid of the boxes to allow for ventilation.

Plate 3.6. Plastic boxes used in the maintenance of the stone weevil culture in the insectary. The holes in the lids of the boxes allowed for ventilation

3.9.3 Test Weevils

The weevils were fed on mango stones for 10–15 days before the start of the experiments. Insects used for any test were taken from the main culture and starved for at least 12 hours prior to the experiment.

3.9.4 Cleaning of Test Apparatus

The olfactometer was washed in water and rinsed with distilled water before use. Before the test materials were interchanged between the chambers of the test apparatus, the apparatus was first cleaned and allowed to dry. At the end of each day's experimental work, the apparatus was washed as described and allowed to air dry until the next day.

3.9.5 Test Colours

Different test colours were obtained as art papers from a stationery bookshop at the Kumasi central market. The colours selected for the study were pink, yellow, blue, green, black, orange, brown, red and black. The colour papers were of A4 (210 x 297mm) size paper.

Plate 3.7. Showing background colour preference test of the weevils

3.10 Determination of Attractiveness of Mango Plant Parts to the Mango Stone Weevil

3.10.1 Foraging arena study on attractiveness of plant parts to mango stone weevils

The experiments were conducted between 0600 and 1800 h. The PVC pipe and the surface underneath the tissue paper were wet using distilled water for each test of the weevils. Five gram of each plant part was used for the various tests in the arena. The plant parts were; fresh mango flowers, cut and dried mango bark, dead mango leaves, dried mango twigs, dead mangoes bark, dead mango twigs (taken from the tree), dried mango leaves (mature leaves), fresh mango fruits (immature) and filter paper (as control). The parts of the mango obtained were all compared together in a foraging arena (Plate 3.1) to determine the most attractive one. Subsequently, each part was compared separately to the fresh flowers for attractiveness to the mango stone weevils in the olfactometer. Before the start of the test, 30 weevils were selected and covered with a petri dish for 1 minute after placing them in the arena to ensure that the weevils were calm. They were subsequently introduced into the response chamber. Using a pair of forceps, a weevil was picked out of the container and released into the centre of the arena. In preliminary tests, the shortest time for weevils to reach the plant part was 25–45 seconds and the longest time was 15 minutes. Therefore, 30 minutes duration was allowed to investigate weevil behaviour. The arenas were placed in the wooden dark box to create complete darkness and were rotated through 72°. The arena was rotated until 12 replicates were done. The number of weevils in each compartment was counted and recorded. Weevils that had not responded to any of the test materials and remained in the response chamber (middle) were considered to have stayed neutral or not taken part in the experiment. The best performing plant parts were run in the olfactometer.

3.10.2 Olfactometer study of attractiveness of plant parts to the mango stone weevils

The best three plant parts which were attracted by the weevils were selected for this study. The three parts (Fresh Mango Flowers, Dead Mango Leaves, Dried Mango Twigs) were tested in the olfactometer (Plate 3.4). Olfactometer tests in this study were run by collecting ten weevils from the main culture and were starved for at least 12 hours. Weevils were placed in the response chamber and allowed 30 minutes to respond. Weevils were allowed to make choices by responding to the test material. The tissue paper was changed after six replicates of test weevils. The positions of the test materials were interchanged between the test chambers in the olfactometer. In each set, ten weevils were used only once for a run. The number of weevils in each compartment was counted and recorded. Weevils that had not responded to any of the test materials and remained in the response chamber were classified as ' no response or neutral.

3.11 Investigation of the Environmental Factors in the Foraging Behaviour of *Sternochetus mangiferae*

3.11.1 Effect of Colour and Shape

The division of the eight colours into two groups and assignment to compartments was done arbitrarily. The colour panals were first tested in groups of four. The tests were conducted in the foraging arena (Plate 3.7). This experiment was aimed at ascertaining whether colour and shape have any influences on the foraging behaviour of mango stone weevils.

3.11.2 The Background Colour Preference and Determination of Colour Experience on the Colour Attraction of Mango Stone Weevil

For this study, the foraging arena was divided into four equal-sized compartments. One colour was stuck to the inner wall of each of the compartments of the arena. The arena was placed in a room with an 18 watt bulb for easy recognition of the colours by the weevils. Thirty weevils were introduced into the middle of the arena at a time and allowed 30 minutes to respond to colour panels. At the end of the test period, weevils which remained in the centre or 20 mm away from the test colour were disregarded. The arena was rotated through angle of 90° after each run to eliminate the effect of responses of the weevils. The test was repeated 12 times. The eight colours were tested in groups of four at a time. At the end of the test for each group, the best two that were most preferred were selected. These were combined to make a set of four colours which were further tested to obtain the most preferred colour. Colour background test was tested in the arena and 10 g mango stone was placed against each of the colour shapes.

3.12 Statistical Analysis

The bio-ecology data (plant parts, colour and shape) collected were subjected to Analysis of Variance (ANOVA) and t-test using Genstat statistical software version 12 (2009). Significant differences were assessed at 5% level of significance and the means separated using least significance difference (Lsd). All the count data were transformed logarithmically (Kihara *et al*., 2011) before analysis.

CHAPTER FOUR

4.0 RESULTS

4.1 Socio-Demographic Characteristics of Respondents

Socio- demographic characteristics of the respondents are important because it can influence the farmer's indigenous technical knowledge and the management of mango stone weevil such as cultivating a particular crop, control of insect's pest and other management practices.

4.1.1 Gender of Respondents

The socio-demographic characteristics of mango farmers interviewed in the field. The results showed that 83.2% of mango farmers in Ghana are males.

4.1.2 Age Structure of Respondents

Generally, 65.7% of mango farmers were outside the youth bracket with 34.3% of respondents representing the youth (Table 4.1).

4.1.3 Educational Level of Respondents

Table 4.1 shows that 22.4% of the mango farmers interviewed had no formal education. The results also indicate that more than half (57.6%) of the respondents had basic education (Primary School, Junior High and Middle School) while 10.4% of the respondents had attained Secondary/Vocational education and 9.6% had tertiary education (which comprises of the Colleges of Education, Nurses' Training Colleges, Polytechnics and the Universities).

4.1.4 Household Size of Respondents

The size of the household is a major factor in mango production, especially with respect to resource poor farmers who depend on family labour to maintain their farms. From the survey, 25.5%, 20.0% and 20.8% of respondents had a household size of 5-6, 7-8 and 10+ persons, respectively (Table 4.1).

Table 4.1. Personal Characteristics of mango farmers from the three zones

Variable	Category	Percentage of respondents
Age	18-25 years	13.6
	26-35 years	8.8
	36-45 years	12.0
	46-55 years	33.6
	55+ years	32.0
Education	None	22.4
	Primary School	9.6
	Junior High School	14.4
	Middle School	33.6
	Secondary/Vocational School	10.4
	Tertiary Institution	9.6
Household members	1-2	7.2
	3-4	14.4
	5-6	25.5
	7-8	20.0
	9-10	12.0
	10+	20.8

4.1.5 Number of years' experience in mango cultivation

The mean number of years farmers have been in mango farming was 9.4, 9.3, and 10.7 for the Southern, Middle and Northern Zone, respectively (Table 4.2).

Table 4.2. Number of years of experience by farmers in mango cultivation

	Experience in mango cultivation (Years)		
Parameters	**Southern Zone**	**Middle Zone**	**Northern Zone**
Minimum	1	2	4
Maximum	30	29	40
Mean	9.4	9.3	10.7

4.1.6 The Mango Farm Size and Plant Population of Mango Trees by Farmers

The mean number of mango farm sizes was high with Southern, Middle and Northern with 30.3, 11.8 and 1.3 acres, respectively (Table 4.3).

Table 4.3. The Mango farm size and plant population of mango trees by farmers

	Plant population of mango trees in the farm		
	Mango farm sizes (Acres)		
Parameters	**Southern Zone**	**Middle Zone**	**Northern Zone**
Minimum	0.25	0.5	0.3
Maximum	400	100	5
Mean	30.3	11.8	1.3

4.2 Mango Production Status of Respondents

4.2.1 Land acquisition

The availability of land has been found to be very important in mango farming. About 53.6% of the farmers owned their farm lands, while the rest had their lands acquired by other tenure systems (Table 4.4).

Table 4.4. Farm land holdings of mango farmers

Land Tenure Types	Percentage of Respondents
Outright purchase	53.6
Rented land	4.8
Family land	28.0
Community land	4.0
Sharecropping	4.0
Leasehold	5.6
Total	100

4.2.2 Mango Varieties Planted By Farmers

Of the ten varieties of mango grown by farmers in Ghana 48% of the respondents grow Keitt and less than 1% grows the local varieties (Table 4.5).

Table 4.5. Mango varieties grown by farmers

Mango variety	Percentage of Respondents
Kent	25.6
Keitt	48.0
Palmer	10.4
Haden	6.4
Tommy Atkins	1.6
Erwin	2.4
Sensation	0.8
Julie	0.8
Jaffna	3.2
Local	0.8
Total	100

4.2.3 Farmers Incentives for Growing a Particular Variety

The results of the study show that about 50% of the farmers have made early maturity and export potential of the mango variety the most important factor in selecting the variety grown (Table 4.6). According to the farmers, local varieties are planted mainly to provide shade in the home. According to farmers the local variety has various advantages over improved varieties; they have better taste and better storage qualities.

Table 4.6. Incentives for growing a particular mango variety

Incentive	Percentage (%) respondents
High yield	9.6
Early maturity	9.6
Export	20.8
High market demand	28.8
Pest/disease tolerance	4.0
High price	16.0
Less post-harvest losses	10.4
Easy access to planting material	0.8
Total	100

4.2.4 Farmers sources of mango planting materials

The unavailability of improved varieties has made the farmers in the Northern Zone rely on local planting materials which are obtained mostly from Extension Agents and certified seed growers (Table 4.7)

Table 4.7. Distribution of farmers sources of mango planting materials

Source of planting material	Percentage of Respondents
Extension agents	29.6
Certified seed growers	28.8
Own production	16.0
Other farmers	14.4
Research institutions	6.4
Seedling hawkers	3.2
Roadside seed vendors	1.6
Total	100.0

4.3 Mango production constraints encountered by mango farmers

About 35.2% of the respondents reported having difficulties accessing capital whilst about 31% cited diseases and pests as important (Table 4.8).

Table 4.8. Major production constraints encountered by mango farmers

Mango Production Constraints	Percentage of Respondents	Rank
Lack of quality seeds	3.2	6
Lack of extension services	9.4	4
Pest and disease control	31.0	2
Unavailability of water	2.4	7
Capital	35.2	1
Difficulty in accessing land	8.0	5
Ready market	10.8	3
Total	100	

4.4 Farmer Awareness and Perception of Mango Insect Pests

About 96% of the farmers interviewed in the survey indicated they had encountered mango insect pests on their farms. The farmers contended that the major insect pests that attack their mango farms are; mango stone weevil, fruit flies, mealybugs and grasshopper. The mango stone weevil and fruit flies were the most important insect pests of mango in Ghana (Table 4.9).

Table 4.9. Farmers ranking of insect pests on mango

Pest	Rank	Percentage of Respondents Holding Perception
Mango stone weevil	Very High	21.6
	High	22.4
	Average	20.8
	Low	10.4
	Very low	4.0
	None	20.8
		100
Fruit Fly	Very High	53.6
	High	15.2
	Average	4.0
	Low	5.6
	Very Low	7.2
	None	14.4
		100
Mealy Bug	Very High	8.8
	High	12.0
	Average	26.4
	Low	11.7
	Very Low	10.4
	None	31.2
		100
Grasshopper	Very High	7.2
	High	1.6
	Average	8.0
	Low	14.4
	Very Low	16.8
	None	52.0
		100

4.5 Farmer Awareness and Perception of Mango Stone weevils

About 81.6% of the farmers interviewed have encountered the mango stone weevils in their mango farms and out of this 46.4% indicated the pest attacked during the fruiting stage of mango. Most of the farmers (62.4%) interviewed indicated that they could identify fruits infested with mango stone weevils in the field with some of the symptoms of infestation being, fruit dropping, black fluid oozing from the mango fruit, rotting of the fruit, black spots on the fruit, holes in the skin of the fruit, among others.

4.5.1 Farmers Perception of the Incidence of Mango Stone Weevils

The results of the survey showed that the highest prevalence of insect pests (60%) especially the mango stone weevils occur during the major fruiting season. Most of the farmers interviewed linked this occurrence to high rainfall during the major fruiting season.

4.6 Mango stone weevils infestations in the three zones

Infestation levels of the mango stone weevils in the various communities in the zones where mangoes were collected and sliced are presented in Table 4.10. This was to investigate the level of infestation in the country. The results showed that, the minimum mean level of infestation were 15.68; 38.12 and 46.15 were recorded in the northern, middle and southern zones, respectively. About 39.2%, 26.4% and 16.8% indicated that the insect causes fruit rot, fruit drop and reduced fruit quality for export, respectively. An overwhelming majority (99%) agreed the insect does not affect local market patronage.

Table 4.10. Levels of mango stone weevil infestation in the three mango production zones in Ghana

Zone	Location	Number of mango fruits examined	Total number of infested fruits with larvae and mature insects	Total number of weevils for the zones	Mean number of weevils for each zone
Northern	Tamale	100	12	53 (15.68%)	13.25
	Savelugu	100	17*		
	Nyamkpala	100	14*		
	Kumbugu	100	10		
Middle	Kintampo	100	27	129 (38.16%)	32.25
	Techiman	100	30		
	Nkoranza	100	22*		
	Ejura	100	50*		
Southern	Koforidua	100	41*	156 (46.15%)	52.00
	Somanya	100	58*		
	Dodowa	100	57*		

*Contains larvae of mango stone weevils

4.7 Farmers' Perception about mango yield prior to invasion of Mango Stone Weevil

Most of the mango farmers interviewed across the country were of the view that yields were higher before the invasion by the mango stone weevil (Figure 4.1). Those who responded ’Average’ could not make any significant difference between the current mango fruit yield and what they used to get before the invasion of the mango stone weevils. It is also interesting to note that mango farmers who responded ’low’ were of the view that yields were lower now than before.

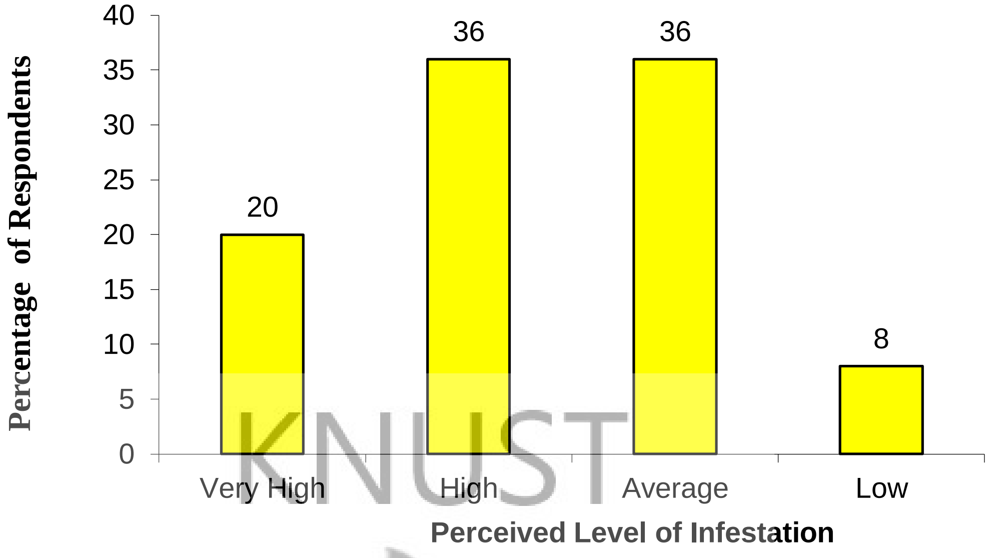


Figure 4.1. Farmer perception of mango yield prior to mango stone weevil invasion in Ghana

4.7.1 Management of Mango Stone Weevils by farmers

4.7.1.1 Chemical control

On the management of mango stone weevils, farmers' preference for the use of chemicals was high (60.8%) with 16.0% opting for orchard sanitation. About 48% use Cydin Super, 12.8%, use Lambda cyhalothrin and 8.8% Fenthion to manage mango stone weevils. Nearly half of the respondent farmers (48.0%) expressed their disappointment with the level of assistance from authorities for the management of mango stone weevils. Those who had some form of assistance (47.2%) indicated that extension agents and research institutes were of great help to them with technical advice. Aside the technical advice that the farmers have been receiving, most (83.2%) of them were aware of the health risk associated with the use of pesticides in controlling insect pests.

4.7.1.2 Cultural control

About 16% of the respondent indicated they collect and destroy dropped fruit whilst 7.2% and 0.8% band the trees with glue and grease and cover destroy of fruits with nets/envelopes, respectively. Most of the farmers (77.6%) interviewed indicated that they have been using both pesticide and orchard sanitation practices to manage mango stone weevil in their farms for the past 1-10 years, but the success level had been low. Regrettably, about 46% of the farmers usually lose about 1-15% of the fruits despite these management practices. In order to reduce the devastating effect of the mango stone weevils on the uninfected mango fruits, more than half (59.2%) of the respondents indicated their preparedness to bury the damaged fruits while 9.6% want to resort to burning them.

4.7.2 Application of Indigenous Management Practices by Mango farmers

The results showed that 39.2% of the farmers interviewed have heard, but not applied any indigenous strategy for the management of insect pests; only 1.6% are practicing any form of indigenous pest management. More than half (59.2%) of the farmers have not heard any the indigenous management technology. The lack of knowledge about any indigenous technical pest management technologies among the farmers in Ghana might be linked to the fact that mango commercial production for export started in the 80s. In addition, commercial mango farmers have adopted the use of chemicals to curb the effect of insect pests. Apart from chemicals a few farmers used Indigenous Technical Knowledge (ITK) to manage insect pests. Some of the local materials used for the management of the insect pests are cow dung, detergent, wood ash, neem extract, garlic, pepper and vegetable oils which are applied in one or a combination of the following;

(i) aqueous extract of neem leaves and seed extract.

(ii) local soap (called alata samina) solution

(iii) ash in aqueous solution

(iv) aqueous garlic spray

(v) solution of cow dung and detergent soap

(vi) pepper and garlic spray

4.8 Mango marketing constraints

Figure 4.2 presents the results on the major marketing constraints confronting mango farmers interviewed. About 42.3% complained that low commodity prices, high transportation cost (20.8%) and lack of transport to convey fresh mango fruits from the hinterland to the nearest marketing centres (12%), hamper marketing of their produce.

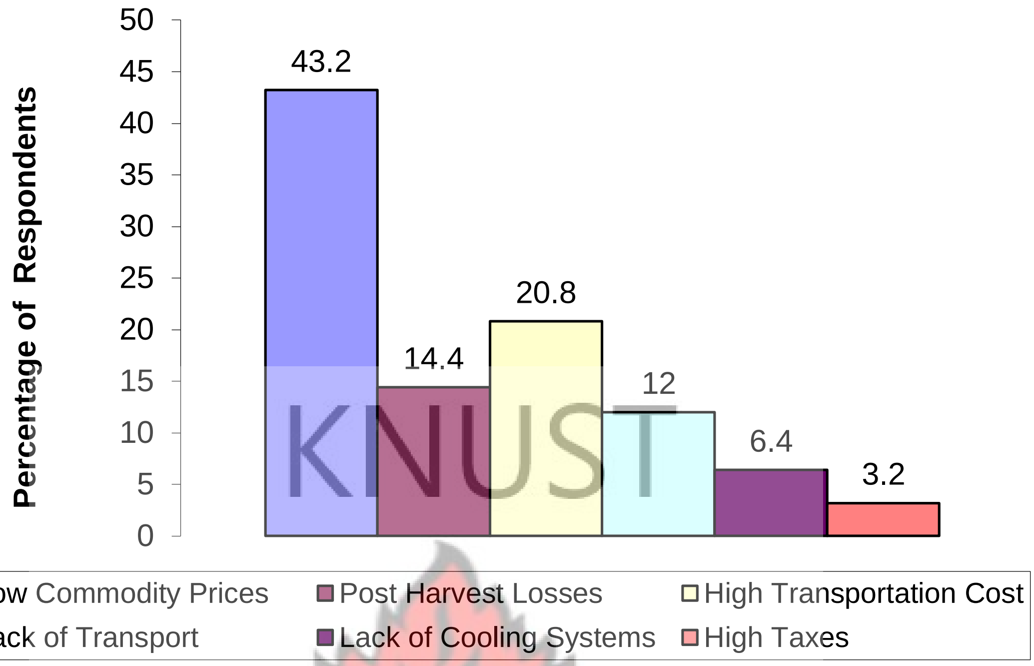


Figure 4.2. Major mango marketing constraints faced by farmers

4.9 Support Services Received By Mango Farmers

About 24.8% of the mango farmers interviewed have not had any formal training in pest management and as high as 75.2% had received some form of training in safe handling of pesticides only a fraction of them practice it (Table 4.11 and 4.12).

Table 4.11. Distribution of mango farmers with respect to training in pest management

Response	Percentage (%) Respondents
Yes	75.2
No	24.8
Total	100.0

Table 4.12. Aspect of training received in pest management

Aspect of Training	Percent
Training on general agricultural pests	47.0
Training on pesticide application	42.0
Training on biological control of pests	11.0
Total	100.0

4.10 Government Assistance

In order to reduce post-harvest losses and other marketing constraints reported by the respondents, government assistance is crucial to mitigate the impact of these factors. Table 4.13 and Table 4.14 showed as high as 82.4% of the farmers interviewed have not had any form of assistance from the central government. For the few (17.6%) who have benefited some form of assistance 8% benefitted from training, 3.2% from financial support , 2.4% from management services, 2.4% from supply of equipment and 1.6% from marketing of produce.

Table 4.13. Farmers perception of assistance from the government

Response	Percent
Yes	17.6
No	82.4
Total	100.0

Table 4.14. Type of assistance from the government

Type of Assistance	Percentage
Financial support	3.2
Training	8.0
Management services	2.4
Provision of equipment	2.4
Purchase of produce	1.6
Total	17.6

PHASE II

4.11 Laboratory Bioassay (Bio-ecological Studies)

4.11.1 Attractiveness of Mango Plant Parts to the Mango Stone Weevil

Dried mango leaves, dried mango twigs and fresh mango flowers were more significantly (P<0.05) attractive to the weevils as compared with clean air (control). The cut and dried mango bark for the group one of the mango parts was most preferred (Table 4.15) whilst in the group two (Table 4.16), dead mango bark and dried mango leaves were the most preferred by the weevils against the clean air (Control), dead mango twigs and fresh mango fruits. However, when the most attractive plant parts in both groups were tested (Figure 4.3), fresh mango flowers was most attractive to the weevils (P<0.05).

Table 4.15. Comparative attractiveness of mango plant parts to the mango stone weevil (*Sternochetus mangiferae*) in group one

Mango parts	Mean log number of weevils (Group one)
Control (Clean Air)	0.5679[b]
Fresh mango flowers	0.8490[a]
Cut and dried mango bark	0.5742 [b]
Dead mango leaves	0.9122[a]
Dried mango twigs	0.9351[a]
Lsd (P=0.05)	0.1452

Values are mean of twelve replicates. Values with the same superscript are not significantly different at $P > 0.05$

Table 4.16. Comparative attractiveness of mango plants to the mango stone weevil, *Sternochetus mangiferae*) in group two

Mango parts	Mean log number of weevils (Group two)
Control (Clean Air)	0.5115[c]
Dead mango back	0.8433[ab]
Dead mango twigs (taken from the tree)	0.5035 [c]
Dried mango leaves (matured leaves)	1.0191[a]
Fresh mango fruits (immature)	0.7735[b]
Lsd (P=0.05)	0.2261

Values are means of twelve replicates. Values with the same superscript are not significantly different at P > 0.05

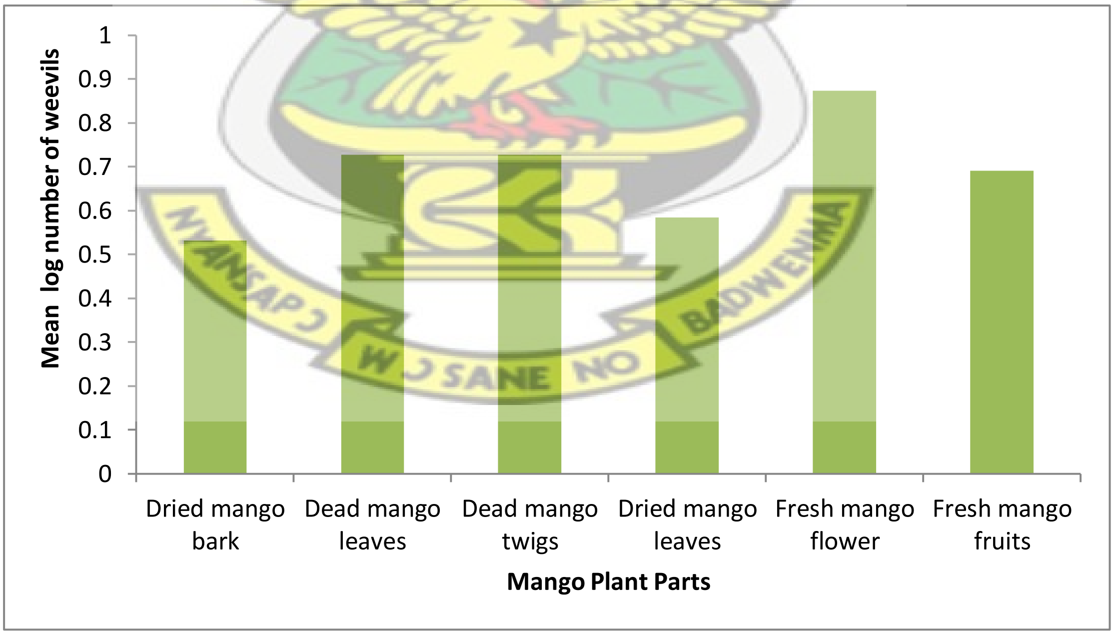


Figure 4.3. Comparative attractiveness of mango plant parts to the mango stone weevil (*Sternochetus mangiferae*) selected from both groups.

4.12 Olfactometer Analysis of Best Three Performing Plant Parts

In the olfactometer bioassay of the mango plant parts for their attractiveness to the weevils, fresh mango flowers significantly attracted more weevils than the dead mango leaves ($P<0.05$) (Figure 4.4). Also, there was no significant difference ($P>0.05$) in weevil attraction between the fresh mango flowers and dead mango twigs (Figure 4.5) as well as between dead mango twigs and dried mango leaves (Figure 4.6).

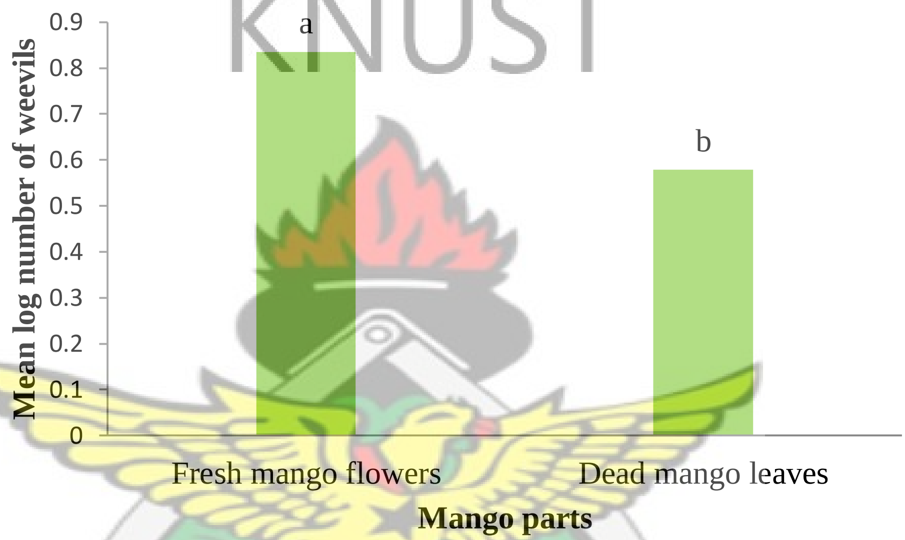


Figure 4.4. Comparative olfactory attractiveness of fresh mango flowers and dead mango leaves to the mango stone weevil, (*Sternochetus mangiferae*)

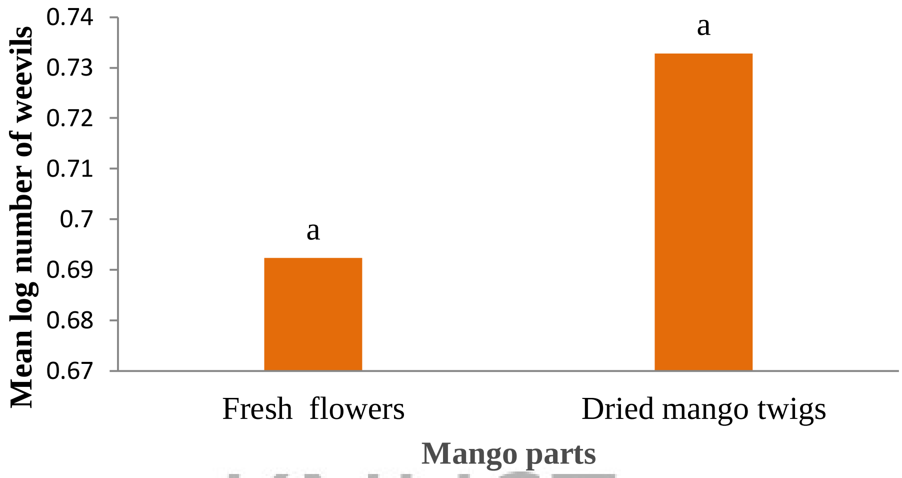


Figure 4.5. Comparative olfactory attractiveness of fresh mango flowers and dead mango twigs to the mango stone weevil (*Sternochetus mangiferae*)

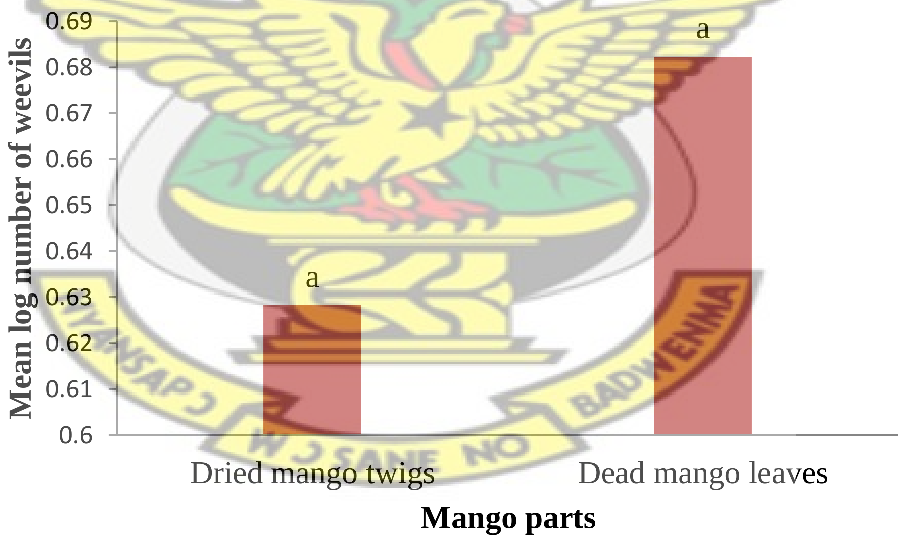


Figure 4.6. Comparative olfactory attractiveness of dried mango twigs and dead mango leaves to the mango stone weevil (*Sternochetus mangiferae*)

4.13 The Role of Environmental Factors on the Foraging behaviour of Mango Stone Weevils: Effect of colour and shape

4.13.1 Colour Experience

Table 4.17 shows the response of the weevils to the eight colours initially selected for the colour response studies. It was ranked by testing them in groups of four. For the initial ranking of colour test, green and blue were found to attract significantly more weevils ($P<0.05$) than pink and yellow. For group two, black was found to attract significantly more weevils ($P<0.05$) than the other colours. Four colours were selected from the two groups; black was found to be significantly more attractive ($P<0.05$) than green, blue and orange (Table 4.18).

4.13.2 Effect of Shape and colour of presentation on mango stone weevils

The Cube shape attracted significantly more weevils ($P<0.05$) than the cylindrical and pyramid shapes when presented in black colour. Also the cube was more attractive when presented in blue, green and orange (Table 4.19).

4.13.3 Shape of Presentation

Testing for the preferred colour of the various shape, black which attracted relatively higher numbers of weevils among all the shapes (Table 4.20). However, there was no significant difference ($P>0.05$) in the number of weevils among the colours when the pyramid was used.

Table 4.17. Attractiveness of colour background to the *Sternochetus mangniferae*

Test colour group	Test colour	Mean log number of weevils
	Pink	0.5662 ^{a}
	Yellow	0.8153 ^{b}
One	Green	1.0377 ^{c*}
	Blue	0.9677^{bc*}
	Lsd (P=0. 05)	0.1605
Two	Brown	0.7498^{a}
	Red	0.8601^{ab}
	Orange	0.8924^{bc*}
	Black	1.0016^{c*}
	Lsd (P=0.05)	0.1332

Comparisons can only be made for colours in a group. Numbers followed by the same letter are not significantly different at P = 0.05 in each test colour group * = Colours selected for further studies.

Table 4.18. The effect of colour attraction of mango stone weevil

Test colour	Mean log number of weevils
Orange	0.6708^{a}
Blue	0.6933^{a}
Green	0.7419^{a}
Black	1.0467^{b}
Lsd (P=0.05)	0.179

Numbers followed by the same letter are not significantly different at P = 0.05

Table 4.19. The effect of colour presentation of a shape preference of *Sternochetus mangiferae*

Test colour	Mean log number of weevils attracted to shapes			
	Cube	Cylinder	Pyramid	LSD (P = 0.05)
Blue	0.862[ab]	0.955[b]	0.800[a]	0.127
Green	0.920[a]	0.831[a]	0.896[a]	0.135
Orange	0.986[b]	0.933[ab]	0.791[a]	0.146
Black	1.144[b]	0.736[a]	0.770[a]	0.146

Numbers followed by the same letter in a row are not significantly different at P = 0.05.

Table 4.20. The effect of shape presentation on the attractiveness of different colours to the mango stone weevil, *Sternochetus mangiferae*

Shape	Mean log number of weevils attracted to colours				
	Blue	Green	Orange	Black	LSD (P = 0.05)
Pyramid	0.756[a]	0.820[a]	0.867[a]	0.909[a]	0.187
Cube	0.727[a]	0.825[ac]	0.872[c]	0.939[bc]	0.137
Cylinder	0.674[ab]	0.568[b]	0.787[c]	1.132[a]	0.165

Note: Comparisons can only be made within each row. Numbers followed by the same letter in a row are not significantly different at P = 0.05. ns= not significant

CHAPTER FIVE

5.0 DISCUSSION

5.1 Socio- demographic characteristics of mango farmers in Ghana

The results of the study showed that, mango production in Ghana is male dominated. This could be attributed to the fact that farming as an enterprise is labour intensive and men are household heads and traditionally control asset such as land and tree crops. More importantly, mango production in Ghana is generally considered a male activity, even though women play major roles in the post-harvest practices and other farm management activities like weed control (MoFA, 2011). Considering the mean of all the zones it can be said that mango farmers used in the study were comparatively old. It was also observed that more than half (57.6%) of the respondents had basic education with few attaining secondary or tertiary education. The educational level of respondents is vital in production and marketing decisions making process as reported by Nzomoi *et al*. (2007) that highly educated farmers and marketers are better adopters of improved technologies than less educated ones.

5.2 Mango Production and Constraints

Farmers demonstrated a deep understanding of the mango crop ecosystem and the constraints that limit production. Capital and insect pests of mango were generally regarded as most important constraint, confirming an earlier report by Abdullahi *et al,* (2011) that majority of mango producers in Ghana face pest problems. Several arthropod species were listed by the respondents as being pests on mango in Ghana but the majority (69.6%) of the respondents indicated that fruit flies and the mango stone weevils were of major economic importance by causing damage that usually lead to the production of unmarketable fruits; these findings contradict the reports by

Abdullahi *et al.* (2011) that mealy bugs were of major economic importance to farmers. Only a few farmers (8.8%) admitted that mealy bugs were causing significantly damage to their fruits. This proportion of farmers believed that, mealy bugs caused a lot of problems a few years ago leading to yield reduction in the mango enterprise, but with recent agronomic practices like orchard sanitation and chemical control, the mealy bugs numbers have reduced drastically.

5.3 Farmer Awareness and Perception of Mango Insect Pest

The qualitative assessment on all the insect pests identified at the level of damage they cause to mango fruits revealed that mango stone weevils and fruit flies caused the highest damage. The study further revealed that, the mean mango fruit damage due to the presence of mango stone weevils was higher in the Southern and Middle zones than in the northern zones. This seems to agree with Braimah *et al.* (2009) that there appeared to be some relationship between the relative humidity within any environment and the levels of infestation of the fruits. This might explain the high prevalence of weevil in the southern and middle zones. This also confirms the study by Nboyine *et al.* (2012) who collected a higher number of fruit flies in the southern sector than the northern sector of the country. The high losses of mango fruits due to the presence of mango stone weevils in the southern and middle zones may be due to high rainfall within the year.

5.4 Impact of Mango Stone Weevils on the production and export of mango

The results revealed that more than half of the respondents interviewed (53.6%) were operating on land parcels that they have purchased outright, while the rest were operating on rented land, family land, leasehold or share cropping. Land as a resource is very vital in every production process. This explains why most of the mango farmers interviewed decided to own the land. Financial constraints had been reported in the study as one of the major factors affecting mango production in the country. In this regard, they are not able to afford recommended practices to produce quality mango fruits to meet export demands. Based on the data obtained from this study, technology adoption among the mango farmers has been very low. All these have been linked to lack of capital to fund mango production. These findings are supported by similar findings by earlier researchers (Salasya *et al*., 1998; Nandwa *et al*., 2007) who also identified costs as key determinants of adoption of improved technologies or improved varieties of seeds, fertilizers, soil conservation methods and irrigation methods among others.

The problem with the mango stone weevil has been a major setback to the export of quality mango fruits. The greatest challenge posed by the mango stone weevils its interference with the export of fruits because of quarantine restrictions imposed by importing countries and the market requirement for blemish-free fruit (Varela *et al*., 2006), and according to Varghese *et al*. (2005), mango stone weevil causes losses (including fruit drop) varying from 5-80%, depending on the place and the variety of mango. In this study, losses of up to 90% of the yield of mango fruits had been reported by respondents. This is because in many instances, the weevil attack remains undetected in the field, and is first noticed in storage or in transit (Varela *et al*., 2006). Other problems in combination with low mango prices, high transportation cost, lack of and high transport cost and post-harvest losses have impacted negatively on the production of mangoes. According to Braimah *et al*. (2010) these constraints contribute significantly to the low productivity of small scale mango farmers in Ghana. The impact of these limitations can be reduced by the provision of market information and infrastructure.

5.5 Mango Stone Weevils infestation levels in Ghana

In Ghana, there is a unique opportunity to use administrative and legal controls to complement other approaches for the management of the weevil (Braimah and van Emden, 1999). Schotman (1989) described a protocol for detection of the weevil that is based on fruit slicing, by shaking branches early in the morning and by visual inspection of the hiding places of diapausing adults. The results showed that, the Northern zone has the least infestation of about 15.6%, Middle zone about 38.1% and Southern zone 46.1%. These results are in agreement with the report of Braimah and van Emden (1999) that infestation levels are higher in the southern parts than in the Northern parts. In the south of Ghana, there are two rainy seasons, from March to July and from September to November, with a peak in May-June. As a result, there are two harvest seasons, the main season from May to July, and the minor season in December and January. Because of the high humidity and two fruiting seasons, mango production suffers from higher pest and disease pressure than in Northern Ghana (FAO, 2009).

5.6 Management strategies of farmers on Mango Stone Weevils (MSW)

5.6.1 Use of pesticides

The results indicated that more than half of the respondents (60.0%) use chemicals to control mango stone weevils in their mango farms. About 40% of the farmers did not use chemical insecticides because of lack of money or lack of trust in the product. Some of the chemicals identified included; Dichloro diphenyl trichloroethane (DDT), Fenthion, Optimal/Marbat/Kombat/lambda (Cyhalothrin), Thiamethoxam (actara) and Cydin Super (Dimethoate). It was clear that Cydin Super (48.0%) and lambda cyhalothrin (12.8%) are the most popular chemicals use by mango farmers interviewed**.** The results revealed that spraying with pesticides and practicing of orchard sanitation received a higher percentage of resources, time and money. These findings are in line with other related work on orchard sanitation and chemical control of mango stone weevils in other parts of the world (Woodruff and Fasulo, 2006). It was reported that among the recommended management practices for this pest, cultural and chemical control are the most effective.

5.6.2 Cultural Control

Cultural control involves the manipulation of normal cultivation practices to reduce the impact of pests and disease (Braimah and van Emden, 2010). According to the results, some farmers prefer orchard sanitation (16.0%) as an insect pest management strategy. Some of the measures under this management strategy involves tree banding with glue or grease, covering of fruits with nets/envelopes, collection and destruction of dropped fruit, and other prudent agronomic practices such as orchard sanitation to rid the farm of MSW. Pinese and Holmes (2005) recommended removal of all fruits and seeds from the orchard as a strategy to reduce infestation in the following season. In Australia, Smith (1996) recommended that fallen fruits and seed should be collected from the field after harvesting. The fruits should then be burnt with diesel or buried at least one metre deep. While reviewing pest management in mango agro-ecosystems, Pena *et al.* (1998) recommended that field sanitation in mango orchards as a strategy to control the mango seed weevil should involve complete removal and disposal of fallen fruits from affected orchards. In Kenya, Muriuki *et al.* (2011) concluded that once per month application of chlorpyrifos combined with sanitation is both effective and economical as it reduced the infestation to very low levels.

5.6.3 Biological Control

As per the results, the awareness of the use of this strategy among mango farmers is very limited. This is not surprising as 68.8% of the mango farmers interviewed were not aware of any natural enemy of mango stone weevils. Hansen (1993) noted that generalist indigenous predators such as ants, rodents, lizards and birds prey on adult weevil but have little impact on populations of the weevil is achieved. However, the contribution of the generalist predators when integrated with other control measures could be appreciable in reducing levels of infestations and the risk of rejection by export markets (Braimah *et al.*, 2009). Although the respondents were aware of the environmental impact of chemicals on agriculture, only 32% believed natural enemies could be used to manage mango stone weevils.

5.6.4 Indigenous management practices by mango farmers for controlling Mango Stone Weevil (MSW)

The results revealed quite a high proportion of mango farmers interviewed (81.6%) have detected mango stone weevil on their mango farms. This is a strong indication of the presence and the problem these insect pests have been causing to mango farmers in the country. These mango farmers are convinced they encounter the mango stone weevils in their production cycle most especially during flowering, fruiting and harvesting of their produce. The study showed that about 39.2% of the farmers were aware of indigenous knowledge but have never used this, whilst 1.6% have used it before. Since few people were aware and have used indigenous knowledge for pest management, it is an indication that the use of indigenous insect pest management practices is very unpopular among mango farmers as pesticide use is known to be effective though expensive.

5.7 Laboratory Bioassay (Bio-ecology Studies)

5.7.1 Comparison of Plant Parts

The fresh mango flower and dead mango twigs were the most attractive part to *Sternochetus mangiferae*. The attractiveness of the fresh mango flower was suspected to have been influenced by bloom, nature and the odour of the mango flowers (Hensen *et al.,* 1989). This also shows that the smell of fresh mango flowers is more attractive to the weevils as compared to other parts of the mango plants and seems to agree with the findings of Hensen *et al.* (1989) who reported that adults become reproductively active when mangoes begin to bloom. Attraction to plant parts has been reported in other weevils (Braimah *et al.,* 2010; Bartlet *et al.,* 1993). The attraction of *Sternochetus mangiferae* to flowers probably explains how it moves out of its hideouts into flowering and fruiting mango trees. It is possible that the odours of flowers provides the cues that direct the weevils to the host plant after hibernation and that while feeding, they also mate and deposit eggs in developing fruits (Braimah *et al.,* 2009) The mango twigs may have similar odours and relationship with the bark of the dead mango fruit. It was also observed in the weevil cultures maintained in this study that, most of the adult weevils were obtained from dead mango seeds from the same locality, which pre-supposes that, the weevils were undergoing diapause. Most of them seemed inactive and it confirms the findings of Louw and Mukhethoni (2006) that few of the captive adult seed weevils terminated diapause as early as late August, although only a very small percentage of all the adults in a breeding box were found to be active, with negligible feeding damage. From the middle to the end of September activity was more pronounced, with more weevils seen among the mango flushes. This information supports the findings of Joubert and Pasques (1994), that the mango seed weevil is extremely inactive and tends to remain in the same spot for several hours if undisturbed.

The fresh mango fruits were the part of the plant expected to have a high attraction to the weevil as was reported by Louw and Mukhethoni (2006). Contrary to the expectation, the weevils were attracted to the fleshy fruits from the first test, but after subsequent selection among the best six, it was least attracted among the best three selected. The results also raise questions about the claims by CABI and EPPO (2005) that the adult seed weevil feeds on leaves and tender shoots. Although adult weevils visited all the fresh mango parts, feeding did not occur in all of them. Dried mango twigs attracted more weevils when fresh mango flowers were compared to dried mango twigs in the olfactometer and this confirmed Louw (2006) findings that adult weevils did not feed on old, mature leaves, but used these flushes and individual leaves mostly as aggregation sites and as shelter. It is probably the dead mango twigs and fresh blooms in the field when not sprayed at early stage or the onset of the flower formation suffer increased infestation of the stone weevils and facilitate their establishment.

5.7.2 Colour Ranking

The colour and shape preferences of the target insect are important considerations in the design and constructions of insect traps (Braimah and van Emden, 1999). Insects have also been noted to rely on various shapes and colour combinations in order to respond to their host (Agee, 1985; Prokopy and Economopoulos, 1975). Numerous studies that examined the effect of shape, size and colour of visual stimuli on fruit fly response (Katsoyannos, 1989; Prokopy, 1973, 1972, and 1968) demonstrated that more *R. pomonella* were captured on fluorescent yellow rectangles and on enamel red spheres than on other shapes in different colours. The colour parameters like colour background, colour experience, colour of the presentation of the shapes as well as shape and shape of presentation of colours showed different effects on the behaviour of the mango stone weevils. The results show that black was found to significantly attract more weevils ($P<0.05$) than the other colours, suggesting that black was the most attractive colour for trapping *Rhagoletis ferruginous* adults (Al- Saoud *et al.,* 2010; Sansano *et al.,* 2008; Ajlan and Abdulsalam, 2000; Hallett *et al.,* 1999).

The interaction between the colour and shape, the cylinder and pyramid shape presented in black appeared to be preferred by the insect. The differences were not repeated when the effect of colour of the presentation of the shapes on the attractiveness to the weevils was investigated. Findings about the cylinder shape seems to agree with Prokopy (1968) who hypothesized that the flat surface of the rectangle together with the fluorescent colour represented leaf-type stimulus that elicits food-seeking and/or plant-seeking behaviour. The darker colours like green and blue seems to be more attractiveness over lighter ones like yellow and pink. These contrast findings of Nakagawa *et al.* (1978) who tested the response of *Ceratitis capitata* to a wide variety of shapes and colours. In tests with 7.5-cm spheres of different colours, black and yellow captured the most females and black, yellow, red and orange captured the most males. The yellow 18-cm spheres were most effective overall. The preference of the weevil for darker colours could be responding to silhouettes (Braimah and van Emden, 1999). The findings indicate the importance of visual cues in the habitat and behaviour of other insects. The fact that similar clear colour and shape responses were not observed in stone weevils could be explained by its dislike for light and general cryptic behaviour as stated by Braimah and van Emden (1999). This has shown that visual stimuli such as the shape and colour have on the host plant searching behaviour of the weevil. The results seem to indicate that manipulation and combining colours around the trapping environment could determine the locations of trapping for the weevils.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Mango cultivation is a male dominated activity in Ghana. Mango farmers are very much aware of pests on their fruit trees, with as many as 96%. Mango farmers have demonstrated an ability to rank pests on their mango fruits on the basis of their destructive potentials. Mango stone weevils (*Sternochetus mangiferae*), remain one of the major insect pests of mango causing significant economic losses. Higher densities of the mango stone weevils are found in Southern and Middle zones than that in the northern zone, with the Southern Zone recording as the highest.

Majority of farmers manage their farms with pesticides. More than half of the respondents (59.2%) had not heard or adopted any indigenous management practice.

The menace of mango stone weevil has been a major setback for the export of quality mango fruits to the European and North American markets. The study revealed that 35.2% of the mango farmers interviewed had problems with pests and diseases.

Mango flowers and dead mango twigs were the most attractive part of all the plant parts tested to mango stone weevil.

6.2 Recommendations

From the study, the following recommendations were made;

(i) To reduce mango stone weevil infestation as recorded in Southern and Middle Zones, orchard sanitation, cultural and insecticides should be integrated to manage the mango stone weevil.

(ii) There is the need to strengthen the existing extension system to enhance information flow between farmers and extension agents on current methods of combating mango stone weevils.

(iii) Mango farmers should form associations (for instance, the Mango Farmers Association of Ghana) to benefit from institutional credit from banks to enhance their productivity and export.

(iv) Provision of accurate market information as well as the provision of sound market infrastructure such as road network, cooling, storage facilities and agro-processing industries will enhance the production of mango fruits in Ghana for the local and international markets.

(v) Since the mango flower and dark colour attracted more weevils, trapping of weevils with dark sticky traps should be encouraged.

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APPENDICES

Appendix 1. Table showing Analysis of variance of Comparative attractiveness of mango plants parts to the mango stone weevil (Sternochetus mangiferae) in group one

Variate: Log Now

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Mango_part	4	1.59397	0.39849	12.66	<.001
Residual	55	1.73142	0.03148		
Total	59	3.32539			

Appendix 2. Table showing Analysis of variance of Comparative attractiveness of mango plants parts to the mango stone weevil (*Sternochetus mangiferae*) in group two

Variate: Log Now

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Mango_part	4	2.36759	0.59190	7.75	<.001
Residual	55	4.20016	0.07637		
Total	59	6.56774			

Appendix 3. Figure showing analysis of variance comparative attractiveness of mango plants parts to the mango stone weevil (*Sternochetus mangiferae*) selected from both groups

Variate:				Log Now	
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Mango_part	5	0.87129	0.17426	3.61	0.006
Residual	66	3.18825	0.04831		
Total	71	4.05954			

Appendix 4: Figure showing comparative olfactory attractiveness of fresh mango flowers and dead mango leaves to the mango stone weevil, (*Sternochetus mangiferae*).

Two-sample t-test

Variates: Dead_mango_leaves, Fresh_mango_flowers.

Test for equality of sample variances

Test statistic F = 1.91 on 11 and 11 d.f.

Probability (under null hypothesis of equal variances) = 0.30

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Dead_mango_leaves	12	0.5783	0.06373	0.2525	0.07288
Fresh_mango_flowers	12	0.8353	0.03338	0.1827	0.05274

Difference of means: -0.2570

Standard error of difference: 0.0900

95% confidence interval for difference in means: (-0.4435, -0.07041)

Test of null hypothesis that mean of Dead_mango_leaves is equal to mean of Fresh_mango_flowers

Test statistic t = -2.86 on 22 d.f.

Probability = 0.009

Appendix 5: Figure showing comparative olfactory attractiveness of fresh mango flowers and dead mango twigs to the mango stone weevil (*Sternochetus mangiferae*).

Two-sample t-test

Variates: Dried_mango_twigs, Fresh_MANGO_flowers.

Test for equality of sample variances

Test statistic F = 1.50 on 11 and 11 d.f.

Probability (under null hypothesis of equal variances) = 0.51

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Dried_mango_twigs	12	0.7328	0.04117	0.2029	0.05857
Fresh_mango_flowers	12	0.6923	0.06166	0.2483	0.07168

Difference of means: 0.0404

Standard error of difference: 0.0926

95% confidence interval for difference in means: (-0.1516, 0.2324)

Test of null hypothesis that mean of Dried_mango_twigs is equal to mean of Fresh_mango_flowers

Test statistic t = 0.44 on 22 d.f. Probability = 0.667

Appendix 6: Figure showing Comparative olfactory attractiveness of dried mango twigs and dead mango leaves to the mango stone weevil (*Sternochetus mangiferae*).

Two-sample t-test

Variates: DEAD_mango_leaves, DRIED_mango_twigs.

Test for equality of sample variances

Test statistic F = 1.80 on 11 and 11 d.f.

Probability (under null hypothesis of equal variances) = 0.34

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
DEAD_mango_leaves	12	0.6823	0.03124	0.1768	0.05103
DRIED_mango_twigs	12	0.6282	0.05622	0.2371	0.06845

Difference of means: 0.0541

Standard error of difference: 0.0854

95% confidence interval for difference in means: (-0.1229, 0.2312)

Test of null hypothesis that mean of DEAD_mango_leaves is equal to mean of DRIED_mango_twigs

Test statistic t = 0.63 on 22 d.f.
Probability = 0.533

Appendix 7: Table showing analysis of variance attractiveness of colour background to the *Sternochetus mangiferae* in the group

Appendix 4. Group one

Variate:			Log Now		
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Colour	3	1.56972	0.52324	13.74	<.001
Residual	44	1.67519	0.03807		
Total	47	3.24492			

Appendix 5. Group two

Variate:				Log Now	
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Colour	3	0.38665	0.12888	4.92	0.005
Residual	44	1.15352	0.02622		
Total	47	1.54017			

Appendix 6. analysis of variance the effect of colour background on the colour attraction of the mango stone weevil

Variate:				Log Now	
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Colour	3	1.10132	0.36711	7.70	<.001
Residual	44	2.09807	0.04768		
Total	47	3.19939			

This shows responses of the weevil towards the four colours selected from the initial eight for further study.

Appendix 9: Table showing analysis of variance of the effect of colour presentation of shape preferences of the *Sternochetus mangiferae*.

Appendix 7. Analysis of variance blue colour

Variate: Log Now

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shape	2	0.14634	0.07317	3.10	0.058
Residual	33	0.77766	0.02357		
Total	35	0.92399			

Appendix 8. Analysis of variance Green colour

Variate: Log Now

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shape	2	0.05022	0.02511	1.07	0.355
Residual	33	0.77455	0.02347		
Total	35	0.82477			

Appendix 9. Analysis of variance Orange colour

Variate: Log Now

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shape	2	0.24493	0.12246	3.97	0.029
Residual	33	1.01909	0.03088		
Total	35	1.26402			

Appendix 10. Analysis of variance black colour

Variate: Log NoW

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Shape	2	1.23163	0.61581	19.81	<.001
Residual	33	1.02597	0.03109		
Total	35	2.25760			

Sample Questionnaire

Preamble

Hello, my name is **ERIC FORDJOUR**, am M. Sc. student of KNUST conducting a study entitled: "**Farmers' Indigenous Technical Knowledge and Management of Mango Pests Especially Stone Weevils.**" The information being sought is meant for academic purposes only, sharing information with scientific community. Therefore, be assured that the strictest sense of anonymity and confidentiality will be maintained in the study. I deeply appreciate your time and cooperation.

Appendix 11. Questionaires on the study of indigenous technical knowledge on the mango stone weevil

Socio-Demographics

Code		Response
Q1	**Name of farmer**	
Q2	**Name of community**	
Q3	**District**	
Q4	**Region**	
Q5	**Date (dd/mm/yy)**	
Q6	**Name of enumerator**	

	Personal Characteristics	Response
Q7	**Gender 1= Male 2 = Female**	
Q8	**Age of farmer (years)**	

Q9	**Are you the household head? 1=Yes 2=No**	
Q10	**Residence status 1= Indigene (Native) 2= Settler (Permanent)** **3= Migrant (Temporary)**	
Q11	**Highest level of formal education of farmer 1 = None 2= Primary School 3=Junior High School 4=Middle School Form Four 5 = Secondary/ Vocational 6= Tertiary (Training college/Polytechnic/university)** **5=Other (Specify)……………………………….**	
Q12	**Marital status 1= Single 2= Married**	
Q13	**Counting yourself, how many people live in your household?**	
Q14	**What are your main sources of income?** (Circle all that apply**)** **1= Food Crop Production 2=Cash crops (mangoes/Cocoa) 3=Trading 4=Artisanship 5= Formal employment 6=Gold business 7=Cassava processing 8=Baker 9=Others (Specify)………………………………….**	
Q15 **a.**	**How many years have you been in farming?**	
b.	**How many years have you been in mango production?**	
c.	**Is mango production your primary or secondary occupation?** **1= Primary 2=Secondary**	
Q16	**What is your motivation for growing mangoes?** (Circle as many as	

	apply) **1=Shade 2=Wind breaks 3= Domestic fruit consumption 4= Income** **Others (specify)……………………………..**	
Q17	**Apart from mango what other major crops do you cultivate?** **1=cassava 2=Plaintain 3=Maize 4=Cocoyam 4=Sorghum 6=Millet** **7=Sweetpotato 8= Vegetables .9 Others** **(Specify)…………………………….**	
Q18	**What is the size of your mango plantation in acres?**	
Q19	**How was your farm land acquire? 1= Outright purchase 2= Rented Land 3= Family Land 4=Community land 5= Share Cropping 6= Leasehold 7= Others (Specify)………………………………………**	
	Production data	Response
Q20	**What is your planting distance (spacing)?** **1=30ft x30ft 2=40ftx40ft 3= 50ftx50ft 4= Others (Specify)……………………….**	
Q21	**What is your plant population?**	
Q22	**Which mango variety(s) do you cultivate?** **1= Kent 2=Keitt 3=Palmer 4=Haden 5= Tommy Atkins 6= Irwin 7= Sensation 8= Julie 9= Jaffna**	

	10=Local 11=Others(Specify)..	
Q23	**What are the incentives for growing a particular variety? (***Check all that apply)* **1=High yield advantage 2= Early maturity 3= Good taste 4=High demand 5= Pest/ disease tolerance 6=High price 8=Easy access to planting materials 9= less post-harvest losses** **10= Others (specify)……………………………**	
Q24	What is your source of planting materials? 1=Own production 2=other farmers 3= MoFA extension 4=Research 5= Seedling hawkers 6=Roadside seed vendors 7=Certified seed growers 9= NGO (Specify)…………………………….. 8= others (specify) ………………...	
Q25	**What is your planting material type?** **1=Grow Direct from seed** **2=Grafted seedling** **3=others (specify) ………………………………...............................**	
	Pest and Disease Awareness and Perception	Response
Q26	**Do you encounter any pest on your mangoes? 1=Yes 2= No**	
Q27	**Which of these mango insect pests have you heard of?** **1= Scale insects 2= Thrips 3= Mealy bugs 4= Mango**	

	stone Weevil 5= Fruit flies 6=Termites / Ants 7= Grasshoppers 8= Mites 9=Aphids 10= Caterpillars (lep.larva) **11=Others (Specify) ....**	
Q28	**Which of these mango insect pests have you experienced on your plantation?** **1= Scale insects 2= Thrips 3= Mealy bugs 4= Mango stone Weevil 5= Fruit flies 6=Termites / Ants 7= Grasshoppers 8= Mites 9=Aphids 10= Caterpillars (lep.larva)** **11=Others (Specify) ....**	
Q29	**Using the scale of 1 to 5 below, please rank the intensity of damage pest to your mango plant**	

Pest	Rank(Intensity of damage)
Scale insects	
Thrips	
Mealy bugs	
Mango stone Weevil	
Fruit flies (*Bactrocera*)	
Termites /Ants	

	Grasshoppers			
	Mites			
	Aphids			
	Caterpillars (lep.larva)			
	Bats			
	Monkeys			
	Humans			
	1= Very High 2=High 3=Average 4=Low 5=Very low 6=Non			
Q30	**Have you ever encountered stone weevils on your mangoes? 1=Yes 2= No**			
a.	**If "Yes" at which stage of production do you encounter them?** **1.Seedling stage 2.Pre-flowering stage 3. Post-Flowering stage 4.Fruiting stage 5. Harvest 6. During Processing** **Other (Specify)……………………**			
b.	**Can you identify infested fruit?** Yes/No			
c.	**If 'Yes, what are the signs of their presence?** **………………………………………………………………………………** **………………………………………………………………………………**			

	…………	
d.	**Which part of the plant is stone weevil mostly attacked?** **1=whole plant 2= Stem 3=Leaves 4=Fruits Other (Specify).............**	
Q31	**How do you control or manage stone weevils? 1= Orchard sanitation 2= Use of chemicals 3= Use of other insects to Control MSW 4=Other (Specify)………………**	
a.	**If you use Orchard Sanitation as insect pest management strategy, what kind of practices do you follow?** **1=Tree banding with glue or grease 2= Spraying with pesticides** **3=Covering of fruits with nets/ envelopes 4= Collection and destruction of dropped fruits 5=Restriction of infested fruits Others (Specify)………….**	
b.	**If you use Pesticide control for stone weevils management, what chemicals do you use frequently?** **1=DDT 2= Fenthion 3= K.Optimal 4= Thiamethoxam (Actara)** **5=Cydin Super 6= Lambad** **7=Other(Specify)……………….**	
Q32	**For how long have you been using your chosen management practices?** .... years	
Q33	**What has been the success rate of your control system?**	

	1=Very High 2=High 3=Average 4=Low 5=Very Low 6= Not sure	
Q34	**Do you know about any indigenous management practices? 1=Yes 2=No**	
a.	**If "Yes" describe it?** **…………………………………………………………………………**	
Q35	**What percentage/ proportion of your produce go waste as result of stone weevil attack**?......................	
Q36	**How do you handle damaged mango fruits by pest?** **1=Leave them on the field 2=Burn** 3= Bury **4= Sell at a reduced price 4=Give out as gift 5=other (specify)……………………….**	
Q37	**How do stone weevils affect your production?** **1= Reduces Fruit quality 2= Increase Fruit drop 3= fruit rot 4=Others** (Specify)**...**	
a.	**Before you detected the stone weevil, what was your fruit yield/acre.............. (Unit)?**	
b.	**What is your current fruit yield/acre.............................(Unit)**	
Q38	**How many fruiting seasons do you have in your location?** **1=One** **2=Two**	

Q39	**If two, which fruiting season were insect pest more prevalent?** **1=Major season 2=Minor season 3= I don't know**	
Q40	**What could be reasons for the prevalence of insect pests chosen season?** **1= High Rainfall 2= Low rainfall 3= Humidity** **4= Hatching stage of stone weevils Other (Specify)…………**	
Q41	**Have you ever received any training on Pest Management?** **1=Yes** **2=No**	
a.	**If yes, which aspects of Pest management?** **1=Training on General Agricultural pest** **2=Training on pesticides application** **3= training on bicontrol** **4= Others (Specify)…………………………….**	
Q43	**Have you ever implemented the technologies you were taught?** **1=Yes 2=No**	

a.	**If "Yes" how effective were they?** **1= Very Effective 2= Not Effective 3= I don't know**	
Q44	**Do you get any assistance in managing stone weevils attack? 1=Yes 2=No**	
	If "Yes" what kind of assistance? **..** **..**	
Q45	**What is the source of this assistance? 1=other farmer 2= Extension (MoFA) 3= Research 4= Chemical input dealer**	
Q46	**Do you know any health risk (disease) associated with the use of pesticides in mango production? 1=Yes 2=No**	
a.	**If yes, what are the risks you know of? 1= abdominal problems such as Diarrhoea 2=Skin rashes 3= Stomachache 4=Eye problems 5=vomiting 6=other (specify)**	
b.	**How do you prevent these?** **1=Use protective clothing 2= Avoid spraying on hot days** **3=Avoid applying on stormy/windy days 4=Other (Specify)………………**	
Q47	**Do you think the use of synthetic chemicals in agriculture has effect on the environment? 1= Yes 2=No**	
a.	**If yes, what are some of the effects you can think of?**	

	1= increased /decreased pest 2= Reduced yield **3= stunted plant growth 4= other** **(specify)...............................**	
Q48	**Which of these chemical application practices are you familiar with?** **1= Recommended procedure on the label 2=use of protective cloth** **3=Read label before use 4= Adherence to expiry dates 5=cocktail mixtures** **6=others (Specify)...**	
Q 49	**Do you use cocktail mixtures? 1=Yes 2= No**	
a.	**How many chemical normally mixed?** **1=2 chemicals** **2= 3 chemicals** **3= 4 chemicals** **Other (Specify)…………**	
b.	**If you practice cocktail mixtures, what chemicals do you use?** **..** **..** **........**	
Q50	**Are you aware of any natural enemies of stone weevils? 1=Yes 2=No**	
a.	**If yes, please list those you are aware of? ....** **1= Red ants 2= Black Ants 3= lizards 4= birds 5= spiders 6=other**	

	(Specify)……………………………..	
	Cultural Practices Adopted	Responds
Q51	**Which of the following cultural practices did you use during the last season?** **1= Induction of mango plants when the leaves of the latest buds are fully matured . 2=Sprayed for pest control 3= Harvested on time. 4=weeding 5= pruning 6=Watering 8= All the above** **9= other (Specify)……………………………..**	
Q52	**Are any of your trees bearing fruits? 1=Yes 2= No**	
a.	**If "Yes" how long have they been bearing fruits?**	
b.	**If "No" what are the reasons for non-bearing?......................................**	
Q53	**Is the fruit yield satisfactory? 1=Yes 2=No**	
	If "Not" what do you think are the causes? 1= lack of Rain 2=Insect pest attack **Others (Specify)…………………..**	
Q54	**What common weeds do you encounter in your mango plantation?** **1= Grasses (Specify)……………………………..** **2= Broadleaves (Specify)……………………….**	

	Production and Marketing constraints	**Response**
Q55	What are your major production constraints? 1=lack of quality seeds 2=lack of extension services 3= pest and disease control 4=unavailability of water 5= Capital 6= Difficulty in accessing land 7= Ready Market 9=Others (Specify)………………….	
Q56	What are your major marketing constraints? 1= Low commodity prices 2= Post harvest losses 3= High transportation cost 4= lack of transport 6= Lack of cooling facilities 7= High taxes 8=others (Specify)…………………….	
	Knowledge Level	**Response**
Q57	Do you frequently get mango production information's? 1=Yes 2= No	
Q58	If "Yes", What are your sources of information? 1=Electronic media 2= Print media 3=Fellow farmers 4=MoFA Extension 5= Research 6=Projects 7= others (Specify)	
	Extension Coverage	**Response**
Q59	Do you have Agric Extension Officer for your area? 1=Yes 2=No	
a.	If "Yes" have you been contacting him/her? 1=Yes 2=No	
Q60	How many times did the extension officer visit you during last cropping season?	
Q61	How many times did you contact extension personally during the last crop season?	
Q62	How far is your house from the nearest extension office? (Miles)	
Q63	Are you a member of any farmer organization 1 = Yes 2= No	
a.	If " No" why?....................	
	Government intervention	
Q64	Do you receive any assistance from the government for mango	

	production? 1=Yes 2=No	
Q65	If yes, what assistance do you receive? 1= Financial 2=Training 3= Management services 4=Equipment 5=Purchase of produce 6= Others (specify)	

Thanks for your co-operation