EVALUATION OF FIVE PROMISING PEARL MILLET LINES TO INSECT PESTS IN UPPER EAST REGION, GHANA

BY

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MUKHTARU ZAKARIA (BSc. Agriculture)

A Thesis Submitted to the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana

In Partial Fulfilment of the Requirements for the Degree

Of

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DECLARATION

I, Mukhtaru Zakaria hereby declare that the results of this study, except for references to other people's work, which have been duly cited, are the account of my own investigations and have not been submitted either in part or in whole for any degree elsewhere other than my master of philosophy (MPhil) degree in entomology at the Kwame Nkrumah University of Science and Technology (KNUST), KumasiGhana.

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ABSTRACT

A study was undertaken in the 2013 cropping season at Manga Agricultural Research Station to determine the resistance of five pearl millet lines to insect pests. The study comprised the following treatments: (i) Bongo short head (ii) Arrow millet (iii) Bristled head millet (iv) Tongo yellow (v) Sox-sat (vi) Manga Naara (Local check) (vii) Manga Naara + insecticide. The main species of insect pests collected at the various phenological stages of the crop included; Stem borer *(Coniesta ignefusalis,* Hampson*)* Shoot fly (*Atherigona* sp) *Lema* spp., *Mylabris* spp. The bugs *(Dysdercus, Acrosternum* and *Agonascelis* species*),Heliocheilus albipunctella*, De-joannisand *Amsacta* spp. Significant differences ($P < 0.05$) were observed among the lines with respect to the abundance of *Lema* spp. *Mylabris* spp. and *Dysdercus* spp. There were significant differences ($P < 0.05$) in the densities of *Lema* spp. between the improved lines and the Local check. Significant differences ($P < 0.05$) were also observed in the numbers of *Dysdercus* and *Mylabris* species between the improved lines. Feeding of *Lema* spp on pearl millet leaves resulted in a significantly higher defoliation of Manga Naara (Local check) as compared to improved lines and Manga Naara + Insecticide. Manga Naara had significantly ($P < 0.05$) greater numbers of (*Lema* spp., shoot fly dead hearts, stem borer larvae and dead hearts, *Mylabris* and *Dysdercus* species). No significant differences in yields were obtained among treatments. The study showed that bristle long head performed better than the other lines and can be recommended for more improvement to enhance yield increase.

DEDICATION

This work is dedicated to the Almighty God and also to my beloved mum Abiba Yahaya Imam, my wife Ruhaima and my children and the entire Mukhtatru family for their love, prayers and invaluable support throughout my study.

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CHAPTER ONE

1.0 INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L) R. BR) is a principal staple food crop in the Upper East region of Ghana, cultivated by about 60% of the farmers (PPMED, 1991). It is usually intercropped with legumes and cereal crops, notably cowpea, soybean, sorghum and late millet. Pearl millet is a very versatile crop and a major source of income and nutrition for many people in the region. The crop is relatively rich in carbohydrates, iron, phosphorus, calcium and zinc. It is also an important source of vitamin complex which is normally concentrated in the outer bran layers of the grain, (Holt, 2000).

A total of 53, 074 ha of land was cultivated to the crop in 2013 with a total output of 42,623 metric tonnes of grain (MoFA, 2011). The crop does well in areas with rainfall as low as 250 mm per annum and on relatively poor soils. Being tolerant to drought and salinity the crop is largely grown in the dryer areas of India, Nigeria, Chad, Tanzania, Mali, Niger, Ethiopia, China, Russia.

The major crop production constraints in the Sudan savannah agro-ecological zone are low soil fertility, rainfall and insect pests and diseases. Grain yields on peasant farms are generally low, due partly to insect pests' damage. However, there is inadequate information on the damage caused by insect pests and the attendant yield losses in pearl millet in the Sudan zone of Ghana particularly in the upper East Region where pearl millet is the most important food security crop. There is the need to increase efforts to screen the available pearl millet germplasm to identify resistant ones for further development.

In rainfed agriculture like that practised in the Upper East Farming Systems, it is difficult to manipulate sowing date to avoid pest damage, as the planting times are determined by the onset of rains. Also, different farmers in the region plant at different times, and use cultivars of different maturities. Usually Pearl millet farmers do not apply insecticides to manage insect pests on their crop as these chemicals are costly, and beyond the reach of poor farmers, in addition to the adverse effects of these chemicals on man and the environment. In view of this, host plant resistance appears to be the option that should be used to contain pests and disease problems in pearl millet in the region.

The Savannah Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI) is about to release five improved pearl millet lines in the Upper East Region. The purpose of this research was to identify genotypes that best maintain high yield potential as well show high resistance to major insects of Pearl millet. The feedback of the research will be useful to peasant farmers who have little resources to effectively manage insect pest populations through chemical application.

It is in the light of this that this study seeks to evaluate the performance of five improved pearl millet lines (soon to be released by CSIR-SARI) against insect pests of the crop was undertaken.

The specific objectives were to;

(i) determine the incidence of key insect pests of pearl millet in the area

(ii) identify the damage caused by the pests at each phenological stage

(iii) identify genotypes resistant to these insect pests

(iv) determine the yield of these genotypes.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 World production of pearl millet

Pearl millet, *P. glaucum* commonly known as millet in Ghana, is a cereal crop cultivated mainly in the Semi-Arid Tropics (SAT). It is an annual crop which serves as a subsistence and a food security crop, especially for nutritive and cultural value (Holt, 2000). It has excellent storability, ideal for food security, management of malnutrition and diet for diabetic patients (Holt, 2000). It also has other desirable attributes such as higher nutritive value (including micronutrients such as iron, calcium, phosphorus and zinc) than most major cereals; higher fodder value and higher tolerance to pests and diseases. This nutritive value makes the crop particularly important in the diets of children, pregnant and breast feeding women (FAO, 2005).

Pearl millet is reported to account for almost half of global millet production, with Africa recording 60% (estimated at 15 million hectares annually) and 14 million hectares in Asia (National Research Council, 1996). Global production of cultivated fields of Pearl millet exceeds 10 million tons. Pearl millet and Sorghum serve as main staple for more than500 million people living in the semi-arid tropics (NRC, 1996).

The crop is widely produced in the Sahelian zone of West Africa, and serves as a major food security crop. It is of particular importance in the African Sahel where it is the only cereal crop that will produce grain yields under harsh environmental conditions. About 25% of the total world estimated production is in West Africa where it is grown as a rainfed subsistence crop especially in areas of low and erratic rainfall (250 to 900 mm per annum). Pearl millet is reasonably tolerant to extreme soil and weather conditions. The average global area grown to pearl millet in 2003 was estimated at about

30 million tonnes and 22 million of it is used for human consumption (FAO 2009). According to Appa Rao (1985) available evidence indicates that pearl millet originated in West Africa some 4000 years ago. Major producing centres include Africa (15 million ha) and India (10 million ha). Being most tolerant to drought and salinity the crop is largely grown in many countries including Nigeria, Chad, Togo, Mali, Niger, and Ethiopia. Pearl millet landraces have been described as different ecotypes of the species, which developed over time, as a result of cultivation under diverse agro-climatic conditions and farming systems
(Appa Rao, 1985). There is a rich diversity of pearl millet landraces cultivated in Ghana, The niche of the crop is in the semi-arid plains of Southern Asia (especially India) and the Sahel (Sub-Saharan) region of Africa (David, 1981). As a feed, grain Pearl millet is comparable to maize but superior to sorghum (Andrews and Kappe,1993)

The main challenges for farmers within the semi-arid and arid tropics and sub-tropics are yield instability, risk of crop failure and food insecurity. These challenges are as a result of erratic and unreliable rainfall during the cropping season (Kasei, 2001).The world has been experiencing increasing unstable climatic situation, resulting from global warming and greenhouse gasses emissions, in the last two or more decades (Akromah, 2012).

According to Virmani (1984), the semi-arid tropics, following Troll's classification, are areas where monthly rainfall exceeds potential evapotranspiration for two to seven months annually and the mean monthly temperature is above 18°C for most of the year. Within this climatic zone, the areas with 2 to 4.5 wet months are called the dry semi-arid tropics, and almost all the millet (> 90%) and most of the sorghum (>75%) are grown.

In the millet producing regions (Sahel region of Africa), solar radiation is relatively high throughout the year with high temperatures (Konate, 1984) which in themselves are not limiting factors to the production of the crop, even though they do strongly influence plant growth and development. The climate of the regions (Sahel region of Africa) is associated with amounts of precipitation that do not normally commensurate with the evaporative demand of the crop (Konate, 1984). Purseglove, (1985) reported that Pearl millet (*Pennisetum glaucum*) also known as spiked millet, bajra and bulrush millet, could be taken as a single species with a number of cultivated races.

The average yields of traditional landrace millet on West African farmers' fields over the years have been as low as 200 to 600 kg/ha depending on country and season (Virmani, 1984; Tanzubil and Yakubu, 1997) even though yields from research fields have reached as high as 2000 kg/ha (Tanzubil and Yakubu, 1997). The low yield situation has been blamed on low erratic rainfall, inherent poor and degraded soil coupled with invasion and increased numbers of insects, diseases and weeds (Tanzubil and Mensah, 2000).

2.2 Pearl millet production in Ghana

In Ghana, the crop is grown only in the Northern, Upper East and Upper West regions. In northern Ghana, pearl millet is a staple crop. The grain is used for the preparation of many popular dishes and snacks, such as porridge, 'tuo', 'zonkom' and cakes. The stalks and leaves of the crop are also used for feeding animals, roofing huts, making garden fences and as fuel-wood for cooking. Pearl millet has become an inseparable part of the traditions of northern Ghana (Davies, 1968). For example, it is a necessary item for presentation and preparation of meals during the performance of traditional ceremonies such as funerals, weddings, and child naming ceremonies.

Pearl millet has high tolerance to stressful environmental conditions (Burton, 1985), such as drought and poor soil fertility, which are common in northern Ghana and which are constraints to the cultivation of crops. It is of short maturity period and hence provides early harvest. Pearl millet is also of a higher nutrient value than most other cereals (Singh *et al*., 1996).

The crop is grown mainly by smallholder farmers covering an area of 177,000 ha in Ghana under rainfed conditions producing about 218,952 metric tons. The mean annual production from 2008 to 2010 was also estimated to be 219,000 MT (MoFA, 2011). However the yield of pearl millet on farmers' farm is reported to be below 16% of the potential yield in the Region. Reasons responsible for the low yields include the use of unimproved cultivars and poor management practices (MoFA, 2011). Youm *et al*. (1996) recorded yield losses of between 15 to 60% attributable to a complex of pests often feeding on the crop at various phenological stages.

In view of its many useful agronomic attributes, wide range of uses, and popularity as a traditional crop, pearl millet could be used for achieving sustainable food security and for enhancing agricultural and socio-economic development. However, the cultivation of pearl millet in Ghana is still mainly traditional, faced with many constraints and characterized by very low yields. A major constraint to the production of pearl millet in Ghana is the lack of improved varieties (Froelich *et al,* 1993), resulting in the use of local landrace cultivars, which have low yield components and which are susceptible to diseases and pests of the crop.

In the upper East Region of Ghana farmers usually cultivate the early maturing pearl millet after early rains, as a sole crop or in mixture with other crops on a subsistence basis (MoFA, 2011).

In African countries such as Ghana, the national average grain yields of pearl millet are generally in the low range of 400-600 kg/ha (MoFA, 2011) and in some countries where pearl millet is a major crop, the average yield is less than 400 kg/ha (ICRISAT, 2011). On experiment stations however, yields of 2-3 tonnes per ha are regularly reported, and undoubtedly many farmers occasionally achieve yields in the 1-2 tonnes per ha range with traditional varieties when conditions are highly favourable for the crop in a particular season (ICRISAT, 2011).

2.3 Pearl millet production zones in Ghana

Pearl millet is grown mainly in the three Administrative regions of Northern, Upper East and Upper West regions of Ghana (covering 29% total land area, Fig. 2.1) (SRID, 2011). Northern Ghana is located within the Sudan and Guinea Savanna zones *(*also known as semi-arid zone or interior Savanna) which cover about 41% of the land area of Ghana (Bennett-Lartey and Oteng-Yeboah, 2008). The regions are bounded to the north by Ivory Coast and Bukina Faso, to the east by Togo, the west by Cote D‘lvoire and to the south by Brong Ahafo Region. Northern Ghana is characterized by a uni-modal type of rainfall which lasts between April/May and September/October with an annual mean ranging from 800 to 1,200 mm (BennettLartey and Oteng-Yeboah, 2008). The mean rainfall for 10- and 30-year period (SRID, 2011) indicates that the amount declines from south to north as observed in Fig. 2.2.

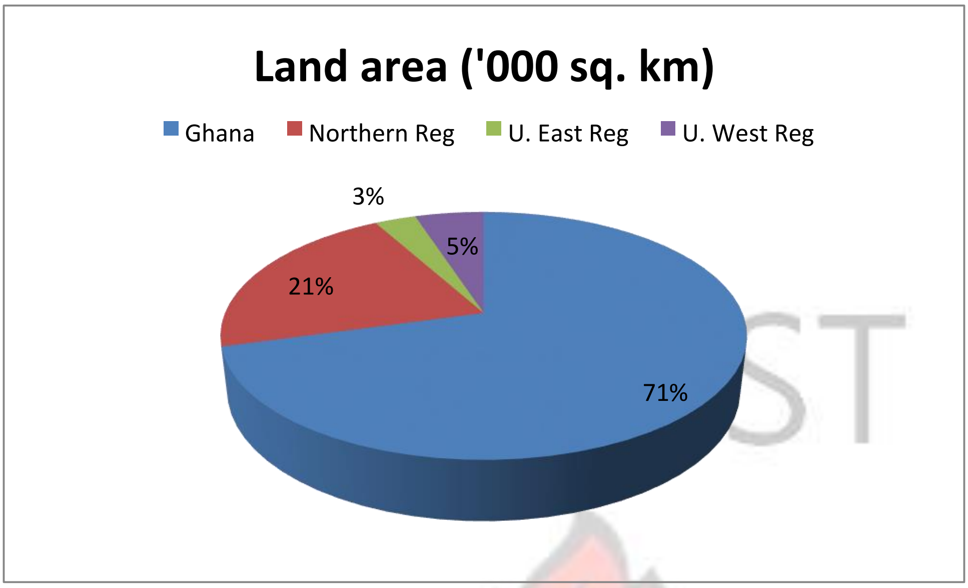

Figure 2.1: Total land area of regions covered

Source: SRID, MOFA (2011)

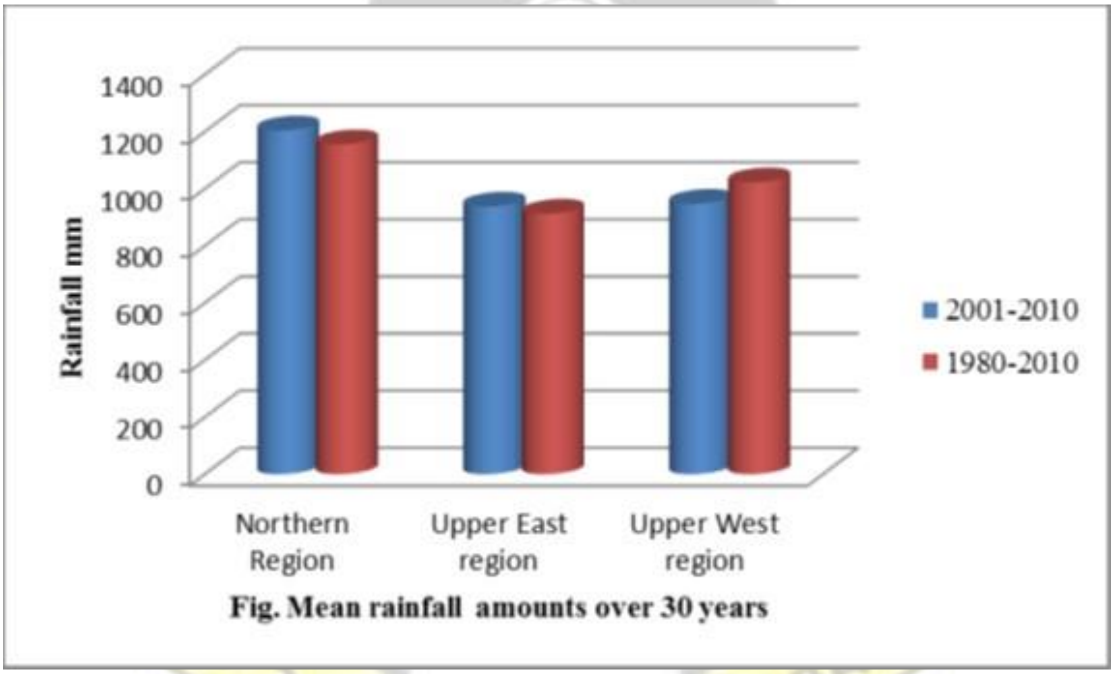

Figure 2.2: Mean rainfall amounts over 30 years in northern Ghana

Source: SRID, MOFA (2011)

Runge-Metzger (1993) described the soils as ranging from granites interspersed withpyroclastic rock in Upper East to voltarian sandstone in the Northern region making them easy to work but prone to concretions and hardpan which affects their physical properties, particularly their water holding capacity. The soils (Table 2.1) of the regions are generally acidic with very low organic matter content.

Table 2.1: Some physical and chemical properties of soil samples from Manga (0 – 30 cm in depth)

Soil properties	Manga
% Sand	80-90
% Silt	5.6-15.6
% Clay	2.4-4.4
% Organic matter	0.14-0.76
PH	4.5-4.79
% Nitrogen	0.014-0.028
Available phosphorus (mg/kg)	17-49
Potassium (cmol/kg)	0.06-0.12

Source: Afribeh, 2005

According to SARI (1994), about 60% (and up to 97% in the Upper East Region) of farmers in Northern Ghana grow Pearl millet in what has been described by Diehl and Sipkens (1985) as a millet-based farming system. The system consists of Millet intercropped with sorghum, maize, cowpea, or groundnut. According to Policy Planning Monitoring and Evaluation Division of the Ministry of Food and Agriculture (PPMED, 1991), in 1990 an estimated 244,000 ha of land put to millet production yielded 80,000 tonnes of grains. In 2010 (20 years later), the actual cropped area declined to 177,000 ha but grain yields increased to 219,000 tonnes (SRID 2011).

2.4 Importance and uses of millet

Approximately 700 g per capita per day of Pearl millet is consumed and this provides the bulk of dietary energy and protein for consumers (James and Oppen, 1984). Rooney and McDonough (1987) reported that Pearl millet is 1 to 2% higher in crude protein, 35% more lysine but deficient in essential amino acids compared with sorghum. Ejeta *et al*. (1987) have also reported that Pearl millet contains 27–32% more protein than maize, higher concentrations of amino acids, twice the ether extract and higher gross energy than maize. Again, Jambunathan and Subramanian (1988) intimated that the proportion of germ in Pearl millet grain (17%) was about double that of sorghum, while the endosperm accounted for 75% as against 82% in sorghum. The afore-mentioned qualities of the Pearl millet make it meet most of the nutrient requirements of its producers who are considered poor and deprived peasant farmers.

2.5 Insect pests of pearl millet and their damage

Nearly 500 species of insects have been reported to feed on millets in different parts of the world (Sharma and Davies 1988; Sharma and Youm 1999), only a few are serious pests worldwide. Not much attention has been paid to insect pests problems of pearl millet even though white grubs, stem borers, head miner, head caterpillars, blister beetles, and chafer beetles cause serious losses in pearl millet in different parts of world including Ghana. Pests' problems in pearl millet may change dramatically with a change in agronomic practices such as the use of farm yard manure. Ammonia based fertilizers increase the severity of white grub damage and early flowering cultivars are highly damaged by the head miner in West Africa. Frequent occurrence of drought in the Sahel increases the severity of stem borer and the head miner

(ICRISAT, 2011).

2.5.1 Major Insect Pest of Pearl millet

2.5.1.1 White grubs (*Holotrichia* spp. *Pachnoda* spp. and *Rhinyptia* spp.)

Numerous species of white grubs damage pearl millet in Asia and Africa, of which, *H. consanguinea* is most damaging in North West India, while *P. interrupta and R. infuscata* are important in West Africa (Nwanze and Harris, 1992). The grubs feed on the roots, and live inside the soil at depths of 2 to 25 cm. Damage leads to withering and death of seedlings. Mature plants remain stunted in growth, become pale yellow in colour, and are prone to lodging. The white grub adults emerge with the onset of rainy season, and lay eggs directly. The grubs feed on the roots, and in most cases, there is only one generation in a year. The adults feed on the leaves of shrubs and trees at sunset.

2.5.1.2 Shoot fly (*Atherigona approximata*)

Pearl millet shoot fly, *A. approximata* Malloch has been reported as a pest of pearl millet from different states in India, and is particularity severe in southern India. Its damage has also been observed in Zambia (Musonda, 1996), Senegal (Gahukar, 1985), and Niger (Sharma *et al*., 2000). The larvae feed on the central whorl leaf, resulting in the production of a dead heart. In many instances, the damaged leaf continues to grow, and as it emerges out of the leaf whorl, it appears half cut or has shoot fly damage along the leaf margins. Maximum loss in grain yield occurs when the developing panicle is damaged inside the boot leaf. The portion of the panicle above the point of shoot fly damage dries up, and is often thrown off. The damaged panicles appear as half or partially-damaged. Shoot fly damage also leads to tillering, although tillers are also damaged under high shoot fly pressure. Shoot fly damage was more pronounced on late sown crop, and the infestation ranged from 10 to 80%.

The dead heart percentage is 20%.

2.5.1.3 Stem borers (*Chilo partellus and Coniesta ignefusalis*)

Twenty-two species of pyralids and noctuids have been reported to feed on pearl millet, of which *C. partellus* Swin is important in India, while *C. ignefusalis* Hampson is predominant in East Africa. Larval feeding first leads to leaf scarification, followed by dead heart formation. In mature plants, the larvae tunnel inside the stem, resulting in partially or completely chaffy panicles. Larvae of *C. Ignefusalis* rarely leave the leaf sheath. Small plants are thoroughly riddled by the larvae, while extensive tunnelling occurs in the mature plants. As a result of stem borer damage during the early stages, the plants produce axial tillers, while damage during the later stages of crop growth results in stem tunnelling and partially or completely chaffy panicles.

Pupae from diapausing larvae of *C. Ignefusalis* contribute to adults that are significantly smaller and have lower reproductive rates than those derived from nondiapausing larvae (Tanzubil *et al*., 2003). Artificial infestations with five and ten larvae per plant at two weeks after plant emergence resulted in 50 to 70% plants with dead hearts and 24 to 100% avoidable yield loss (Yaye *et al*., 2003). *C. ignefusalis* larvae enter diapause only in late pearl millet and sorghum, with a higher incidence in the former (Tanzubil *et al*., 2003). The insect neither attacked nor entered diapause in maize planted during the same period. Diapause incidence in pearl millet is greater in older than in younger plants, suggesting that host plant maturation is a key factor influencing induction of diapause in *C. ignefusalis*.

Monitoring of changes in populations of *C. Ignefusalis* based on pheromone indicated that solar radiation in the preceding ten days and minimum air temperature in the preceding 40 to 50 days explained 84.9% of the difference in population and flight activity of male moths at Samaru, Nigeria, in 1997; while wind direction and speed in the preceding 20 and 60 days, respectively, accounted for 80.6% of the variance in 1998

(Gwadi *et al.*, 2006). Maximum air temperature and relative humidity in the preceding 40 and 20 days, respectively, explained 99.9% of the variance in 1999. Monitoring of *C. Ignefusalis* population through pheromone baited traps in Ghana indicated that there were four generations per year, with peaks in June, July, September, and October (Tanzubil *et al.*, 2003).

There was a positive relationship between trap catches and larval numbers in pearl millet, and also between trap catches and the number of bored plants three weeks later. There was no important relationship between larval infestation and crop damage, suggesting that larval count alone may not be a consistent indicator of *C. Ignefusalis* damage to pearl millet.

2.5.1.4 Defoliators (*Mytimna* spp. *Spodoptera* spp *Myllocerus* spp. *and Marasmia* spp.*)*

The oriental armyworm*, M. separata* Walker is a significant defoliator in Asia, while *S. exempta* Walker is important in Africa. The larvae feed on the leaves, resulting in extensive defoliation. Grey weevils, *Myllocerus* spp. are serious pest of pearl millet in some parts of India. When the adult numbers reach outbreak proportions, the entire crop may be skeletonised. Adults of oriental armyworm, *M. separata* were generally caught in light traps 15 to 20 days after the initiation of the monsoon rains in the first week of June, and reached a peak in September, nearly one month after the peak in larval density (Sharma *et al.*, 2002). Rainfall maximum and minimum relative humidity were positively correlated with moth catches in light traps, while maximum temperature, open pan evaporation, solar radiation, sunshine hours, and wind velocity had negative correlation with moth abundance. Five hymenopteran and five dipteran parasitoids, a mermithid, and nuclear polyhedrosis virus regulated its populations under natural

conditions, of which *Cotesia ruficrus* (Holiday) was the principal mortality factor, resulting in up to 47% parasitism. Its activity was greater in sorghum
(24.6% plants with larvae) than in pearl millet (14.9%). Leaf defoliator, *M. trapezalis* Guen is a sporadic pest of pearl millet, (Mittal *et al*., 2006).

2.5.1.5 Sap sucking insects *(Peregrinus* spp, *Oligonychus* spp, *and Pyrilla* spp.)

Shoot bug, *Peregrinus maidis* (Ashmead) is pantropical in distribution. It absorbs the sap from the whorl leaves, resulting in leaf chlorosis, stunted growth, shrivelled grain, and chaffy spikelet. The spider mite, O. *Indicus* Hirst is an occasional pest of pearl millet in India. It feeds on the under surface of leaves, resulting in leaf chlorosis, and drying. Infestation by *P. perpusilla* Walker is severe in North India and greatest population has been recorded between 36th to the 38th week (Mittal *et al*., 2006).

2.5.1.6 Head caterpillars (*Heliocheilus* spp. *Helicoverpa* spp. and *Eublema* spp).

The head miner, *H. albipunctella* De-joannis is one of the most destructive pests of pearl millet in West Africa. The young larvae feed on the flowers and glumes, and then on the interior portion in the panicle on the grain. The later instars cut the floral rachis in a spiral manner, and prevent grain formation. Head miner infestation is highly influenced by maturity cycle. Extra-early and late-flowering cultivars escape head minor damage (Nwanze, 1985). Plant escape from insect damage is an adaptive character, and extra early maturing cultivars can be an important component to minimize head minor damage. Larvae of *H. armigera* Hubner feed on the developing grain, while the larvae of. *E. silicula* Swin feed on relatively mature grain, and remain hidden under a dome-shaped or elongated gallery formed from silken threads and
anthers.

The first reports of millet head miners causing economic damage occurred in 1972–1974 (Gahukar 1984), when Sub-Sahelian Africa experienced severe droughts. In Niger, some of the earliest reports of millet head miner infestation reported 15% yield loss in 1974 (Vercambre, 1978). The millet head miner is univoltine and has a geographical distribution between 11° and 15° N latitudes within the Southern Sahel and Sudan bioclimatic zones (Nwanze, 1992). Damage to pearl millet is caused by developing millet head miner larvae feeding on flowers and seeds during the entire plant reproductive phase. Gahukar (1990) observed that millet head miners lay 70–90 eggs in individual pearl millet heads and that the density of young larvae (1st and 2nd instars) was about 10–40 individuals per millet head. In the weeks before grain maturity, a fourth instar millet head miner larvae descend and pupate in the soil and diapause until the onset of the subsequent growing season after the first seasonal rainfall.

Due to challenging socioeconomic conditions, effective and widespread use of insecticides is not an option for most smallholder farmers in Sub-Sahelian Africa. Cultural practices [i.e. late planting (Youm *et al*., 1993), intercropping and planting density (Gahukar, 1989), and use of fertilizer (Tanzubil *et al*., 2004)] have been examined experimentally as possible management options, but they have not been developed further. Since the 1980s, Pearl millet resistant to the millet head miner has been developed (Gahukar, 1989 and Youm *et al*., 2001). However, these efforts have so far produced few tangible results and have not been made available to smallholders throughout the region (Payne *et al*., 2011).

2.5.1.7 Blister and chafer beetles (*Mylabris* spp. *Psalydolytta* spp. and *Pachnoda* spp.).

Huge numbers of blister beetles *(Coniesta tenuicollis. and Psalydolyta fusca Oliv*) damage the pearl millet inflorescences and grain during the reproductive stage. Infestations of blister and chafer beetles are occasional, and vary considerably over space and time. Greater infestation by *Pachnoda interrupta* Oliv has been observed in pearl millet in August and September in West Africa. Insect damage and grain yield loss were found to be significantly higher in pearl millet sown between mid to late July than in the early sown crop (Sastawa and Lale, 2000).

In a study of the pest status and control of blister beetles in West Africa, Gahukar (1984) concluded that blister beetles have gained importance in species diversity and as pests of food crops. Severe infestations by meloid beetles reportedly caused considerable yield losses in certain parts of West Africa (Gahukar *et al.*, 1986; Lale and Sastawa, 2000). Specifically, the blister beetles, *Psalydolytta* vestita (Dufour) and *Psalydolytta fusca* Olivier were recorded as pests of millet (*Pennisetum americanum* Leeke) in Sahelian areas of West Africa (Doumbia, 1992). Grunshawa *et al*. (1994) observed the blister beetle *Psalydolytta pilipes* Maklin in pearl millet fields in northwest Mali and *P. fusca* are the most serious pests of pearl millet among ten meloid species feeding on millet spikes in the Gambia (Zethner and Laurense, 1988).

As observed by Ajayi (1985), blister beetles are a major pest in Nigeria feeding on pearl millet panicles. Since they feed on flowers, pollination is reduced affecting grain yield as well. Ajayi *et al.* (1998) conducted some field trials in 1997 in Nigeria and their results indicated that *Coryna* spp. can cause severe yield losses, especially when high populations occur. They obtained results supporting the view expressed by Tanzubil and Yakubu (1997) that pollen beetles are potentially serious pests of pearl millet in West Africa.

2.6. Insect Resistant Genotypes of Pearl millet

Although specific and intensive efforts have not been made to screen for resistance to insect pests in pearl millet, researchers elsewhere have reported resistance to some major insect pests in pearl millet.

2.6.1 Resistance to *Coniesta ignefusalis*

Pearl millet variety Zongo grown in West Africa, was relatively resistant to *C. Ignefusalis* (N'Doye, 1977). Ajayi (1985) also reported that Douro type pearl millet varieties were heavily infested by *C. ignefusalis*, followed by Gero, and Maiwa types. Hairiness of leaves and leaf sheaths were partly responsible for the differences in genotypic vulnerability to the borer. Varieties such as INMB 106, INMB 218, and INMB 155 were observed to be resistant to stem borer under natural infestation.

Plants with trichomes were not preferred for oviposition as the non trichomed types (Youm *et al.*, 1996).

Kishore (1991) screened 2,345 accessions, and 1,000 breeding lines for resistance to insects, of which 26 J, 29 MD; IP numbers 366, 1176, 1178, 1289, 1302, 1317, and 1330; and the lines BM 46, WC-C 75, PHB 47, MP 14, MH 46, PHB 14, MH 419, MH 1248, MH 1272, and MH 1274 were found to be less vulnerable to leaf roller, *M. trapezalis* (Kishore, 1991, 1993; Kishore *et al*., 2005).

2.6.2 Head miner (*Heliocheilus albipunctella* De-joannis)

Varieties such as MV 8001, Souna, ICMS 7838, H 9-127, H 24-38, ICMS 7819, ICMS,7703,ICH 165, CIVT II, 3/4 HK, Moroni, Nigerian Composite, HKB tif, HKP, Zongo, Nieuluwa, Boudouma, IBMV 8302, INMG 1, SRM-Dori, P 8, P 3 Kolo, ITV 8001, Kass-blaga, Youmee-Nini, and Tass-Yombo were found to be less vulnerable to head miner (Gahukar, 1984, 1985, 1989, 1990; Gahukar *et al*., 1986). Gahukar (1989,

1990) reported that IBV 8001 and P 8 were less vulnerable to head miner. However, Kadi and Pendelton (2005) observed that damage scores did not vary significantly in the pearl millet genotypes such as ANKOUTESS, ICMH 2003, SOSA T-C88, ICMH 2104, TMK, lA x TMK, IA x KBH, KBH, ICMV IS 99001, ICMV IS 90311, ICMV IS 92326, HKP-GMS, and 3/4 HK B-78. The highest yields were recorded in genotypes such as; lA x TMK, ICMV IS 99001, HKP-GMS, TMK, and IA x KBH (1.0 to 1.1 t ha-^{I}). TMK, HKP-GMS and ICMV IS 99001 were tolerant to head minor damage.

2.6.3 Blister beetles *(Psalydolytta* and *Pachnoda* spp)

Proportion of grain damage and grain yield loss caused by blister beetles were significantly higher in GB 8735 and Ex-borno in 1997, and in GB 8735, Ex-borno, Zangari, and Warne in 1998 (Lale and Sastawa, 2000). Mboderi did not suffer any damage in 1997, while Gargasori was damage-free for two years. Damage caused by *Coryna* spp. was significantly greater in GB 8735, Ex-borno, and Mboderi in 1997 and 1998 cropping seasons. Injury by *P. interrupta* was higher in GB 8735 and least in Gargasori (Sastawa and Lale, 2000).

2.6.4 Head caterpillars (*Helicoverpa armigera* Hubner and *Eublemma silicula* Swin)

Compact panicled genotypes are less damaged by the head caterpillars. Cultivars with a thick cover of pollen tubes on the panicle suffer more damage by *H. Armigera* (Sharma, *et al*., 2000). Tift 23S is less preferred for oviposition (compared to Tift 23H) by *H. zea* because of the absence of pubescence on the foliage. For instance IP numbers 57,164, 326, 1046, 1130,1316,1324,1949, and 1964 suffered less damage by *E. silicula* and *Cryptoblabes gnidiella*Mill. (Kishore, 1991).While genotypes such as Pusa 605 and MLBH 104 suffered least damage (Kishore, 1996).

2.7 Management of pearl millet insects in the field

Tanzubil *et al*. (2004) observed that, applying higher doses of N fertilizers to pearl millet will lead to higher prevalence of insect pests such as stem borer, *Coniesta ignefusalis* Hampson and cotton stainer, *Dysdercus* spp. in West Africa. They also observed that, Stem borer larvae reared on pearl millet grown on high doses of N have increased insect survival and led to crop damage. However, N application reduced the incidence of the head miner, *Heliochelus De-joannis. albipunctella*. Percentage grain damage and grain yield loss from *Mylabris* spp. have been found to be greater in pearl millet grown with cowpea than in pearl millet grown with sorghum in 1997 (Lale and Sastawa, 2000).

Another study in 1997 showed that there were no significant differences between cropping systems for percentage damage and grain yield loss from *Coryna* spp. However grain yields were significantly higher in sole pearl millet as compared to pearl millet - sorghum intercrops (Sastawa and Lale, 2000). Pearl millet grain yields were also greater when intercropped with cowpeas than when intercropped with sorghum. Kishore and Barman (2003) observed that two rows of pearl millet intercropped with one row of mung bean produced the highest yield.

Juneja *et al*. (2004) observed that, spraying 5% extracts of mint and *Oscimum sanctum* leaves, and neem seed kernel suspension were effective in reducing shoot fly infestation. It was also reported that spraying 10% extra seed + endosulfan 4% dust or fenvalerate 0.4% dust at 30 days after germination or seed treatment with imidacloprid at 5 ml kg^{-1} seed + sprays of 5% neem oil at 30 days after germination + endosulfan 4% dusting at 50% flowering resulted in > 40% increase in grain yield (Kishore and Barman, 2003).

Cypermethrin has been found to be effective for controlling sorghum webworm, striped grass worm, and stink bugs; while spinosad was effective against corn earworm, striped grass worm, and sorghum webworm, but not against stink bugs (Buntin *et al*., 2007). In another experiment it was observed that *Azadirachtin* was not effective against any of the insects tested while Malathion dusting (20 kg ha^{-1}) and endosulfan sprays (2 ml $litre^{-1}$) were able to protect 75% of the crop from blister beetles and plant bugs for 10 days (Balikai and Guggari, 2006).

The smoke produced by burning rhizomes of sweet flag, *Acorus calamus* provided good control of panicle feeding insects for seven days. Lale and Yusuf (2000) observed that *Tribolium castaneum* Herbst, *Oyptolestes ferrugineus* Step. and *Liposcelis bostrychophilus* Bad. constituted 47.7, 27.8 and 17.0%, respectively of the total number of insects collected from pearl millet samples.

2.8 Pest management in stored pearl millet

Piper guineense at the rate of 80 mg/5g of seed completely suppressed the development of *T. castaneum* adults and larvae in pearl millet grains (Lale and Ajayi, 2000). Seed dressing with deltamethrin + thiram preserved the pearl millet germination above the certification standards up to 18 months when stored in 700 gauge polyethylene bag than in gunny bags (Srimathi *et al*., 2001).

According to Raghvani *et al.* (2002) germination of pearl millet seeds stored in polyethylene bags was greater than the minimum seed certification standard (75%), and the seeds stored in gunny bags (27.4%). They also observed that all pesticides, except malathion resulted in >75% germination in seeds stored in polyethylene bags for five months and no insect damage was observed in seeds treated with thiram, deltamethrin + thiram, and malathion + thiram. Deltamethrin solely or in combination with thiram was effective against *Corcyra cephalonica* Stains. The insecticide + fungicide treatment was more effective than insecticide alone.

Aspergillus incidence was also found to be lower in seeds stored in polyethylene bags. However, higher levels of organophosphates hamper seed germination, and therefore, should not be used for seed treatment (Choudhary and Dashad, 2002). Fenvalerate, cypermethrin, deltamethrin, alfamethrin, and imidacloprid did not affect seed germination. Chlorpyrifos at 20 ml kg^{-1} seed was most effective, followed by imidacloprid, cypermethrin, and fenvalerate at 10 ml kg^{-1} seed. Seed treatment with deltamethrin 2.5 WP at 40 mg kg^{-1} of seeds (1.0 ppm) gave complete protection for six months without hampering seed viability (Patil *et al.*, 2004). Seed treatment with carbendazim alone was more effective in reducing seed mycoflora than when applied in combination with diflubenzuron.

Tanzubil and Yakubu (1997) listed potential insect pests of millet together with the damage they cause, which are shown in Table 2.1.

Table 2.1 : Potential insect pests observed at the various phenological stages and the damage cause to Pearl millet crop at Manga.

Insect	Nature of damage
White grubs (Soil pest)	Feed on seedling roots

Stem borer**:** *Coniesta ignefusalis*)	Hollows stems causing them to lodge or leading to empty or chaffy heads.
Shoot fly: (*Atherigona* spp.)	The larvae feed on the central whorl leaf, resulting in the production of a dead heart.
Lema spp.	Damage pearl millet from the seedling stage to head exertion stage. Damaged plants can have a drought stressed appearance, and generalised death of lower leaves. Early infestation can also wither and kill plants before flowering. Damage is usually caused by both adults and nymphs.
Spittle bugs (*Poophilus costalis*) .	Feed on whorl of plant producing froth
Flower beetles *Mylabris* spp.)	Feed on pollen of first flowers
Cotton strainers (*Dysdercus* spp.)	Feed on grains at milky and soft dough stages.
Mirperus spp.	Feed on grains at milky and soft dough stages.
Chaffer beetles (*Pachnoda* spp.)	Feed on grains at the soft - dough to hard - dough stages.
Stinkbugs (*Nezara*, *Agonoscelis* spp .)	Feed on grain at the Milky to dough stages causing grain shrivelling.
Head miner (*Heliocheilus albipunctella*)	Bores into head causing it to crack and shatter grain bearing spikes
Head caterpillars (*Amsacta* spp.)	Feed on mature grains leading to low yield.

Source: Tanzubil and Yakubu 1997

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1Experimental Location

3.1.1 Environmental conditions at test sites

The trial was conducted at the Manga Agricultural Research Station of the Savannah Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR – SARI) Bawku Station located between Latitude 11^o – 01^o N and Longitude 00 ^{o} -16 ^{o} W with and elevation of 249mabove sea level in the Upper East region.

3.1.2 Rainfall condition

Manga Research Station is situated in the Sudan Savanna ecological zone, which has a single rainy season (May to October) and relatively less rainfall (800-1000 mm) than the rest of the country (Sarpong, 2001). Rainfall figures were obtained from the Manga Meteorological Station (Table 4.1). In 2013, the total annual rainfall at Manga was 884.5mm which was within the normal total for the region. In addition to mean temperatures and rainfall conditions over the period soil data were collected and are presented (Table 4.2)

3.1.3 Soils of Manga

Soils of Manga range from sandy to sandy-loam, which according to Spencer and Sivakumar (1987). Features common of the soils at Manga include low fertility, low organic matter content, low pH and a moderately acidic upper layer easily prone to erosion.The content of organic matter and nitrogen in the soils is considered very low for most crops but is typical for pearl millet cultivation (Adu, 1969).

3.2 Evaluation of Lines

3.2.1 Test crop and source of seeds

Five improved pearl millet lines were evaluated at Manga in 2013 and 2014 cropping seasons (Bongo short head, Arrow millet, Tongo yellow, Bristled long head and Soxat). Manga Nara an improved local early pearl millet variety was included as a check in the evaluation. The test material was obtained from the Millet Breeder at the Savannah Agricultural Research Institute Manga sub-station, Bawku. These varieties were improved ones ready to be released by CSIR-SARI.

3.2.2 Treatment structure and experimental design

The trial had seven treatments, made up of five improved pearl millet lines namely; (i) Bongo short head, (ii) Arrow head, (iii) Bristled long head (iv) Tongo yellow and (v) Soxat, and a local check (vi) Manga Nara and (vii) Manga Nara + Insecticide. The seventh treatment was to protect the plants from insect pests by applying a seed dresser Furadan (3G) at 2 g per hill two weeks after sowing (2WAS) (against soil and some vegetative pests) followed by two sprays with Lambda cyhalothrin at the rate of 600 ml ha^{-1} using CP 14 knapsack sprayer at 4 WAS and at 50% flowering against vegetative and reproductive pests, respectively.

3.3 Field establishment

The five improved varieties collected from the breeder at CSIR–SARI Manga station were cleaned before planting. Both improved varieties and a local check were planted at the Manga outstation located in Bawku in the Upper East Region, Ghana, following the on-set of rains in June. The field was prepared with a tractor-mounted harrow, whiles ridges were made using bullocks at an approximately 0.7 m interval. Each material was planted on a six-row plot at a planting distance of 0.75 m X 0.3 m and row length of 5 m (approximately 20 stands per plot). A randomized complete block design was used with each material replicated four times (with 1m distance between replicates).

3.4 Cultural practices

Atranex (Atrazine) was applied immediately after sowing as a pre-emergent weed control. Plants were thinned to two plants per stand two weeks after sowing to obtain the desired plant density. Refilling of dead seedlings as a result of poor emergence due to soil pests (millipedes and white grubs) was also carried out at the same time. A single dose of NPK (15-15-15) fertilizer was applied at the rate of 75 kg/ha (12.66 g $plot^{-1}$) 25 days after emergence and after first weeding. The ridges were also tied at 40 cm intervals. A second weeding was done at 45 DAS and final reshaping carried out 15 days later. The reshaping and the tying of the ridges was to give support to the plants against lodging during heavy rains and to conserve moisture at the root level of plants as well as enhance drainage after heavy rains.

3.5 Data collection

Data was taken from the four middle rows. Plant establishment count was taken 2 WAS. Data on plant population, stem borer dead hearts, *Lema* spp incidence and damage, days to 50% blooming, meloids and stink bugs incidence and head worm incidence were taken. Head caterpillar incidence and incidence of chaffy heads due to head insect pests, plant height, maturity period, field weight of ear heads were also collected according to procedures prescribed by ICRISAT (2005). Plant population was estimated by counting the number of hills in a plot. Days to 50% blooming was used as an indication of maturity period and recorded as the number of days from planting to when 50% of plants in a plot had stigma emerging on the main earheads.Plant height was measured from ground level to the tip of the main ear heads of five randomly selected plants that were tagged per plot. The percent incidence of stem borer damage was also estimated under natural occurrence of the pest, two weeks before harvest, by counting the number of chaffy ear heads caused by stem borer larvae (indicated by bored stems) in a plot. This number was then calculated as a percentage of the total number of tillers in the plot. The weight of ear heads from each plot was recorded at harvest. The weight was multiplied by a factor of 54% (average threshing percentage) to convert to grain yield per plot ICRISAT (2005).

3.6 Sampling of insects

Sampling of insect pests was carried out at 4, 6 and 8 WAS before application of insecticide (Lambda cyhalothrin). The four middle rows of each plot were used for insect sampling. Insect pests' densities and damage were estimated from each plot by walking along the middle rows, examining the plants visually and counting and recording the insects on the plants, in the case of vegetative insects. Stem borer dead hearts incidence were also recorded. Insect incidence and damage (plants showing leaf feeding symptoms and leaf feeding score) was also evaluated at the various phenological stages on 0–9 and 1–9 point scale using a visual damage rating scale for leaf eating and chaffy panicles caused by *Lema* spp, and head insect pests infestation using the method by Nwanze (1992) as follows;

1 = A few *Lema* spp present with no apparent damage to the leaves

9 = Heavy *lema* spp density on infested leaves

Injury rating based on visual scoring to screen for resistance to *Lema* spp. (0–9 scale)

0 = No injury

9 = Severe injury

3.7 Dead hearts and *Lema* spp. Count

Stem borer, dead hearts and *Lema* spp. incidence and damage (Leaf defoliation) were observed on plants from 4-6 WAS. From the seedling stage to maturity five randomly selected plants were observed between 0800–1000 h for the various pests and each identified insect species was recorded. Head insect pests such as *Mylabris* spp., stink bugs (*Dysdercus* spp., *Acrosternum and Agonoscelis* spp.), and head miner (*H.albipunctella*) were equally observed and recorded from flowering to the dough stages. The percent incidence of stem borer damage was also recorded under natural occurrence of the pest, two weeks before harvest, by counting the number of whitehead caused by stem borer larvae (indicated by bored stems) in a plot. This number was then calculated as a percentage of the total number of tillers in the plot.

3.8 Yield and yield components

3.8.1 Grain yield estimation

The number of grain heads in two rows of each plot was counted, excluding small heads without grain. At maturity, the panicles were harvested from each plot; the harvested heads were stored in labeled bags and sun–dried for about 10 days. The net gain weight was determined by weighing the harvested grains using a scale (Electronic balance). Plot yield was estimated from head number and grain weight. Head and grain yield were determined from the inner two rows of each plot. The weight of ear heads from each plot was recorded at harvest. The weight was multiplied by a factor of 54% (average threshing percentage) to convert to grain yield per plot.Yield per ha was also estimated from the grains yield per plot using the formular: Yield/ ha = Yield/ plot (g) * 10000/plot area ($m^{2)}$

3.9 Statistical analysis of data

All count data were transformed using square root transformation [√X+0.5] and the data subjected to Analysis of Variance (ANOVA) using Statistix (Version 9.0). Treatment means were separated using Tukey test at 5% probability, when ANOVA was significant.

CHAPTER FOUR

4.0 RESULTS

4.1 Insects collected during 2013 cropping season

The species of insects collected at the study site were; Stem borer, (*Coniesta ignefusalis*), Leaf defoliators, *Lema* spp., Head feeders (*Dysdercus* spp., *Acrosternum* spp. and *Agonoscelis* spp.), Flower beetles (*Mylabris* spp), Head miners (*Heliochelus albipunctella*) and *Amsacta* spp.

4.1.1 Stem borer larvae (*Coniesta ignefusalis*)

Significantly more *C. ignefusalis* ($P < 0.05$) larvae per stalk were collected on Manga Naara than on Bristle long head and Manga Naara + insecticide (Table 4.1). Arrow head, Bongo short head, Bristle long head, Soxat and Tongo yellow hosted similar numbers of the larvae (Table 4.1). Manga Naara had significantly more exit holes of the insect than Bristle long head.

Table 4.1: Mean number of *Coniesta ignefusalis* and their exit holes per stalk at dough stage of Pearl millet during 2013 cropping season at Manga.

Treatments	Mean No. of Exit holes	Mean No. of larvae
Arrow head	1.50 ± 0.09ab	2.34 ± 0.19a
Bongo short head	1.50 ± 0.09ab	2.08 ± 0.12a
Bristled long head	0.98 ± 0.16b	0.90 ± 0.19b
Manga Naara	1.87 ± 0.26a	2.35 ± 0.27a
Soxat	1.49 ± 0.09ab	1.79 ± 0.64ab
Tongo yellow	1.45 ± 0.09ab	2.20 ± 0.24a
Manga Naara + Insecticide	0.95 ± 0.15b	1.24 ± 0.32ab

Means with same letter (s) in a column are not different significantly from one another ($P < 0.05$, Tukey Test)

Significantly (P < 0.05) more stem borer dead hearts were observed on Bongo short head than Manga Naara + insecticide plants (4.2).

Table 4.2: Mean number of *Coniesta ignefusalis* dead hearts observed on Pearl millet at vegetative stage during 2013 cropping season at Manga

Treatments	Mean number of Stem borer dead hearts / 7.5 m^2
Arrow head	0.71 ± 0.00b
Bongo short head	2.03 ± 0.59a
Bristled long head	0.71 ± 0.00b
Manga Naara	1.23 ± 0.32ab
Soxat	0.71 ± 0.00b
Tongo yellow	0.92 ± 0.21ab
Manga Naara + Insecticide	0.71 ± 0.00b

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.2 Lema incidence (Lema spp.)

Significant differences ($P < 0.05$) were observed in *Lema* spp. densities between treatments. Significantly more *Lema* spp. aggregated on Manga Naara than the other treatments whilst significantly more also aggregated on Soxat and Tongo yellow than the rest (Table 4.3)

Table 4.3 Mean number of *Lema* spp. (Leaf defoliators) collected at vegetative stage of the Pearl millet during 2013 cropping season at Manga.

Treatments	Mean number of *Lema* spp. per plant
Arrow head	7.68 ± 1.65c
Bongo short head	10.96 ± 1.72c
Bristled long head	9.43 ± 1.85c
Manga Naara	42.32 ± 1.84a
Soxat	30.50 ± 9.32b
Tongo yellow	29.17 ± 12.80b
Manga Naara + Insecticide	15.26 ± 1.55b

Means with same letter(s) in a column are not different significantly from one another ($P < 0.05$, Tukey Test)

4.1.3 *Lema* spp. damage

Lema spp. damage observed on Soxat, Bristled long head and Manga Naara was significantly more than on Bongo short head (Table 4.4).

Table 4.4 *Lema* spp. (Leaf defoliators) damage observed on the Pearl millets during 2013 cropping season at Manga.

Treatments	*Lema* spp. Damage score
Arrow head	2.63 ± 0.31b

Bongo short head	1.42 ± 0.34c
Bristled long head	3.70 ± 0.43ab
Manga Naara	3.77 ± 0.47ab
Soxat	4.39 ± 0.33a
Tongo yellow	2.31 ± 0.69b
Manga Naara + Insecticide	0.91 ± 0.00c

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.4 Flower beetles (*Mylabris* spp.)

At flowering, there was significantly more *Mylabris* spp. per panicle on Manga Naara, Soxat and Tongo yellow than Bongo short head. Significantly more of the insects were also recorded on Bongo short head than Arrow millet (Table 4.5).

Table 4.5: Mean number of pollen feeders (*Mylabris* spp.) observed at flowering on Pearl millet during 2013 cropping season at Manga

Treatments	Mean number of *Mylabris* spp. / head
Arrow head	2.17 ± 0.52bc
Bongo short head	2.98 ± 0.31b
Bristled long head	0.71 ± 0.00c
Manga Naara	3.28 ± 0.42ab
Soxat	3.47 ± 0.18ab
Tongo yellow	3.65 ± 0.16a
Manga Naara + Insecticide	0.71 ± 0.00c

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.5 Cotton strainers (*Dysdercus* spp.)

Manga Naara hosted significantly greater number of Cotton strainers than the other treatments at the soft to hard dough stages, with no significant differences between the other treatments (Table 4.6).

Table 4.6: Mean number of grain feeders (*Dysdercus* spp.) observed at milky and dough stages Pearl millet during 2013 cropping season at Manga.

Treatments	Mean number of *Dysdercus* / head
Arrow head	1.29± 0.24b
Bongo short head	1.16 ± 0.19b
Bristled long head	0.94 ± 0.23b
Manga Naara	3.23 ± 0.15a
Soxat	1.24 ± 0.24b
Tongo yellow	1.31 ± 0.31b
Manga Naara + Insecticide	0.92 ± 0.23b

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.6 **Stink bugs** (*Agonoscelis*, *Nezara*, *Acrosternum* species)

There were significant differences (P< 0.05) in the number of stink bugs per head. Significantly greater number of these insects was recorded on Manga Naara than on Arrow head, Bristle long head, Soxat, Tongo yellow and Manga Naara + insecticide. Significantly more of the insects were also recorded on Bongo short head than on Soxat and Tongo yellow (Table 4.7)

Table 4.7 Mean number of stinkbugs (Grain feeders) collected on soft dough stage Pearl millet during 2013cropping season at Manga

Treatments	Mean number of Stink bugs / head
Arrow head	1.42 ± 0.26b

Bongo short head	2.30 ± 0.55ab
Bristled long head	0.71 ± 0.00c
Manga Naara	3.66 ± 0.69a
Soxat	0.71 ± 0.00c
Tongo yellow	0.71 ± 0.40c
Manga Naara + Insecticide	1.58 ± 0.26b

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.7 Head worm (Head miner)

The number of *Heliocheilus albipunctella* recorded on Manga Naara was significantly greater than on all the other treatments except arrow head. (Table 4.8)

Table 4.8: Mean number of Head feeders *(Heliocheilus albipunctella*) collected on hard dough stage Pearl millet during 2013 cropping season at Manga.

Treatments	Mean number of Head miner /head
Arrow head	2.21 ± 0.09ab
Bongo short head	2.15 ± 0.12b
Bristled long head	1.09 ± 0.13b
Manga Naara	2.33 ± 0.07a
Soxat	2.03 ± 0.05b
Tongo yellow	1.84 ± 0.07bc
Manga Naara + Insecticide	1.09 ± 0.13c

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.1.9 Hairy caterpillar (*Amsacta* spp)

The differences in Amsacta numbers were not significant between the treatments (Table 4.9).

Table 4.9 Mean number of Hairy caterpillars (*Amsacta* spp.) observed on hard dough stage Pearl millet during 2013 cropping season at Manga.

Treatments	Mean number of Amsacta / head
Arrow head	0.84 ± 0.13a
Bongo short head	0.84 ± 0.13a
Bristled long head	0.71 ± 0.00a
Manga Naara	1.06 ± 0.35a
Soxat	0.84 ± 0.13a
Tongo yellow	0.84 ± 0.13a
Manga Naara + Insecticide	0.71 ± 0.00a

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.2 Per cent damaged panicles by insects

Significantly more chaffy heads were recorded on Tongo yellow than Bongo short head and Bristled long head which was virtually not damaged at all. (Table 4.10).

Table 4.10: Mean number of chaffy heads due to insects damage observed at flowering on Pearl millet during 2013 cropping season at Manga.

Treatments	Per cent chaffy heads / 7.5 m^2
Arrow head	2.79 ± 0.23ab
Bongo short head	2.05 ± 0.46b
Bristled long head	0.71 ± 0.00d
Manga Naara	2.49 ± 0.14ab
Soxat	2.91 ± 0.29ab
Tongo Yellow	3.15 ± 0.40a
Manga Naara + Insecticide	1.75 ± 0.29bc

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.3 Phonological data (plant height and Days to 50% flowering)

There were no significant differences (P > 0.05) among the varieties with respect to days to 50% flowering and plant height (Table 4.11).

Table 4.11: Mean days to 50% flowering and plant height observed on Pearl millet during 2013 cropping season at Manga

Treatments	Days to 50% flowering	Mean Plant height (cm)
Arrow head	46 ± 0.98a	203 ± 8.49a
Bongo short head	46 ± 0.98a	191 ± 8.49a
Bristled long head	44 ± 0.98a	195 ± 8.49a
Manga Naara	42 ± 0.98a	186 ± 6.93a
Soxat	48 ± 0.99a	195 ± 8.49a
Tongo yellow	45 ± 0.98a	193 ± 8.49a
Manga Naara + Insecticides	44 ± 0.98a	186 ± 6.93a

Means with same letter(s) in a column are not different significantly from one another (P < 0.05, Tukey Test)

4.4 Yield and yield components (Yield per Panicle and yield per hectare)

There was no significant differences (P > 0.05) in grains per panicle and grain yield per hectre however, the yield of Manga Naara was lower as compared to the other lines. (Table 4.12).

Table 4.12: Mean of grain weight per panicle and yield of Pearl millet during 2013 cropping season at Manga

Treatments	Grain per panicle	Yield (kg/ha)
Arrow head	18.29 ± 2.29a	1788 ± 193a
Bongo short head	15.21 ± 2.29a	1693 ± 193a
Bristled long head	18.94 ± 2.29a	1714 ± 157a
Manga Naara	14.95 ± 1.87a	1461 ± 193a
Soxat	19.98 ± 2.29a	1755 ± 193a
Tongo yellow	17.18 ± 2.29a	1775 ± 193a
Manga Naara + Insecticides	14.96 ± 1.87a	1472 ± 193a

Means with same letter(s) in a column are not different significantly from one another ($P < 0.05$, Tukey Test)

Table 4.13: Some physical and chemical properties of the surface soil(0 - 30 cm) at the study site at the Manga Agricultural Research Station, 2013

Soil properties	Quantity/Description
Sand (%)	80.30
Silt (%)	14.88
Clay (%)	4.82
Soil pH	4.88
Organic carbon (%)	0.62
Total nitrogen (%)	0.06
Available P (mg kg^{-1})	11.98
Ca	0.95
Mg	0.40
K	49.50
CEC [cmol (+) kg^{-1}]	2.28

CHAPTER FIVE

5.0 DISCUSSION

5.1 Implication of results for crop improvement

The yield of the pearl millet lines studied would be considered generally high, which was partly due to the favourable environmental conditions that prevailed during the period of experimentation even though insect pests numbers also increased considerably. The results of the soil analysis indicate that the soil at Manga ranges from sandy to sandy-loam, which according to Spencer and Sivakumar (1987), is typical for pearl millet cultivation. However, the content of organic matter and nitrogen in the soils at the trial location would be considered very low for most crops (Prof. E.Y Safo, Personal communication). The low pH of the soils observed showed that the soils were acidic in nature.

Adu (1969) stated that features common of the soils at Manga include low fertility, low organic matter content and a moderately acidic upper layer easily prone to erosion. The poor soil conditions, coupled with the late planting coincided with may have created conditions that promoted the outbreak of *Lema* species which resulted in more leaf damage at the vegetative stage.

The long maturity periods observed in bristle long head and Soxat is a major agronomic limitation in pearl millet. Early maturity is desirable in Ghanaian pearl millet populations because of the need for early harvests to offset food shortages, which are common during the cropping season in northern Ghana. Short maturity also enables pearl millet populations to make better use of available moisture and to escape terminal droughts and increased incidence of insect pests and diseases which usually occur in the later parts of the cropping season.

The results of this study confirmed the importance of insect pests as limiting factor to increased and sustainable millet production. It showed that Lema spp. (defoliators), head miners, (H. albipunctella) flower beetles, (Mylabris spp.) and grain feeders (Dysdercus spp.) were the key pests of millet at the study site. Lema spp. Mylabris spp. and Dysdercus spp. were important insect pests that attacked both vegetative and reproductive structures of pearl millet in the Upper East Region of Ghana. Early feeding by flower beetles on the pollen could lead to poor seed set, while Dysdercus and stink bugs attacked the developing seeds from milky to dough stages leading to wrinkled, discoloured, shrivelled or unfilled seeds. This could lead to germination failure and lack of vigour in seedlings. Earlier studies by Tanzubil and Yakubu (1997) cited head feeders as the most important pests of cereal crops (especially millet and sorghum) in Northern Ghana, which is confirmed by the result of this study as cotton stainers and other stink bugs were responsible for the serious damage caused to millet heads

Generally, the local check (Manga Naara) had greater number of insect pests than the new lines. There were two spray applications at the vegetative stage at weekly intervals on the local check. Infestation by *Lema* spp. was high as compared to that of head insects. Bristled long head was relatively less attractive to the head insects except for *Lema* spp. at the vegetative stage. The most infested among treatments was the local check (Manga Naara) with a high rate of infestation.

The improved lines attracted significant less aggregation of some of the insects identified. The amount of Lambda–cyhalothrin applied in the present study was effective in reducing the numbers of *Lema*, *Mylabris*, and *Dysdercus* species. It is unclear why it was not effective against the other insects except to state that some level of resistance is being shown by these insects. Tanzubil *et al*. (2004) reported that Lambda–cyhalothrin applied at the rate of 30 g a.i ha^{-1} was effective against shoot and stem borer on Pearl millet.

Phenological changes in the growth of the millet plant in space and time have impact on the distribution of the insects as they are presented with more hiding places and difficult to reach by pesticides. Tanzubil and Yakubu (1997) noted that *Lema* spp. aggregated and fed on leaves at the initial stage of the plant growth; it is more difficult to reach them with pesticides when they aggregate on the leaf sheath. The ineffectiveness of the insecticides used in this study seems to confirm what some of the millet farmers indicated, when we visited them during the outbreak of *Lema* spp. in 2013 growing season that these insects are difficult to control using insecticides.

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The following Insect pests were identified at the various phenological stages of the crop during the study; stem borer *(Coniesta ignefusalis)* (Feed on hollow stems), *Lema* spp. (Seedling to head exertion stage), *Mylabris* spp. (Pollen of flower), Stink bugs *(Dysdercus, Acrosternum and Agonoscelis* species*)* (Grains at milky to dough stage), *Heliocheilus albipunctella* (Feeds on the head), and *Amsacta* spp. (Mature grains).

Feeding of *Lema* spp. on pearl millet leaves resulted in a significantly higher defoliation of Manga Naara (Local check) as compared to Manga Naara+Insecticide and the improved varieties. Manga Naara (local check) hosted significantly ($P < 0.05$) greater numbers of (*Lema*, *Mylabris*, and *Dysdercus* species), and lower population densities of *Amsacta* spp. and head miners.

From the results of the study, it can be concluded that there were less L*ema* spp infestations on the improved varieties than the local check. Generally, bristled long head performed better than the other lines in terms of insect numbers and damage an d can be recommended for more improvement for increased yield.

Although significant ($P<0.05$) differences were observed between Manga Naara + Insecticide and Manga Naara untreated for insect pests incidence and damage, the resistance of Manga Naara + Insecticide was similar to the improved varieties.

6.2 Recommendation

The Action Threshold or the Economic Threshold for determining the need to apply insecticide should be determined for the various pests on the millet.

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APPENDIX

The improved local landraces, namely, Bongo Short head (BSH), Tongo Yellow (TY), Bristled Long Population (BLH) and Arrow head (AH) (Table 1).

APPENDIX 1: Pearl millet genotypes and source

Population	Type	Source
Bongo Short head (BSH)	Improved landrace	Ghana
Togo Yellow (TY)	Improved landrace	Ghana
Bristled longhead head (BLH)	Improved landrace	Ghana
Arrow head (AH)	Improved landrace	Ghana
Manga Naara (MN)	Local check	Ghana
Soxat (SS)	Improved variety	ICRISAT

Source: David Afribeh 2005

APPENDIX2: Genotypes attributes

Genotype	Special attributes
Bongo Short Head	**OPV Recurrent selection** Potential yield: 1.2 t/ha Physiological maturity - 70days Drought tolerant Short, compact head
Arrow Head	**OPV Recurrent selection** Potential yield: 1.2 t/ha Physiological maturity – 70 days Drought tolerant Grain colour: Yellow
Bristled Long Head	**OPV Recurrent selection** Potential yield: 1.3 t/ha Physiological maturity – 77 days Drought tolerant Presence of bristles on head Resistant to bird damage
Tongo Yellow	**OPV Recurrent selection** Potential yield: 1.2 t/ha Physiological maturity – 70 days Drought tolerant Grain colour: Yellow
Soxat	**OPV Recurrent selection** Potential Yield: 1.1 t/ha Physiological maturity – 80 days Drought tolerant Resistant to Downy mildew Dual purpose (grain, fodder & fuel wood)

Source: Asungre Anabire peter 2012

APPENDIX 3: Regional Rainfall data for the period 2001–2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	U/E Region
2001	0	0	0	22	126.5	150.5	183.2	281	153.5	0	0	0	916.7	936
2002	0	0	0	0	126.5	116.1	288.2	282.6	81.6	126.3	0	0	1021	898
2003	0	0.5	12	0	21.7	128.3	151.1	335.5	327	87.8	0	0	1064	1117
2004	0	0	0	14.5	246.3	161.1	153.2	190.2	185.5	10.2	0.5	0	961.5	613
2005	0	0	0	19	81.6	152.4	315.6	229.8	121.8	45	0	0	965.2	791
2006	0	0	0	0.5	94.4	125.6	255.9	226.7	184.6	62.7	0	0	950.4	925
2007	0	0	0	108.2	52.9	108.1	566.4	625.9	141	23.6	0	0	1626	1320
2008	0	0	0	0.6	41.8	146.7	240.5	259.2	138.8	50.3	0	0	877.9	902
2009	0	0	0	34.8	78.4	153.4	94.9	298.5	246.6	49.6	0	0	956.2	884
2010	0	0	0	13.5	114.6	130.7	198.3	357.8	149.6	126.5	0	0	1091	884
2011	0	0	0	12.7	66.9	114.3	87.3	294.9	132.5	35.5	0	0	744.1	937
2012	0	0	0	34.3	38.4	150.9	251.6	214.8	222.8	118.4	0	0	1031	912
2013	0	0	11	87.9	54.5	135.4	193	161.4	198.6	42.7	0	0	884.5	932
Total	**0**	**0.5**	**23**	**348**	**1145**	**1774**	**2979**	**3758**	**2284**	**778.6**	**0.5**	**0**	**13090**	**11119**

Source:Manga Agricultural Research Station, Weather Station

Plate 1: Land preparation with bullocks

Plate 2: Stem borer damaged (dead heart) plant at seedling stage

Plate 3: ***Mylabris*** **spp. Infested Soxat millet head at flowering**

Plate 4: ***Mylabris*** **spp. Damaged millet head at anthesis**

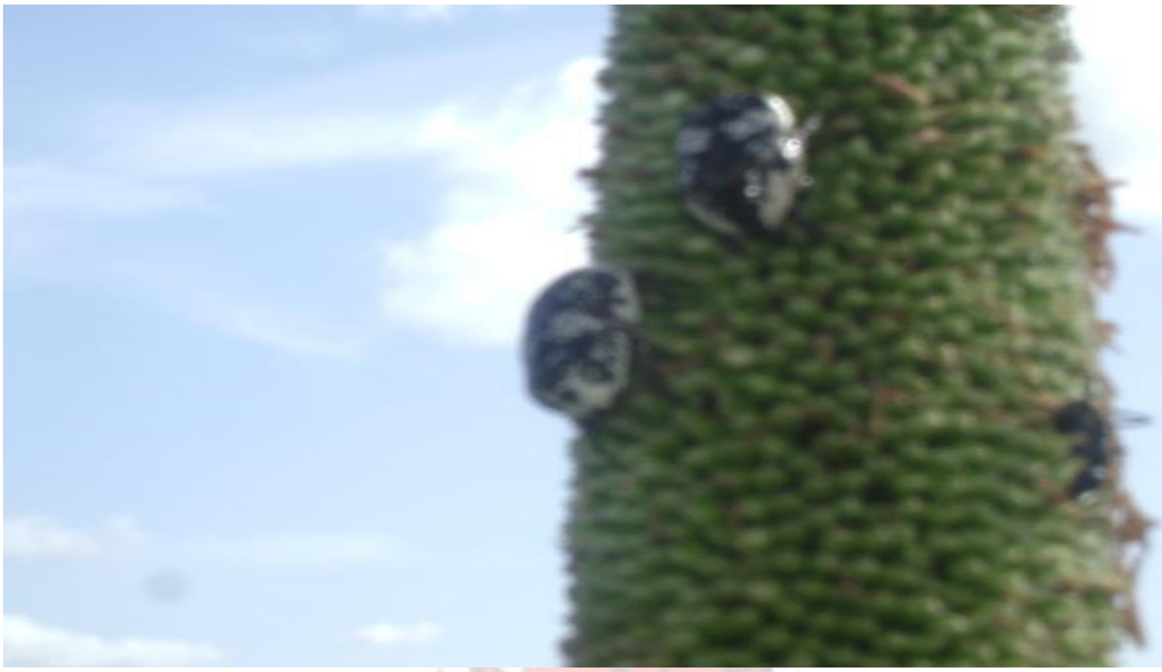

Plate 5 : *Pachnoda* spp. Infested head at milky stage

Plate 6 : Nymph of dysdercus spp. on bristled millet head at dough stage

Plate 7: Adult *dysdercus* spp. Damage on bongo short head at milky stage

Plate 8: Cotton Steiner (*Dysdercus* sp.) infested panicle at milky stage

Plate: 9: *Psalydolytta* spp damaged head at dough stage

Plate: 10: Stink bug (N*ezara viridula)* damaged head at dough stage

Plate 11 : Flower beetles feeding on millet panicle at flowering

Plate 12: ***Mirperus jaculus*** **infested millet head at hard dough stage**

Plate 13: ***Aspavia armigera*** **infested head at milky stage**

Plate 14: ***Agonoscelis*** **spp. On millet head at hard dough stage**

Plate 15 : ***Amsacta*** **spp. Damage on millet head at soft dough stage**

Plate 16 : Head miner larvae damage on bongo short head at physiological maturity stage

Plate 17 : Tongo yellow millet

Plate 18 : Bongo short head

Plate 19 : Bristled Long head