UNIVERSITY OF CAPE COAST

STUDIES OF MEALYBUG WILT OF PINEAPPLE IN THE CENTRAL AND EASTERN REGIONS OF GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

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Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of the thesis laid down by the University of Cape Coast.

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ABSTRACT

A study of the mealybug wilt disease of pineapple (MWP) in the Central and Eastern regions of Ghana was conducted. The objective was to study the features of the mealybug species responsible for the MWP to characterize the mealybugs to facilitate their recognition and management in pineapple production in Ghana. The study was divided into a questionnaire survey, field disease assessment, identification of species of mealybug causing the MWP together with their symbiont ants, determined the effect of the MWP on the photosynthetic ability of the pineapple plants during the attack by the virus and evaluated alternative management strategies for minimizing incidences of virus spread and mealybug wilt of pineapple. Farmers did not harvest suckers from infected mother plants and did not harvest from within 1 m^2 perimeter of an infected plant and those farmers had a high level of knowledge of the MWP on their farms. Many of the farms surveyed from the two regions from Ghana had MWP incidence of 10-20%, indicating that the disease seriously threatens pineapple production in the regions. The patterns of spread or distribution of the MWP across the various districts surveyed in the Central and Eastern regions of Ghana is more of clustering than random or even distribution on the field. Propagation with crowns gave a lower incidence of the MWP disease and a lower population of ants and mealybugs compared to the slips and the suckers. The feeding by the mealybugs and attack by the PMWaV in the MWP are responsible for the loss of the chlorophyll in the leaves that eventually lead to wilting of the plants. White vinegar and neem oil worked best in reducing the incidence and severity of the MWP and the mealybug and ant populations and could be used alternately with insecticides.

KEYWORDS

Ant

Mealybug

Pineapple

Suckers

Virus

Wilt

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DEDICATION

To Mildred, my wife, Nhyira, Ayeyi, Aseda and Nkunim, our children

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CHAPTER ONE

1 INTRODUCTION

1.1 Background to the Study

Pineapple, *Ananas comosus* (L. Merr.) is the most economically significant member and a foremost edible member of the family Bromeliaceae (Bencini, 1991; Bruce & Oku, 2000; United States Agency for International Development, 2006). It is produced largely for its fruit that is utilised fresh or as canned fruit or juice. The eatable portion makes about 60% of the fruit. The fruit which has a sweet and sour taste contains around 80-85% water, 12-15% sugars. The fruit contains 19.9% carbohydrates; 0.1% fat, 0.4% protein; 10.6% ash, 0.5% crude fibre, 0.6% fruit acids (citric, malic and nalic); vitamins: 3.6% B_1 (Thiamine), 1.2% B_2 (Riboflavin), 1.6% A, 20% C, 1.1% Niacin, and minerals; 2% Calcium, 1% Phosphorus, 5% Iron, 3% Potassium and Sodium. An approximately 150 cm^3 of juice will contain an average of 75 calories (Bencini, 1991; De La Cruz Medina & García, 2005).

Pineapple is the only source of bromelain, which is a complex proteolytic enzyme contained in the shell of the fruit used in the pharmaceutical industry. Bromelain which consists mainly of cysteine proteases has been established to affect the immune response, namely, stimulation of the leukocyte population (Mynott, Ladhams, Scarnato, & Engwerda, 1999; Hale, Greer, Trinh & Gottfried, 2005; Secor Jr. et al., 2005). The unripe fruit is used for anti-hypertension and the prevention of constipation (Aiyeloja & Bello, 2006).

The stems and leaves of the pineapple plant are a source of fibre that is white, creamy, and lustrous as silk that can be used to make clothing (Montinola, 1991; Coppens d'Eeckenbrugge & Leal, 2001).

The fibre from pineapple has also been processed into paper with extraordinary qualities of thinness, smoothness, and flexibility, and for the development of low-density polyethene composites (Rice, Rice, & Tindall, 1990; Montinola, 1991; International Tropical Fruits Network, 2016).

The top three pineapple producers in the world in 2020 were the Philippines, Costa Rica, & Brazil. With a world production figure of 27.82 million metric tonnes, the Philippines is the world's leading producer that produced 2.7 million metric tonnes in 2020 (Shahbandeh, 2020).

The area of pineapples in Ghana was 10,595 hectares in 2020, up from 10,571 hectares the previous year, with a yield of 668,946 metric tonnes growing at an average annual rate of 15.26% (Knoema, 2020).

Pests and diseases such as weeds, mealybugs, mealybug wilt disease of pineapple (MWP), Phytophthora rot declining soil fertility in most production areas, bad harvesting and post-harvest handling procedures, and environmental degradation are all likely to have an impact on the future productivity of pineapples in Ghana. Credit and price volatility in freight costs, the cost of inputs that have been occasioned by the Covid-19 pandemic are all some of the challenges facing the industry in Ghana (Donkoh and Agboka, 1997; The United Nations Conference on Trade and Development, 2021).

1.2 Problem Statement

Despite the economic importance of pineapple in Ghana, its production is threatened by pests and diseases. The MWP is one of the most destructive diseases of pineapple in Ghana. It is a major constraint to the global production of pineapple with yield losses of up to 100% (Wakman, Teakle, Thomas, & Dietzgen, 1995; Rohrbach, Beardsley, German, Reimer, & Sanford, 1998; Sether & Hu, 2002a).

Viruses associated with MWP are members of the genus *Ampelovirus*, and the family Closteroviridae. Pineapple mealybug wilt-associated virus-1 (PMWaV-1), PMWaV-2, PMWaV-3, PMWaV-4, and PMWaV-5 have been acknowledged as five distinct species in *Ampelovirus* from diseased pineapples from Hawaii and Australia (Sether & Hu, 2001; Sether, Melzer, Busto, Zee, & Hu, 2005a; Gambley, Steele, Geering, & Thomas, 2008).

There is very little available information on the PMWaV which causes MWP in Ghana, and it is also not known which of the above five species of PMWaV is responsible for the wilt disease in pineapple. There is also limited available evidence on the management of the virus in Ghana.

Two species of mealybugs, namely: The Pink pineapple mealybug, *Dysmicoccus brevipes* (Cockerell), and the Grey pineapple mealybug, *D. neobrevipes* Beardsley, transmit the MWP (Beardsley, Su, McEwen, & Gerling, 1982; Sether, Ullman & Hu, 1998). Numerous ant species are associated with mealybugs (Beardsley et al., 1982; Petty & Tustin, 1993). There exists a symbiotic relationship between mealybugs and ants; (Jahn et al., 2003).

There are about 28 species of ants that tend the pineapple mealybugs. The ants support the establishment of colonies of mealybug (Jahn et al., 2003) by depending on the honeydew produced by the mealybugs for food and they can have an inhibitive effect on the natural enemies of the mealybug (Cudjoe, Neuenschwander & Copela, 1993; Jahn et al., 2003).

Management of MWP disease is quite important to save the pineapple industry and the economy of Ghana. Information on the species and abundance of mealybug vectors and their ant symbionts prevailing at the various pineapple growing areas in Ghana is an important prerequisite for developing effective strategies for the management of the MWP.

1.3 Justification

MWP attack results in significant crop losses because the disease causes cosmetic damage and a reduction in yield. MWP leads to a total loss of the economic value of pineapple. The MWP is one of the most devastating pineapple diseases, and its control/management has been difficult in Ghana because adequate information on the disease and possible effective management strategies to combat the disease are lacking. With the inherent economic potential and immense benefit of pineapple to the local economies and the nation at large, it is imperative to manage the MWP complex that include the mealybugs with their symbiont ants.

Effective management of the MWP would result in improved productivity and production of pineapple in the country and could be a tool to attract more youth into pineapple production, leading to a reduction in unemployment. This will improve farmers' income and their livelihoods. It will also generate foreign exchange from pineapple export and consequently improve the economy of Ghana.

1.4 Study Objectives

The objective of the study is to study the features of the mealybug species responsible for the MWP and come up with more reliable species-specific data to characterize the different species and develop appropriate concepts to facilitate their recognition and management in pineapple production in Ghana.

The specific objectives were to:

1. conduct a questionnaire survey to determine farmers' perception of the MWP disease, management practices and the effect of the disease on their income.
2. determine the incidence, severity, and spatial distribution of the MWP disease in pineapple crops in Central and Eastern regions of Ghana
3. identify the mealybug and ant species associated with the MWP disease in Central and Eastern regions of Ghana
4. determine the effect of MWP on the photosynthetic ability of pineapple plants
5. develop an appropriate strategy aimed at the effective management of the disease.

The thesis was organised into chapters one to eight, where chapters one and two gave a general introduction to the whole of the thesis and the literature review respectively. Chapters three to seven each looked at the five objectives as chapter headings and each was divided into the introduction to the chapter, materials and methods, results, discussions, and recommendations. Chapter eight is the general summary, conclusion, and recommendations to the thesis.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Morphology of Pineapple

Ananas comosus is a herbaceous perennial and halophile plant that has thirty to eighty trough-shaped and pointed leaves which are 30-80 cm that surrounds a thick stem. It has a terminal inflorescence with 100-200 flowers that give origin to multiple fruits. The spirally placed flowers are each supported by bracts. Pineapple one of the few important fruiting monocots is autosterile and fruits develop parthenocarpically (Coppens d'Eeckenbrugge & Leal, 2001; Wikiversity contributors, 2018).

The pineapple develops new shoots from axillary buds after the first fruit reaches maturity, and these new growth axes can produce new fruit. A pineapple plant can go through many different development cycles. The vegetative reproduction is also dominant in wild pineapples, where the crown and slips, in addition to the lateral shoots, serve as propagation materials as they resume rapid growth at fruit maturity. The long peduncle that bends is because of its weight; the slips and crowns may reach the ground and root thereon (Coppens d'Eeckenbrugge & Leal, 2001).

The pineapple is also described as a terrestrial herb that can grow to a height of 0.75-1.5 m and the leaves could spread to cover up to 0.9-1.2 m. The stem is short and stout with a rosette of waxy strap-like leaves that are pointing at the tips. These tips are needle-like and generally bear sharp, upcurved spines on the margins (Morton, 1987; De La Cruz Medina & García, 2005).

The vegetative, or traditional, planting materials are graded according to their location on the plant. Suckers appear on the lower part of the stem with roots that grow into the earth, these are also known as ground suckers. They typically emerge from the "mother plants" after harvest. Slips are stem shoots or hapas that grow in the transition zone between the stem and the peduncle of the plant and appear on the peduncle (Coppens d'Eeckenbrugge & Leal, 2001; Reinhardt et al., 2018).

The slips are arranged in a regular pattern near the base of the fruit. Crown may also be used for planting. Some plants, on the other hand, may be devoid of a crown or, otherwise, have several crowns. Crownlets sprout from the base of the main crown or any of the upper fruitlets (Coppens d'Eeckenbrugge & Leal, 2001; Reinhardt et al., 2018).

The main morphological structures that can be used as distinguishing features include the leaves, peduncle, stem, multiple fruit, crown, shoots, and roots. The leaves have a sword-like concave form, which helps the pineapple plant to gather water in the rosette, which is then absorbed by the aerial roots that pass along the stem or through the sheath's epidermis. Pineapple leaves are particularly fibrous, and their colour varies from light to dark green to dark red or purple, depending on the variety and the climatic conditions at a time.

Peltate trichomes cover both sides of the leaf, with the abaxial side being densely furfuraceous and silvery, giving it a high reflectance. The trichomes serve as one-way valves, improving and preserving the abilities of the plants to boost and retain their water status, and consequently shield the plant from excessive transpiration and direct sunlight. The thick cuticle, the water-storage tissue, the disposition of the stomata, the trichomes, and the Crassulacean Acid Metabolism (CAM) all contribute to the impressive water economy of pineapple plants.

The leaf margins are generally prickly, but some varieties are partially or fully inermis. The lower epidermal layer of some smooth varieties is rolled over the leaf margin and extended over the top surface, resulting in a thin shimmering stripe described as 'piping' (Coppens d'Eeckenbrugge & Leal, 2001; Ming, Vanburen, Wai, & Tang, 2015).

The main roots of pineapple are only present in very juvenile plantlets. These roots die quickly, and the root hairs take their place. The adventitious roots form a compact structure with multiple deep roots and minimal branching at the stem base of the plants (Coppens d'Eeckenbrugge & Leal, 2001).

The apical meristem of the pineapple plant gives rise to the peduncle and inflorescence. Because of the five to seven reddish peduncle bracts at its base, the process of inflorescence appearance is called "red heart." These bracts are smaller and shorter than normal leaves (Coppens d'Eeckenbrugge & Leal, 2001).

Following the development of the flower, the peduncle spreads, and its length varies greatly between varieties. It bears a variable number of slips in addition to its bracts, which can be placed more or less frequently between the stem and the fruit, at the axis of the peduncle bracts, or clustered just beneath the fruit in many varieties (Coppens d'Eeckenbrugge & Leal, 2001).

These slips may be a valuable source of planting material for potential cultivation (Coppens d'Eeckenbrugge & Leal, 2001).

The inflorescence is made up of 50 to 250 individual flowers, capped by a crown composed of several short leaves, up to 150 on a short stem. The pineapple flowers are hermaphroditic and trimerous. The tubular corolla and abundant nectar production are especially suited to hummingbird pollination (Coppens d'Eeckenbrugge & Leal, 2001).

The stem lengthens and expands near the apex during blooming, bringing forth small individual purple or red flowers that are 1.27-2.54 cm long (Morton, 1987).

Parthenocarpically, the entire blossom grows into a berry-like fruitlet. The weight of a cultivated pineapple rises twenty-fold as it grows from a blossoming inflorescence to mature fruit. The ovaries, the bases of sepals and bracts, and the cortex of the axis are the most edible sections of the fruit. The sepal and bract tissues, as well as the ovaries' apices, make up the bulk of the fruit body (Coppens d'Eeckenbrugge & Leal, 2001).

A single red, yellowish, or green bract borne laterally on the rachis of a spike of one hundred to two hundred individuals covers the flower. The stem keeps growing and produces a compact tuft of rigid, short leaves known as the crown or top at its apex. In addition to the usual one, a plant can bear two or three heads, or as many as twelve fused, on rare occasions (Morton, 1987).

Individual fruits form a cone-shaped, compound, juicy, fleshy fruit up to 30 cm or more in height as they grow from the flowers. The fibrous yet succulent heart is made up of the stem. When the fruit is ripe, the tough, waxy rind, composed of hexagonal segments, turns dark-green, purple, orange-yellow, or reddish; the flesh varies from nearly white to yellow (Morton, 1987).

2.2 Botanical and Physiological Adaptations

The large cups are formed where the leaves attached to the stump are effective reservoirs for water and nutrient solutions. The pineapple is a xerophyte with numerous extra characteristics that allow it to survive and grow in water stress situations: the leaf shape and orientation that take full advantage of the capture of moisture and sunlight most effectively, ability to absorb nutrients from axillary roots in the leaf bases and directly through basal white tissue on the leaf surfaces; small numbers of stomata, and insulated leaves to reduce water loss; water storage tissue that can be up to one-half the thickness of the leaf and is used to keep the plant growing during periods of low rainfall; a dedicated metabolic system (CAM) for capturing carbon dioxide at night for utilisation through the day that significantly decreases water loss (Queensland Department of Primary Industries, 2005).

The ability of pineapple to adapt to dry, harsh environments derives from not only its evolution in dry climates but also its epiphytic lineage. It is important to remember, however, that it is sensitive to cold and unaccepting of high temperatures above 40 °C, as sun exposure injury to plants and fruit can be serious, and it has a delicate root system that requires well-drained soil conditions (Queensland Department of Primary Industries, 2005).

2.3 Leaf Shape and Arrangement

Pineapple leaves are spirally ordered around the stump, and are extended, trough-shaped, tapering from base to tip, and approaching horizontal. This plant form makes for optimum sunlight capture as well as extremely efficient rain capture and movement to the stem and root system of the plant. Most of the leaves, particularly those at the top of the plant that is most exposed to the sun, are angled toward the sun (i.e., tauter), which helps to minimize leaf temperature and moisture loss. Due to their long, tapering form, the thirteenth leaf on the spiral is the first to overlay and shade a lower leaf on that plant. Their long, tapering form prevents the shading of leaves of neighbouring plants until they are wide and mature, (Queensland Department of Primary Industries, 2005).

2.4 Axillary Root System

Axillary roots, which are undeveloped roots that can soak up moisture and dissolved nutrients without changing directions, are in the cupped leaf axils (Queensland Department of Primary Industries, 2005).

2.5 Basal White Tissue

Water and dissolved nutrients can be directly absorbed by this white tissue. When the leaves mature, they turn green (Queensland Department of Primary Industries, 2005).

2.6 Stomata and Trichomes

Stomata are air-breathing holes in leaves that can open and close. Via the stomata, carbon dioxide enters the plant, while moisture and oxygen exit. Stomata are small and often found on the underside of the leaves in depressed channels, with only a few per unit of leaf area. They support the plant in several ways, such as herbivory defence, because they are small, deep, and covered in a thick layer of waxy trichomes (leaf hair structures). The plant has a very low rate of transpiration due to the transmission of radiation or the regulation of temperature by trichomes (Queensland Department of Primary Industries, 2005).

The trichomes are the heaviest around the undersides of the leaves, giving them a silvery look. The leaves take on a "polished" appearance when trichomes are lacking due to copper deficiency or are removed by insects (hymenopterans, and hemipterans like mealybugs) and arachnids or urea heart rot. The trichomes give the leaves their silvery colour, which intensifies reflection (Queensland Department of Primary Industries, 2005; Scharffetter, Korsberg, & Bickford, 2015).

The multicellular leaf hairs or foliar trichomes structures that grow from the epidermal tissues (Bell, 1991) are almost ubiquitous in Bromeliaceae (Benzing, 1976) and maybe the family's most distinctive vegetative characteristic of the family. The ability of peltate trichomes to confer epiphytism on pineapple shoots by enhancing the absorptive functions of roots is well known. It is well known that the peltate trichomes bear epiphytism by bestowing the shoot of pineapples with the capacity to boost the absorptive roles of roots (Benzing, 1976).

The trichomes perform a crucial function in the adaptive radiation of Bromeliaceae through the process of the dissimilar ecophysiological plans. In a high population, bromeliad trichomes give rise to a hoary leaf surface that throwback light once dry and it is highly indicative of a function in photoprotection by bromeliads (Pierce, Maxwell, Griffiths, & Winter, 2001).

In a study, Scharffetter et al. (2015) found that trichome manipulations significantly reduced mealybug population counts by 50 to 75 per cent relative to control leaf levels.

The photosynthetic rates of the control and two manipulated classes were different. As compared to control leaves, leaves with abaxial trichomes removed showed a 14.6% decrease in photosynthesis, and leaves with abaxial and axial trichomes removed showed a 21.4% decrease in photosynthesis. In the 550-650 nm range, leaf transmission in manipulated leaves was found to be lower than in control leaves (Scharffetter et al., 2015).

2.7 Water Storage Tissue

The cross-section of a mature pineapple leaf cross-section can be up to 4 mm thick, with water-storage tissue occupying about half of its volume. When moisture levels are sufficient, dedicated water storage tissue accounts for up to half of the cross-sectional thickness of a mature leaf. This tissue functions as a reservoir ensuring plant and fruit growth even when their moisture is inadequate. Following prolonged dry periods, this tissue deteriorates to near zero (Queensland Department of Primary Industries, 2005).

2.8 CAM Photosynthesis

CAM is a unique photosynthetic pathway found in pineapples. Certain plants, such as prickly pear cactus, have adapted this function to retain moisture. Many crops including pineapple must capture carbon dioxide at the same time as the sun is shining to conduct photosynthesis and manufacture starch and sugars; as a result, their stomata become exposed during the hottest, driest period of the 24 hours, and a significant amount of moisture escapes through the open stomata (Queensland Department of Primary Industries, 2005; Zhang, Liu & Ming, 2014).

Conversely, CAM plants, such as pineapples, possess an exceptional capacity to accumulate carbon dioxide within the plant, enabling them to keep their stomata closed throughout the day but open them at night-time when the weather is colder and more moist. The stomata close as soon as the sun rises the next day, but release carbon dioxide into the plant cells from the accumulated malic acid, allowing photosynthesis to occur. Pineapple is an 'obligate' CAM plant, meaning it uses only the CAM pathway for photosynthesis (Queensland Department of Primary Industries, 2005; Zhang et al., 2014).

2.9 Main Commercial Varieties in Ghana

Previously, commercial pineapple production in Ghana was focused on the Smooth Cayenne variety. There is also the Sugarloaf variety, which is more generally cultivated for home consumption. In recent times, the MD2 variety has become the typical variety preferred on the global market. The MD2 variety can grow to an even size, has a sweeter taste than the other varieties and ripens uniformly.

As of 2004, the European Union's (EU) market share of pineapple was represented by 70%-75% of the MD2 variety and its price was about twice as much as the Smooth Cayenne variety (Pesticide Initiative Programme, 2004). Accordingly, farmers were enticed to swiftly increase the cultivation of the MD2 variety. The Ghanaian government, consequently, allocated US$ 2,000,000.00 in its budget to support the expansion drive (Ablordepey, 2006). Additionally, in 2005 the World Bank also allocated US$ 2,000,000.00 through the Ministry of Food and Agriculture of Ghana to provide backing of small-scale farmers in Ghana to have access to planting materials of the MD2 variety to guarantee the non-stop cultivation (Ablordepey, 2006).

In 2004 Ghana was enjoying an 11% portion of the export market for the MD2 variety from developing countries to the European Union, (Pesticide

Initiative Programme, 2004). However, the demand for the other varieties such as the Smooth Cayenne and the Sugarloaf varieties steadily increased in volumes by exporting companies who were exporting by air. Since the local small-scale farmers left their farms, they were not able to respond to the rejuvenated market owing to the non-existence of vigorous pineapple field planting materials to produce more pineapples (Agricultural Cooperative Development International and Volunteers in Overseas Cooperative Assistance, 2015).

Owing to the high air freight costs, most air freighted pineapples (Smooth Cayenne and Sugarloaf) sold on European markets come from Africa (West, Central and South Africa) being closer to the European Union.

2.9.1 Smooth Cayenne

Smooth Cayenne was grown by Indians in Venezuela for several years before being introduced from Cayenne (French Guyana) in 1820. From this group of varieties, it is the most important cultivar. The production cycle of Smooth Cayenne is longer than most of the other varieties. It has an average fruit size of 1.8-3 kg, cylindrical shape, and an orange shell with shallow eyes, yellow flesh with low fibre, juicy and mildly acidic flavour, and turns out to be of utmost importance globally because of its resistance to the Phytophthora rot, although susceptible to the MWP. It is coveted for canning because it has enough fibre for strong slices and cubes, as well as a great taste (International Tropical Fruits Network, 2011).

2.9.2 Sugarloaf

Sometimes called white Sugarloaf or Kona Sugarloaf is believed to have originated from West Africa in the early 19^{th} century. It is cylindrical in shape and has an average fruit weight of 2.5-3 kg. This pineapple variety has smooth leaves, and the edible core of the fruit is not woody. The flesh is white with high sugar content but low acid. The fruit is very fragile and prone to bruises and shocks from mishandling. It is susceptible to the mealybug wilt of pineapple (International Tropical Fruits Network, 2011).

2.9.3 Baby pineapples

Baby pineapple is also known as Queen Victoria Pineapples was introduced into the French Island of Reunion in 1668. It thrives well in tropical climates. The tart baby pineapple fruits are conical in shape, and sweet, have a bold, rich flavour, deep-yellow and fragrant flesh with deep eyes that requires thick cutting to remove peel completely, with golden skin. The Queen Victoria variety is wholly edible, with no need to take away the core. Since it is less fibrous unlike in the other varieties. The average fruit size is about 11.5 cm high (excluding the crown) and approximately 8.9 cm in diameter, rendering it ideal for an individual serving (International Tropical Fruits Network, 2011; Produce for Better Health Foundation, 2018).

The baby pineapple plant is miniature in size, with short, spiky, dark purplish-green leaves that are disease resistant compared to the Smooth Cayenne variety. Some varieties of the plant develop robust slips, and most have two or more suckers, which are appropriate for replanting.

2.9.4 MD2

MD2 is a hybrid developed by the Hawaiian Pineapple Research Institute in the mid-1990s and is also known as 'Golden Ripe,' 'Extra Sweet,' or Maya Gold. It produces 1.3-2.5 kg fruits that are cylindrical and square-shouldered in form, with wide flat eyes and an extreme orange-yellow colouration when fully ripe. The clear yellow pulp of the fruit is sweet, compact, and fibrous. It has a high sugar content of 15-17° Brix and four times the ascorbic acid of normal varieties but contains less total acid than Smooth Cayenne. This variety was designed for a market that was looking for a fruit that was extra sweet and standardized in size and ripeness (International Tropical Fruits Network, 2011; Ehler, 2018).

MD2 is resistant to the physiological disorder condition known as internal browning but susceptible to the fruitlet core rot and Phytophthora rot diseases than the Smooth Cayenne variety (International Tropical Fruits Network, 2011).

2.10 Ecology of Pineapple

Pineapple grows from 0 to 1600 m above sea level; however, elevation has a major effect on taste, as they become gradually sour and acidic above 1800 m. Pineapple can bear fruit if it receives 650-3,800 mm of annual precipitation, depending on the variety. The ideal average rainfall is between 1,000 mm to 1,800 mm per annum. The most favourable rainfall for good growth is 1,500 mm per year even though the crop can do well in areas having 500 mm to 5,550 mm of rainfall. It tolerates high humidity of 70-80% and an average temperature of 18-30 °C but the ideal temperature for good yield is 25 °C. Very little growth occurs below 20 °C or at 36 °C (Bruce et al., 2000; Kaudo, 2014).

While pineapple plants can withstand cool nights for short periods, prolonged cold hampers growth slows maturity, and makes the fruit more acidic. Intense sunshine results in sunscald or sunburn of portions of the fruit that fall over and are unprotected from the sun. This leads to more acidity in parts of the fruit exposed to the sun (Bruce et al., 2000; Kaudo, 2014).

Water supply has been reported to have influenced the concentration of free acids. Where there is a water deficit the acid level is low. On the other hand, too much water increases the fragility of the flesh, resulting in cellular lesions- the "green ripe" phenomenon. Fruits harvested during a rainy period do not keep well (Gil, 2017).

Pineapples grow in any free-draining soil. A non-favourable soil type for the development of soil-borne diseases like Phytophthora rot is a well-drained sandy loam with a pH of 4.5 to 5.5. Soil pH greater than 7.0 is the best for the growth and development of the Phytophthora rot and should be avoided. Most indigenous pineapple habitats have high-organic-matter soils, and the crop thrives in soils with an organic matter content of 8% or more at a depth of at least 60 cm (Faber & Ohr, 1999; National Bank For Agriculture and Rural Development, 2006: Manicom, 2011).

High calcium and manganese content result in water logging in chlorotic plants. Excess manganese prevents response to sulphur or iron (den Dass, 1993). Pineapples require normal spraying with very weak sulphate or iron. Heavy clayey soil is not a preferred type of soil for pineapple production. Pineapple can do well in sandy, alluvial or laterite soils. If the acid levels of the soil are not sufficient the soils should be treated with sulphur to achieve the preferred level of acidity (Bencini, 1991; Central Coastal Agricultural Research Institute, 2013).

Pineapple is a xerophytic crop and consequently can withstand drought but not waterlogging. Hence drainage must be enhanced where the subsoil is impervious. Organic matter is generally needed to amend pure sand, red loam, clayey loam, and gravely soils. (Bruce et al., 2000; CABI, 2017).

2.11 Agronomic and Cultural Practices

2.11.1 Planting

Pineapples are perennials that can be grown all year with the aid of vegetative planting materials like suckers, crowns, and slides (Purseglove, 1984; Bartholomew, Paull, & Rohrbach, 2003). These drought-tolerant vegetative propagules can be stored and survive for up to six months apart from the "mother" plant, depending on the conditions. Until planting, fungicides and insecticides should be applied to all plant materials used for vegetative propagation (Coppens d'Eeckenbrugge & Leal, 2001).

In Ghana, farmers are advised to dip selected propagules into a solution made up of water – 400 l, fosetyl-Al-1150 g, metalaxyl and mancozeb -1250 g, and cypermethrin - 400 ml, for five seconds, allowed to drip dry before planting (Pesticide Initiative Programme, 2004; National Bank For Agriculture and Rural Development, 2006).

Large rocks, leaves, and tree stumps are removed from pineapple-growing soils; root weakness is a key factor in recognizing and achieving pineapple-growing performance. The plant roots are shallow, with the bulk of the roots found in the top 40 cm of the soil. Since the roots are so delicate and can only grow in loose, well-aerated soil, an impediment in the soil would affect the growth of the plant (van Santen and Stice, 2017).

Ploughing, subsoiling, harrowing, and ridging are the land preparation processes that should be carried out before planting to make the soil loose enough for better growth. Soil erosion is a strong constraint that needs to be considered (van Santen & Stice, 2017).

The root systems are underdeveloped, and the rows of plants cover the soil poorly two or three months after planting. As a result, runoff from rain between the rows exposes the soil to major erosion. When the slope is steep and the soil is sandier and less clayey, this effect is exacerbated (van Santen and Stice, 2017).

Since drainage is reduced during heavy rainfall, gentle sloping land should be sought for planting. Nitrogen, potassium, and phosphorous fertilizers are used as a basal application before planting. To sustain good levels of growth in pineapple plantations, higher levels of nutrients are applied (Bartholomew et al., 2003; Pesticide Initiative Programme, 2004), since the plant has a high level of nitrogen and potassium requirement (Punjab National Bank, 2007).

Based on research trials, it is estimated that 12 g of nitrogen and 12 g of potassium should be given per plant. Magnesium (0.79 g/plant) and Zinc (0.10 g/plant), Boron at 0.05 g per plant, as well as iron at 0.10 g per plant, should be added to the plant. Phosphorus application is not needed. If the soils are deficient in phosphorus, 4 g of P_2O_5 per plant can be added (Yayock, Lombin, & Owunobi, 1998; Pesticide Initiative Programme, 2004; Punjab National Bank, 2007).

The planting depth is determined by the type of planting material used; crowns and plantlets are the most vulnerable to deep planting and should be planted at a depth of five to ten centimetres; slips and suckers should be planted at a depth of ten to fifteen centimetres. The management of butt rot is helped by exposing the planting materials to light. In controlling weeds to avoid severe damage and slow plant growth, plastic mulches are often used on planting beds to prevent weed growth (Coppens d'Eeckenbrugge & Leal, 2001; Bartholomew et al., 2003).

2.12 Pests of Pineapple

2.12.1 Common weeds of pineapple plantations

In several parts of the world, weeds are a major issue in pineapple production, the effective control of weeds is imperative through the early stages of growth because tolerating weeds will lead to competition with your pineapple for nutrients, light, and water. Plant yield can be reduced by severe weed by up to 80%. Weeds may also act as hosts for pests and viruses (Bartholomew et al., 2003; Torres & Garcia, 2005).

The weeds associated with pineapple production, according to Akobundu (1987), are comparable to those associated with other field and plantation crops. The type of weed and the strength of its overgrowth, depending on the land-use system, cropping system, climatic and soil factors, *Pennisetum clandestinum*, *Cyperus rotundus* and *Cyperus esculentus* are some of the most problematic weeds of pineapples in Eastern Africa.

In other parts of the tropical regions that include Ghana, persistent weeds such as *Chromolaena odorata*, *Cynodon dactylon*, *Imperata cynlinderica*, *Paspalum conjugatum*, and annual weeds such *Bidens pilosa*, *Digitaria* spp. and *Eleusine indica* are challenging on pineapple fields. Rohrbach & Johnson (2003) had similarly stated that each pineapple production area has its specific range of weeds that are at times determined by historical weed-control practices.

Weed species that are for the most part difficult to deal with include *Panicum maximum* var. *maximum*, *Sorghum halepense* and the Paspalums, (*Paspalum dilatatum* and *Paspalum urvillei*). The sedge *Cyperus rotundus* (nutgrass) is as well a serious pest. Morning glories, *Ipomoea cairica*, *Ipomoea plebeia*, *Ipomoea indica*, *Ipomoea purpurea* and *Ipomoea triloba* are all major broad-leaved weeds (Rohrbach & Johnson, 2003).

2.12.2 Pests

Nematodes (*Rotylenchulus reniformis*, *Meloidogyne javanica*, *Pratylenchus brachyurus*, *Ditylenchus* spp., and *Helicotylenchus* spp.), insects (scale, mealybugs termites, ants) symphylids, mites (*Steneotarsonemus ananas*, *Dolichotetranychus floridanus*) are among the pests that attack the pineapple plant (Bartholomew, Kenneth, Rohrbach, Dale, & Evans, 2002; Pesticide Initiative Programme, 2008b).

The incidence of these pests and diseases is dictated by environmental influences, cultivar vulnerability, and the existence or exclusion of the organism. Pineapple pests and diseases with high population densities emerge at various times in the life cycle of the pineapple and thus have different consequences (Rohrbach & johnson 2003).

Pesticide Initiative Programme (2011) reported that in Ghana the damage caused by nematodes is very heavy throughout the year and the optimum temperature for the Rotylenchulus, for instance, is 29 °C and 30 °C, very susceptible to drought and excess water. Mealybugs (*D. brevipes* and *D. neobrevipes*) attack leaf bases and cause wilt, a serious disease of pineapple due to the considerable damage they can cause (Bijzet & Sippel, 2001; Food Market Exchange, 2004; Pesticide Initiative Programme, 2008b).

The leaves of the pineapple turn orange-brown and dry up due to root rot. Since there are so many weeds and other local plants that serve as mealybug hosts, control becomes difficult (Bijzet & Sippel, 2001).

In Florida, the parasitic wasp, *Hambletonia pseudococciaa* Comp. had been effective in controlling mealybugs, but the widespread use of insecticides restricted the activity of wasps (Morton, 1987). Spraying and dusting are required to prevent fire ants (*Solenopsis* spp.) from bringing mealybugs from diseased to healthy plants (Bijzet & Sippel, 2001).

2.13 The Mealybug Complex of Pineapple

The mealybug is the most common insect pest of pineapple in many countries around the world. Two mealybug species are identified to attack pineapples (Ullman, German, Gunasinghe, & Ebesu, 1989). The Pink pineapple mealybug, *D. brevipes* (Cockerell) and the Grey pineapple mealybug, *D. neobrevipes* (Beardsley) are the two species linked with pineapple acting as the vector for the wilt virus that attacks the pineapple.

The *D. brevipes* and *D. neobrevipes* were initially thought to be unrelated strains of the same species (*D. brevipes*) but Beardsley (1959) discovered that they were distinct species and suggested the name *D. neobrevipes* for the Grey mealybug.

2.13.1 *Dysmicoccus brevipes* (Cockerell)

The adult body is oval or rotund, pink, or pink-orange in colouration, legs are yellowish-brown, and the body is coated with a thin layer of white mealy wax that allows the body colour to show through. There are no bare areas on the dorsum, the dorsal ovisac is missing, and the venter has a few filamentous strands with 17 pairs of prominent lateral wax filaments. It is often slightly bent, with the posterior pairs being the longest and measuring one-third to half the length of the body. The filaments in the front are thinner than those in the back. *D. brevipes* can be found in all parts of the plant but is most common in the protected area. It lays pink eggs and is ovoviviparous (ScaleNET, 2007; Egelie & Gillett-Kaufman, 2015).

According to Mau and Kessing (2007), *D. brevipes* (Cockerell) reproduces only by parthenogenesis in Hawaii, where only females are established, whereas both sexual and nonsexual reproductions occur in Brazil, in which both males and females are available.

The life cycle of *D. brevipes* has been comprehensively researched. This insect undergoes three larval stages before becoming an adult, according to Ito (1938). The lifespan (from the first instar to adulthood) ranges from 78 to 111 days, with an average of 95 days. The larvae, called "crawlers", are the principal dispersal stage in the *D. brevipes* species. Their flattened bodies are covered in long hairs that help in wind dispersal.

Before reaching maturity, the larvae moult three times. The larval stages of the first, second, and third instars last 10 to 26 days, 6 to 22 days, and 7 to 24 days, respectively. As a result, the overall larval stage ranges from 26 to 55 days, with an average of 34 days. As a first instar and in the early stages of the second instar, the larvae do not feed (Mau & Kessing, 2007).

Adult females have a plump and rounded body shape with pinkish colouration, according to Mau & Kessing (2007). The length of lateral wax filaments is generally less than a fourth of the circumference of the body, and those during the back of the insect are half of the length of the body of the insect. These wax processes are divided into 17 pairs (CABI, 2018).

Pink pineapple mealybug females mimic Grey pineapple mealybug females in appearance. Adult females go through a prelarviposition stage that lasts about 27 days, followed by a 25-day larviposition period. Pink pineapple mealybug females can have up to 1000 crawlers and can give birth to around 234 offspring. Adult female life span ranges from 17 to 49 days, whereas adult males live for one to three days. The first instar stage is the main dispersal stage which moves about energetically for a short period (CABI, 2018).

Pink pineapple mealybugs are nocturnal and tend to hide at the bases of the host plants, such as the roots, leaves, stems, fruits, and crowns of pineapples. In the absence of *D. neobrevipes, D. brevipes* can appear on the aerial parts of the plant (Rohrbach et al., 1988; Jahn & Beardsley, 2000; CABI, 2018).

2.13.2 *Dysmicoccus neobrevipes* (Beardsley)

As their common name suggests, the adults are mostly grey in colour. Their bodies are brown to greyish orange in colour, but the waxy exudation that coats them gives them a greyish look. The body is generally oval, measuring 1.5 mm in length and 1.0 mm in width.

Small tufts of white mealy wax cover the back of the head. Wax filaments spread from the margins of the body at short intervals. Lateral wax filaments are typically only about a quarter of the length of the body of the insect, while those toward the back are about half the body length. The Grey pineapple mealybug has ten antennal segments (Mau & Kessing, 2007; CABI, 2015).

D. neobrevipes is bisexual and reproduces sexually (Mau & Kessing, 2007). This species does not reproduce by laying eggs. They are ovoviviparous, which means the eggs hatch within the female. As a result, they give birth to living young (nymphs). Around 26 days after reaching maturity, adult females begin giving birth to larvae and this continues for the next 30 days. Each female produces 350 larvae on average, but some can produce up to a thousand.

Females die four days after they stop producing young ones. Adult life spans between 48 and 72 days, with an average of 61 days. Males have a shorter lifespan than females. The winged males have a life span of 2 to 7 days. (Mau & Kessing, 2007).

The larvae of *D. brevipes* are known as "crawlers," and they are the species' primary dispersal stage. Their flattened bodies are covered in long hairs, that help in wind dispersal. Before reaching adulthood, female larvae moult three times. The first, second, and third larval instars or stages, respectively, last 11 to 23 days, 6 to 20 days, and 7 to 28 days. As a result, the overall larval period ranges from 26 to 52 days, with an average of about 35 days (Mau & Kessing, 2007).

Males, on the other hand, moult four times before reaching adulthood. The first, second, third, and fourth larval instars or stages, respectively, last 11 to 19 days, 7 to 19 days, 2 to 7 days, and 2 to 8 days. As a result, the overall larval period ranges between 22 and 53 days. The first instar and the early part of the second instar are the only occasions that larvae consume food (Mau & Kessing, 2007).

The life period (from the first instar to adult death) ranges from 59 to 117 days, with an average of 90 days. The Grey Pineapple Mealybug feeds on the upper parts of its hosts, such as leaves stems, aerial roots, flower, and fruit clusters. These attacked sites vary from those of *D. brevipes*, which lives at the base of their host plants, such as the lower portions of stems and exposed roots of grasses and herbaceous plants, pineapple butts, and sugar cane flower stalks. (Mau & Kessing, 2007; CABI, 2018).

2.13.3 Host range of pineapple mealybug

The *D. brevipes* attack more than one hundred and forty plant species all over the tropical and subtropical parts of the world. Contrarily, the *D. neobrevipes* have a rather smaller geographical distribution, limited to South and Central America, the Caribbean, some Pacific Islands, and a few Asian countries bordering the Pacific Ocean, and infest approximately 50 plant species (Beardsley, 1965; Williams & Watson, 1988; Williams & Willink, 1992; Ben Dov, 1994).

2.13.4 The ants tending the mealybugs

In the 1920s, pineapple growers in Hawaii discovered that ants were abundant in the wilted areas of their fields. The assumption was made that these ants were responsible for MWP in the pineapple fields, and steps were taken to extinguish them to avoid infestations. Based on his earlier findings, Jahn et al. (2003) concluded that the ants were not the cause of the wilt disease. He mentioned that mealybugs are pineapple pests, so the ants appeared to benefit from the mealybugs by preventing the mealybugs' natural enemies from attacking them.

It had been established that mealybugs, not ants, were to blame for pineapple wilt. He had observed that if there were no ants present, the natural enemies on the field could hold the mealybug population in check. As a result, he indicated that killing ants would be a more successful way to end MWP. Since then, MWP has been managed mainly through the control of ants on the field (Jahn et al., 2003).

It has been established through experiments that the control of the ant population on the field decreases the mealybug population and thus checks MWP in pineapple (Jahn et al., 2003). Although several ant species have been discovered in Hawaiian pineapple fields, the big-headed ants, *Pheidole megacephala* (Fabricius), the fire ant, *Solenopsis geminate* (Fabricius), and the Argentine ant *L. humile* (Mayr) are the most perversive. *P. megacephala* and *Solenopsis geminate* are the most common ant species in low-lying pineapple fields (Reimer & Beardsley, 1990a; Jahn et al., 2003, Mau & Kessing, 2007).

2.13.5 The role of the ants in mealybug population perpetuation

When fire ants move mealybugs into the shelters made by *S. derogata* on an enemy-infested plant portion, these defensive efforts by fire ants tending to the survival of mealybugs in shelters are noticeable. As a result, mealybugs in shelters are guaranteed to survive in the presence of the natural enemies of the mealybug (Zhou, Zeng, Lu, Xu, & Liang, 2012).

2.14 Diseases

2.14.1 Fungal diseases

Fungal pathogens attack pineapples at all the growth stages. Fungal diseases of pineapple include anthracnose caused by *Colletotrichum ananas* (Garud), butt rot caused by *C. paradoxa* (De Seyn.) Sacc., leaf spot caused by *Curvularia eragrostidis* (Henn.), heart rot caused by *Phytophthora cinnamomi* (Rands) and *Phytophthora nicotianae var. parasitica* (Dastur), root rot caused by *Pythium* spp. (Pringsheim), and *Pythium arrhenomanes* (Drechsler) seedling blight caused by *Pythium* spp. and fusariosis caused by *Fusarium* spp. (The Pineapple Working Group, 2010).

2.14.2 Phytophthora diseases

Phytophthora diseases are of major importance in the pineapple industry in Ghana. These diseases threaten the pineapple plant at all stages of its growth. Heart and root rot disease are the two most severe phytophthora diseases in pineapples, and they are severe in the months of April to June (Messenger-Routh, 1996; Pesticide Initiative Programme, 2011).

2.14.2.1 *Phytophthora root rot disease*

Pineapple plants that are suffering from root rot caused by *Phytophthora cinnamomi* will often begin by exhibiting symptoms of deficiency and undernourishment and they are compromised and susceptible to other pathogens. The disease can kill young seedlings in a matter of days, weeks, or months, while the disease can kill older plants' roots slowly or rapidly, depending on the fungi population in the soil and the normal environmental conditions. Aged plants, consequently, exhibit yellow leaves, die-back, necrotic brown lesions, dead roots, stunting, and low yield coupled with smaller fruit size (Zentmyer, Menge, & Ohr, 1998; Pesticide Initiative Programme, 2011).

2.14.2.2 *Phytophthora Heart Rot Disease*

Phytophthora heart rot disease is caused by either *P. cinnamomi* (Rands) or *P. nicotianae* var. *parasitica* (Dastur). The fungus, for the most part, affects plants of all ages near or at the soil line, causing water soaking of the stem and a dark appearance. Conditions that favour the development and spread of the fungus are heavy rains, high relative humidity, temperatures between 20-30 °C, 2011).

Phytophthora attacks on aged plants, particularly after flower induction with calcium acetylide are not unusual. The heart leaves turn yellowish or light coppery brown, and dark. The dark area spreads in all directions, and if the plant is immature and succulent, the darkening will easily encircle the entire stem, causing the entire plant to wilt. Owing to the invasion of secondary species, this disease is often distinguished by yellow-red leaves that are quickly pulled from the plant and emit a foul odour. The growing points of the stems appear yellowish-brown, with a dark line separating stable and diseased regions. Stored crowns and suckers are more susceptible to rot than fresh ones.

2.14.3 Base (butt) rot

The fungus *Chalara paradoxa* causes butt rot, and the symptoms appear only on crowns, slips, and suckers before or shortly after planting. The soft butt tissues rot becomes grey to black, leaving stringy fibres and a hole at the base of the stem. When infected material is planted, minor decay of the butt stunts plants growth significantly. Plants with extreme butt decay fail to grow, wilt quickly, and the leaf tissue dies. The young leaves, unlike those affected by Phytophthora heart rot, remain tightly attached to the top of the stem. At ground level, infected plants can be quickly broken off. (Secor Jr. et al., 2005: Joy & Sindhu, 2012).

The fungus is involved in the breakdown of pineapple remnants after harvesting and can be found as chlamydospores mostly in the soil and rotting pineapple remains. The fungus typically infects plants through new wounds caused by the detachment of planting material from the parent plant, which kills soft tissue at the base of the stem. Conidia are formed in high-humidity environments and can be spread by wind. The disease can cause significant losses in planting material at times (Secor Jr. et al., 2005; Joy & Sindhu, 2012).

2.14.4 Fruitlet core rot (green eye)

Penicillium funiculosum and *Fusarium guttiforme* cause fruitlet core rot, which is one of the most common diseases affecting pineapple fruit production around the world. It is a fruit disease that affects the inside of the fruit. Smooth Cayenne fruits normally have no visible symptoms. The fruits of Queen Victoria, on the other hand, can produce fruitlets that are colourless, a condition known as "green eye." As the fruit ripens, severely affected fruitlets can turn brown and sunken. Browning of the centre of the fruitlets, beginning below the floral cavity, and occasionally spreading to the core, is one of the internal symptoms. The browning, which is still very firm, varies in size from a speck to complete discolouration of one or more fruitlets (Joy & Sindhu, 2012).

2.14.5 Fusariosis

Fusarium guttiforme causes fusariosis. It is intermittent and attacks different parts of the pineapple plant but is most noticeable and harmful to the fruit. Stem rosetting occurs in fruits, and parts of the stem of the plant are girdled or destroyed (Joy & Sindhu, 2012; Secor Jr. et al., 2005).

Insect-caused injuries to the inflorescence and fruit, especially the pineapple fruit caterpillar (*Thecla basilides*), and infected planting materials are the main sources of infection (Secor Jr. et al., 2005; Pesticide Initiative Programme, 2011: Joy & Sindhu, 2012).

2.14.6 Green fruit rot

The Oomycete of *P. cinnamomi* is the pathogen that causes this disease. Green fruit that meets the soil is susceptible to infection (Joy & Sindhu, 2012).

2.14.7 Inter fruitlet corking

Phytophthora funiculosum is the fungus that causes this disease. Early in the growth of fruits damaged by inter fruitlet corking, glossy spots on the shell appear where the trichomes are being lost to feeding by mites. Corky tissue forms on the skin between the fruitlets on the outside, but only 'patches' of eyes are normally affected. The sepals and bracts can also develop fine, transverse splits. Corkiness around fruitlets inhibits their growth in mild to extreme instances, and one side of the fruit may be misshapen (Pesticide Initiative Programme, 2011; Joy & Sindhu, 2012).

2.14.8 Leathery pocket

P. funiculosum causes this disease. The outside symptoms are rare in fruits. The development of corky tissue on the surfaces of the fruitlets causes them to become leathery and brown on the inside. Occasionally, a leathery pocket will appear. Between initiation and an exposed flower, *P. funiculosum* infects the growing fruit. Cool temperatures of 16-20 °C favour the disease progression during the five weeks after flower induction, when the fungus masses up in mite-damaged trichomes. From around 10-15 weeks after flower initiation, the infection needs similar cool temperatures (Joy & Sindhu, 2012).

2.14.9 Fruit rot by Yeast and *Candida* spp.

Candida spp. and *Saccharomyces* spp. are the pathogens that cause this disease. The sugar solution is fermented by the yeast, which produces alcohol and carbon dioxide. A bubbling exudation of gas and liquid through the split or injury where the infection emerges is the primary symptom. When the juice leaks, the fruit turns fibrous, and the skin becomes brown and leathery. The rotting flesh within becomes a bright yellow colour and produces huge gas cavities. Eventually, only the skin and fibrous tissues of the fruit are left (Joy & Sindhu, 2012).

2.14.10 Nematodes associated diseases

Root-knot nematode (*Meloidogyne javinca*), the root-lesion nematode (*Pratylenchus brachyurus*) and the reniform nematode (*Rotylenchulus reniform*) are the pathogens associated with the nematode diseases of pineapple (Joy & Sindhu, 2012).

Root-knot nematodes cause distinctive terminal growths on the roots, which prevent the roots from developing further. The root-lesion nematode infects the outer root tissues, causing black lesions on the root surface caused by dead or injured plant cells. The root may be fully encircled by these lesions. Reniform nematodes minimize the number of lateral and fine feeder roots, while the rest lengthens normally, allowing plants to maintain good soil anchorage. Root-knot nematodes cause plant stunting, yellowing, and plant dieback (Pesticide Initiative Programme, 2008a; Joy & Sindhu, 2012).

2.15 Bacteria and Phytoplasmas Associated Diseases

2.15.1 Marbling

Pantoea ananatis and *Acetobacter* spp. are the pathogens that cause this disease. External symptoms are absent in infected fruits. The flesh is red-brown, granular, and has a woody consistency on the inside. When flowers are induced and fruit grows in humid, conditions, the disease develops. The bacteria invade the fruit through the open flower and natural growth cracks. The acidity and sugar content of infected fruit is normally low (Secor Jr. et al., 2005; Joy & Sindhu, 2012).

2.15.2 Pink disease

The bacteria that cause this disease are *Pantoea ananatis Acetobacter aceti* or *Gluconobacter oxydans*. Fully mature, diseased fruits have no external symptoms. Internally, the skin may be wet or light pink, with an aromatic odour, but these signs may not be apparent right away. Infected tissue darkens to colours varying from pink to dark brown when sterilized by heat during canning. Just one or a few fruitlets can be infected in some fruits (Joy & Sindhu, 2012).

The entire cylinder can be invaded in highly transparent, low-Brix fruit. During cold weather, the bacteria infect open flowers (Joy & Sindhu, 2012).

In highly translucent, low- Brix fruit, the entire cylinder can be invaded. The bacteria infect through open flowers during cool weather. Disease incidence increases in dry conditions before flowering, followed by rainfall during flowering. The bacteria are thought to be carried by nectar-feeding insects and mites to open flowers from infected, decaying fruit near flowering fields (Joy & Sindhu, 2012).

2.16 Virus Associated Diseases

2.16.1 Yellow spot

The tomato spotted wilt virus and capsicum chlorosis virus (Tospoviruses) are the viruses that cause the disease. Infection occurs o fresh and tender crowns when they are either attached to the fruit or in the first few months after planting. On the upper surface of the leaves of young plants are small (2-5 mm), circular yellow spots occur (Joy & Sindhu, 2012).

2.16.2 Mealybug Wilt of Pineapple (MWP)

In Ghana, the MWP has a limited attack in the months of January, February, August, and November to December, from April to June the disease' damage is heavy and control essential whereas, in March, July, September and October damage is and control necessary (Zentmyer et al., 1998; Joy & Sindhu, 2012; Secor Jr. et al., 2005; Pesticide Initiative Programme, 2008a; 2011).

MWP is transmitted by two species of mealybugs: The Pink pineapple mealybug, *D. brevipes* (Cockerell), and the Grey pineapple mealybug, *D. neobrevipes* (Beardsley), (Beardsley et al., 1982; Sether, Ullman, & Hu, 1998).

A mild reddening of the leaves about halfway up the plant is one of the first indications of the disease in pineapples. MWP wilt is a form of wilt that begins in small spots of pineapple plants. The leaf colour changes from red to pink, and they lack rigidity, roll down at the edges, yellow, and roll under, eventually dying. The leaf tips die back, and the infected leaves droop and become limp. Diseased leaves eventually dry out. The plant also appears wilted as the root tissue crumbles. Plants may regenerate to have less symptomless leaves and smaller fruit compared to healthy plants. Plants with mealybug wilt die infrequently. The wilt "virus" spreads further, due to the recovered plants. The MWP is more common during the dry and hot seasons but can be found all year round.

In Hawaii, pineapple mealybug wilt-associated virus-1 (PMWaV-1) infection has been linked to a 5 to 15% decrease in ratoon crop yields and up to 30% production losses due to premature or asynchronous fruit ripening. The most common virus species in that location, however, is PMWaV-2, which can cause fruit loss of up to 100% (Sether & Hu, 2002a).

In Australia, on the other hand, MWP symptoms are closely linked to infections with PMWaV-3 alone or with both PMWaV-1 and PMWaV-3, but not with PMWaV-2 (Gambley et al., 2008).

Plant age at the time of mealybug infestation affects disease development and occurrence, with younger plants showing symptoms two to three months after feeding by the mealybug and ageing plants taking up to twelve months to develop symptoms (Pesticide Inititative Programme, 2011; Joy & Sindhu, 2012).

2.17 Aetiology of MWP

Carter (1933a, 1933b) concluded from his early experiments that mealybug wilt was toxaemia and that the mealybugs' saliva was toxic to the plant, based on the observations that: wilt occurred only when large numbers of mealybugs were present, there was a clear relationship between the number of mealybugs feeding, the length of time they fed, and the intensity of wilt that resulted, recovery from wilt was difficult. He also discovered that mealybug toxicity was affected by the type and state of the host plant from which the mealybugs were extracted.

2.18 Management of MWP

The most used method of controlling MWP is a combination of bio-ecological measures and chemical treatment (Py, Lacoeville, & Teisson, 1987). All treatments aim to maintain the population of mealy bugs as low as possible to prevent the disease from becoming active. Also, all measures should be preventive since there is a delay between the attack by mealybugs and the appearance of the first symptoms.

The length of the delay of the appearance of MWP depends on the age of the plantation. The control of mealybugs starts with the preparation of the soil to destroy all residues from the previous crop that enables the mealybugs to survive. Control continues with the preparation of the planting material, which must be disinfected to prevent new attacks. The control must continue throughout the whole cycle of the pineapple plant in the form of direct control (Py, Lacoeville, & Teisson, 1987).

Concurrently, there should be control of the ant population, whenever these are encountered in large numbers, from the preparation of the soil onwards. Ants are responsible for protecting and disseminating mealybugs (Py et al., 1987).

2.18.1 Physical and cultural control of MWP

The manipulation of some of the agricultural production systems or the physical exclusion of the mealybugs or ants to reduce or eliminate the mealybug or ant population on the pineapples some of the methods that recommended and proven successful to a large extent include:

The use of planting materials that have been produced through tissue culture or hot water treated in water of 50 °C for 30 minutes before planting.

Select planting materials from fields with no apparent wilting symptoms.

Not planting new pineapple fields next to fields with a known or suspected history of MWP occurrences.

Cultivating the soil in a way to expose and destroy colonies of the big-headed ant (*Pheidole* spp.) as their nests occur near the soil surface, and re-invasion from surrounding areas will be slow.

Plants exhibiting symptoms of MWP must be immediately removed and burned.

Keep weeds out of your borders since they can harbour mealybugs and ants.

After harvest collect and burn all plant remnants and plough the soil if possible (CABI, 2015).

2.18.1.1 *Altering the pineapple resistance and agronomic practices*

One of the most susceptible varieties to MWP is the commercial variety of Smooth Cayenne pineapple cultivated by the Hawaiian pineapple industry (Carter & Collins, 1947). Unfortunately, resistant hybrids are undesirable in other ways (Collins & Carter, 1954), and the study on resistance was ultimately abandoned in favour of ant and mealybug control at the Pineapple Research Institute (Jahn, Sanchez, & Cox, 2001).

The intensity of certain pest problems may be influenced by soil nutrient management (Jahn, Sanchez, & Cox, 2001). Carter (1945b) tried to do the same thing with wilt disease, but he could not find any connection between plant nutrition and pineapple susceptibility to mealybug wilt.

2.19 Chemical Control

Insecticides have been used to try to suppress the mealybugs population, but the efficiency in the control have not worked too well. MWP treated with oil emulsions or mineral oil in the. It is instructive to note that most of the. with organophosphorus compounds such as parathion, malathion, and diazinon that became a more efficient chemical control method after World War II have all been banned or their use restricted on pineapples (Jahn et al., 2003).

Some of the 'chemical' control means being adopted by most farmers now are the use of insecticidal soaps, horticultural oil, or neem oil insecticides applied directly on mealybugs can provide some suppression, especially against younger nymphs that have less wax accumulation (Flint, 2016).

2.20 Biological Control

Biological control is also being used in the pineapple industry to combat MWP. Mealybug population are dominated by the plethora of natural enemies found in pineapple fields for example the *D. brevipes* is preyed upon by a variety of predators and parasitoids, including the ladybird (coccinellid) beetles, particularly *Cryptolaemus* spp., wasps (encyrtids), green and brown lacewings, spiders, minute pirate bugs, and larvae of predaceous midges. When ants (*Pheidole*, *Iridomyrmex*, and *Solenopsis*) are managed, biological control is effective in many areas (González-Hernández, Johnson, & Rei, 1999a; 1999b, Jahn et al., 2003; CABI, 2015).

CHAPTER THREE

3 FARMERS' PERCEPTION OF THE MWP DISEASE, MANAGEMENT PRACTICES USED, AND THE EFFECT OF THE DISEASE ON THEIR LIVELIHOOD

3.1 Introduction

For many farmers and other actors in the pineapple value chain, pineapple production is a major source of income. In Ghana, pineapple production is mainly by smallholder farmers for local consumption and large-scale farmers for export (Trade and Markets Division-FAO, 2009). The Sugarloaf variety is grown by the smallholder farmers and the large-scale farmers are producing mainly the MD2 and the Smooth Cayenne.

The MWP is one of the most damaging diseases of pineapple in the world, and it is threatening pineapple production in Ghana (Sether & Hu, 2002a). The MWP has been linked to the PMWaV and is distributed by the mealybug (Sether & Hu, 2002a). Aside from the mealybug spreading the disease, the virus can also be transmitted by humans through the inadvertent use of contaminated planting materials. The effect of the disease on the farmers' income and that of the actors in the value chain is serious. Therefore, it is very important to manage the disease to improve the yield and production to increase the income levels of farmers. Information on farmers' awareness of MWP disease and their perception of the effect of the disease on the productivity of pineapple is an important prerequisite for developing an effective strategy for managing the MWP disease in pineapple orchards. Such information is, however, very scanty in Ghana. It is against this background that this study was conducted to determine the perception of pineapple farmers in Ghana on the effect and management of MWP.

The objectives of the study sought to determine:

i. farmers' knowledge level on MWP
ii. farmers' perception of the incidence and severity of the mealybug wilt of pineapple
iii. management practices used by farmers against the MWP
iv. effect of the disease on their income

3.2 Materials and Methods

3.2.1 Study area

The study included farmers from Gomoa-East, Gomoa-West, Awutu-Senya-West, and Ekumfi Districts in the Central region of Ghana (Figure 1) and Akuapem-North and South Districts, Upper-West-Akyem Municipal in the Eastern region of Ghana (Figure 2) with the targeted respondents being registered pineapple growers in the two regions who are members of farmer-based associations. The two regions rank highest in pineapple production and are homes to many of the commercial, and small-scale pineapple farms producing all the four major varieties of pineapple viz. MD2, Smooth Cayenne, Sugarloaf, and Queen Victoria in Ghana (Sea-Freight Pineapple Exporters of Ghana, 2007).

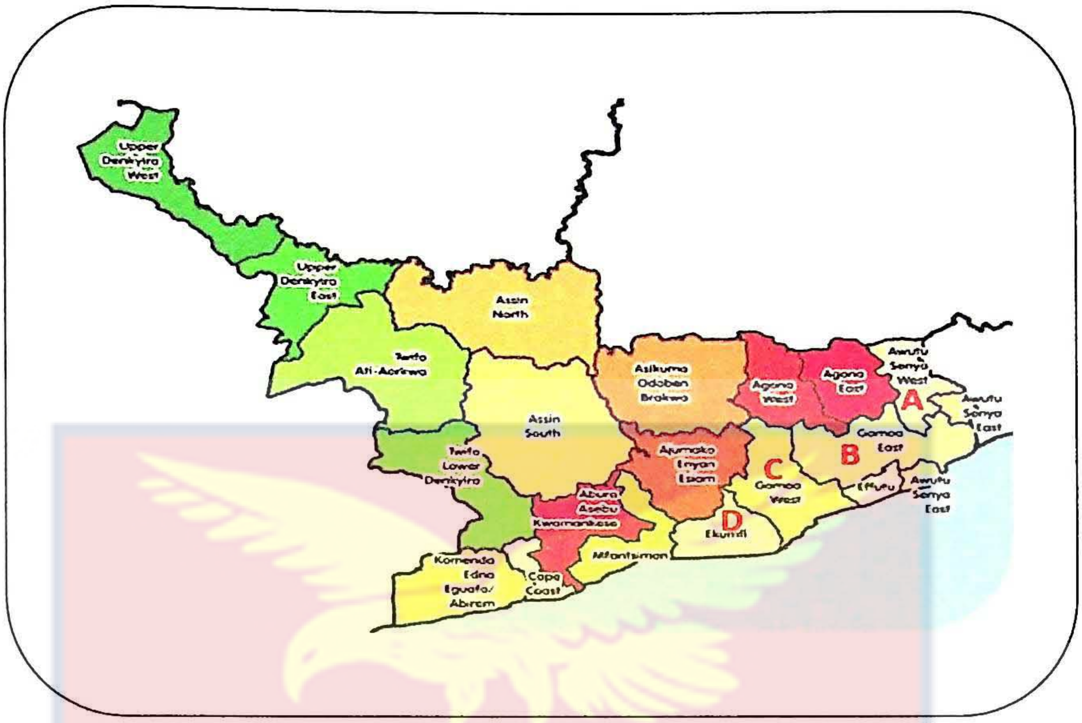

Figure 1: Map of the Central region of Ghana showing the study areas (labelled A, B, C, and D): A = Awutu-Senya-West, B = Gomoa-East and C = Ekumfi, D=Gomoa-West Map Source: (Macabe, 2017)

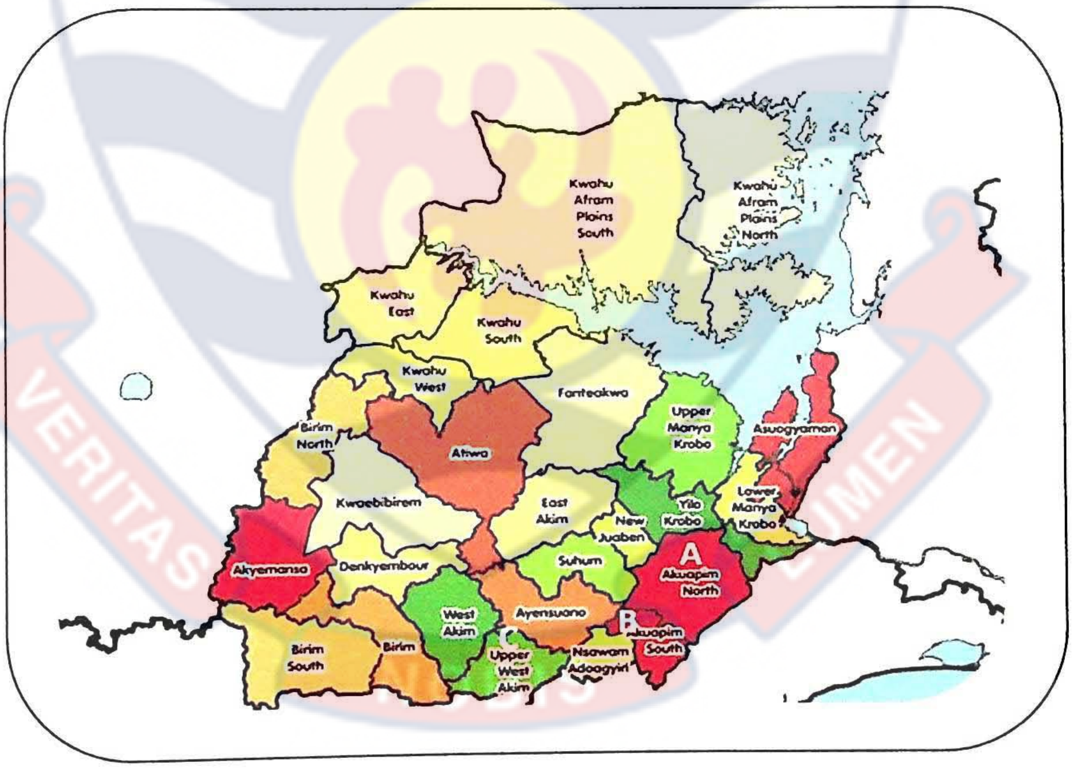

Figure 2: Map of the Eastern region of Ghana showing the study areas (labelled A, B, and C): A=Akuapem-North B=Akuapem-South and C=Upper-West-Akyem Map Source: (Macabe, 2017)

3.2.2 Population and sampling

The total number of target respondents was three hundred and fifty. This was made up of one hundred and fifty from the Eastern region and two hundred from the Central region. According to Krejcie and Morgan (1970), the required sample size for the study should be one hundred and eighty-three. However, to reduce the sampling error, two hundred and twenty-seven respondents were selected.

To ensure a fair representation from the two regions, the proportionate stratified sampling procedure was used to select one hundred farmers from the Eastern region and one hundred and twenty-seven from the Central region. A structured interview schedule and questionnaires were used to collect data from the respondents.

3.2.3 Instrument

After the questionnaire design was done, ten farmers were selected for the pretesting and content validation of the questions. The farmers were made to answer the questions and as they did were made to give their opinion, or understanding of the questions, whether the options provided fits their preferred choice, whether the response being sought for makes them uncomfortable to answer, etc. a list of all the questionnaire sought to measure namely and then the items in the questions were checked against this list, this ensured that the desired measurement in terms of the needed data would be collected during the actual deploring of the actual questionnaire.

Improvement based on the outcome of the pretesting and the content validation was done and then the final questionnaire was validated.

The questionnaire (Appendix A) attached, had questions relating to farmer characteristics or demographics, farm characteristics, farmers' knowledge on MWP, farmers' perception of the pineapple MWP, farmers' agronomic management practices. Closed-ended questions were mainly used in the questionnaire.

The respondents were the owners of the respective small-scale farms and the managers or senior management members of the commercial farms. The literate respondents were made to answer the questions and for the illiterate respondents, they were led by the enumerators by asking and explaining the questions and the expected answers to the respondents.

Except for gender and type of labour, respondents used for fruit harvesting which were measured on a nominal scale, all the other socio-demographic data were measured on an ordinal scale. Respondents were presented with a series of statements to test their knowledge level where they were required to respond with either 'yes or no'.

A five-Point Likert-type scale in which respondents specified their level of agreement to a statement in five points was used to measure the respondents' perception of the incidence and severity of the MWP.

Means were calculated from a scale of ranking, with 1= strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = agree and 5 = strongly agree (Preedy and Watson, 2010). With management practices the respondents used to deal with the disease, they were asked to respond to a series of statements by ticking. The researcher and two trained enumerators were involved in data collection which lasted for one month.

3.2.4 Data analyses

Data were analyzed using descriptive statistics mainly percentage distribution, mean and standard deviation with Statistical Product and Service Solutions (SPSS) programme, version 25.

3.3 Results

3.3.1 Farmer and farm characteristics

Table 1 provides information on farm and farmer characteristics. Questions asked here included age, educational level, number of years in pineapple cultivation, size of land under cultivation with the various varieties of pineapples, type of land ownership, source of planting materials, type of labour used in some of the agronomic practices, source of information, and contact with agricultural extension agents were sought from the respondents.

Most of the respondents (91.5%) were between 20 and 50 years of age while only 8.5% were above 50 years. All the respondents (100%) were males.

Most of the respondents (52.2%) were Senior secondary school/Senior High school leavers while 2.5% of the respondents had technical or vocational education as their highest educational qualification. It was noted that 20.9% and 8.0% of the farmers had bachelors' and masters' degrees, respectively.

The results on the farmers' experience in pineapple cultivation as shown in Table 1 indicates that most of them (78.7%) had been cultivating pineapples between five and twenty years.

A further 15% of them had been in pineapple cultivation for over 20 years while only 2.5% of them had less than five years experience. The results of the study indicate that most of the respondents (51.6%) were large scale farmers cultivating pineapple on land sizes of over 20 hectares, with 47.4% cultivating a land of less than 20 hectares.

The common type of land ownership predominant among the respondents (82.1%) was leasehold while others acquired their lands either through inheritance (8%) or through outright purchase (9.9%). More than two thirds (68.7%) of respondents indicated that they were getting their planting materials from their own and neighbours' farms.

Most of the farmers (68.7%) employed permanent workers as a main source of labour while the others (57.8%) use casual/contract workers for their farm activities. 88.1% of the farmers have never had contact with agricultural extension agents (AEAs) and had not received any type of agricultural services (Table 1).

Table 1: Farmer and Farm Characteristics

Farmer Characteristics	Frequency	Percentage (%)
Age		
20-30 years	37	18.4
31 -40 years	77	38.3
41-50 years	79	34.8
Above 50 years	17	8.5
Total	201	100
Gender		
Male	227	100
Female	0	0.0
Total	227	100
Educational level		
JHS/JSS	23	11.4
Middle school	20	5.0
SSS/SHS	105	52.2
Bachelor	42	20.9
Masters	16	8.0
Technical/Vocational	2	2.5
Total	208	100
Number of years in pineapple cultivation		
Below 5 years	5	2.5
5 – 10 years	54	26.9
10 – 15 years	58	28.8
15 - 20 years	54	26.9
Above 20 years	30	14.9
Total	201	100
Total farm size under pineapple cultivation		
<20 ha	93	47.4
20-40 ha	11	5.6
40-60 ha	6	3.1
>60 ha	86	43.9

Farmer Characteristics	Frequency	Percentage (%)
Total	196	100
Farm Size under MD2 cultivation		
<20 ha	28	23.1
20-40 ha	93	76.9
Total	121	100
Farm Size under Smooth Cayenne cultivation		
<20 ha	61	48.8
40-60 ha	27	21.6
>60 ha	37	29.6
Total	125	100
Farm Size under Queen Victoria cultivation		
<20 ha	52	77.6
>60 ha	15	22.4
Total	67	100
Farm Size under Sugarloaf cultivation		
<20 ha	149	65.6
40-60 ha	78	34.4
Total	227	100
Type of labour for Agronomic activities		
Permanent	156	68.7
Casual/contract	71	31.3
Total	227	100
Type of land ownership		
Leasehold	165	82
Inherited	16	8.0
Outright purchase	20	10.0
Total	201	100
Source of planting materials		
Own farm	64	28.0
Other farms	5	2.0
Own and other sources	158	70.0
Total	227	100
Source of information		
Agricultural Extension Agents	6	7.6
Agro input dealers	6	45.8
Mass media (television, newspaper, radio)	92	53.9
Family and friends	11	45.8
Other farmers	68	69.2
Others	92	64.1

Source: Field Survey, Sarpong (2014)

3.3.2 Farmers' management practices

Table 2 shows the disease and pest management practices adopted by the respondents. The majority (88.5%) of respondents kept fallow plots whereas the remaining 11.5% did not. Out of those who kept fallow plots, 2.5%, 44.8%, 35.2% and 17.4% did it for six months, twelve months, eighteen months, and twenty-four months, respectively.

The majority (76.0%) of the respondents flagged plots with diseased plants, while 8.0% tagged diseased plants and this prevented the farmers from harvesting suckers from infected mother plots. A greater percentage of the respondents (87.2%) said they prevented MWP on their farms by not harvesting suckers from infected fields (mother plots) (Table 2).

Most of the respondents also controlled ants and mealybugs vectors from the mother plots with insecticides, mainly at 3 months (46.6%) and 6 months (41.9%) intervals. Some farmers (8.8%) also physically destroyed infected mother plots (Table 2). Whereas 53.7% did not treat their new plots against insects and MWP before planting, 46.3% treated their soil mainly with insecticides (78.1%) and by ploughing to expose soil to sun/burning (14.3%) before planting new suckers on plots that had previously been planted with pineapples. About 48.6% of those who treated their soil before replanting was doing spot treatment whereas 51.4% did whole plot treatment.

As a preventive measure against MWP, most farmers (87.6%) drench suckers 3-7 days after planting in new plots, whereas others (12.4%) dipped suckers in fungicide/insecticide solution. The majority (94.6%) of respondents applied insecticide as a preventive measure as opposed to 5.5% who applied as a curative measure.

Most (88.5%) farmers said the treatment against the ants and mealybugs was effective while 11.5% were indifferent as shown in Table 2.

Table 2: Farmers' Management Practices

Variable	Frequency	Percentage (%)
Keeping of fallow plots		
Yes	201	88.5
No	26	11.5
Total	227	
Duration of Fallow		
6 months	5	2.5
12 months	90	44.9
18 months	71	35.2
24 months	35	17.4
Total	201	100
Keeping track of the diseased areas of a planted field		
Flagging plots with diseased plants	104	76.0
Tagging individual diseased plants	11	8.
Indicating on the map of the plot	22	16.
Total	137	100
Control of mother plots against MWP		
3 months interval	106	46.1
6 months interval	95	41.9
No treatment	26	11.5
Total	227	100
Means by which MWP is prevented on mother plots		
Insecticide spraying to destroy ants and mealybugs	200	88.1
Physical destruction of infected mother plants	20	8.8
Not planting at the same spot for at least two seasons	7	3.1
Total	227	100
Sucker harvesting from mother plots		
Not harvesting suckers from an infected mother plant	198	87.2
Not harvesting from within 1 m^2 perimeter of an infected mother plant	5	2.2
Harvesting from all mother plants provided the suckers look healthy	24	10.5
Total	227	100
Soil treatment before new planting		
Yes	105	46.3
No	122	53.7
Total	227	100
Means by which soil is treated		
Spraying with insecticides	82	78.1
Ploughing to expose soil to sun soil/burning	15	14.3
No action	8	7.6
Total	105	100

Variable	Frequency	Percentage (%)
Type of treatment used when replanting on an infected field		
Spot treatment	71	48.6
Whole plot treatment	75	51.4
Total	146	100
Means of treating suckers to prevent MWP		
Dipping of suckers in fungicide/insecticide solution	27	12.4
Drenching of planted suckers 3-7 days after planting	190	87.6
Total	217	100
Aim of application of insecticide		
As preventive measure	191	94.5
As curative measure	11	5.5
Total	202	100
Effectiveness of treatment against MWP		
Yes	201	88.5
Indifferent	26	11.5
Total	227	100

Source: Survey data, Sarpong (2014)

3.3.3 Farmers' knowledge of MWP

Table 3 provides information on the knowledge level of farmers on the MWP disease. Pineapple farmers were very familiar with the symptoms of the MWP and other wilting conditions. All (100%) of the respondents indicated that they knew about the MWP disease.

The result also indicated that between 84% and 100% of the respondents were able to differentiate between the MWP and water stress or agrochemical wilt in pineapple. They indicated that definite and sudden change in leaf colour, drying up of affected leaves, leaf tip dieback, new central leaf growth and presence of mealybug underneath were characteristics of MWP.

Concerning the wilting conditions due to water stress or agrochemicals, respondents (100%) indicated that the affected plants were evenly distributed on the field, symptoms appeared a few days after fertilizer/agrochemical application and were isolated and spotted as in contrast to the wilting conditions by the MWP.

Table 3: Farmers' Knowledge on MWP

Variable	Frequency	Percentage
Do you have any knowledge of the MWP?		
Yes	227	100
Total	227	100
Symptoms of MWP		
Light reddening of leaves	201	100
Definite and sudden change in leaf colour	201	100
The leaf tip die-back	186	81.9
Affected leaves dry up	201	88.5
New central leaf growth	191	84.1
Presence of mealybug underneath	201	88.5
How other wilting conditions other than the mealybugs wilt appear		
Yellowing of leaves	227	100
Tip burn	227	100
Evenly distributed among the plants	227	100
Appear a few days after agro-inputs application	227	100
Isolated and spotted	201	88.5

Source: Survey data, Sarpong (2014)

3.3.4 Farmers' management practice on sucker harvest from mother plots

In Figure 3, 87% of respondents said they would not harvest suckers to be used as planting material from an infected mother plant, 11% said they would harvest from all mother plants provided they looked healthy while 2% of respondents said they would not harvest suckers from within the one-metre square of any infected mother plant that has been identified during the growing season.

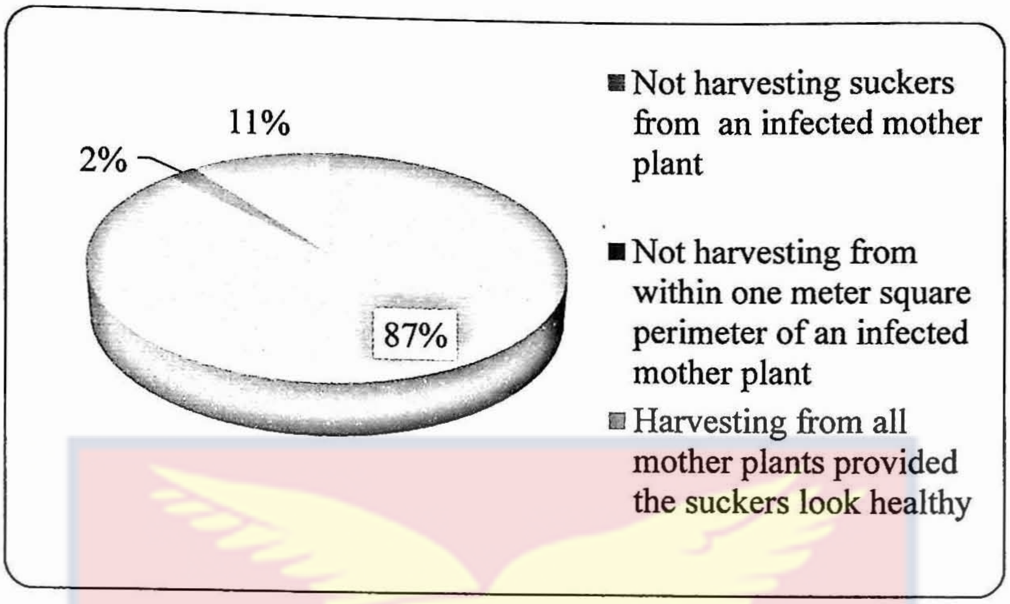

Figure 3: Farmers' management practice on sucker harvest from mother plots

3.3.5 Control of MWP in the mother plots

Forty-seven per cent of the respondents said that they were controlling their mother plots against the disease at three monthly intervals while 12% of respondents indicated that they were not doing any treating or controlling of the disease in their mother plots (Figure 4).

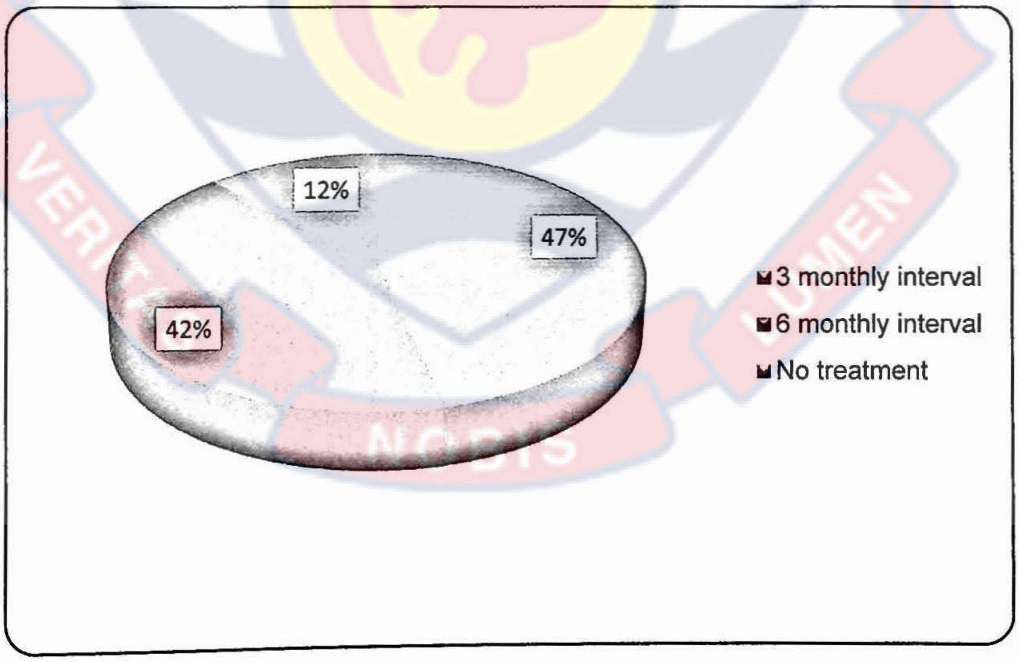

Figure 4: Farmers' control of pineapple MWP in mother plots

3.3.6 Frequency of insecticide application among the different varieties of pineapple

Responses of farmers to the frequency of insecticides application are presented in Figure 5, Fifty-five per cent of Queen Victoria producers, 48% of MD2 producers 28% of Smooth Cayenne producers and 16% of Sugarloaf producers of pineapple varieties were applying insecticides monthly. Only, 12% of MD2 pineapple growers were applying insecticides quarterly (Figure 5).

Most Sugarloaf producers (84%) and Smooth Cayenne producers (72%) applied insecticides bi-weekly.

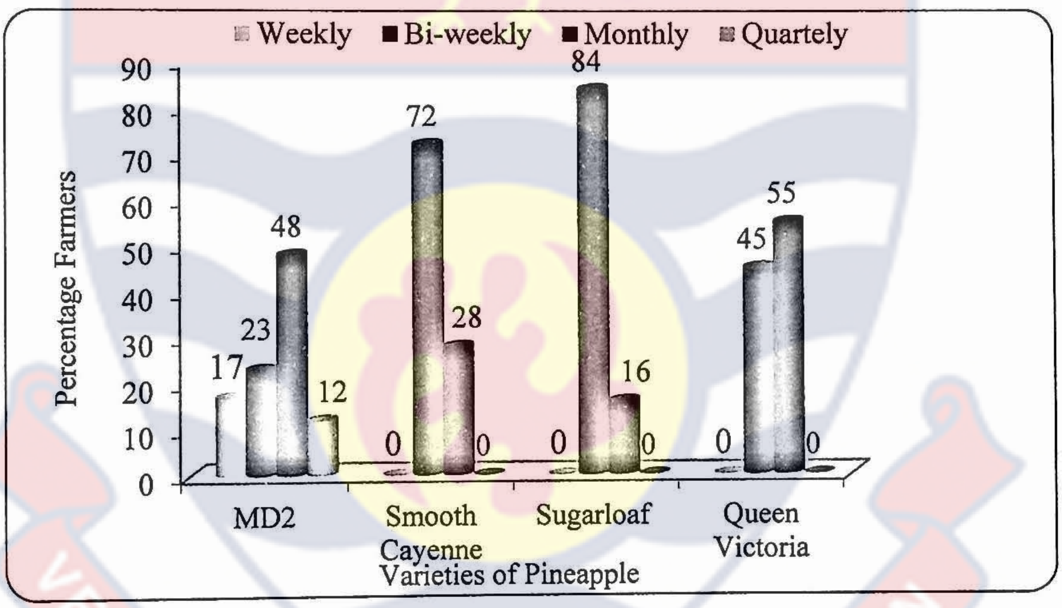

Figure 5: Farmers' frequency of insecticide application on the different varieties of pineapple

3.3.7 Soil treatment before new planting

From Figure 6, 54% of the farmers said they were treating soil before new planting was done in the ensuing year.

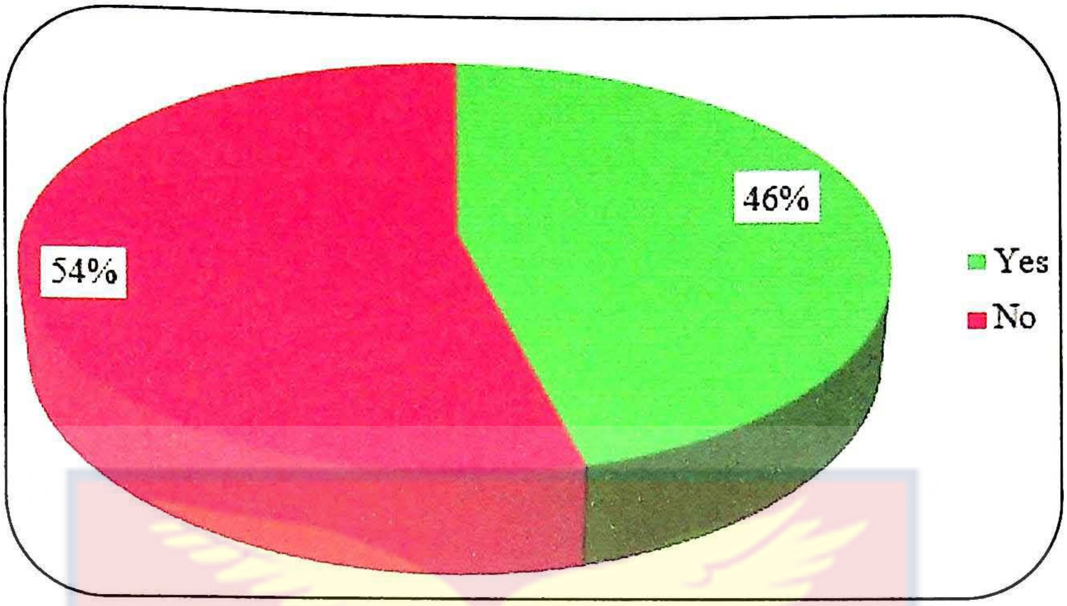

Figure 6: Soil treatment before new planting

3.3.8 The method by which soil is treated to manage the MWP

Figure 7 shows that 78% of the farmers were applying approved insecticides as a method of treating the soil against the MWP; 14% plough to expose the soil to the sun while the remaining 8% took no action in treating the soil against MWP.

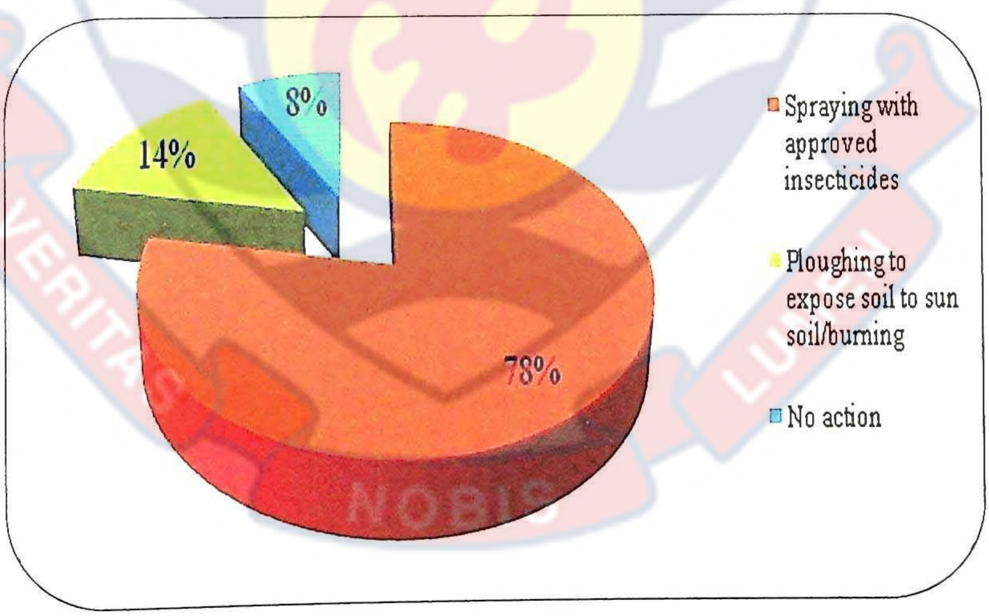

Figure 7: Method by which soil is treated to manage MWP

3.3.9 Farmers' perception of the MWP

Information on farmers' perception of the MWP is shown in Table 4. The respondents strongly agreed that the MWP reduces the yield of pineapple (mean = 5.00, SD = 00). Means were calculated from a scale of 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Agree and 5 = Strongly Agree. They also strongly agreed that the disease was severe in the field with no plastic mulch (mean = 4.99, SD = 0.21), in bushy fields (mean = 4.98, SD = 0.16) and during the rainy season (4.62, SD = 0.72). They agreed that the MWP can destroy the entire farm if not treated (4.05, SD = 1.03).

The majority agreed that ants are the carriers of the mealybugs from place to place4.36, SD 1.03), that the greater the mealybug population of the pineapple farm the greater the incidence and severity of the Pineapple MWP (4.11 SD=0.91) and that Incidence of MWP is high in fields with high plant density (3.95, SD=1.47).

Respondents somewhat agreed with the statements, MWP is very serious during the dry season (3.17, SD=1.33) and controlling the ants and mealybugs populations checks the spread of the disease (3.28, SD=3.28) some also, however, strongly disagreed with the statement that MWP is more serious on the field that plastic mulch is used (1.56, SD=0.75).

Table 4: Distribution of Respondents According to their Perceptions of the MWP

Statement	Mean	Stand. Dev
The Mealybug wilt of pineapple reduces the yield of pineapples	5.00	0.00
The MWP is more serious on the field that no plastic mulch is used	4.99	0.21
The MWP is serious when the field is bushy	4.98	0.16
The MWP is very serious during the rainy season	4.62	0.72
The MWP can destroy the entire farm if not treated	4.05	1.03
Ants are the carriers of the mealybugs from place to place	4.36	1.03
The greater the mealybug population of the pineapple farm the greater the incidence and severity of the Pineapple MWP	4.11	0.91
Incidence of MWP is high in fields with high plant density	3.95	1.47
Plants affected by the MWP need to be destroyed together with all plants within a $1m^2$ radius around them	3.39	1.31
MWP is very serious during the dry season	3.17	1.33
Controlling the ants and mealybug population checks the spread of the disease	3.28	1.20
MWP is more serious in the field that plastic mulch is used	1.56	0.75

Source: Survey data, 2014

3.3.10 Farmers' perceptions about the effect of MWP on different varieties of pineapple

Table 5 highlights the respondents' perception of the effect of MWP on different varieties of pineapple. All the respondents (100%) indicated that the effect of the MWP was low in MD2 variety and high in Smooth Cayenne.

Also, between 91.2% and 96.9% of the respondents indicated that the effect of the disease was high in the Sugarloaf and Queen Victoria.

Table 5: Farmers' Perceptions about the Effect of MWP on Different Varieties

Variety	Frequency (Percentage)		
	High	Medium	Low
MD2	-	-	110 (100)
Smooth Cayenne	159 (100)	-	-
Sugarloaf	154 (96.9)	-	5 (3.1)
Queen Victoria	62 (91.2)	6 (8.8)	-

Source: Survey data, Sarpong (2014). Note: Values in parentheses are percentage values

3.3.11 Farmers' perceptions on incidence and severity of MWP at pre- and post-flower induction growth stages of four varieties of pineapple

Most of the respondents indicated that the incidence and severity of the MWP were higher during the pre-flowering growth stage than the post-flowering growth stage in all four pineapple varieties (Table 6). The highest incidence occurring at the pre-flowering induction stage was observed by 81% of farmers in Sugarloaf production followed by 76% for Queen Victoria. The severity of MWP at this stage was observed by 93.3% of farmers in Smooth Cayenne and 89.6% by farmers in Sugarloaf production.

Table 6: Distribution of the Respondents' Perceptions on the Incidence and Severity of MWP at Pre- and Post-Flower Induction Stage of the Various Pineapple Varieties

Varieties	Percentage (%)	
	Pre-flower induction	Post-flower induction
Growth Stage at which incidence of MWP is high		
MD2	69.4	30.6
Smooth Cayenne	66.5	33.5
Sugarloaf	81.0	19.0
Queen Victoria	76.2	23.8
Growth stage at which MWP is severe		
MD2	76.7	23.3

Varieties	Percentage (%)	
	Pre-flower induction	Post-flower induction
Smooth Cayenne	93.3	6.7
Sugarloaf	89.1	10.9
Queen Victoria	52.4	47.6

Source: Survey data, Sarpong (2014)

3.3.12 Farmers' perception of the effect of MWP on fruit yield

Table 7 shows the farmers' perception of the effect of MWP on fruit yield. Growers of the MD2 variety indicated that they were losing below 1% of their yield to the disease. The majority (45.3%) of the growers of Smooth Cayenne were losing between 41-60% of their yield, followed by 37.8% who were losing 21-40% of their fruit yield, with 16.9% losing 1-20% of their fruits.

The majority (46.3%) of respondents who grew the Sugarloaf variety said they were losing between 1 to 20% of their yields, followed by 37.6% who were losing 41to 60% of their fruits, with 16.1% losing 21 to 40% of their fruits.

The majority (88.9%) of the growers of Queen Victoria said they were losing between 21-40% of their yield while 11.1% were losing 1 to 20% of their fruits (Table 7).

Table 7: Farmers' Perception on the Effect of MWP on Fruit Yield

Yield loss (%)	Percentage (%)			
	MD2 (n =116)	Smooth Cayenne (n = 148)	Sugarloaf (n = 149)	Queen Victoria (n = 63)
Below 1	100	-	-	-
1 - 20	-	16.9	46.3	11.1
21 - 40	-	37.8	16.1	88.9
41 - 60	-	45.3	37.6	-

Source: Survey data, Sarpong (2014)

3.3.13 Effect of MWP on farmers' income

Table 8 highlights the effects of the MWP on farmers' income. In respect of the respondents who sold their produce locally, 33.9% said they were losing between 1001-2000 Ghana Cedis (US$ 244-488); 27.8% said the disease caused losses in income ranging between 2001 and 3000 Ghana Cedis (US$ 488-732) while 26.9% said they lost between 1 and 1000 Ghana Cedis (US$ 0.244-243) in revenue due to MWP.

Table 8: Effect of (MWP) on Farmers' Income

Loss (GH¢)	Percentage (%) Loss	
	Export (n=186)	Local sales (n=201)
1-1000	31.3	26.9
1001-2000	16.3	33.9
2001-3000	7	27.8
Above 3000	27.3	-

Source: Survey data, Sarpong (2014)

3.4 Discussion

3.4.1 Farm and farmer related characteristics of the respondents

Most of the respondents (91%) were between the ages of 20 and 50, according to the study suggesting that most of the respondent farmers were within the productive age (Apantaku, Aromolaran, Shobowale, and Sijuwola, 2016). Thus, pineapple production in these two regions is dominated by the youth. This finding of the present study is also consistent with that of Asare-Bediako, Addo-Quaye, Boakye, Sarbah, Asante, & Dorm, (2015) who stated that most pepper farmers in Ghana are in the age range of 30-59 years.

There were only male pineapple farmers who responded to the survey questions. This is expected because pineapple production is labour intensive which may be too tedious for most women, as reported by Apantaku et al. (2016). Again, the customary land ownership types existing in most areas of Ghana are more favourable to males than females, and this is corroborated by Duncan (2004) who reported that access to and control of land is influenced by customary law and the limited role of women in original acquisition and leadership in traditional authority.

Most of the respondent farmers were found to have Senior High school /Senior Secondary School education qualifications. This suggests that the pineapple business is considered mainly a vocation by literate farmers. It was also discovered that most farmers (78%) had five to twenty years of experience growing pineapple suggesting that most farmers find the pineapple business a lucrative one and therefore would continue with the business for a relatively long period. The high level of education and vast experience in farming among respondents are likely to aid the adoption of improved agronomic practices aimed at managing MWP and improving yields of pineapple as reported by Afari-Sefa et al. (2015).

The land ownership type predominant among the respondents was leasehold and this is so because most of the respondents were non-indigenes, and the common means of land acquisition is through leasehold (Sarpong, 2006). The issue of employing casual/contract workers is a very common practice among pineapple producers in the study areas. This could be because it is very expensive to employ permanent workers. More so some of the activities in pineapple production such as planting, fertilizer application, weedicide application and harvesting are occasional and do not require permanent workers.

The non-availability of agricultural extension officers could affect the adoption of good crop husbandry practices and new technologies by the farmers since farmers might depend solely on other sources such as electronic media, social media, and colleague farmers for information which in most cases are inaccurate. This could account for the misuse of pesticides by the farmers a situation that could lead to pathogens and pests developing resistance to these chemicals. Consequently, this partially explains the high occurrence of pests and diseases on most of the pineapple farms in the study area. The role and the need for agricultural extension workers have been underscored by Anaeto et al. (2012).

3.4.2 Farmers' management practices

The study revealed that most of the farmers keep fallow plots as a means of breaking the disease cycles to contribute to the management of the MWP. This practice is consistent with the recommendations by Pesticide Initiative Programme (2004) which requires the farmers to practice fallowing in pineapple production. This is to ensure that lands regain their fertility during the fallow period and help to break diseases and pests cycles on the fields.

It was also observed that farmers flag diseased plots, do not harvest suckers from infected mother plants, control ants and mealybugs on the mother plots every 3 months. These were indicative of the preventive measures farmers take against MWP development on their respective farms. This practice is in line with the recommendations by Pesticide Initiative Programme (2004; 2008a).

Generally, most of the respondent farmers use recommended insecticides for the control of ants and the mealybugs on their fields (Table 2). This could be because most farmers see pineapple farming as a business and a means of livelihood. Again, most of the farmers are large scale growers and need to protect their investments. Despite the use of recommended pesticides by the farmers interviewed, the disease incidence was quite high in the study area. This could be due to the reason that the overreliance on pesticides as the means of controlling the vector is resulting in the development of resistance to these pesticides.

Mamoon, Bushra, & Tarig (2014) and Jallow, Awadh, Albaho, Devi, & Thomas (2017) had reported that the use of recommended pesticides applied properly is effective in controlling and managing the ants and mealybug population in pineapple production.

The study further revealed that the farmers do not harvest suckers from infected mother plants and do not harvest from within 1 m^2 of an infected plant.

These farmers' management practices are indicative of their preventive measures against MWP development in their farms. These findings are thus in line with the recommendations of Pesticide Initiative Programme (2004; 2008a) who reported that since mother plots are sources of planting materials, they should be kept weed-free, fertilized, and protected from diseases and pests to ensure the production of healthy suckers. It has also been recommended by Joy & Sindhu (2012) that if the incidence of MWP on a field is less than 3% farmers should avoid using plants growing within a one-metre radius as a source of planting material; and if incidence is more than 10%, the entire field should be destroyed, and planting materials should not be collected from it.

3.4.3 Farmers' knowledge of MWP

The study showed that the level of knowledge of MWP among farmers is high. They could differentiate between the symptoms of MWP and other wilting conditions. This result was not surprising since most of the respondents had some level of education and had vast experience in pineapple cultivation and had probably encountered the disease more often on their fields and were familiar with all the stages of the symptoms as described by (Broadley, Wasserman, & Sinclair (1993); Pesticide Initiative Programme (2004) and Queensland Department of Primary Industries (2005).

The MD2 variety was perceived to be more resistant to the MWP compared to the other varieties (Queen Victoria, Smooth Cayenne, and Sugarloaf) which were more susceptible to the MWP. This finding is in line with the reports by Jahn et al. (2003) which indicated that Smooth Cayenne and Queen Victoria varieties are susceptible to the MWP but resistant to the Phythophtora rot disease whereas the MD2 is resistant to MWP but rather susceptible to the Phythophtora rot disease.

The farmers who grew the Sugarloaf, Queen Victoria and the Smooth Cayenne all perceive to register what appeared to be very high yield losses in terms of percentages of their plants to the disease is in line with assertions of Jahn et al. (2003) that the three varieties of pineapples –the Sugarloaf, Queen Victoria and the Smooth Cayenne are more susceptible to the disease and so the high losses farmers were reporting was therefore not surprising.

3.4.4 Effect of MWP on farmers' income

The study revealed that the MWP disease has a huge negative effect on the farmers' income; consistent with the findings of Dey, Borth, Melzer, Wang, and Hu (2015). Farmers were losing money due to the devastating effect of the disease. It was also evident that the Smooth Cayenne variety suffered the most in terms of loss of income to the farmer. These findings support the reports of Rohrbach et al. (1988) and Wakman et al. (1995) which stated that MWP is a major constraint on the global production of pineapple. Pineapple is an important non-traditional export crop in Ghana and hence the source of foreign exchange (Ministry of Food and Agriculture, 2013). MWP, therefore, can affect the foreign earnings of the country.

3.5 Conclusions

i. Results of the study indicate that all the respondents had adequate knowledge of MWP. They were able to identify the major symptoms of MWP and could distinguish between MWP and other wilting conditions such as water stress and agrochemical burns.

ii. According to the study, the incidence and severity of MWP were high during the pre-flowering stage of the growth of pineapple than the post-flowering stage.

iii. Again, the study showed that MD2 was resistant to MWP while Smooth Cayenne was the most susceptible variety.

iv. The findings further showed that the respondents employed varying strategies to manage the disease. Some of the management strategies included the keeping of fallow plots to break the life cycle of the disease-causing pathogens, treating mother plots and soil with insecticides especially plots with the history of MWP incidence, as well as avoiding infected mother plots for planting materials, flagging of affected plots and destruction of affected plants.

3.6 Recommendations

i. The MoFA through the agricultural extension agents should extend services to pineapple farmers on good agronomic practices involved in pineapple cultivation.

ii. Farmers should be educated on factors that affect the epidemiology of MWP in pineapple farms and effective disease management strategies.

CHAPTER FOUR

4 INCIDENCE, SEVERITY AND SPATIAL DISTRIBUTION OF MEALYBUG WILT DISEASE OF PINEAPPLE IN THE CENTRAL AND EASTERN REGIONS OF GHANA

4.1 Introduction

MWP, which is caused by PMWaV in pineapple and is transmitted by mealybug, is the most dangerous pineapple disease in Ghana and the world. In Africa, the Incidence of MWP has been reported in Ghana (Pesticide Initiative Programme, 2004; CABI, 2018), Benin, Ivory Coast, Niger, Nigeria, South Africa, Togo, Uganda. The disease has been documented in Australia, Hawaii, India, the Philippines, Thailand, and throughout the pineapple-growing regions of the world. (CABI, 2018) MWP is reported to cause yield losses estimated at 30% of the most prevalent virus species that is the PMWaV-2, up to a hundred per cent loss can arise from the virus attack in pineapples (Sether & Hu, 2002a).

Management of MWP is very pertinent to improving the production of pineapple in Ghana. Information on the occurrence and extent of damage of MWP is very significant in developing an effective management strategy. For instance, it has been reported by the (Queensland Department of Primary Industries, 2005) that when the incidence of MWP is less than 3%, planting material should be selected from outside a $1m^2$ radius of the infected mother plant. It has also been reported that when the incidence of MWP on a field is greater than 10%, planting materials should not be collected from that field (Queensland Department of Primary Industries, 2005).

The objective of this study was to determine the prevalence, magnitude, and geographic distribution of MWP in the Central and Eastern regions of Ghana.

4.2 Materials and Methods

4.2.1 Study area

The disease assessment was conducted in four districts of the Central region and three districts of the Eastern region, leading pineapple growing areas in Ghana. The districts were chosen based on many factors such as the availability of farmers growing more than one variety of the pineapple, the availability of both large- and small-scale farmers. In the Central region, the districts were as in Figure 1 and for the Eastern region too as in Figure 2.

To determine the incidence and severity and spatial distribution of the MWP of farms in the Eastern and Central regions of Ghana. Incidence and severity scoring, and spatial distribution was done for two seasons, 2014/2015 and 2015/2016. Twenty farms/plots with of minimum size of 0.20 hectares were selected for the incidence and severity scoring respectively for 2014/2015 and 2015/2016 in the two regions.

Twenty plots with of minimum size 0.20 hectare and with a minimum of potential thirty diseased plants (for a true presentation of the distribution pattern, ArcGIS uses a minimum of thirty waypoints for calculating the Moran's I) were selected for the spatial distribution determination respectively for 2014/2015 and 2015/2016 in the two regions. In both instances, pineapple suckers that had been induced to flower and those yet to be induced were all assessed.

4.2.1.1 *Gomoa-East District*

The Gomoa-East District (Figure 1, B) is situated between latitudes 5° 31' 0.0006" North and longitude 0° 45' 0" West. The district is in the Southeastern part of the Central region (The Central Regional Coordinating Council, 2015).

The district has two main rainfall seasons: The major rainy season is from March/April–June/July while the minor season is from September- November. The main dry season is from November to March and a minor one from mid-July to mid-August. The average annual rainfall in the southern coastal belt is between 700 and 900 mm, while it is between 900 and 1100 mm in the north-western semi-deciduous forested areas.

The mean annual maximum and minimum temperatures of the district ranges between 28 °C and 24.3 °C which occurs in March and August respectively. The presence of large water bodies like rivers, oceans lagoons and streams influence the high levels of relative humidity of the district. For the northern and southern sectors, the relative humidity of 80% respectively. Gomoa East has the benefit of experiencing two wind systems; the south-western monsoon winds, whose direction influence the rainfall pattern and the north-eastern trade winds which herald the dry harmattan season. The effects of the harmattan winds are severely felt between January and February. The district lies within the coastal savannah ecoregions (Figure 8) (The Central Regional Coordinating Council, 2015).

4.2.1.2 *Gomoa-West District*

The Gomoa-West District (Figure 1, C) is situated between latitudes 5° 14' 12.9984" North and longitude 0° 22' 0.0012" West. The district is in the Eastern part of the Central (The Central Regional Coordinating Council, 2015). The district has two main rainfall seasons: the major season, which runs from April to July, and the minor season, which runs from September to November. From December to March, it also has a dry season with several variations. The average annual rainfall in the southern coastal belt is between 700 and 900 mm, while it is between 900 and 1100 mm in the Northern Northwestern semi-deciduous forested areas.

The mean annual maximum and minimum temperatures of the district ranges between 29 °C and 26 °C which occurs in February to March and August respectively. The presence of large water bodies like rivers, oceans lagoons and streams influence the high levels of relative humidity of the district. For the northern and southern sectors, the relative humidity ranges from 70% and 80% respectively. The district lies within the coastal savannah ecoregions (Figure 8) (The Central Regional Coordinating Council, 2015).

4.2.1.3 *Ekumfi District*

The Ekumfi District (Figure 1, D) is positioned in the Central region of Ghana, it lies between latitude 5° 19' 7.68" North and 0° 53' 32.9994" West on the Atlantic Coastline. The Ekumfi District is a lowland area with loose quaternary sandy soil type. The nearness of the Ekumfi District to the Atlantic Ocean explains why its mild temperatures range between 22 °C and 34 °C and with a relative humidity of about 70%. Two maximum rainfalls peak from May to June and in October. The annual average rainfall ranges between 900 and 1600 mm.

The months of December to February, as well as July to early September, are significantly drier than the rest of the year. The lower slope of the soil is Sandy Loam while the upper slope is Clay Loam. The district lies within the coastal savannah ecoregions (Figure 8) (The Central Regional Coordinating Council, 2015).

4.2.1.4 *Awutu-Senya-West District*

The Awutu-Senya-West District (Figure 1, A) lies between latitude 5° 32' 59.9994" North and longitude 0° 31' 0.0006" West. It is characterized by isolated undulating highlands. maximum and minimum temperatures are 22 °C and 38 °C respectively. The rainy and dry seasons are the two main seasons in the district. The rainy season is typically from April to July while August to November of every year is the minor season. From November of the previous year to March of the ensuing year represent the dry season of Awutu-Senya-West District. Rainfall figures of 400 mm-500 mm which quite low is recorded for the areas along the coast but are higher rainfall figures of 500 mm-700 mm could be recorded in the hinterlands (Ministry of Local Government and Rural Development of Ghana and Maks Publications and Media Services, 2006).

4.2.1.5 *Akuapem-South Municipal*

Akuapem-South Municipality (Figure 2, B) lies between latitude 5° 51' 3.1644" and longitude -0° 10' 22.728" West and is positioned in the moist deciduous ecological zone of Ghana. The district has a bimodal rainfall pattern, with annual rainfall ranging from 1270 mm to 1700 mm (Nabila and Kofie, 2001, Frenken, 2005) with the average day-to-day temperature reaching from 24.8 °C to 27.5 °C. During the nights and mornings, relative humidity of over 80% could be recorded but then decreases in the afternoons.

4.2.1.6 *Akuapem-North Municipal*

Akuapem-North (Figure 2, A) lies between latitude 5° 56' 27.24" North and longitude 0° 11' 13.2" West and is located in the moist deciduous ecological zone of Ghana (Figure 8), a bimodal rainfall pattern characterises the rainfall of the District. The main rainfall occurs between the months of May and August every year while in October there is minor rainfall. Average annual rainfalls are about 1,270 mm and the mean temperatures range between 24 °C and 29 °C and night temperature between 13 °C and 24 °C (Ministry of Local Government and Rural Development of Ghana and Maks Publications and Media Services, 2006).

4.2.1.7 *Upper-West-Akyem Municipal*

Upper West-Akyem municipality (Figure 2, C) lies between latitude 5° 48' 24.4074" North and latitude 0° 32' 24.2046" West and is situated in the moist deciduous ecological zone of Ghana. A bimodal rainfall pattern characterizes the rainfall of the district with yearly figures of 1270 mm to 1700 mm and an average of 1500 mm being recorded (Frenken, 2005). The yearly average temperature stands at about 26.6 °C (Nabila & Kofie, 2001) with the average day-to-day temperature ranging from 24.8 °C to 27.5 °C. The area has generally high relative humidity of over 80% all through nightfall and the early morning. There is a decrease in the relative humidity during afternoons.

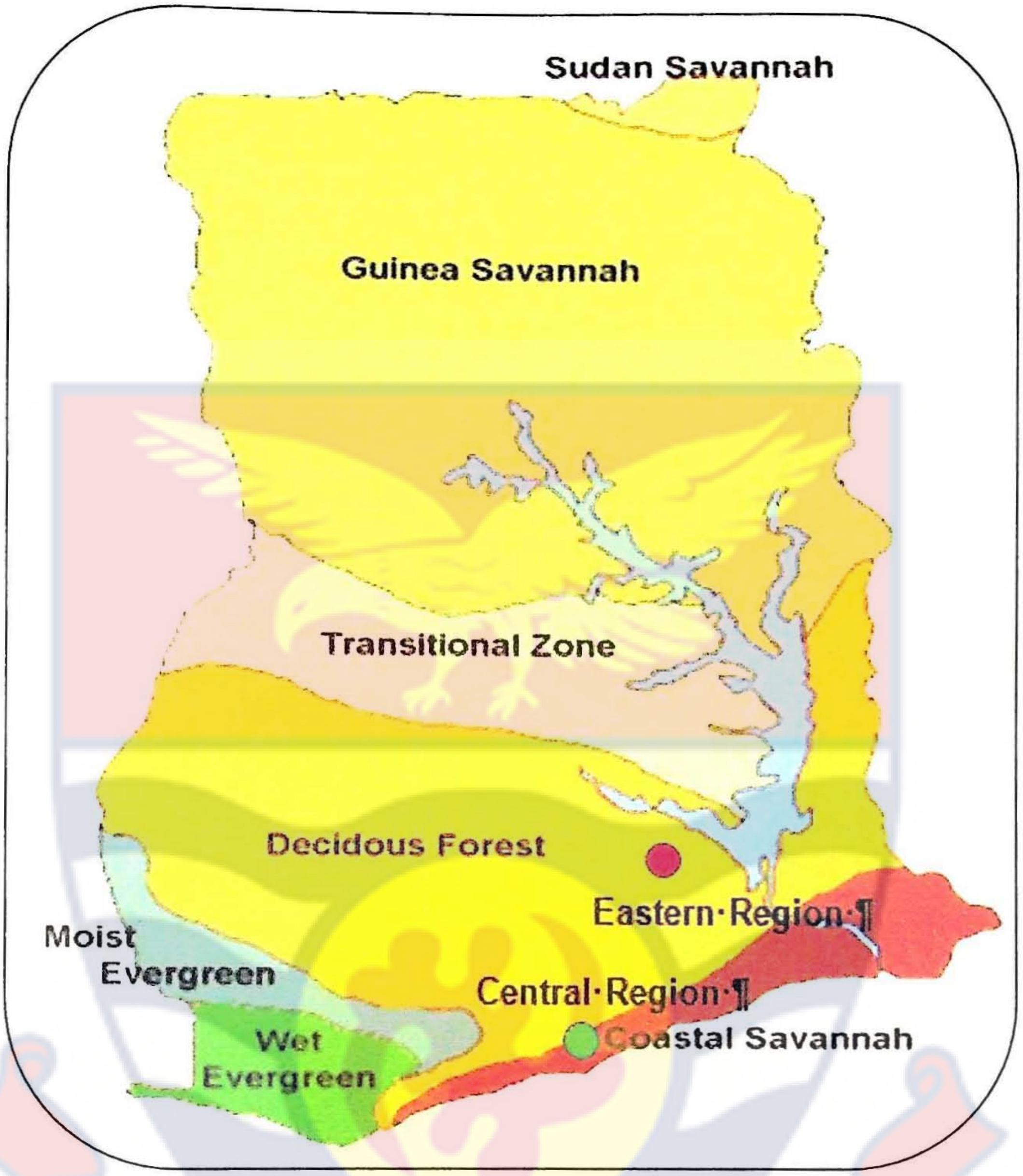

Figure 8: Regional map of Ghana showing the seven ecoregions of Ghana: The Eastern region and the Central region of Ghana. Source: (Antwi, Boakye-Danquah, Asabre, Yiran, Loh, Gyekye, & Owusu, 2014)

4.2.2 Incidence and Severity Assessment

Eight fields each with an average size of about 0.2 hectares were selected at random from farms across the districts of the two regions. Each of the fields was visually divided diagonally into two halves and a total of four hundred plants per plot were randomly selected along the diagonal for incidence and severity assessment of the MWP. Incidence was determined by recording the presence or absence of the disease on the plants and calculated using the formula:

Equation 1: Percentage incidence of MWP calculation

Incidence (%) of MWP = $\frac{\text{Number of diseased plants}}{\text{Total number of plants observed}} \times 100$ (Manandhar et al., 2016).

Mean severity was measured (scored) by using the following adapted key (Broadley et al., 1993 and Pesticide Initiative Programme, 2005).

Score	Interpretation
1	There is a minor reddening of the leaves that runs about midway up the plant. This normally starts in small patches of plants -The Isolated wilt stage
2	Starting at the leaf tips, the leaf colour changes abruptly from red to pink, and the leaf margins turn yellow and roll under
3	The affected leaf become limp and droop and there is a leaf tip die-back
4	Much of the length of the affected leaf dries up
5	Total dryness of the entire leaf affected

Mean severity for each farm determined by using the formula:

Equation 2: Mean severity of MWP calculation

Mean Severity of MWP = $\frac{\text{Total score for all plants}}{\text{Total number of plants}}$ (Manandhar et al., 2016).

Box plots charts were used to represent the incidence and severity data. The box plots visually showed the distribution of numerical data and skewness.

From the box plots the skewness of the data, whether positive or right-skewed, normal or symmetric distribution and negative or left-skewed. For a negative skew box, the whisker is longer on the top part of the box plot while the positive skew box plot has a longer whisker to the lower part of the box plot. Again, positively skewed box plots show a box with the median closer to the lower or bottom quartile or equal to the Q1 value. The maximum and minimum values are also determined from the box plots.

The median is the midpoint value which is the point where half of the observations are above the value and half the observations are below the value. The quartiles are made up of the three values namely: the first quartile (Q1) which is at 25% the second quartile (Q2) which is at 50% also the median (Q2 or median). and the third quartile (Q3) which at 75% that divide a sample of ordered data into four equal parts (Minitab Ltd., 2021).

4.2.3 Determination of the spatial distribution of MWP on pineapple fields

To determine the autocorrelation of the MWP among the pineapple plants on the various selected plots. Ten plots each were selected; the minimum field size was about 0.20 hectares were selected in the districts of the Central and Eastern regions respectively. Sampled pineapple plants were those that showed visible symptoms of infection with MWP. A minimum of thirty waypoints needed to be collected per field to make the results reliable (Environmental Systems Research Institute (ERSI), 2013).

Mapping was undertaken with the help of a hand-held Garmin Etrex 30 Global Positioning System (GPS) receiver. Individual diseased plants were each picked and recorded as a series of waypoints (longitudes and latitudes) across the entire fields surveyed. The survey was carried out over two growing seasons of the pineapples: 2014/2015 representing year one and 2015/2016 representing year two. For each of the years, the survey was divided into two phases, that is the pre flower induction and the post flower induction stages of growth of the pineapples. The series of waypoints were downloaded from the GPS receiver and processed in ArcGIS 10.1 software.

Processing was of transforming the data format from Generalized Plane Xanthoma (GPX) data file to Environmental Systems Research Institute (ESRI) shapefile through the data interoperability tool in ArcGIS 10.1. Also, the coordinate system of the downloaded data was changed from a World Geodetic to the Ghana Metre Grid projected coordinate system. These were undertaken to ensure easy data integration in ArcGIS, measurement purposes and data analysis. The mapped data had attributes such as the incidence, severity, mealybug, and ant population which were used as the field for spatial autocorrelation. Spatial autocorrelation analysis was run with the ArcGIS software, using:

Equation 3:The Moran's I function:

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \overline{x})(x_j - \overline{x})}{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \right) \sum_{i=1}^{n} (x_i - \overline{x})^2}$$

Where:

N is the number of observations (points)

$\overline{X}$ is mean of the variable

Xi is a variable value at a particular location

Xj is a variable value at another location and

Wij is the weight indexing location of i relative to j (Environmental Systems Research Institute (ESRI), 2013).

The Moran's I index predicted or expected index, variance, z-score, and p-value are the five values recorded by the Spatial Autocorrelation tools. The assumption underlying Moran's I is that there is a relationship between occurrences of events and the space within which they occur.

The p-value is an outcome when the pattern analysis tool runs a probability that determines whether the spatial pattern that is observed was created by some random process, dispersed, or clustered pattern. The p-value must be very small to dismiss the null hypothesis, which means that the spatial pattern observed is very unlikely to be the outcome of random processes. The standard deviations are represented by the z-scores. The distance threshold stipulates a cut-off distance for reverse distance and fixed distance options (Environmental Systems Research Institute, 2013)

4.3 Results

4.3.1 Percentage incidence of MWP across the districts across the Central and Eastern regions of Ghana

The percentage incidence of MWP ranged from 0 and 12 across the seven districts of the two regions (Figure 9). The data for Akuapem-North, Ekumfi, and Gomoa-East all in the Central region were all positively skewed, while Akuapem-South and Upper-West-Akyem in the Eastern region were negatively skewed, data for Awutu-Senya-West and Gomoa-West in the Central region showed no skewness in the distribution of the data. There was high variability in the incidence of the MWP in the Akuapem-South and Upper-West-Akyem both in the Eastern region. The highest incidence of 12% was recorded in the Akuapem-South District of the Eastern region of Ghana (Figure 9).

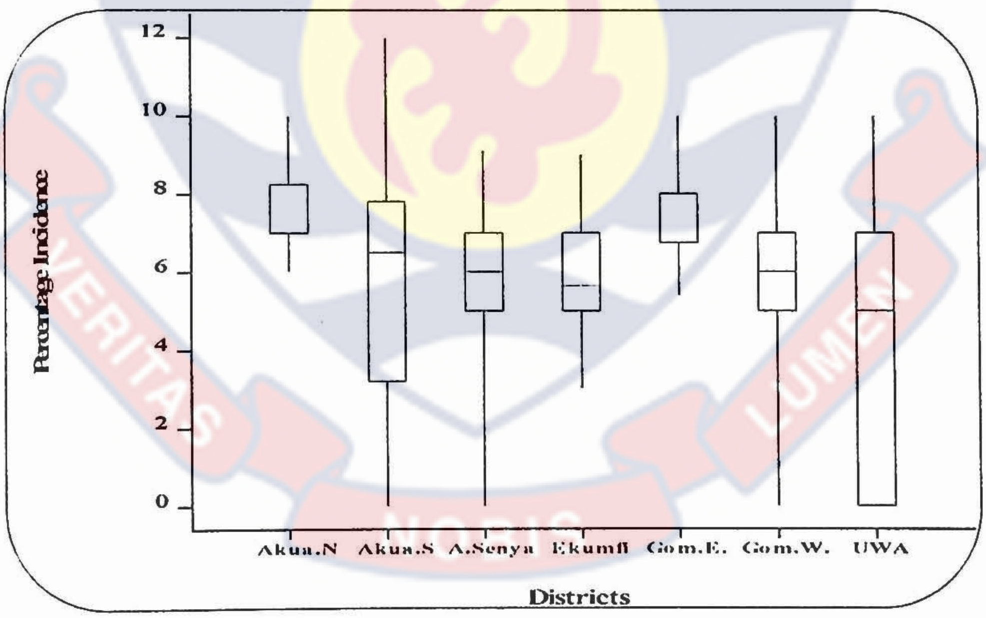

Figure 9: Percentage incidence of MWP in the districts in the Central and Eastern regions of Ghana: Akua.N. =Akuapem-North, Akua.S=Akuapem-South, Gom.E=Gomoa-East, Gom.W=Gomoa-West, UWA=Upper-West-Akyem

4.3.2 Incidence of MWP at the growth stages of pineapple

Percentage incidence of the MWP before flower induction had a range of 0 and 12% with a median around 6% and at least 75% of the incidence falling between 5% and 12% while 25% fell between 0 to 5%. The distribution of the incidence of MWP data was positively skewed before flower induction and was symmetric during the period after flower induction (Figure 10).

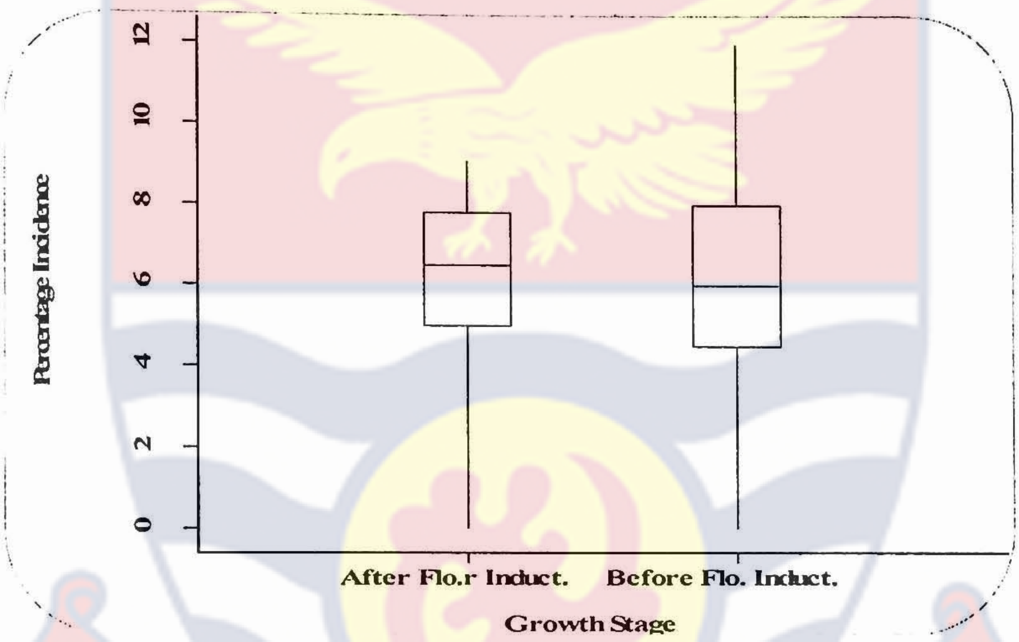

Figure 10: Percentage incidence of MWP at the two growth stages of pineapple: After Flor. Induct=After Flower Induction, Before Flo. Induct. =Before Flower Induction

4.3.3 Percentage incidence of MWP in the seasons

The maximum percentage incidence value of 12 was recorded for the month of December. Higher variations in the data distribution existed in the months: March, November, and December. The months of April, May and September had a skewness equal to zero indicating the distribution is symmetrical around the mean. There was positive skewness in the distribution of the incidence data for the months of July and August while the months of

March, November and December had incidence distribution negative skewed (Figure 11).

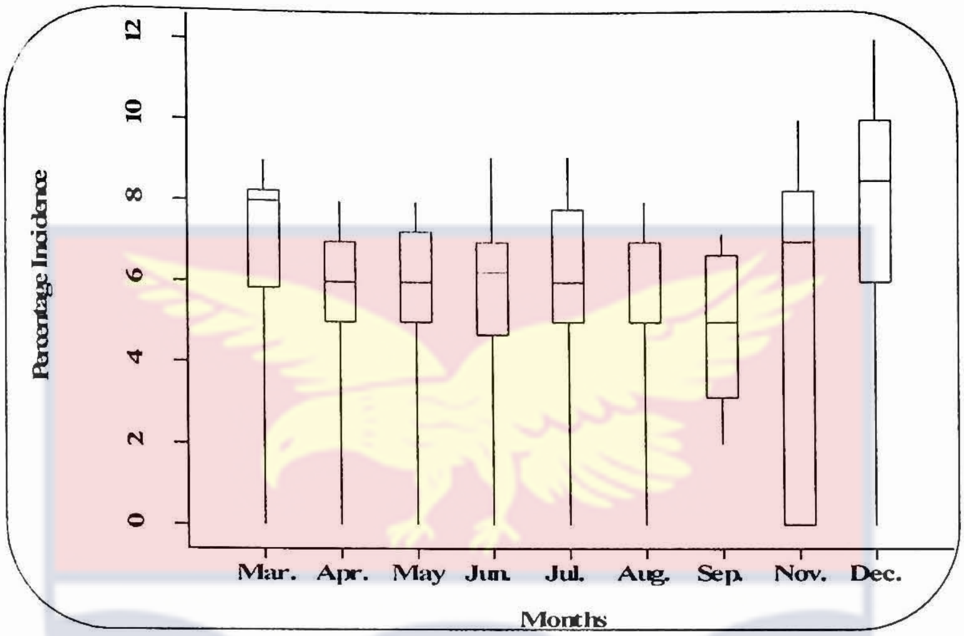

Figure 11: Percentage incidence of MWP in the seasons

4.3.4 Percentage incidence of MWP in the Regions

Figure 12 presents the box plot for the Percentage incidence of MWP in the Central and Eastern regions of Ghana.

It is seen that the range for the percentage of the disease over the two regions was 0-12% for the Eastern region compared to the Central region with a disease incidence of 10%. The relative mean of the percentage score for the Eastern region varies much more than the percentage incidence for the Central region.

The medians for both regions were close to 6% meaning for about 50% of the period of the scoring both had a percentage incidence of over 6%. There was high variability in the data for both regions.

Incidence distribution was positively skewed for the Central region while for the Eastern region there was negative skewness (Figure 12).

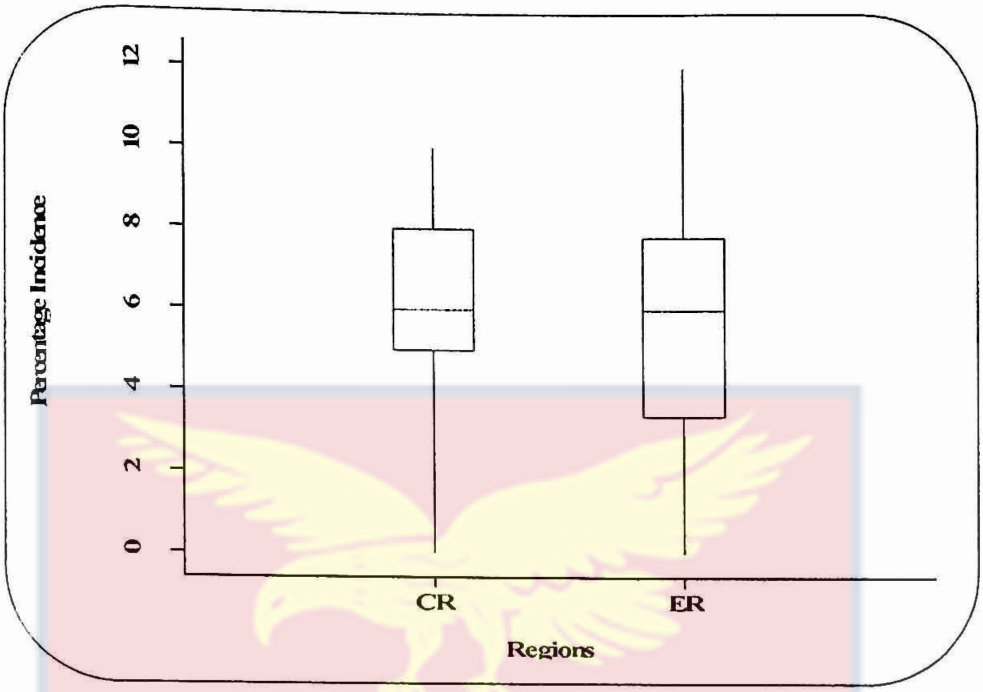

Figure 12: Percentage incidence of MWP in the regions: CR=Central region, ER=Eastern region

4.3.5 Percentage incidence of MWP of the varieties

The percentage incidence of MWP on pineapple varieties: MD2, Queen Victoria, Smooth Cayenne and Sugarloaf is presented in the boxplot chart in (Figure 13). it is seen that there was no incidence of wilt disease on MD2. The incidence for the three other varieties -Queen Victoria, Smooth Cayenne and Sugarloaf were 8.5, 12 and 10%, respectively. The distribution of the incidence of the MPW on the varieties showed a positive skewness in Queen Victoria while that of Smooth Cayenne was negatively skewed. Meanwhile, there was no relationship among the disease incidence in the MD2 and Smooth Cayenne showed no skewness in the incidence data.

There was high variability in the percentage incidence score for Sugarloaf, but low variability for Smooth Cayenne respectively (Figure 13).

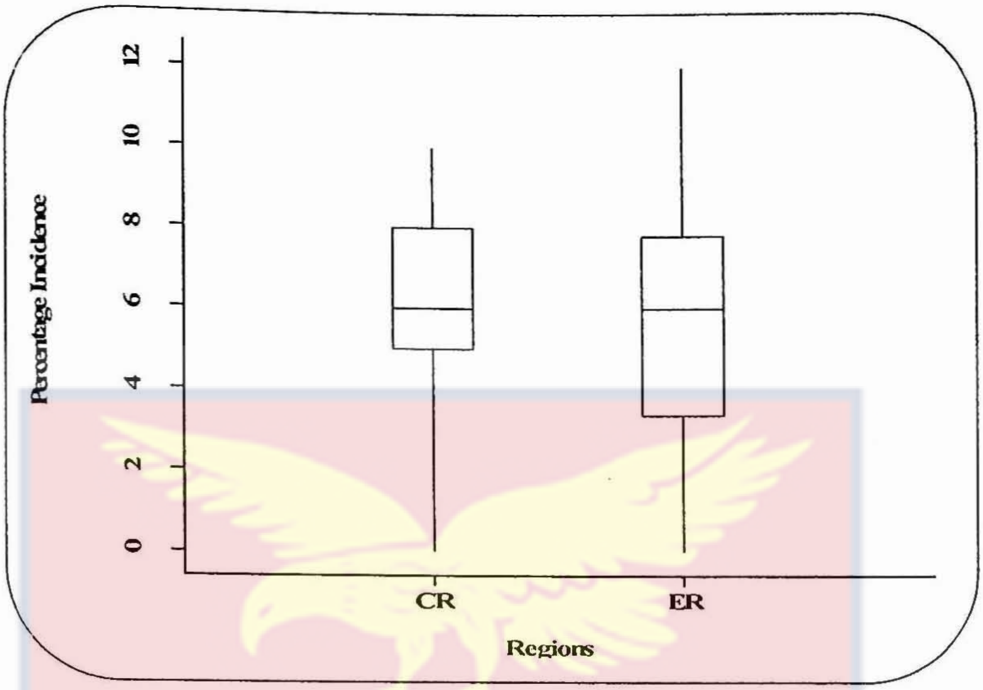

Figure 13: Percentage incidence of MWP on pineapple varieties: Queen Vic= Queen Victoria, Smooth Cay. = Smooth Cayenne

4.3.6 Mean severity of MWP in the districts

The highest mean score of severity of the MWP of 4 was recorded in the Awutu-Senya-West District of the Central region as can be seen in Figure 14. Apart from Gomoa-West in the Central region and Upper-West-Akyem in the Eastern region of Ghana that had positive skewness in the distribution. Akuapem-North, Akuapem-South, in the Eastern region and Ekumfi and Gomoa-East in the Central region had a positive skewness in the distribution of the mean severity of the MWP.

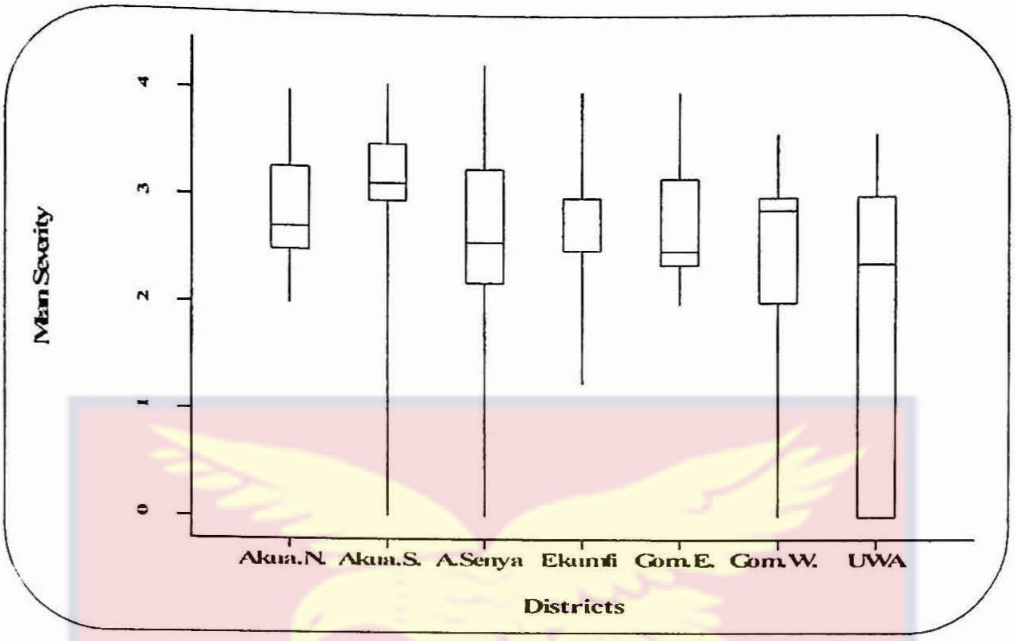

Figure 14: Mean severity of MWP at the districts across the Central and Eastern regions of Ghana: Akua.N.=Akuapem-North, Akua.S=Akuapem-South, Gom.E=Gomoa-East, Gom.W=Gomoa-West, UWA=Upper-West-Akyem

4.3.7 Mean severity of MWP at the growth stages

In Figure 15 the observed mean severity for the growth stages of the pineapple in the Central and Eastern regions of Ghana is presented, before flower induction, the mean severity, was 2.5 while that after flower induction was 3, the highest score of 4.3 was recorded after the flower induction while before flower induction was 4.

The mean severity data for both the before and after flower induction stages were normally distributed indicating a distribution is symmetrical around the mean.

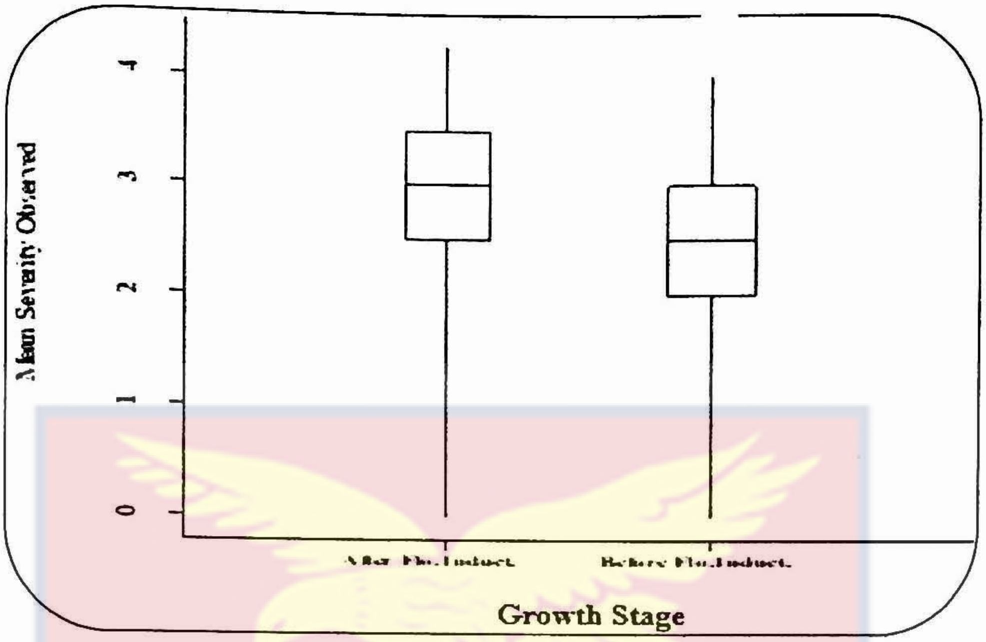

Figure 15: Mean severity observed at the growth stages across the Central and Eastern regions of Ghana: After Flo. Induct=After Flower Induction, Before Flo. Induct. =Before Flower Induction

4.3.8 Mean severity of MWP in the months

The mean severity of the MWP across the various months of scoring are presented in Figure 16. June had the highest mean severity score of 4.3 while November recorded the least score of 3.2. There was positive skewness in the distribution of the mean severity for the months of March, April, May, June, July, and September. There was symmetrically distribution in the months of August and December, while November was negatively skewed. The month of November was at the same time was the month with the highest variability in the data distribution.

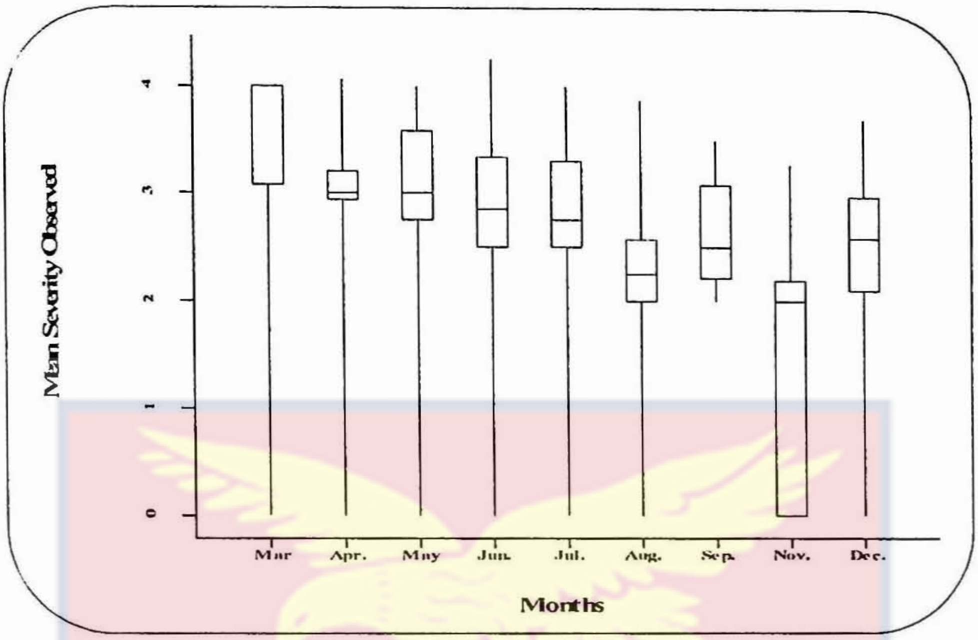

Figure 16: Mean severity observed at the months across the Central and Eastern regions of Ghana

4.3.9 Mean severity of MWP in the regions

The Central region had the highest maximum value score of 4.3 while the after-flower induction score was 4.1 (Figure 17). The distribution was negatively skewed in both regions which shows that the mean severity of the MWP was more closely below the median score than the scores above the median. There was greater variability in the mean severity scores for the Central region than that of the Eastern region where variability was low. At Q3 of the data, the mean severity for both regions was still below 3.5 (Figure 17).

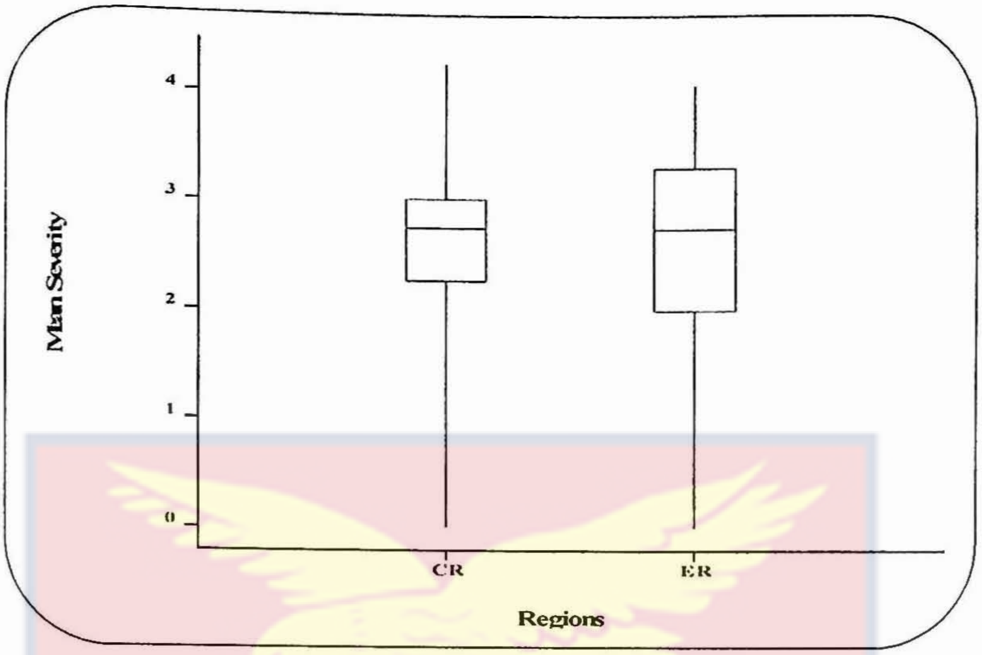

Figure 17: Mean severity of MPW in the Central and Eastern regions of Ghana: CR = Central region, ER = Eastern region

4.3.10 Mean severity of MWP on the varieties

There was a 0 mean severity score for the MD2 variety of pineapple and the score for Smooth Cayenne was the highest maximum score of 4.3 (Figure 18). Queen Victoria and Sugarloaf had the biggest IQR of 0.7 while apart from the MD2 scoring 0, the Smooth Cayenne scored 0.5. The shape of the distribution was symmetrical for Smooth Cayenne, Queen Victoria and Sugarloaf were all negatively skewed. There was high variability in the scores for Queen Victoria while Smooth Cayenne and Sugarloaf showed moderate variability (Figure 18).

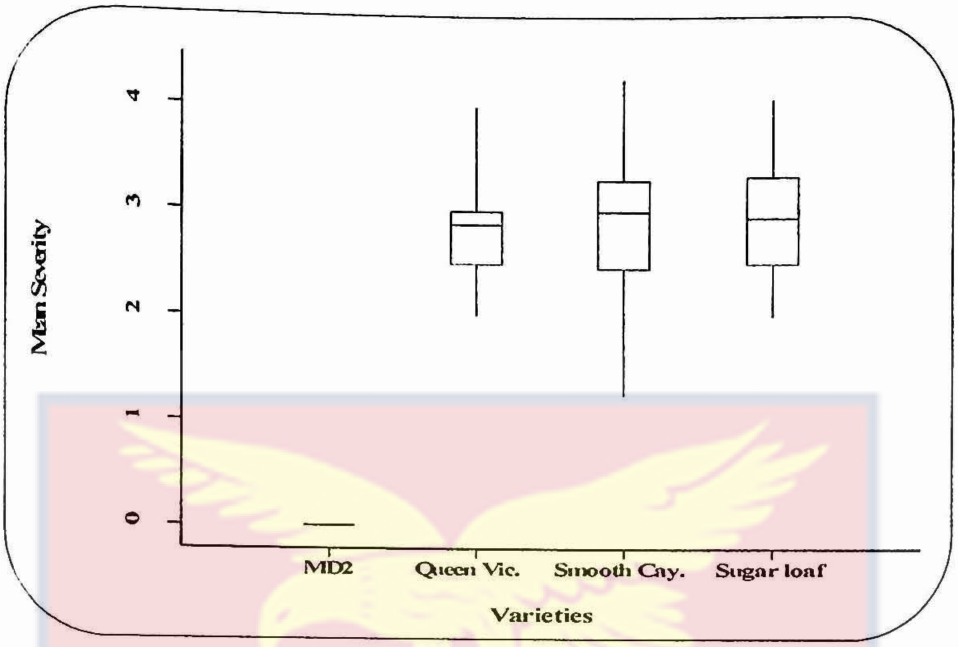

Figure 18: Mean severity observed on the varieties grown in the Central and Eastern regions of Ghana: Queen Vic= Queen Victoria, Smooth Cay. = Smooth Cayenne

4.3.11 Mean ant population in the districts

There was high variability in the mean ant population in all the districts across the two regions. All the population distribution of the ants were positively skewed for the distracts The IQR for Gomoa-East was the highest with a score of 7.5 while all the rest had an IQR score of 5 even though Upper-West-Akyem had the highest mean population 30. The highest median score for the population was 10 which was recorded in Akuapem-North, Ekumfi and Gomoa-East and the least median score of 5 was recorded Akuapem-South, Awutu-Senya-West, Gomoa-West and Upper-West-Akyem (Figure 19).

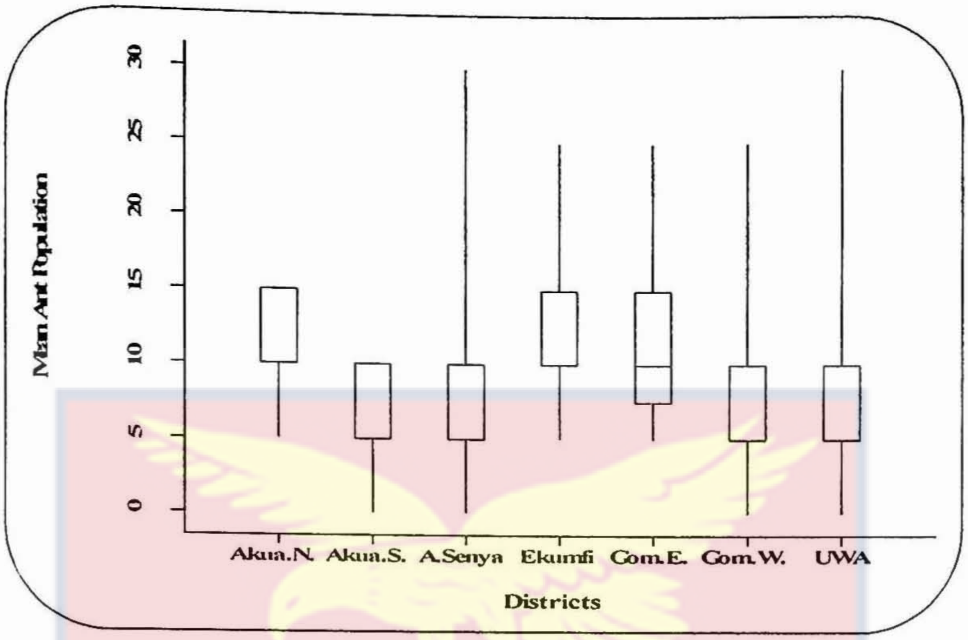

Figure 19: Mean ant population at the districts in the Central and Eastern regions of Ghana: Akua.N. =Akuapem-North, Akua.S=Akuapem-South, Gom.E=Gomoa-East, Gom.W=Gomoa-West, UWA=Upper-West-Akyem

4.3.12 Mean ant population at the growth stages

The mean ant population on the plants before the flower induction growth stage and after the flower induction growth stage showed that both populations were positively skewed and with high variability in the data for both growth stages. The IQR for both growth stages were 5. The highest mean population between the two growth stages was 30 for the post flower induction growth stage (Figure 20).

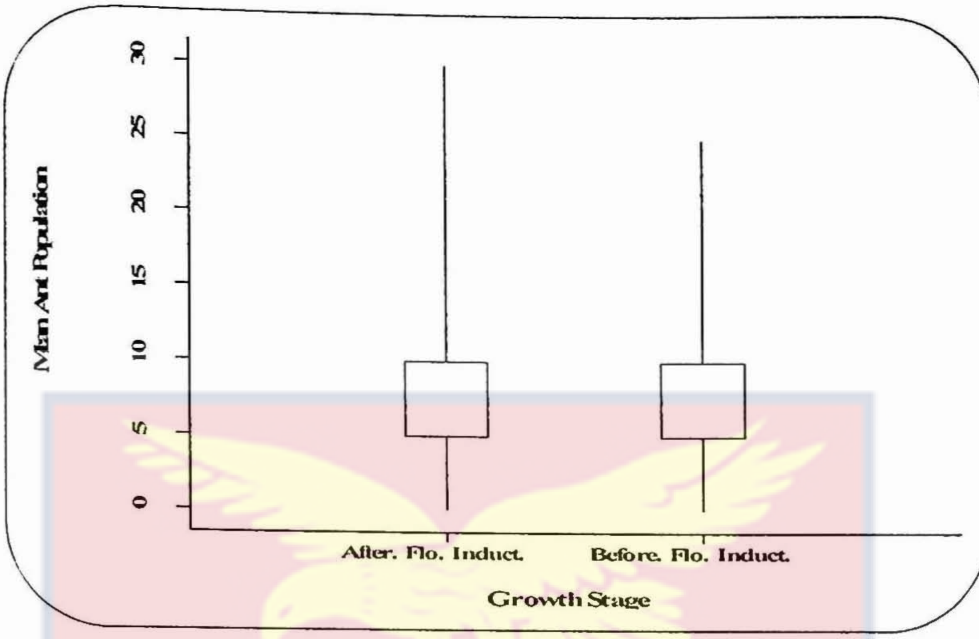

Figure 20: Mean ant population at the two growth stages in the Central and Eastern regions of Ghana: After Flo. Induct=After Flower Induction, Before Flo. Induct. =Before Flower Induction

4.3.13 Mean ant population at the different months

The maximum mean population of ants which is 30 was recorded in March and July while August and September was the month with the least mean population recording of 10. May was the month with the highest IQR of 10 whereas the least mean ant population of 5 was recorded in all the other months observed (Figure 21).

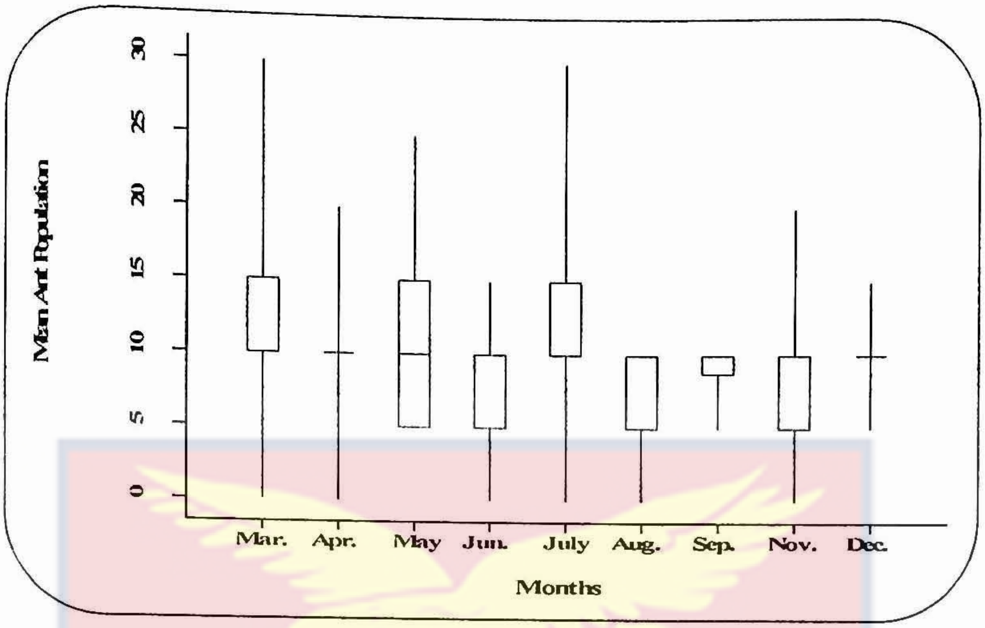

Figure 21: Mean ant population at different months in the Central and Eastern regions of Ghana

4.3.14 Mean ant population at the regions

Mean ant population for the two regions showed that both had a higher score of 30, the distribution of the data for the Central region was negatively skewed while that of the Eastern region was positively skewed. There was, however, high variability in the data for both regions (Figure 22).

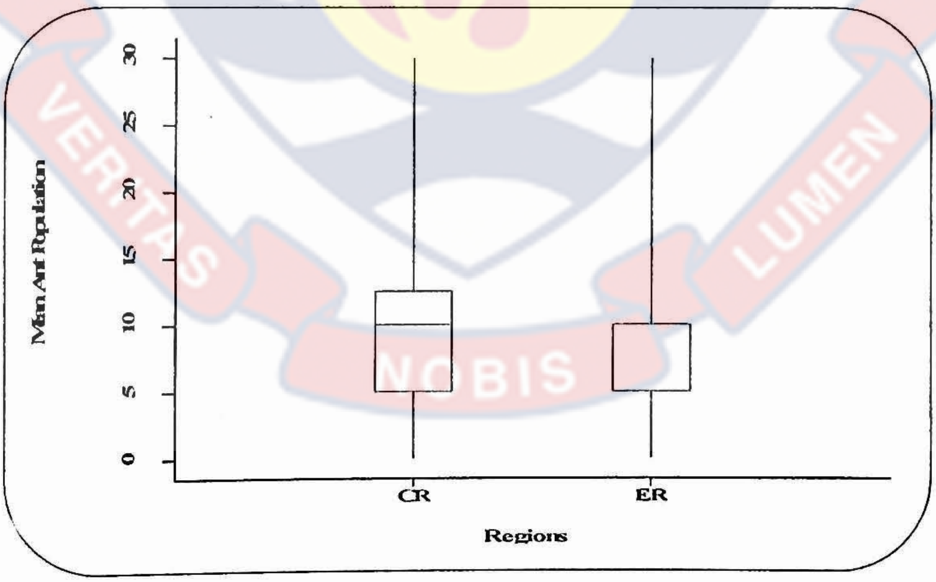

Figure 22: Mean ant population at the Central and Eastern regions

4.3.15 Mean ant population on the varieties

There were higher variations in all the data on mean ant population on all the varieties of pineapple. A Relatively high population of ants was recorded on both Smooth Cayenne and Sugarloaf varieties. The least mean population was recorded on the MD2 variety (10) (Figure 23).

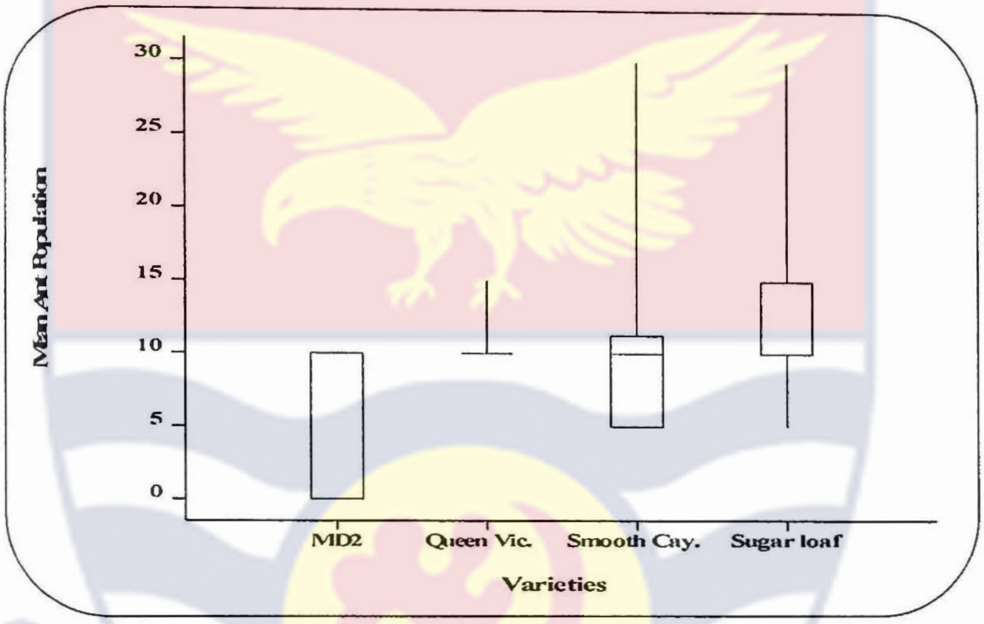

Figure 23: Mean ant population on pineapple varieties in the Central and Eastern regions of Ghana: Queen Vic= Queen Victoria, Smooth Cay. = Smooth Cayenne

4.3.16 Mean mealybug population at the districts

Figure 24 shows the mean mealybug population on pineapple plants in the various districts surveyed. It showed the highest population of 25 was recorded at Awutu-Senya-West, Ekumfi in the Central region, and Upper-West-Akyem in the Eastern region while Akuapem-North had the least population of 15. The distribution of data for all the districts showed high variability. Akuapem-North, Akuapem -South in the Eastern region, and Gomoa-East of the Central region were positively skewed in the distribution of the data while Awutu-Senya-West. The data distribution was symmetrical meaning there was evenness in the skewness for Awutu- Senya, Ekumfi, Gomoa-West in the Central region and Upper-West-Akyem in the Eastern region.

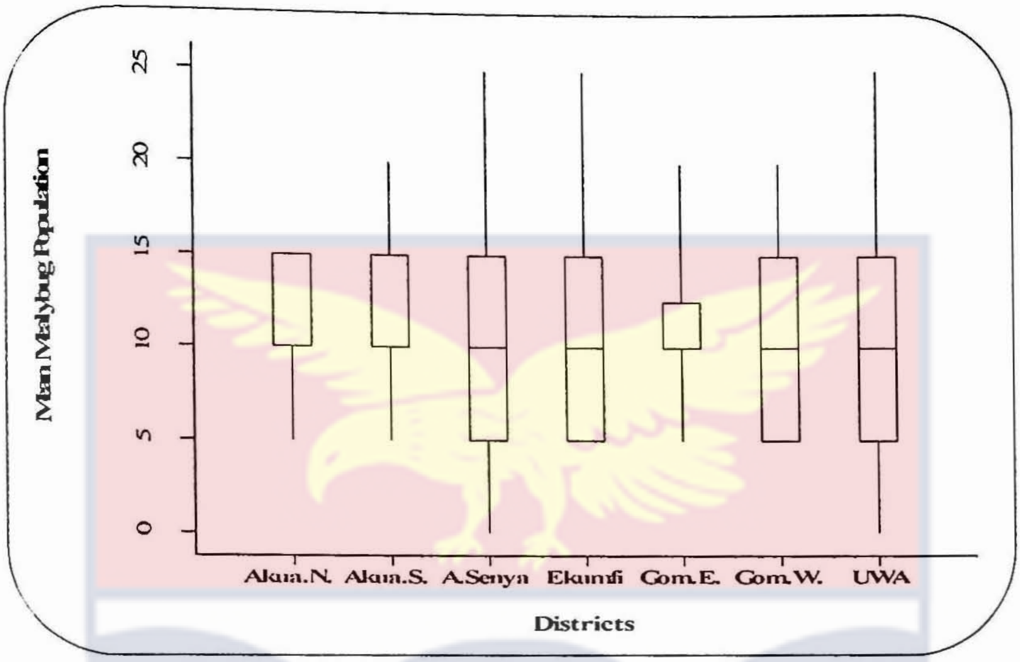

Figure 24: Mean mealybug population at the districts in the Central and Eastern regions of Ghana: Akua. N=Akuapem-North, Akua.S=Akuapem-South, Gom.E=Gomoa-East, Gom.W=Gomoa-West, UWA=Upper-West-Akyem

4.3.17 Mean mealybug population at the two growth stages

The mean mealybug population before flower induction and after flower induction is presented in Figure 25. Both recorded a maximum value of 25 and the skewness of data distribution for both growth stages was positive. There was high variability within the population of mealybug in both the before forcing and after forcing stages.

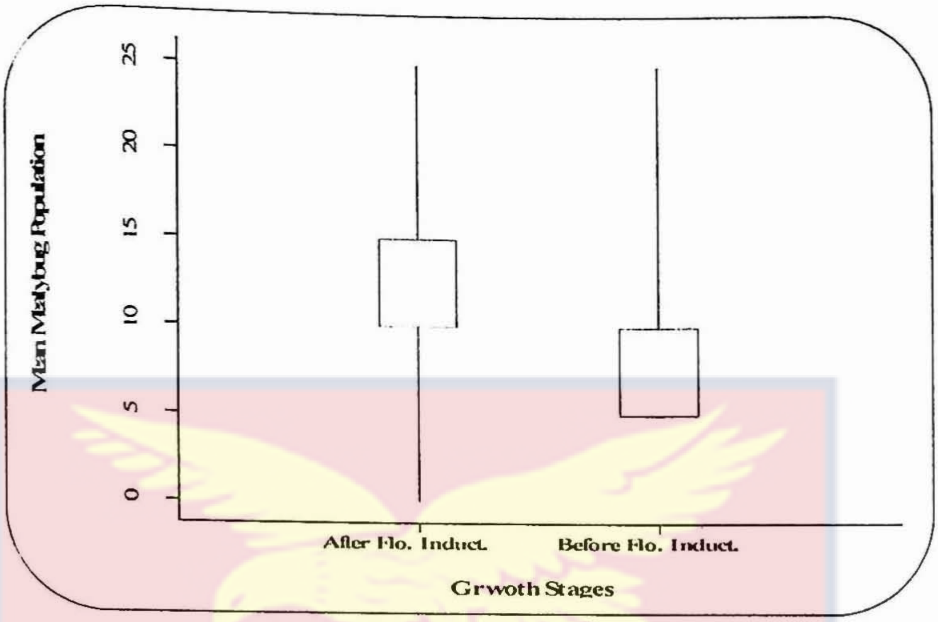

Figure 25: Mean mealybug population at the growth stages in the Central and Eastern regions of Ghana: After Flo. Induct=After Flower Induction, Before Flo. Induct. =Before Flower Induction

4.3.18 Mean mealybug population at the months

The highest mean mealybug population of 30 was recorded in April, May, and June while the least mean mealybug population of 10 was recorded in September. The month with the range mealybug population was April with a figure of 25. Most of the months recorded a Q3 figure of 15 which meant that 75% of the mean mealybug population in the months surveyed were around 15 per plant. March had the highest IQR of 11 and December had the lowest IQR of 0.

Most of the months recorded a median range of 10. March, April, July, August, September, and November had their mean mealybug population data positively skewed while May and December were symmetrical. There was low variability in the mean mealybug population for March, May, and June while high variability existed in the population for April, July, August, September, November, and December (Figure 26).

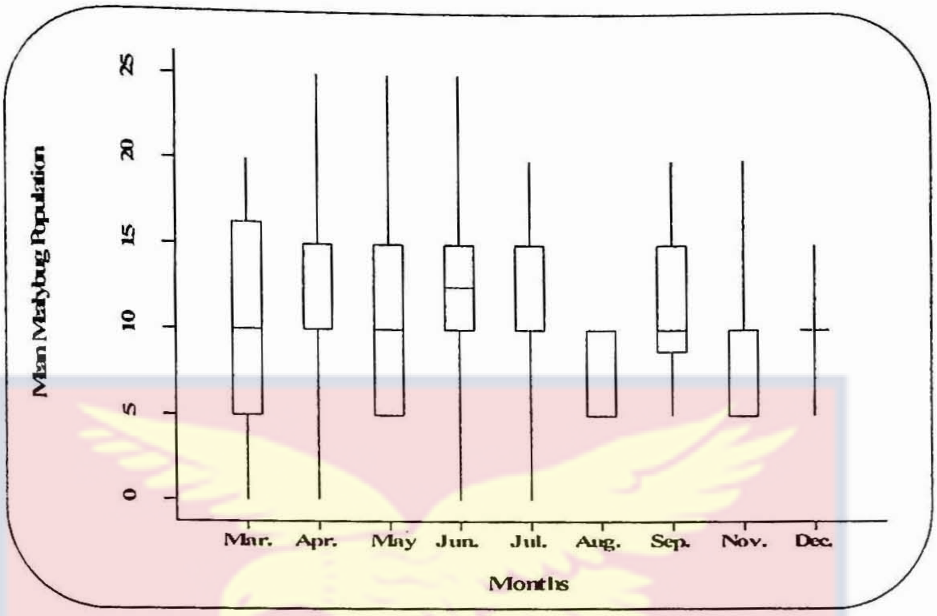

Figure 26: Mean mealybug population in the months in the Central and Eastern regions of Ghana

4.3.19 Mean mealybug population in the regions

Figure 27 presents the mean mealybug population in the Central and Eastern regions of Ghana. The mean mealybug population recorded for both regions peaked at 25. The minimum mean population recorded for both was 0 and the maximum mean mealybug population was 25 for both regions.

The population distribution was positively skewed in the Eastern region and for the Central region, it was symmetrical. There was moderate variability in the population of the Central region.

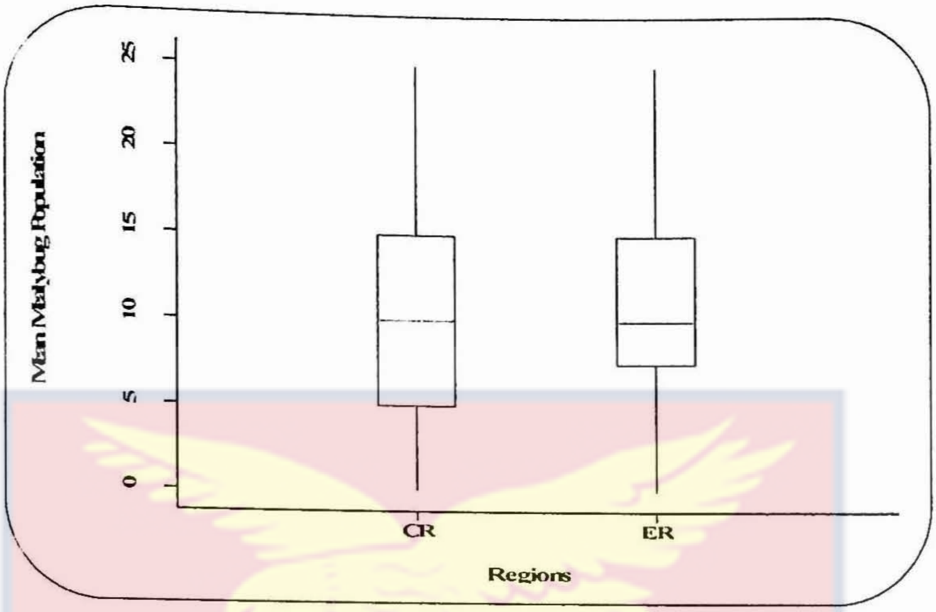

Figure 27: Mean mealybug population in the Central and Eastern regions of Ghana

4.3.20 Mean mealybug population on pineapple varieties

There was high variability in the mealybug population among all the varieties of pineapple surveyed. The shape of distribution was positively skewed in all the four varieties –MD2, Queen Victoria, Smooth Cayenne and Sugarloaf had a positively-skewed shape of the distribution. Queen Victoria and Sugarloaf varieties recorded the highest maximum value of 25 while the MD2 recorded 10 as the maximum population value (Figure 28).

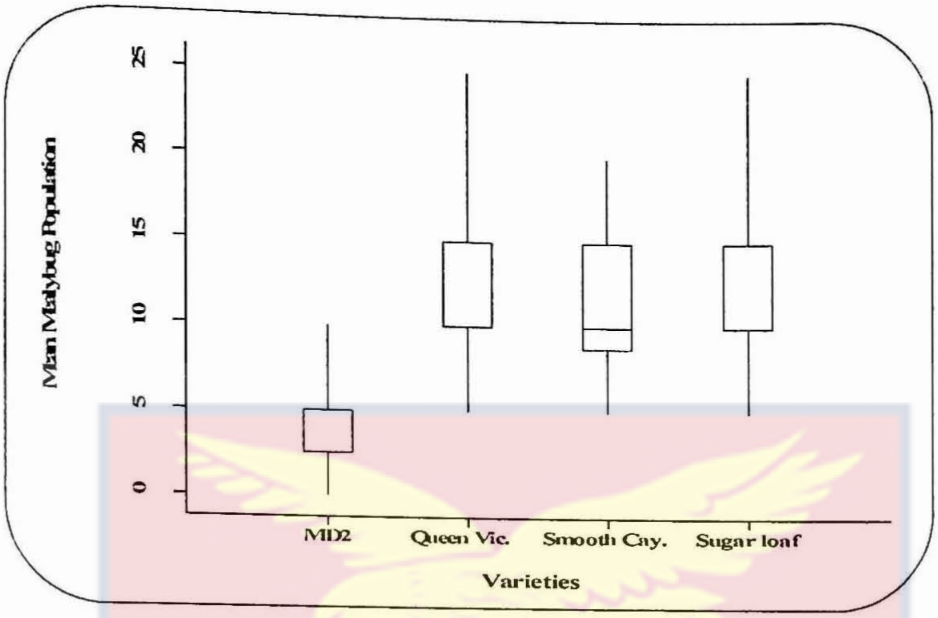

Figure 28: Mean mealybug population on the varieties in the Central and Eastern regions of Ghana: Queen Vic= Queen Victoria, Smooth Cay. = Smooth Cayenne

4.3.21 Spatial distribution reporting of MWP at the study locations

In the first year of before the flower induction stage of the pineapples survey incidence of the MWP was high (15-20%) in some of the farms surveyed in the Awutu-Senya-West District in the Central region, some farms surveyed in the Upper-West-Akyem in the Eastern regions of Ghana and Awutu-Senya-West, Gomoa-East and Ekumfi Districts all in the Central regions of Ghana recorded incidence with values (5.1-10%) while some farms in the Akuapem-South and Upper-West-Akyem in the Eastern regions of Ghana, as well as Awutu-Senya-West, Gomoa-East, and Ekumfi Districts in the Central regions of Ghana, reported incidence levels of (5.1-10%), while others in the Akuapem-South (Figure 29).

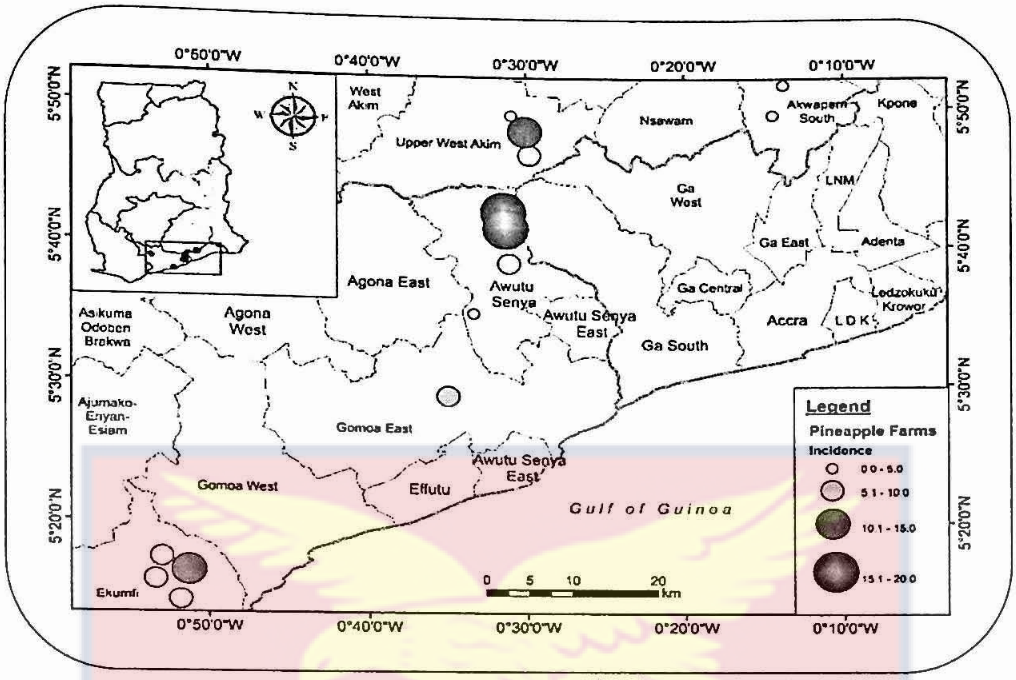

Figure 29: Percentage incidence of MWP before flower induction for the first year on farms across the districts of Central and Eastern regions of Ghana

Figure 30 shows the incidence map of the MWP at the post-flowering stage of the plants in the first year of the survey. Farms in the Akuapem-South and Upper-West-Akyem Districts in the Eastern region recorded incidence of below 5%. Farms in Akuapem-South, Upper-West-Akyem in the Eastern region and Awutu-Senya-West and Ekumfi Districts in the Central region recorded incidence ranging between 5-10% while farms in Gomoa-East, Ekumfi and Awutu-Senya-West in the Central region of Ghana had incidence values of 10-15%.

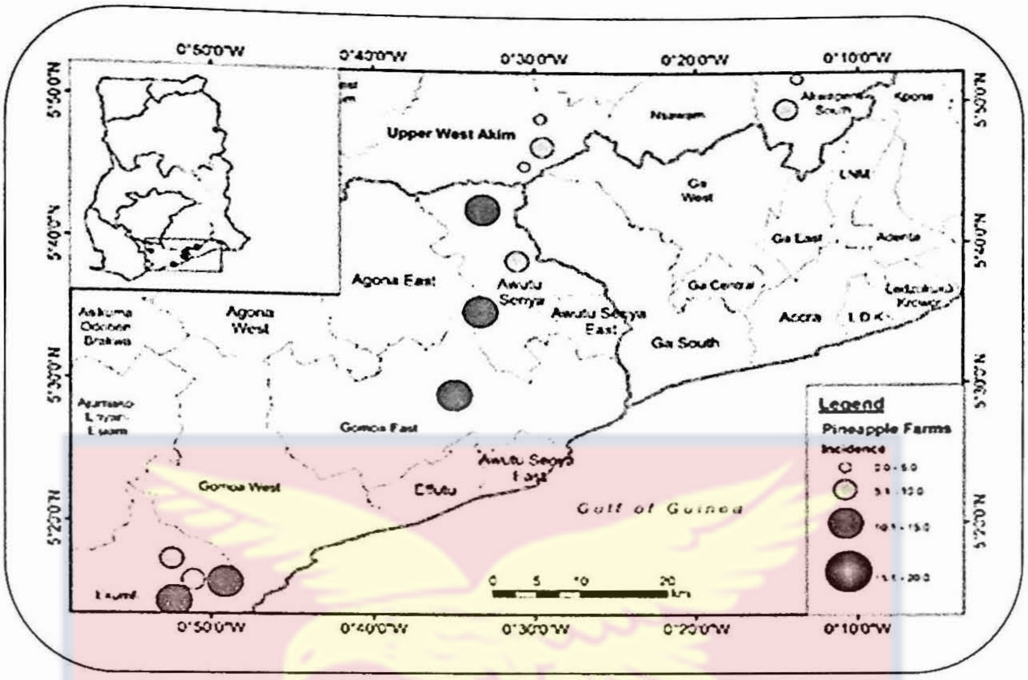

Figure 30: Percentage incidence of MWP after flower induction for the first year on farms across the districts of Central and Eastern regions of Ghana

Figure 31 and Figure *32* represent the mean severity maps for MWP for the first year of the survey for plants that were at the pre-flowering and post-flowering induction stages of growth of the pineapple.

Most of the farms surveyed across the two regions –Eastern and Central regions of Ghana had mean severities scores of 2.5-3.8, few farms in the Ekumfi District of the Central scored from 2.8-5.0.

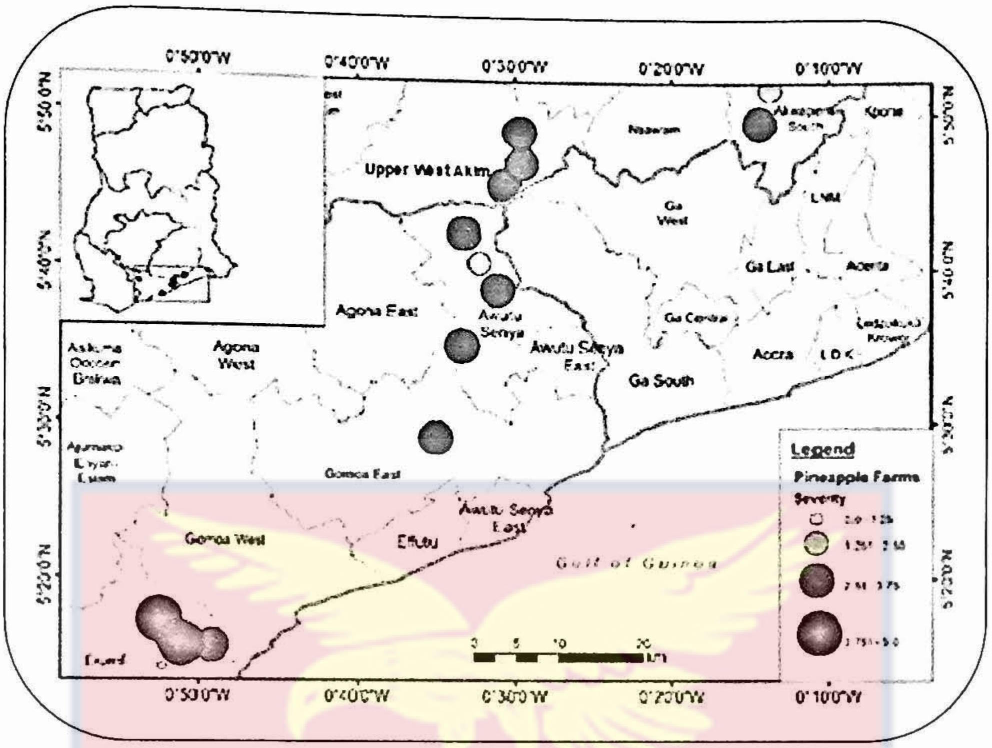

Figure 31: Mean severity of MWP before flower induction for the first year on farms across the districts of Central and Eastern regions of Ghana

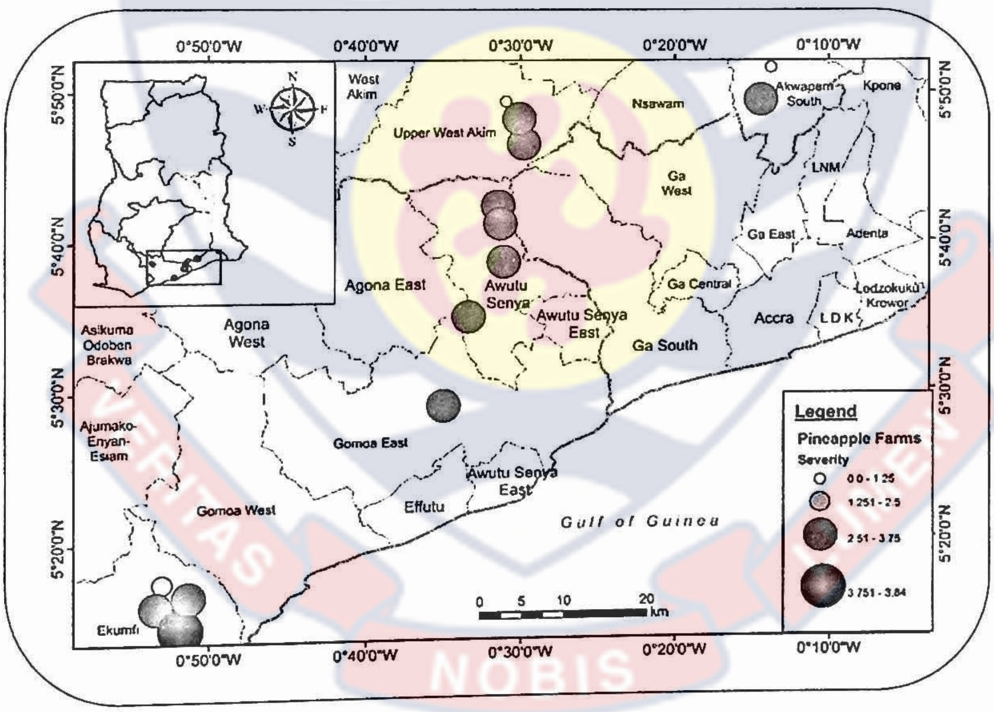

Figure 32: Mean severity of MWP after flower induction for the first year on farms across the districts of Central and Eastern regions of Ghana

Figure 33 andFigure *34* represent the percentage incidence maps for farms across the two regions surveyed. The scoring was done on plants that at before and after flower induction stages respectively in the second year of the survey.

Akuapem-South and Upper-West-Akyem Districts in the Eastern region and Ekumfi Districts of the Central region had some farms recording 0-5% of disease incidence (Figure 33) while most farms that recorded 5.1-10% were in the Central region of Ghana.

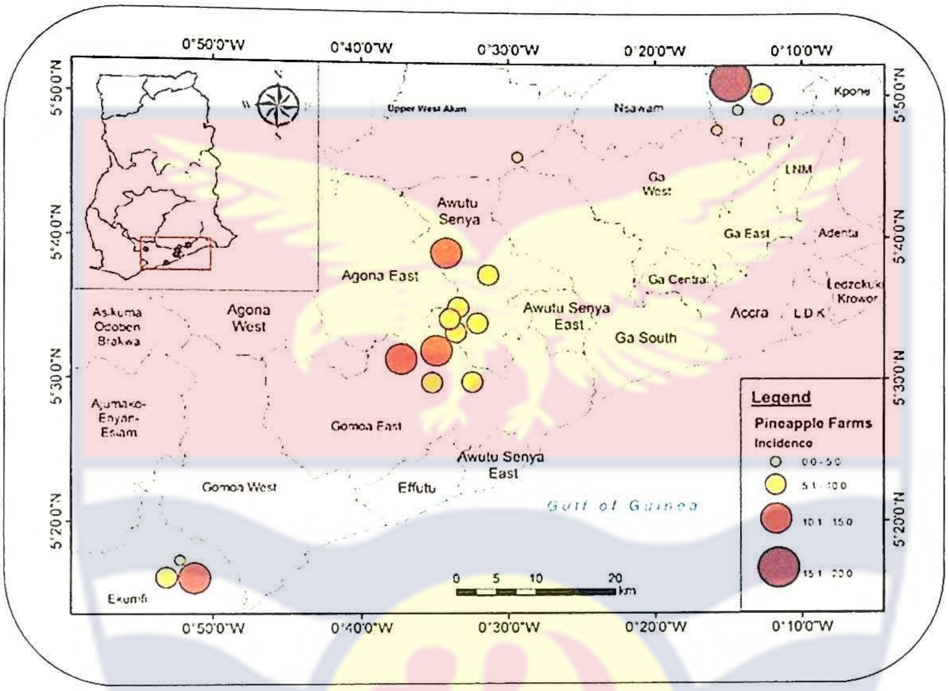

Figure 33: Percentage incidence of MWP before flower induction for the second year on farms across the districts of Central and Eastern regions of Ghana

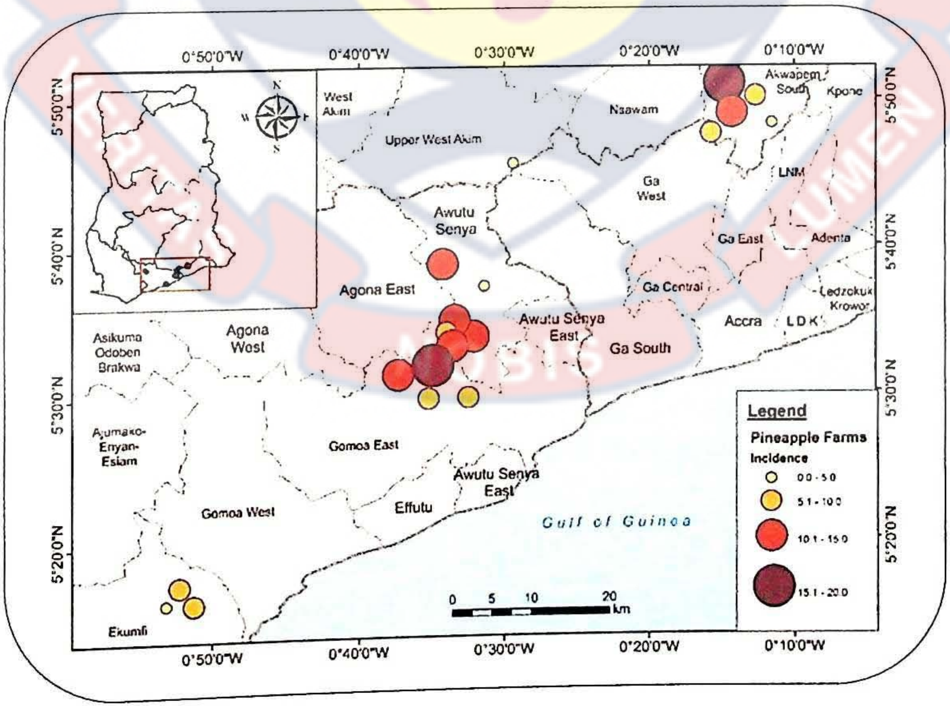

Figure 34: Percentage incidence of MWP after flower induction for the second year on farms across the districts of Central and Eastern regions of Ghana

Figure 35 andFigure *36* are the mean severity maps of the plants at the pre-flower induction and post flower induction stages of the plant growth. These maps are for the second year of the survey.

In the pre-flower induction stage of the second-year farms in Akuapem-South, Awutu-Senya-West, and Gomoa-East recorded severity values between 2.51 and 3.3, Upper-West-Akyem, Ekumfi and Awutu-Senya-West had farms recording mean severity values of 1.26-2.5. At the post-flower induction stage apart from farms in Akuapem-South and Gomoa-East which recorded severity figures of 3.8-5.0 most of the farms in all the surveyed areas recorded the severity of 2.5-3.8.

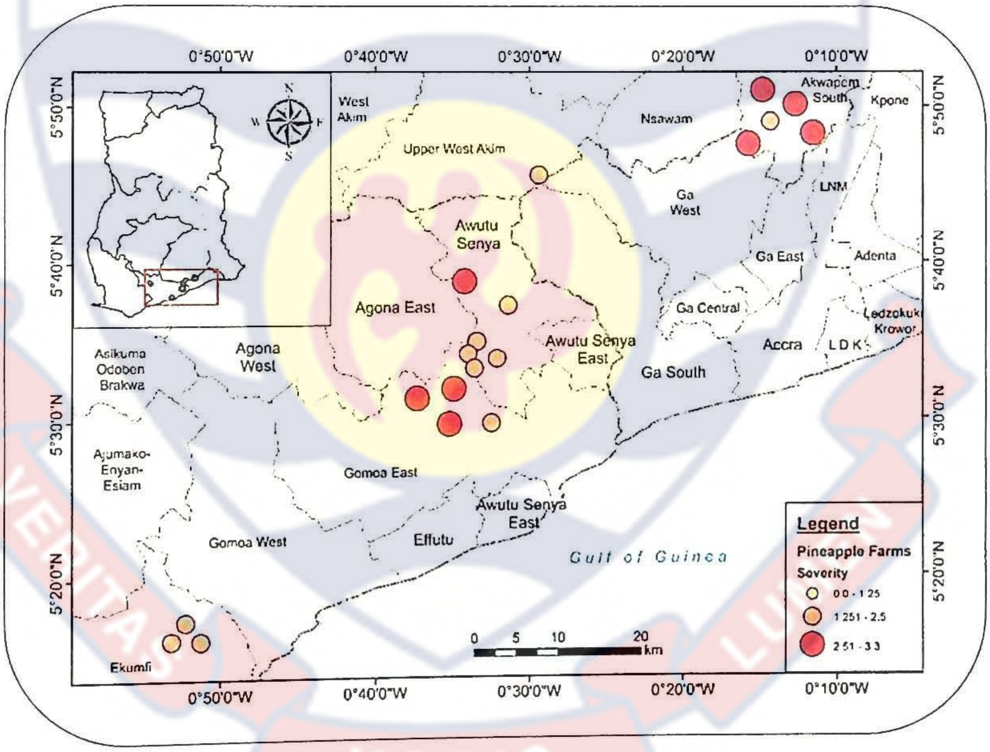

Figure 35: Mean severity of MWP before flower induction for the second year on farms across the districts of Central and Eastern regions of Ghana

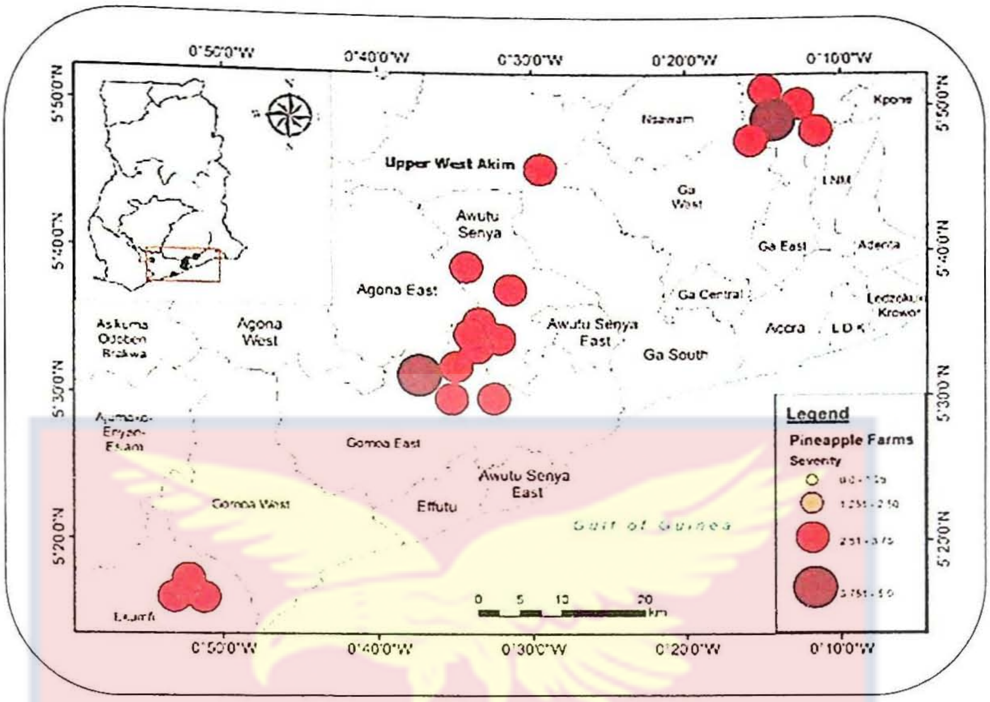

Figure 36: Mean severity of MWP after flower induction for the second year on farms across the districts of Central and Eastern regions of Ghana

4.3.21.1 *Spatial distribution for MWP before flower induction in the first year of disease assessment for the Central region of Ghana*

Table 9 present the summary of the first-year spatial autocorrelation report for the MWP field assessment at the pre-flowering stage of growth of pineapple in the Central region of Ghana. It could be seen that with farms in the Central region of Ghana the MWP distribution was mainly clustered in its pattern of spread on the fields that were yet to be induced for flowering in the first year of the assessment.

It could be seen that: the autocorrelation, the report returned the z-scores of 2.88, 3.66, 4.34, 4.24 and 8.22 for farmers: Kofi Basua, K. Yomo, MAGM, Shalom and Kwei Larbie respectively. With z-scores of 2.03 and 2.32 for Manna Farms and Ufruit Farm, respectively, there was a less than 5% probability that the clustered pattern observed was due to chance. With a z-score of -0.56, the pattern observed at the MEG farm does not appear to be significantly different than random.

Table 9: Summary of Spatial Autocorrelation Report for MWP Before Flower Induction in the First Year of Disease Assessment for Central Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
Kofi Basua	0.33	-0.03	0.02	2.88	0.00	7.59	Clustered
K. Yomo	0.60	-0.042	0.03	3.663	0.00	13.76	Clustered
MAGM	0.43	-0.02	0.01	4.342	0.00	10.47	Clustered
Manna	0.15	-0.02	0.01	2.03	0.04	11.66	Clustered
MEG	-0.08	-0.02	0.01	-0.56	0.57	8.42	Random
Ufruit	0.15	-0.01	0.00	2.30	0.02	5.35	Clustered
Shalom	0.12	-0.01	0.00	4.24	0.00	8.48	Clustered
Kwei Larbie	8.22	-0.02	0.00	8.22	0.00	4.88	Clustered

Source: Survey data, Sarpong (2014)

4.3.21.2 *Spatial distribution for MWP after flower induction in the first year of disease assessment for Central region of Ghana*

Table 10 represents the summary of the first year's Moran's I of the survey of the plants at the post-flower induction stage of growth for the Central region of Ghana. It could be realised that given the z-scores of 8.39, 8.38, 3.09, 8.96, 8.02, 5.24, and 17.19 for Kofi Basua, K Yomo, MAGM, Manna, MEG, Shalom, and Kwei Larbie Farms respectively there was less than 1% likelihood that these clustered patterns could be the result of chance. However, given the z-score of 1.05, for the Ufruit farm, the observed pattern did not appear to be significantly different from random.

Table 10: Summary of Spatial Autocorrelation Report for MWP after Flower Induction in the First Year of Disease Assessment for Central Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
Kofi Basua	0.4	-0.00	0.00	8.39	0.00	6.08	Clustered
K. Yomo	0.4	-0.01	0.00	8.38	0.00	6.08	Clustered
MAGM	0.25	-0.01	0.01	3.09	0.00	8.51	Clustered
Manna	0.32	-0.01	0.00	8.96	0.00	7.38	Clustered
MEG	0.16	-0.01	0.00	8.023	0.00	24.90	Clustered
Ufruit	0.23	-0.10	0.11	1.05	0.29	9.21	Random
Shalom	0.12	-0.01	0.00	5.24	0.00	8.48	Clustered
Kwei Larbie	0.99	-0.01	0.00	17.19	0.00	5.49	Clustered

Source: Survey data, Sarpong (2014)

4.3.21.3 *Spatial distribution for MWP before flower induction in the first year of disease assessment for the Eastern region of Ghana*

The spatial autocorrelation for first-year survey results for plants in the pre-flowering stage of their development in the Eastern region of Ghana is shown in Table 11. Given the z-scores of 0.61 and 0.55 for Adom Farm and Riverside Farm, respectively, the clustered patterns did not appear to be significantly different from random, and given the z-scores of 7.07, 2.92, 2.99, 3.22, 5.01, 32.87 for B Mart, Kofi Yeboah, Mokwa, Donkor, Ike, and Mgrand farms respectively.

Table 11: Summary of Spatial Autocorrelation Report for MWP Before Flower Induction in the First Year of Disease Assessment for Eastern Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
B. Mart	0.630	-0.02	0.00	7.07	0.00	6.99	Clustered
Adom	0.02	-0.03	0.01	0.61	0.54	13.57	Random
Mokwa	0.26	-0.04	0.01	2.99	0.00	5.60	Clustered
Donkor	0.19	-0.01	0.00	3.22	0.00	47.54	Clustered
Ike	0.29	-0.05	0.00	5.01	0.00	36.19	Clustered
Riverside	0.01	-0.02	0.00	0.55	0.55	35.28	Random
Kofi Yeboah	0.31	-0.03	0.01	2.92	0.00	13.76	Clustered
Mgrand	0.85	-0.00	0.00	32.87	0.00	6.74	Clustered

Source: Survey data, Sarpong (2014)

4.3.21.4 *Spatial distribution for MWP after flower induction in the first year of disease assessment for Eastern region of Ghana*

Table 12 shows the spatial autocorrelation first-year survey results for the plants at the post-flowering stage of the plant growth in the Eastern region of Ghana. Given the z-scores of 2.99, 3.22, 2.93, 5.01 for Mokwa, Donkor, Kofi Yeboah, and Ike Farms respectively, there is less than 1% likelihood that these clustered patterns could be the result of random chance. Given the z-scores of 1.39, 0.562, for Adom and Riverside Farms respectively, the patterns did not appear to be significantly different from the random pattern of distribution.

Table 12: Summary of Spatial Autocorrelation Report for MWP after Flower Induction in the First Year of Disease Assessment for Eastern Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
B_Mart	0.15	-0.01	0.00	2.32	0.02	5.34	Clustered
Adom	0.29	-0.11	0.08	1.39	0.17	7.06	Random
Mokwa	0.27	-0.03	0.01	2.99	0.00	5.60	Clustered
Riverside	0.01	-0.02	0.00	0.56	0.57	35.28	Random
Kofi Yeboah	0.31	-0.03	0.01	2.93	0.00	13.78	Clustered
Donkor	0.19	-0.038	0.01	3.22	0.00	47.54	Clustered
Ike	0.29	-0.05	0.00	5.01	0.00	36.19	Clustered
Mgrand	0.12	-0.01	0.00	7.64	0.00	97.42	Clustered

Source: Survey data, Sarpong (2014)

4.3.21.5 *Spatial Distribution for MWP Before Flower Induction in the Second Year of Disease Assessment for Central region of Ghana*

Table 13 presents the spatial autocorrelation for the second year before flower induction in the Central region of Ghana. It is seen that given the z-scores of 10.25 for Atigli Farm and 6.20, for Fred Farm, there was less than 1% likelihood that these clustered patterns could be the result of random chance. There was a less than 5% likelihood that these clustered patterns could be the result of random chance for Kow Bani and Nhyira farms with the z-scores of 2.34 and 3.79 respectively, there was respectively while the z-score of 1.81 for Amoanda suggested that there was less than 10% likelihood that this clustered pattern could be the result of chance. However, given the z-scores of -0.28, 0.76, and 1.58 for Dan, Aseda and Ayeyi Farms respectively the patterns did not appear to be significantly different from random.

Table 13: Summary of Spatial Autocorrelation Report for MWP Before Flower Induction in the Second Year of Disease Assessment for Central Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metre)	Distribution
Atigli	0.44	-0.01	0.00	10.25	0.00	3.52	Clustered
Dan	-0.14	-0.09	0.03	-0.28	0.78	17.18	Random
Fred	0.32	-0.01	0.00	6.23	0.00	3.36	Clustered
Kow Bani	0.04	-0.01	0.00	2.34	0.02	87.95	Clustered
Amoanda	0.12	-0.02	0.01	1.81	0.07	5.49	Clustered
Aseda	-0.06	-0.03	0.00	0.76	0.45	33.45	Random
Ayeyi	0.18	-0.02	0.02	1.58	0.11	6.35	Random
Nhyira	0.26	-0.01	0.00	3.79	0.00	4.76	Clustered

Source: Survey data, Sarpong (2015)

4.3.21.6 *Spatial distribution for MWP after flower induction in the second year of disease assessment for Central region of Ghana*

Table 14 shows the spatial autocorrelation for the second-year survey results for the MWP on pineapple plants at the post-flowering stage in the Central region of Ghana. Given the z-scores of 10.36, 5.01, 21.58, 3.89, 8.22, and 32.30 for Atigli farm, Dan, Fred, Nhyira, Amoanda, and Aseda farms respectively, there was less than 1% likelihood that these clustered patterns could be the result of random chance. With the z-score of 30.68 for Kow Bani Farm, there was less than a 5% likelihood that this clustered pattern could be the result of random chance. However, given the z-score of 1.58 for Ayeyi Farm, the pattern did not appear to be significantly different from random.

Table 14: Summary of Spatial Distribution for MWP after Flower Induction in the Second Year of Disease Assessment for Central region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
Atigli	0.45	-0.01	0.00	10.36	0.00	4.53	Clustered
Dan	0.07	-0.01	0.00	5.01	0.00	27.90	Clustered
Fred	0.54	-0.00	0.00	21.58	0.00	7.41	Clustered

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
Kow Bani	0.42	-0.01	0.00	30.69	0.00	87.95	Clustered
Amoanda	0.67	-0.02	0.01	8.22	0.00	4.88	Clustered
Aseda	0.82	-0.00	0.00	32.30	0.00	6.84	Clustered
Ayeyi	0.19	-0.02	0.02	1.58	0.12	6.25	Random
Nhyira	0.27	-0.01	0.01	3.89	0.00	4.76	Clustered

Source: Survey data, Sarpong (2015)

4.3.21.7 *Spatial Autocorrelation Report for MWP Before Flower Induction in The Second Year of Disease Assessment for Eastern region of Ghana*

Given the z-scores of 5.03, 3.08, 3.501, 10.81, 4.39, 13.23, and 6.62 for M and M, Issah, Mawuko, Miwani, Milano, Nhyira, and Yaw Preko Farms respectively, there was less than 1% likelihood that this clustered pattern reported may perhaps be the result of random chance. For Chacko Farm, the z-score of 1.43, shows that the observed pattern did not appear to be significantly different from random (Table 15).

Table 15: Summary of Spatial Autocorrelation Report for MWP before Flower Induction in the Second Year of Disease Assessment for Eastern Region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
M & M	0.35	-0.03	0.02	3.07	0.00	6.16	Clustered
Issah	0.22	-0.01	0.00	5.03	0.00	5.68	Clustered
Chacko	0.072	-0.06	0.01	1.43	0.15	32.17	Random
Mawuko	0.44	-0.02	0.02	3.50	0.004	2.59	Clustered
Miwani	0.69	-0.00	0.00	10.81	0.00	4.56	Clustered
Milano	0.45	-0.01	0.01	4.39	0.00	4.34	Clustered
Nhyira	0.54	-0.00	0.00	13.23	0.00	4.55	Clustered
Yaw Preko	0.21	-0.01	0.00	6.62	0.00	13.10	Clustered

Source: Survey data, Sarpong (2015)

4.3.21.8 *Spatial Distribution for MWP After Flower Induction in the Second Year of Disease Assessment for Eastern region of Ghana*

Given the z-scores of 10.83, 30.30, 19.71, 3.62, 9.07, 17.24, 8.15, and 32.87 for M & M, Issah, Chacko, Mawuko, Miwani, Milano, Nhyira, Yaw Preko Farms respectively, there was less than 1% likelihood that this clustered pattern may perhaps be the result of random chance (Table 16).

Table 16: Summary of Spatial Distribution for MWP after Flower Induction in the Second Year of Disease Assessment for Eastern region of Ghana

Farm	Moran's Index	Expected Index	Variance	z-score	p-value	Distance Threshold (Metres)	Distribution
M & M	0.98	-0.01	0.01	10.83	0.00	6.16	Clustered
Issah	0.79	-0.00	0.00	30.31	0.00	7.41	Clustered
Chacko	0.87	-0.01	0.01	19.71	0.00	5.07	Clustered
Mawuko	0.23	-0.01	0.00	3.62	0.00	2.59	Clustered
Miwani	0.60	-0.01	0.00	9.07	0.00	5.31	Clustered
Milano	0.45	-0.00	0.00	17.24	0.00	7.41	Clustered
Nhyira	0.49	-0.01	0.00	8.15	0.00	2.58	Clustered
Yaw Preko	0.845	-0.00	0.00	32.87	0.00	6.74	Clustered

Source: Survey data, Sarpong (2015)

4.4 Discussion

4.4.1 Spatial distribution of MWP at the study location

The observed incidence levels of the MWP above 3%in most of the districts surveyed are indicative of the high prevalence of the disease and hence the seriousness of the mealybug problem.

Incidence figures above 3% mean that farmers have been recycling old diseased planting materials with latent infections over the years. This was evident where most farmers were sourcing their planting materials from their farms and those of colleague farmers. It is by this practice that man spread the MWP. Again, the common practice of farmers transporting planting materials across the various districts in the two regions could aid the establishment of the disease across the districts. It is, therefore, not surprising that all the districts were recording a high percentage of disease incidences.

Queensland Department of Primary Industries (2005) and Flint (2016) had made the following recommendations as a measure of controlling or managing the MWP: avoid using plants growing within a one-meter square (1 m^2) radius of an infected mother plant as a source of planting material, if less than three per cent (3%) of pineapple plants were showing wilt symptoms, pull out and destroy those affected plants, if more than three per cent (3%) wilt was observed in a field as well as destroying the individual plants also implement a mealybug control spray program, if more than ten per cent (10%) of plants in a field exhibited MWP symptoms early, destroy the individual plants and implement a mealybug control spray program and do not pick planting materials from this field even if control of wilt appeared effective.

Queensland Department of Primary Industries (2005) again had observed that above-ground symptoms took between two to three months to appear on young plantings and a year on older plants to appear after actual feeding had taken place. A year after planting in pineapple will mean almost two months to harvest. Flint (2016) corroborated that the tendency for the disease to appear after this long while results in the plant going through the full cycle of the pineapple. Wolfenbarger & Westgate (1949) had reported that a plant may wilt or show symptoms of the MWP three months or so after a mealybug attack and Carter (1945a) also stated that depending on the age of the plant, the period for the development of MWP symptoms can range from forty-three to two hundred and ninety-five days. The majority of the districts within the study area, (Figure 35 and Figure *36*) recorded a mean severity of the MWP above 1.25 in the first and second years before flower induction in both regions. The mean severity of the MWP symptoms increasing to above 2.5 was indicative that the disease development was rapid and typical of the progression of the MWP as described by Broadley et al. (1993) and Pesticide Initiative Programme (2004). Plantwise (2011) had also reported that when MWP attack plants there is an eventual cessation of root growth and reduced root systems that lead to the plants finally wilting and not producing fruits at all, or when attacked at the early stages of growth, producing very small fruits.

It is worth noting that most of the farms surveyed from both the Central and the Eastern regions of Ghana recorded incidence scores of 10-20% which showed that disease incidence had increased over time.

Generally, the patterns of spread or distribution of the MWP across the districts surveyed in the Central and Eastern regions of Ghana were more clustered than random, or even. This could be because of the non-migratory nature of the mealybugs; the vector that carries the wilt virus. The mealybugs need the presence of the symbiont ants to relocate from one plant to another. As a result, they, remain on one plant for a relatively longer period feeding and depositing the virus into the system of pineapple plants within a certain radius of the field.

This observation agreed with that of Sether & Hu (2002a) who reported that MWP movement and spread on the field was key in epidemiological studies and that a random pattern of diseased or symptomatic plants suggested that the pathogen had ceased to spread from one plant to the other at the time of the observation or that there was a lag between infection and symptom appearance. Masses of diseased or symptomatic plants, on the other hand, indicated pathogen spread from one plant to another at the time of observation.

Mealybugs were acquiring viruses from the virus-infected plants earlier on the fields, due to the substantial overdispersion of MWP symptomatic plants and the incidence observed in plot rows, relocating to a neighbouring plant, and later transmitting the virus. There could be diseased plants within the fields that could be carrying latent infection and so if fields were surveyed earlier the resulting randomness could show but with age there are a lot more of the incidence as the infection begin to show.

Carter & Schmidt (1935) assumed that mealybug wilt had a longer period of incubation which is more than two months. Carter (1945a, 1963) also reported that the plant that had been attacked by the mealybug some three months earlier could be a reservoir of the mealybug as there was occasionally a significant delay in the period between the mealybugs' suckling and the appearance of symptoms. Periods for the disease development of symptoms vary from forty-three to two hundred and ninety-five days, contingent on the age of the plant at the time of infestation.

Nitrogen fertilization is another reason that could result in mealybug re-infestation and or the addition of other mealybug colonies. Therefore, with time even most of the disease patterns that appear as random could change to clustering and this was corroborated by Sether et al. (1998) who posited that an initial reason for the appearance of MWP was because of the toxins existing in the salivary discharges of mealybugs which were accountable for the symptoms of the MWP. However, they later observed that symptoms seldomly manifested if mealybugs were allowed to feed on healthy plants before being transferred to experimented plants. Additionally, symptoms commonly manifested when mealybugs were fed on infected plants before being transferred to the non-infected before the experiment. Consequently, the previously held hypothesis that indicated the involvement of a latent transmissible factor in the disease was likely and that this latent infection might resurface later in the existence of the plant was modified.

4.4.2 Percentage incidence, mean severity of MWP, mean mealybug and ants populations in the study area

The generally high incidence and mean severity of the MWP, as well as the mean ant and mealybug population in the two regions surveyed where the least incidence recorded (10%), indicative of how pervasive the MWP had been in the two regions. According to findings by Joy & Sindhu (2012), the economic threshold of the disease is 3% and anything above 10% it is recommended that the field be destroyed and no planting materials are collected from such a field for replanting. This relatively high incidence could be attributed to the movement of planting materials with inherent disease and mealybug infestation across the Central and Eastern regions of Ghana. Because of the need for sometimes farmers to augment their planting materials other colleague farmers and the practice is common in the two regions.

The Smooth Cayenne variety which is now very scarce in the Central region but is produced quite a lot more by farmers in the Eastern region and the Sugarloaf variety which was a lot more produced in the Central region than the Eastern region called for the transporting of suckers of these two varieties across the two respective regions which could have been a contributory factor to the spread of the disease and the ants and mealybugs.

Farmers sometimes were leaving the procurement of the planting materials to contractors who do not do any thorough search for healthy and disease-free planting materials because they have a target to meet by way of their contract, go about procuring suckers from all sources some with very poor disease management history. Mother plants from which some of these planting materials are picked from mostly abandoned with lots of pests and diseases. As a common practice, suckers brought in fresh from one location to another are left for some time to cure before planting and mostly these are left close to already established pineapple fields and so the ants that came with the suckers would easily transport the mealybug from these suckers to the already established fields to start a new disease this is reiterated by Bartholomew et al. (2003) that in general, the crowns, slips or suckers which serve as the 'seed material' for propagation are infested with the same pests that were present on the mother plants from which these seed materials are collected from. The movement of these 'seed materials' from one field to another field has been the primary means of the spread of the major pineapple pests and diseases which include MWP.

The human being as an important factor in the spread of diseases among plants by deliberate actions or inactions is underscored by Pesticide Initiative Programme (2004). They stated in their findings that in Ghana the MWP is the prevalent virus disease accounting for the reduced root growth, fruit quality and production. The MWP is transmitted by mealybugs that subsist and feed on the roots, stem, flowers, leaves and fruits of newly planted pineapples and on the remains of harvested pineapples and other crops in unmanaged fields which are previously infected with the virus.

One of the major factors of the spread of the MWP as reported by Wolfenbarger & Westgate (19469 is that mealybug infestations may originate from planting materials –slips and suckers used to establish new fields.

At the newly established fields, farmers are not doing effective roguing of the diseased plants because of the misconception that the change in leaf colouration is a result of water stress and will disappear with time, or the onset of the rains. This is again suggested by Pesticide Initiative Programme (2004) as a sure means of perpetuating because the disease symptoms are wrongly linked to the deprivation of water.

4.4.3 Percentage incidence, mean severity of MWP, mean mealybug and ants populations on the growth stages of the pineapple

The observed high disease incidence above 3% in the before and after flower induction growth stages and the steady progression of the observed mean severity of 3 to 4.3 from before flower induction to after flower induction show a generally high MWP situation.

The high incidence and mean severity of the MWP after the flower induction stage of growth of the plant is only indicative of the fact that like all viral diseases progression is steady and sometimes exponential because no known cure for the disease. According to Infonet Biodivision (2019), mealybugs kill pineapples by sucking sap from roots, tender leaves, petioles, and fruit, while the MWP attacks the very young stage, vegetative growth stage, flowering stage, and fruiting stage.

The maximum population of ants per plant at the pre- flower induction and post flower induction stages were 25 and 30 respectively as shown in Figure 20 this shows that there were more ants present as the plants progressed in age at both before and after flower induction stages.

The maximum mealybugs population per plant for before flower induction was after flower induction was up to 25 respectively. The mealybug feed on the sap of the pineapple plants so if there is enough vegetative growth of the pineapple plant there will be enough food for the mealybug. Constant fertilization of the pineapple plants for a long before harvest leads to the presence of mealybug and ants.

Flint (2016) observed that avoiding unnecessary nitrogen fertilizer applications to mealybug-infested plants may help control the population because the high amount of nitrogen available to pineapples, combined with reliable irrigation, may encourage new plant growth as well as mealybug egg development.

The increase in the population of the ants and mealybugs or otherwise during the period of observation, however, did not give a clear picture as to their correlation to the disease incidence which made it sound that the increase in wilt disease is not directly proportional to the number of mealybugs present. The population of mealybug alone could not be the contributory factor to the disease incidence progression.

Jahn et al. (2003) had earlier observed that MWP happens only when a large population of mealybugs are available and there is a clear connexion between the population of mealybugs feeding at a time, the span of the period they feed, and the severity of disease that will result and recuperating of the pineapple plants from MWP is common after the mealybugs had been taken off. Carter et al. (1935a) in an experiment also reported that 5 mealybugs, 25 mealybugs, and 40 mealybugs induced 7%, 25%, and 36% MWP, respectively.

4.4.4 Percentage incidence, mean severity of MWP, mean mealybug and ants populations in the months of planting

For the Central and Eastern regions, it was seen: in Figure 11 that the incidence of MWP were all above the 3% threshold with November and December recording 10% and 12% respectively. That the months of March, April, May, and June recorded mean severity values 4 and above with June recording 4.3 (Figure 16). That the maximum mean ant population per plant was recorded in the months of March and July with 30 per plant (Figure 21) and the maximum mean mealybug population was recorded in the months of April, May, and June with a recorded value of 25 per plant.

The major rainy season in the southern part of Ghana runs from April to July, with the minor season beginning in September to November each year.

The observation of the high disease incidence, mean severity, mean ants, and mealybug populations fall in the major and minor rainy seasons. This could be explained that the more vegetative growth on the pineapple plants during this period and since the mealybug subsists on the leaf sap and the roots, there is increased activity of the mealybugs and ants.

That could trigger the onset of the disease and again because there would be enough sap to feed on by the mealybugs, they tend to stay on plants longer.

According to Jahn et al. (2003) and Joy & Sindhu (2012), total MWP in an area is correlated to the population of mealybugs present because wilt occurs only when large numbers of mealybugs are available, and the numbers of mealybugs feeding as well as the corresponding ants tending them at any given time have a clear relationship between the period they feed and the resulting severity. MWP of the leaves is detected roughly two months after a period of feeding by a huge population of mealybugs which, is a likely occurrence during the rainy season in Ghana.

The period of rains in Ghana span over two months and provide ample conducive conditions such as the plush vegetative growth of the pineapple plants and the rapid growth of weeds that include alternate hosts of the mealybugs that aid the growth and multiplication and intensive feeding of mealybugs.

The month of September showed the least incidence of the MWP could be because of plants recovering from that attack or that the plants were in a latent disease infections stage as reported by Wolfenbarger & Westgate (1949).

4.4.5 Percentage incidence, mean severity of MWP, mean mealybug and ants populations on the varieties of pineapple

The least mean severity and percentage incidence, mealybug and ants populations were observed on the MD2 variety is indicative of the fact the MD2 is not known to be susceptible to the MWP while the Smooth Cayenne and the Sugarloaf are highly susceptible to the MWP. This observation had earlier been underscored by Coppens d'Eeckenbrugge & Leal (2003) and Jahn et al. (2003) who indicated that Smooth Cayenne and Queen Victoria varieties are susceptible to the MWP but resistant to the Phythophtora rot disease whereas the MD2 is resistant to MWP but rather susceptible to the Phythophtora rot disease.

4.5 Conclusions

i. Most of the farms surveyed in the Central and Eastern regions of Ghana had disease incidence scores of 10-20%, indicating that the disease had become more prevalent over time and beyond the minimum economic threshold of 3%.

ii. The progression of the disease continued after the attack because conditions that favour the disease was always available during the period of study.

iii. The recording of the incidence levels above 3% in Awutu-Senya-West, Gomoa, East, Gomoa-West and Ekumfi in the Central region and Akuapem-North, Akuapem-South and Upper-West-Akyem in the Eastern region at both before and after flower induction stages of the pineapples surveyed was indicative of the fact that the prevalence of the disease was high and serious than may have been estimated.

iv. Generally, the patterns of spread or distribution of the MWP across the various districts in the Central and Eastern regions of Ghana is more of clustering than random or even distribution on the field.

v. The sum of diseased or symptomatic pineapple plants suggested pathogen transfer from one plant to another at the time of observation.

vi. There was generally high percentage incidence, mean severity and ants and mealybug populations across the two regions due to the active movement of planting materials among farmers in the two regions. Since there would be a lot of leaves, root sap to feed on by the mealybugs all through the rainy season activity of mealybugs may well increase giving rise to the incidence of the MWP.

4.6 Recommendations

i. MWP management and control should be taken seriously to prevent the increasing incidence and severity of the disease.

ii. Farmers are encouraged to destroy suckers or plants that show symptoms of the MWP.

iii. If possible, the Ghana government working through the Ministry of Food and Agriculture (MoFA) should embark on an intensive clean planting material multiplication and distribution to farmers at subsidized prices to encourage farmers to rogue out all the diseased mother plants that give rise to planting materials that are infected and carrying latent infections.

iv. Effective treatment of the mother plots that is the source of the planting materials should be given equal attention like the main crop to control the ants and the mealybugs that are normally not controlled on the mother plots. Farmers often think these mother plots are not producing fruits and so treating and taking care of the mother plots is usually seen as a waste of resources.

v. Mother plots are usually overgrown with weeds and look abandoned with all the alternate hosts of the mealybugs in there., Therefore the destruction of the harvested and unmanaged pineapples fields is important. Planting materials selection should always be from non-infected fields.

vi. Farmers should put in place and sustain suitable ants and mealybug control regimes and develop good planting material selection and treatment.

vii. Controlling the ants that tend the mealybug exposes the mealybugs to their natural enemies that significantly suppress the population of the mealybugs. Also, it is important to clear fields and the boundaries of fields of weeds especially the alternate hosts for mealybugs that could serve as a reservoir for the ants and the mealybugs.

viii. Dipping of planting materials rootstock in insecticide solution before planting, control of ants and mealybugs in especially the Smooth Cayenne variety of pineapple is a must for all producers to reduce the incidence of the MWP.

ix. A lot of control measures and precautionary measures need to be employed in the cultivation of the highly susceptible varieties of pineapple to the MWP

CHAPTER FIVE

5 SPECIES OF MEALYBUGS AND ANTS ASSOCIATED WITH MWP IN THE CENTRAL AND EASTERN REGIONS OF GHANA

5.1 Introduction

The MWP is a pineapple disease that has been around for a long time in tropical regions where pineapples are grown. In all parts of the world where pineapple is grown, the disease has been a major hurdle, contributing to lower yields.

It is transmitted by two species of mealybug, the pink pineapple mealybug, *D. brevipes* (Cockerell), and the Grey pineapple mealybug, *D. neobrevipes* Beardsley (Dey, Green, Melzer, Borth, & Hu, 2018).

The MWP has traditionally been labelled as either a "slow" or "quick" wilt. The drying and wilting symptoms start at the leaf tips, which turn a reddish-yellow or pinkish colour in the quick wilt, particularly in the "Smooth Cayenne" variety. However, in new hybrid varieties such as the MD2, disease symptoms or intensity are less and the result is more of a yellow chlorotic leaf than the red to pink discolouration observed when the attack is in the "Smooth Cayenne" "Sugarloaf" or the "Queen Victoria" (Dey et al., 2018).

Mealybugs are believed to be tended by at least twenty-eight different ant species on pineapple fields. The reciprocal relationship exists between mealybugs and aggressive ants are known for their ferociousness and high group density of the mealybugs (Jahn et al., 2003; Brightwell & Silverman, 2010).

The symbiotic association between mealybugs and ants is characterized by the shield provided by the ants that offer protection to the mealybugs against predators and parasitoids (Bishop & Bristow, 2001). In exchange, the mealybugs provide the ants with large amounts of honeydew, which is made up of a mixture of sugars and amino acids and is essential for the growth and survival of the ants (Davidson, Cook, & Snelling, 2004). Previous research has shown that the ability of the ants to care for mealybugs results in increased population growth, by reducing not only predation and parasitism from natural enemies, but also the risk of fungal infection (Zou, Lu, Zeng, Xu, & Liang, 2012). Fire ants, for example, can defend honeydew-producing mealybugs by preventing natural enemies from approaching the mealybugs (Helms & Vinson, 2002).

Previously, all elements of the pineapple mealybug complex were the same *D. brevipes* species. Historically, *D. brevipes* are divided into two types: those that produce green spots because of feeding and those that did not cause green spots. *D. brevipes*, the non-green spotting ones are known as the pink pineapple mealybug, and *D. neobrevipes*, the green spotting ones are known as the Grey pineapple mealybug. *D. brevipes* and *D. neobrevipes* are found in every area where pineapples are grown, with *D. brevipes* being more widely distributed than *D. neobrevipes*. *D. neobrevipes* feeds on the upper parts of the pineapple, such as the fruits and flowers, and is sometimes found within the flowers, while *D. brevipes* feeds on the lower parts of the leaves, stems, roots, and crowns, and is occasionally found in the soil around the root region. However, it is worth noting that when *D. neobrevipes* is not present, *D. brevipes* can be found on the aerial portions of pineapple plants that would mostly be occupied by the *D. neobrevipes* (Dey et al., 2018).

Considering the above interaction, it is significant to recognise the kind of mealybug and tending ants that are joining to cause the MWP in the Eastern and Central regions of Ghana.

5.2 Materials and Methods

Sample collection formed an important aspect of the laboratory study of the ants and the mealybugs. Pre-filled vials of 5.5 cm tall and 2 cm in diameter at the mouth with 70% alcohol, a paper bag, a permanent marker and an 8mm flat artist's paintbrush were sent to the field.

The mealybugs and ants were found in the soils around the roots, the base of the fruits the heart of the plant. The ants were very agile, therefore, in locating them they were quickly immobilised by use of the artist's paintbrush dipped in the 70% alcohol on them and picked by the brush and lowered into the vial. Due to the relatively slow movement of the mealybugs and their soft bodies they were gently brushed off either the roots or leaves when found into the vial. At each location, the ants and the mealybugs were collected with ants (Figure 37) in one vial and labelled with the permanent marker and placed in the paper before they were brought to the laboratory.

The collection of the ants and mealybug samples from the two regions was done from 1st January to 30th April 2017. A total of 16 vials (specimen), 8 each from the Central and Eastern regions of Ghana were collected for the laboratory studies.

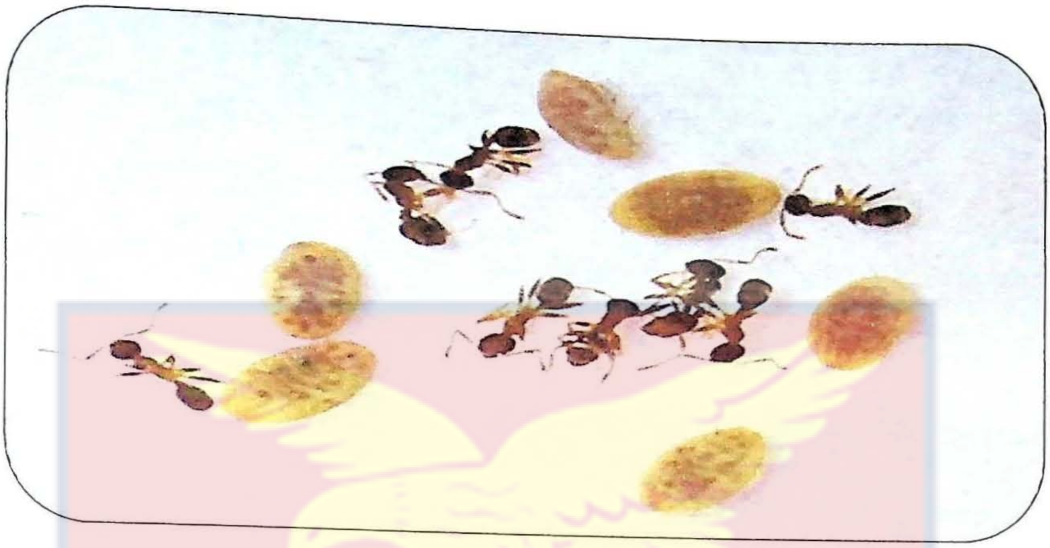

Figure 37: Mealybugs and associated ants captured together on the field and preserved in alcohol (Photo: M.T Sarpong, 2017)

5.2.1 Slide preparation

The slide preparation technique by Systematic Entomology Laboratory (SEL) (n.d) was adopted for this study, with a slight modification in the concentration of the KOH (potassium hydroxide) solution and the length of time for heating the specimens in the laboratory. All adult mealybugs that had been collected from the Central and Eastern regions of Ghana by brushing them off gently from the plant parts or the soil into a vial were prepared, cleared, stained, and mounted on slides.

5.2.1.1 *Preparation techniques*

The specimens from the field collections were heated in 10% solution of KOH on a hot plate at 40 °C for ten to twenty minutes for the body contents to soften. The beaker with the specimens was covered to prevent evaporation during the heating. Using a sharp probe or needle, a minor slit was made on the lateral of the abdomen, and with a small spatula, the abdomen was gently pressed down to pump out the body contents. In instances where the body contents did not all come out after pumping, specimens were placed back onto the hot plate for another five minutes then pumped in distilled water and left for five minutes. This process is generally known as maceration. Specimens were pumped again in 70% EtOH and left for five to ten minutes to make sure all the body contents had come out.

Specimens were then placed in Wilkey's solution for staining to clearly show all transparent features to facilitate identification. If specimens were too dark, water was added - a drop at a time, to remove most of the dark stain and left in 95% EtOH for a minimum of five to ten minutes. If water was left in the legs or the antennae, it could cause them to collapse so it was necessary to ensure that specimens stayed in the 95% EtOH long enough to get rid of all the water from the legs and antennae by dehydration.

The specimens were then transferred to clove oil for a minimum of five minutes for final dehydration. It was noted that the mealybugs needed to be light brown, showing the leg margins and other structures for identification.

For specimens that were not mounted immediately, they were left in clove oil overnight. The specimen was gently moved onto microscopic slides after a drop of thinned-out Canada balsam was placed in the centre of a glass slide. The specimens were placed on the slides with the head pointing downwards. Coverslips of 18 mm was placed over the balsam and placed on a hot plate to spread the balsam evenly and then the slides were cured in an oven at 40°C for three to four weeks till the balsam was permanently dry.

5.2.2 Image capture and specimen identification

The mounted mealybugs were identified using morphological characters and relevant keys under a Leica EZ4 D microscope connected to a high-capacity laptop via a USB data transfer cable. The microscope had an inbuilt camera for capturing images of specimens on the slides and a capability to measure straight-line distances (Figure 38). Images of the specimen were taken at all stages, which were displayed on the computer screen, and saved in a retrievable format in a folder for later use.

The key to identifying the mealybug followed what has been described by Beardsley (1965). Females of the *D. brevipes* (Cockerell) species complex has a combination of characteristics that help to distinguish them from other *Dysmicoccus genera*.

Each anal lobe cerarii has two conical setae plus many slender accessory setae; anterior cerarii have two or more conical setae, sometimes more than five or six, plus a small slender accessory seta. The ventral circulus is present, and it runs diagonally between abdominal segments three and four, forming an inter-segmental line (Beardsley, 1965).

Tubular ducts of the oral rim are absent, but oral collar tubular ducts are present and mostly confined to the venter, with a few on the dorsum. The ventral setae, on the other hand, are short, generally 35 cm or less in length, with a maximum of 65 cm in the vulva region; a multilocular pore is less common, with around thirty to fifty usually present; and the dorsal tubular ducts are absent (Beardsley, 1965).

The multilocular disk pores are only found in the ventral part of the disc. On the margin of each eye, one or more small sieve-like or unclearly loculated discoidal pores are usually present but appear to be absent on one or both sides in a few specimens of certain species or positioned near to but not on the margin of the eye. Similar small discoidal pores can be found in other parts of the body, including the dorsum of the preanal abdominal segment and around the vulva opening. Micropores can be found on the upper surface of the femora, tibiae, and sometimes the coxae and trochanters in the hind legs (Beardsley, 1965).

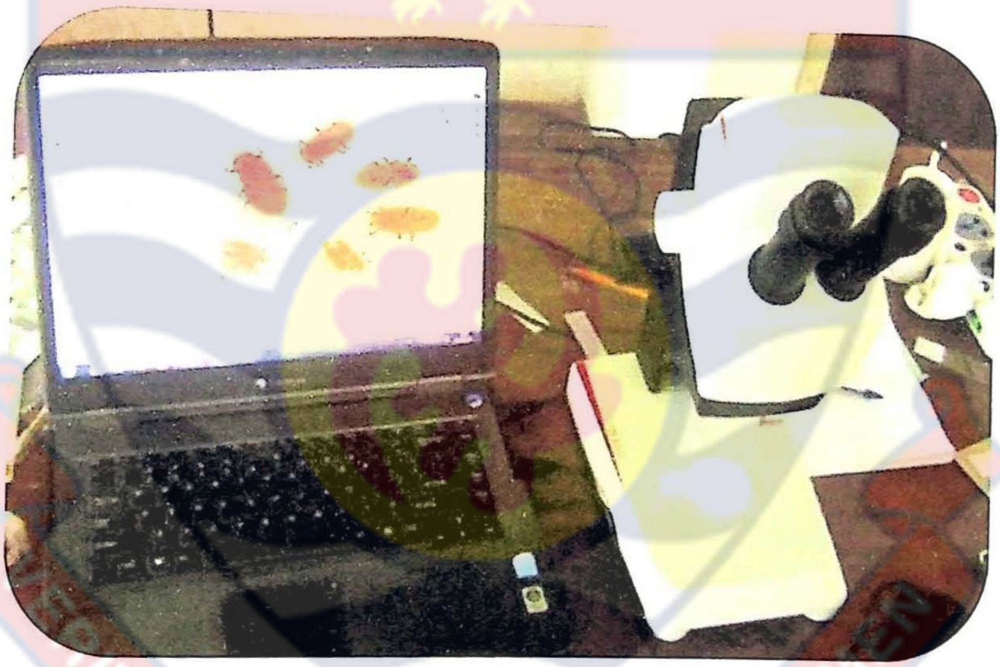

Figure 38: EZ4 D Leica microscope (with in-built camera) fitted to a high-capacity laptop used for capturing images of mealybugs (Photo: M.K. Billah, 2017)

The adult male of *D. brevipes* has eight-segmented antennae and a body length of around 540 mm, with separate scape segments projecting outwardly and measuring 45, 60, 90, 72, 63, 69, 66, and 75 μ, respectively. The antennae have slender filamentous setae with a maximum length of 45 μ and small, fleshy clavate setae with a length of 8-10 μ (Figure 39, A). The filamentous setae are somewhat more than the clavate type and predominantly on the apical segment. Elongated digitiform sensory setae are present on three distal segments, four or five on segment eight, one or two each on segments six and seven; and these are about 33 μ maximum in length (Figure 39, A) (Beardsley, 1965).

With a relatively well-defined mid-cranial ridge protruding dorsally to a point between dorsal eyes, the head lacks a well-developed dorso-medial sclerite. But for the sclerotized region between the eye sockets, the venter of the head is largely membranous. The eyes are wide, with a dorsal pair measuring about 32 μ and a ventral pair measuring about 45 μ (Beardsley, 1965).

The dermal discs are about 6 μ, with four peripheral loculi on average, and three such loculi distributed along the sides of the abdomen irregularly, with a collection of four to six on each side of the dorsum of abdominal segment seven, and six to eight on each side of the first abdominal segment. One or two of the dermal discs on each side of each of several other abdominal segments (Beardsley, 1965).

There are four to six of the dermal discs ventrally located on the membranous part of the mesothorax behind a mesosternal sclerite; one to three present membranous area behind each anterior spiracle (Beardsley, 1965).

There are four to six laterally of the dermal discs on each side of the prothorax, two to four on the venter of the prothorax between front coxae with one or two on each side of the anterior part of the head between the bases of the antennae. The pore clusters that shape the tail are only found on the eighth abdominal segment. Each is made up of about forty stellate pores with a diameter of around 4.5 μ the dorsum and ventral surfaces are sparsely covered in slender filamentous setae, which are mostly 18-24 μ in length.

In addition to filamentous setae, the membrane-forming sections of the head, thorax, and two basal abdominal segments have small fleshy clavate setae of the kind found on antennae. The penial sheath (Figure 39, C) is about 150 μ long; without discernible median lobes and 9 μ before the tip. The aedeagus (Figure 39, C) is divided into two equal parts at the apex with the cleft extending about 20μ from the tip and 8-9 μ width at the base of the cleft. The legs are of moderate length with hind femora of about 200 μ long that is clothed with slender filamentous setae about 25 μ maximum length, plus short fleshy clavate setae of the type occurring on the antennae; the latter is slightly less numerous than the former. The hind tarsal claws are 37 μ long (Beardsley, 1965).

A large transverse patch on the dorsum of segment eight and a small sublateral patch on either side of venter segment seven, make up the abdominal sclerotization. On the dorsum between segments one and two, there are a pair of inter-segmental transverse patches that are sometimes confluent middorsally, as well as a pair of smaller dorsal inter-segmental patches between the second and third segments (Beardsley, 1965).

The dorsal ostioles in the back are broad and well developed. The males of *D. brevipes* are readily different from those of *D. neobrevipes* by the presence of eight-segmented antennae as opposed to the ten-segmented in the *D. neobrevipes*, by the rare, short, clavate setae which occur on the body and attachments in place of the usual digitiform type of setae found on males of *D. neobrevipes* (Beardsley, 1965).

D. brevipes males have a similar penial sheath and aedeagus structure to *D. neobrevipes males*. In *D. neobrevipes* males, the aedeagus is a little wider, 11-12 μ at the base of the apical cleft, and the cleft is a little deeper about 26 μ (Beardsley, 1965).

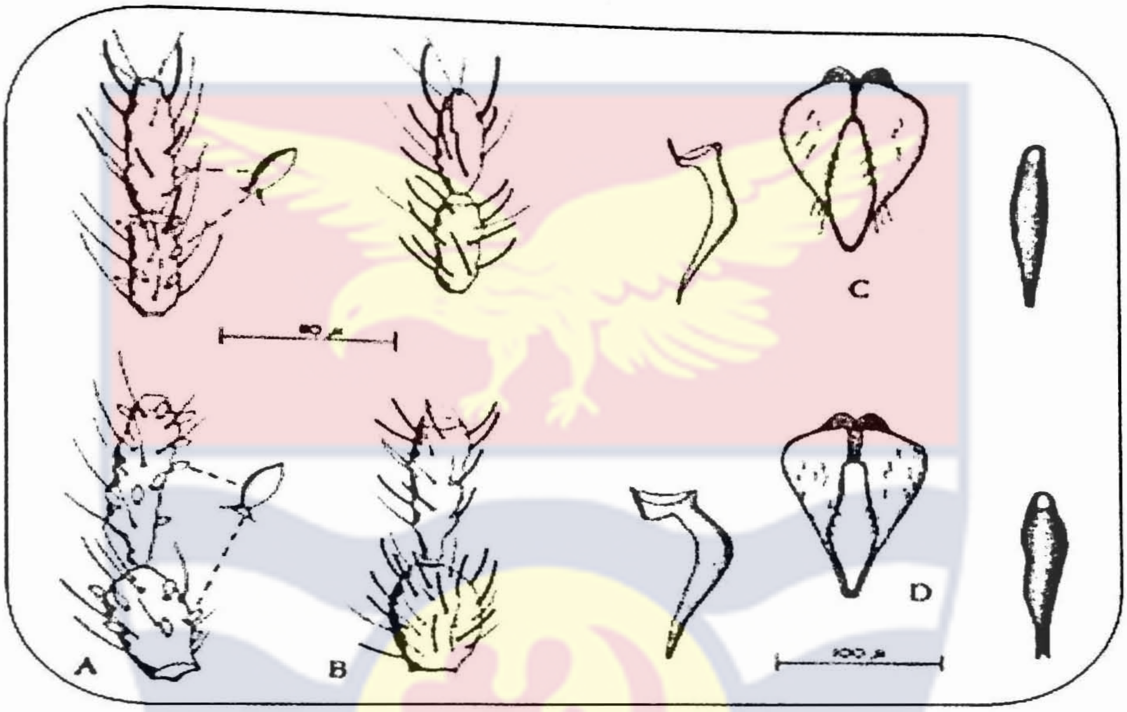

Figure 39: Antennae and genitalia of *D. brevipes* and *D. neobrevipes*. A = antenna of *D. brevipes*, male: from bottom to top, segments 2-3; 7-8, B = antennae of *D. neobrevipes*, male: from bottom to top, segments 2-3; 9-10, C = genitalia of *D. brevipes*, male: centre, ventral aspect of the penial sheath; left, lateral aspect; right, ventral aspect of aedeagus, D = genitalia of male *D. neobrevipes*, aedeagus is a little broader and the cleft a little deeper Source: Beardsley (1965)

5.2.3 Identification of Ants Tending the Mealybug Associated with MWP

Since ants play such an important role in the movement of mealybugs from one plant to the next, they help in the transition of the MWP from one plant to the next. Careful identification of the species associated with the MWP within the two regions in Ghana surveyed was important. The ant species were collected with the mealybugs from the fields in vials containing 70% EtOH. They were sent to the laboratory and with the aid of the Leica EZ4 D microscope (Figure 38) and an adapted key by Haines (2008) and Bayer Environmental Science (2010) in combination with the key developed by Nichols (2013), the ant specimens were identified based on the following features: The main abdomen colouration was either black, dark brown, light brown, red or yellow; the antenna scape length was either long and reaches well past the top of the head, or medium and with scape ending about at top of the head, or short with scape ending well before topping off the head.

The body length from the front of the head to the end of the abdomen was either under 1, 1-3, 3-5, 5-7, or over 7 mm. The main face was smooth texture. The main head colour was black, dark brown, light brown, red or yellow. The head top shape was dented, flat, or round. The mandible shape was long and skinny, sickle-shaped, not long, and skinny, or not sickle-shaped. There was the presence of spines on the rear thorax and the colour of the thorax was mainly black, dark brown, light brown, red or yellow. The top of the thorax is either bald or hairy. Waist petiole may be minute or not visible. The ant species collected were compared to some of the very common ants likely to be found on pineapple fields in the tropics. With the assistance of M.K. Billah (PhD), an Insect Taxonomist at the University of Ghana, Legon, confirmation of the various ants identified was done.

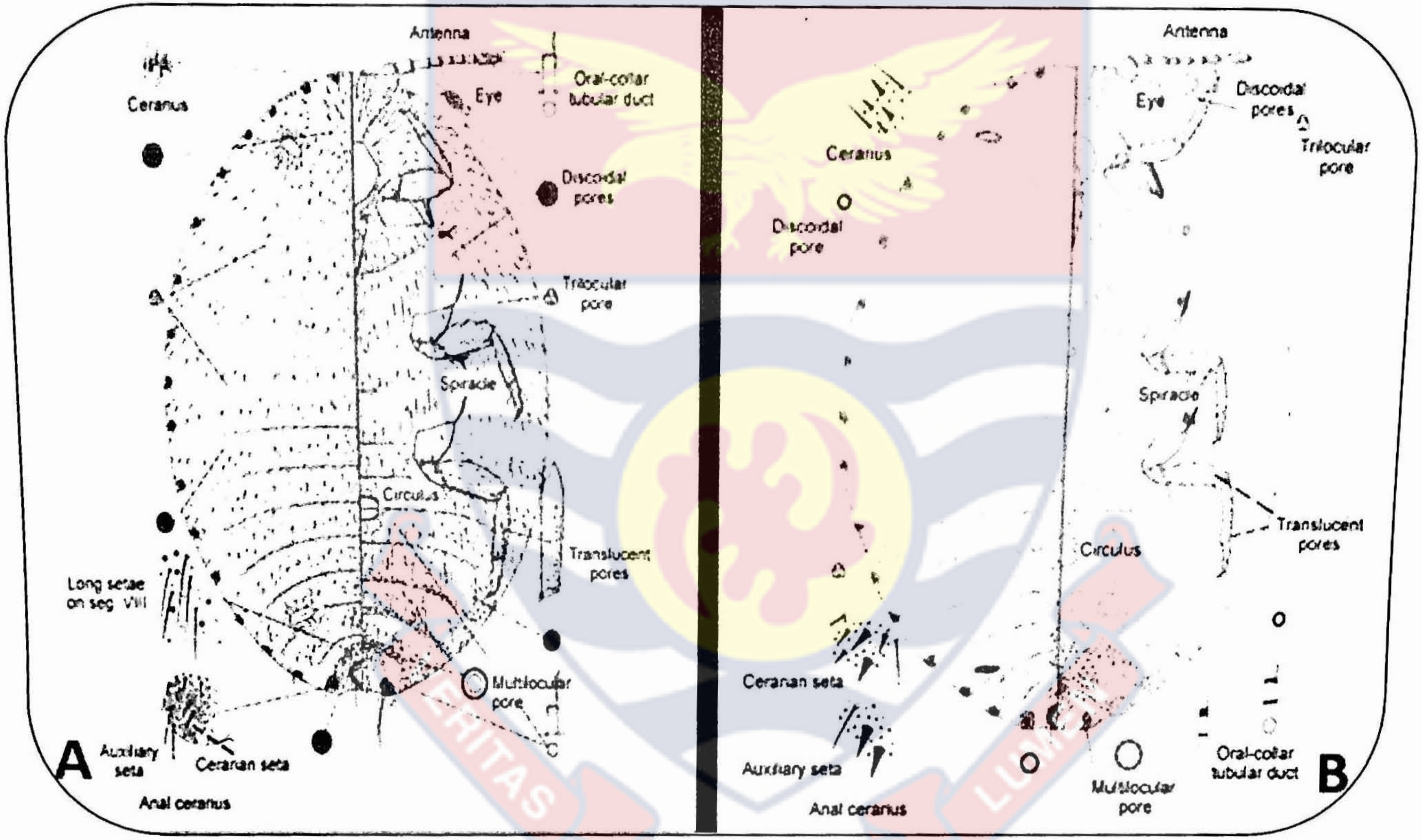

Figure 40: Generalized illustration of pineapple mealybugs. A. = *D. brevipes* (Cockerell), B. = *D. neobrevipes* (Beardsley). Source: Miller, Rung, Parikh, Venable, Redford, Evans, & Gill (2014)

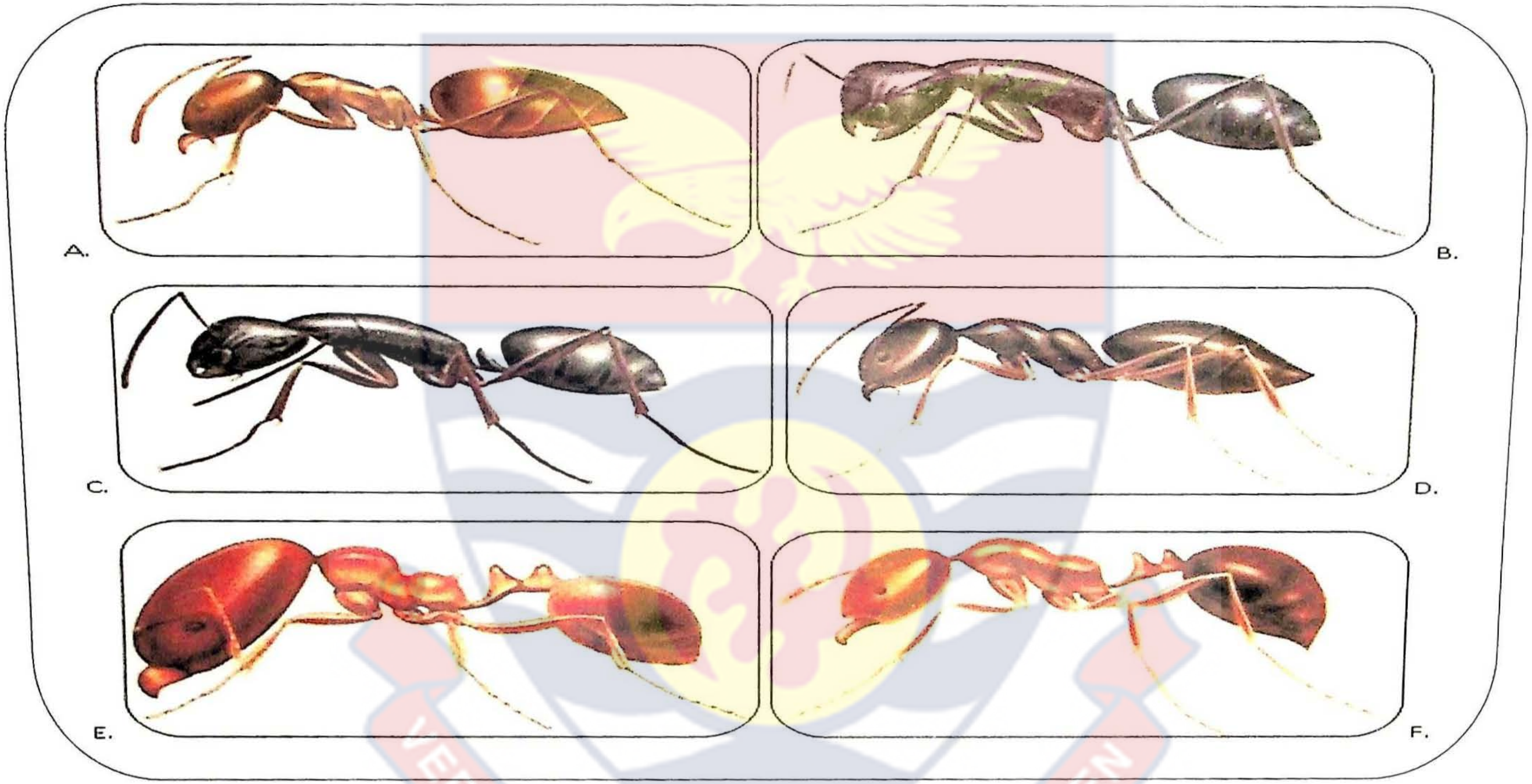

Figure 41: Ant species that are found to be associated with mealybugs in pineapple growing areas across the world. A = the Argentine ant, *Linepithema humile* (Mayr), B =The Black Carpenter Ant, *Camponotus pennsylvanicus* (DeGeer), C =the western carpenter ant, *Camponotus modoc* (Wheeler), D = The Odorous Ant, *Tapinoma sessile* (Say), E =: The Big-Headed Ant, *Pheidole* spp., and F = the Fire ant, *Solenopsis invicta* (Buren) Source: Bayer Environmental Science (2010).

5.3 Results

5.3.1 Mealybug species identification

The species of mealybug found in the Central and Eastern regions of Ghana are described in Table 17. Only the Pink pineapple mealybug (*D. brevipes*) was found in both regions and throughout the seven districts that were studied (Figure 40 and Figure *42*).

Table 17: Species of Mealybugs Found on Pineapples in the Seven Districts of the Central and Eastern regions of Ghana

District	*Dysmicoccus brevipes* (Pink Pineapple Mealybug)	*Dysmicoccus neobrevipes* (Grey Pineapple Mealybug)
	Central Region	
Awutu-Senya-West	+	-
Gomoa-East	+	-
Gomoa-West	+	-
Ekumfi	+	-
	Eastern Region	
Akuapem-South	+	-
Akuapem-North	+	-
Upper West-Akyem	+	-

Figure 42: *Dysmicoccus brevipes* identified to be causing the MWP disease in the Central and Eastern regions of Ghana (Photo: M.T Sarpong, 2017)

5.3.2 Ant Species Identification

Three ant species, *Camponotus pennsylvanicus*, *Solenopsis invicta*, and *Pheidole* spp., were discovered in the four districts of the Central region of Ghana (Table 18). In the Eastern region of Ghana, however, only *Pheidole* spp. were found in all three districts, while *Solenopsis invicta* and *Camponotus pennsylvanicus* were only found in Akuapem-South and Upper West-Akyem. In both the Central and Eastern regions of Ghana, *L. humile*, *Camponotus modoc*, and *Tapinoma sessile* were not found to be associated with pineapples (Figure 43 and Table 18).

Table 18: Ant Species Associated with Mealybugs in the Seven Districts in the Central and Eastern regions of Ghana

District	*Linepithema humile* (Argentine ant)	*Camponotus pennsylvanicus* (Black Carpenter Ant)	*Camponotus modoc* (Western carpenter ant)	*Tapinoma sessile* (Odorous ant)	*Pheidole* spp. (Big-headed ant)	*Solenopsis invicta* (Fire ant)
			Central Region			
Awutu-Senya-West	-	+	-	-	+	+
Gomoa-East	-	+	-	-	+	+
Gomoa-West	-	+	-	-	+	+
Ekumfi	-	+	-	-	+	+
			Eastern Region			
Akuapem-South	-	+	-	-	+	+
Akuapem-North	-	-	-	-	+	-
Upper-West-Akyem	-	+	-	-	+	+

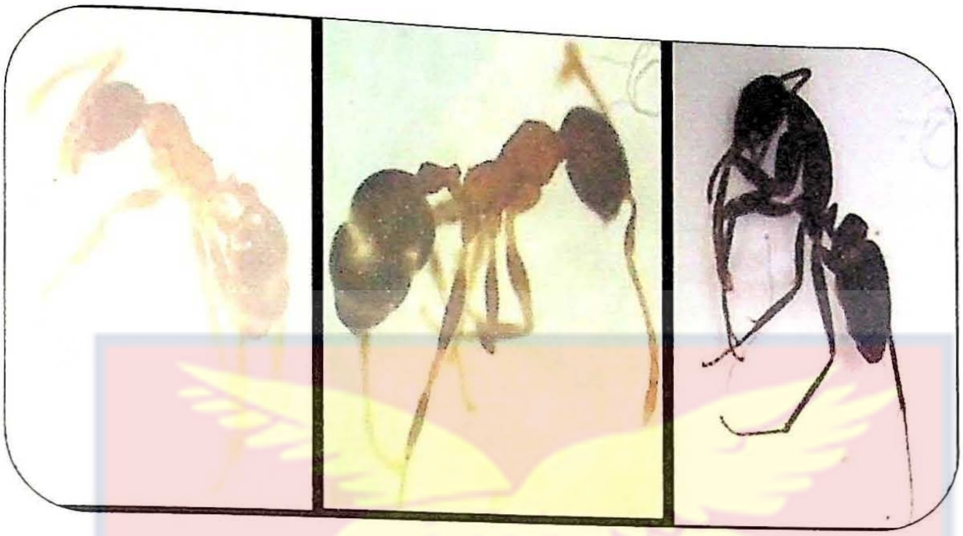

Figure 43: Ant species found to be associated with mealybugs in the two regions of Ghana-Eastern and Central A= The Big-Headed Ant, *Pheidole* spp.) B= the Fire ant, *Solenopsis invicta* (Buren) C =The Black Carpenter Ant, *Camponotus pennsylvanicus* (DeGeer) (Photo: M.T Sarpong, 2017)

5.4 Discussions

Even though many species of mealybug have been identified as pineapple pests, the *D. brevipes* and *D. neobrevipes* have been identified as the two most important species associated with pineapple production worldwide (Jahn et al., 2003; Dey et al., 2015).

Only the *D. brevipes* (Figure 42) are found in all seven districts throughout the Central and Eastern regions, according to the results of the identification. This is consistent with earlier findings by Beardsley (1993), Jahn et al. (2003), and Dey et al. (2015), who all stated that while *D. brevipes* and *D. neobrevipes* are both present in all pineapple cultivation areas of the world, *D. brevipes* is more widely distributed than *D. neobrevipes*, and only *D. brevipes* is known to attack pineapples in Africa. CABI (2018) had also reported that the *D. brevipes* which is a widely distributed pest of pineapple and a vector of MWP disease, originating from tropical America, is present in all zoogeographical regions, mostly in the subtropics and tropical zones including Ghana. *D. neobrevipes* and other mealybug species that target pineapples in other parts of the world are yet to be discovered in Africa (CABI, 2018).

On pineapple fields all over the world, there are at least twenty-eight distinct mealybug tending ant species. Ants aid in the establishment of mealybug colonies, and they play an important role in the movement of mealybugs from alternative hosts or older pineapples to newly planted pineapple fields by eating the mealybug honeydew, which is a rich source of amino acids and sugars for the ants. It has been documented that ants' tending abilities help the mealybug population grow by reducing not only natural enemies' predation and parasitism but also the risk of fungal infection. Efforts to stop the mealybugs from spreading are often targeted at the ants control (Sether & Hu, 1998; Jahn et al., 2003; Zhou et al., 2012; Dey et al., 2018).

Three ant genera *Camponotus*, *Pheidole* and *Solenopsis* (Figure 43) were identified to be associated with pineapples in the two regions surveyed. Réal (1959) and Jahn et al. (2003) confirmed all three genera (*Camponotus*, *Pheidole*, and *Solenopsis*) to be associated with pineapple mealybugs in West Africa and, by extension, Ghana. According to Dey et al. (2018), the *Pheidole* and *Solenopsis* species are the ants most associated with pineapple mealybugs around the world.

5.5 Conclusions

i. The Pink mealybug, *D. brevipes*, was found to be present and dominant in the study field. Three ant genera, *Camponotus*, *Pheidole*, and *Solenopsis*, were found in the study areas and were related to pineapple production.

5.6 Recommendations

i. Although the Pink mealybug was the common mealybug seen in the study areas, it is also likely that the Grey mealybug could be occurring within the study area and so further work should be geared towards finding the Grey mealybug and its association with the ants.

ii. Other ant genera could be present in the study districts or from other districts not surveyed that could be introduced to the study area, therefore, further work in identifying other ant genera associated with the mealybugs and the MWP should be done

CHAPTER SIX

6 EFFECT OF MWP ON PHOTOSYNTHETIC ABILITY OF PINEAPPLES IN THE CENTRAL AND EASTERN REGIONS OF GHANA

6.1 Introduction

The elongated pineapple leaves are waxy, luscious, and ensiform, measuring 50-180 cm in length. They are spirally arranged around the stem in a rosette and are specifically designed to allow for adequate sunlight capture as well as effective accumulation and translocation of rainwater to the stem and root systems of the pineapple plant. Pineapple leaves are spirally organized around the stump and are long, trough-shaped, tapered from the base to the tip, and approaching horizontal. This plant design allows for optimal sunlight absorption as well as effective rain collection and transfer to the stems of the plant. Most of the leaves, particularly those at the top of the plant that is most exposed to the sun, are orientated at a relatively erect angle to the sun, which helps to reduce leaf temperature and moisture loss. Stomata are also used to increase water intake (Ecocrop (FAO), 2011; Yuan & Luo, 2016).

There is the presence of globular trichomes found on the upper (adaxial) surface and the lower (abaxial) surface of the leaves with the abaxial side having more densely furfuraceous and silvery trichomes. Trichomes are epidermal protuberances (tiny hair-like structures) that cover the stomata on the aerial parts of pineapples and other plants to protect them from overwatering, radiation, high temperature, UV light, and herbivorous insect attack (Yuan & Luo, 2016).

Chlorophyll occurrence in the pineapple leaf like in many plants gives the pineapple leaf its green colour. Chlorophyll plays a vital role in photosynthesis, and with pineapple being a CAM plant, chlorophyll is an important component for the formation of carbohydrates. The pineapple leaf consists of two parts – the chlorophyllous part that has the lanceolate blade or lamina and, an expanded, non-chlorophyllous base (Krauss, 1949).

The mealybug is a sap-sucking insect that removes nutrient-laden sap from the pineapple leaves thereby restricting their ability to make more of the chlorophyll and reduce photosynthesis. It also sucks sap from the roots and lower (underground) stems causing poor growth and weakening the plants in the process.

Since the MWP leads to the loss of the green pigmentation of the plant and eventual withering of the leaves the effect of the MWP on the photosynthetic ability of the pineapple and the determination of the extent of deterioration of the morphological characteristics of the pineapple leaves as the MWP develops from one stage of the symptoms to another (Jackson, 2017) is important.

The volume of solar radiation taken in by a pineapple leaf is principally a role of the foliar concentrations of photosynthetic pigments. Reduced concentrations, therefore, limit the photosynthetic potential directly and consequently primary production of the pineapple plant (Curran, Dungan, & Gholz, 1990; Fillela, Serrano, Serra, & Peñuelas, 1995).

Secondly, since chlorophyll contains a significant amount of nitrogen in pineapple leaves, computing chlorophyll for MWP disease progression can be used better indication of the chlorophyll content if all the leaf samples came from plants of the same age. It has been proved that the age of leaves is an important factor for chlorophyll content in higher plants (Kamble, Giri, Mane, & Tiwana, 2015). For each disease stage, four readings of the chlorophyll content index (CCI) from four-leaf samples were taken and the means computed.

The hand-held chlorophyll meter classically provided a comparative sign of chlorophyll in the leaves of the pineapple plant. It evaluates by measuring the relative chlorophyll content and outputs an approximate of an actual chlorophyll concentration in absolute units of μmol per m^2 (μmol m^{-2}) of the surface of the leaf of the plant.

Diseased pineapple leaf samples that fitted the description of the MWP stages 1-4 (Figure 44 and Figure 45) (Broadley et al., 1993; Pesticide Initiative Programme, 2005) were collected across the seven districts in the two regions of Ghana where the field survey for disease assessment was carried out. During the collection of the samples, it was ensured that clear disease symptoms of the MWP were ascribed to the plant before the samples were collected. This caution was important because severe water stress conditions could be confused with the MWP situation if care was not taken. Control samples made up of leaves with no disease representing disease stage 0 (Figure 44 andFigure 45), were also collected from these districts in the two regions and were used as the standard. To ensure uniformity and eliminate bias plant leaf samples were picked from plants that were planted in the same week.

The leaf samples were kept in grocery bags with their respective labels-date of collection, disease stage, district, and region from where samples were taken. Water was sprinkled on the top of the grocery bags on hot days during sample collection to prevent the fresh part of the leaves from crushing (Owusu et al., 2011). High-quality photographic shots were taken of the collected samples for reference purposes.

Figure 44: Samples collected for SEM from Eastern region of Ghana: A= disease stage 0, B= disease stage 1, C= disease stage 2, D= disease stage 3 and E= disease stage 4. (Photo: M T Sarpong, 2017)

The samples were sent to the Electron Microscopy Laboratory of the Department of Animal Biology and Conservation Science of the University of Ghana, Legon, Ghana and were first kept in a controlled room with a temperature of 18 °C to maintain the integrity of the morphological structures just like as the time of collection.

Figure 45: Samples for SEM collected from Central region: A= disease stage 0, B= disease stage 1, C= disease stage 2, D= disease stage 3 and E = disease stage 4 (Photo: M.T Sarpong, 2017)

Cut samples from the pineapple leaves were placed on double-sided adhesive carbon paper (Figure 47 A) and SEM images were captured with the Jeol JSM 6390LV Scanning Electron Microscope (Figure 47 B). The progress of the deterioration of the trichomes at each of the stages of the disease symptom of the leaf samples from the two regions was compared with Figure 46 SEM images analysed.

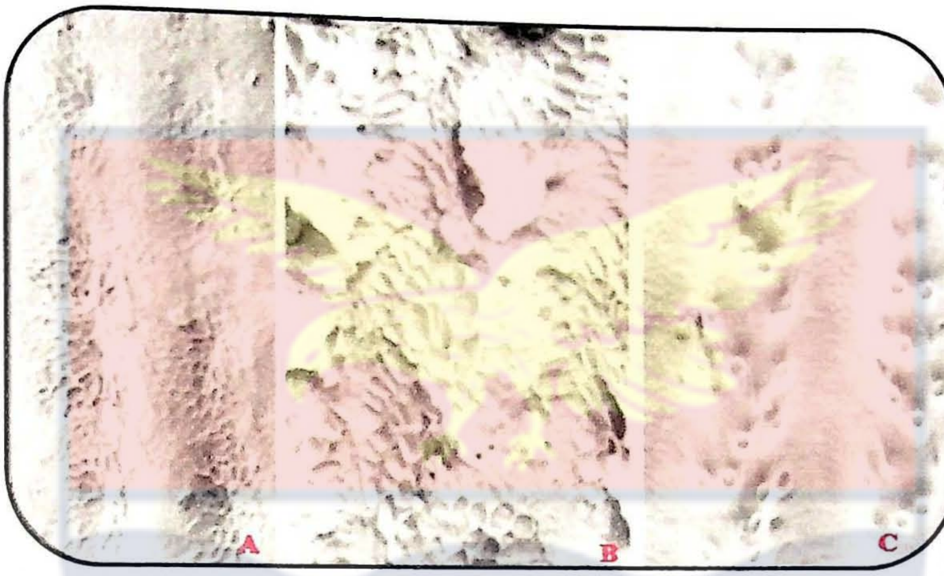

Figure 46: SEM images of pineapple leaf surfaces A = Upper surface of pineapple leaf with not too dense trichome growth B = Lower surface of the normal leaf showing dense trichome growth concealing the stomata C = Lower surface with the trichomes rubbed off revealing the location of the stomata in the furrows (Source: Malezieux, Cote, & Bartholomew, 2003)

Figure 47: A=Cut samples placed on double-sided adhesive carbon paper, B= the Jeol JSM 6390LV Scanning Electron Microscope (Photo: M.T Sarpong, 2017)

6.3 Results

6.3.1 Measurement of the chlorophyll content index of the leaf samples

Figure 48 and Figure *49* are line charts with trendlines showing the chlorophyll content index (µmol m^{-2}) at the different stages of MWP progression of the MWP on leaf samples from the Central and Eastern regions of Ghana, respectively. It is seen that at disease stage 0 or the control for both regions the CCI was 84.18 µmol m^{-2} and 93.7µmol m^{-2} respectively, but after the onset of the MWP at mean severity of 1, there was a drop in the CCI from the 84.18 µmol m^{-2} and 93.7 µmol m^{-2} respectively, to 39.35 µmol m^{-2} and 49.95 µmol m^{-2}. At disease mean severity stage 4 it is seen that the CCI had dropped to below 20 µmol m^{-2} in both cases.

In both cases of the graphs (Figure 48 and Figure *49*) coefficient of determination (the R^2) was 81.1% and 83.7%, respectively, showed a strong negative relationship between the MWP mean severity and the CCI. As the MWP mean severity increased the CCI also decreased significantly in both data from the Central and Eastern regions of Ghana.

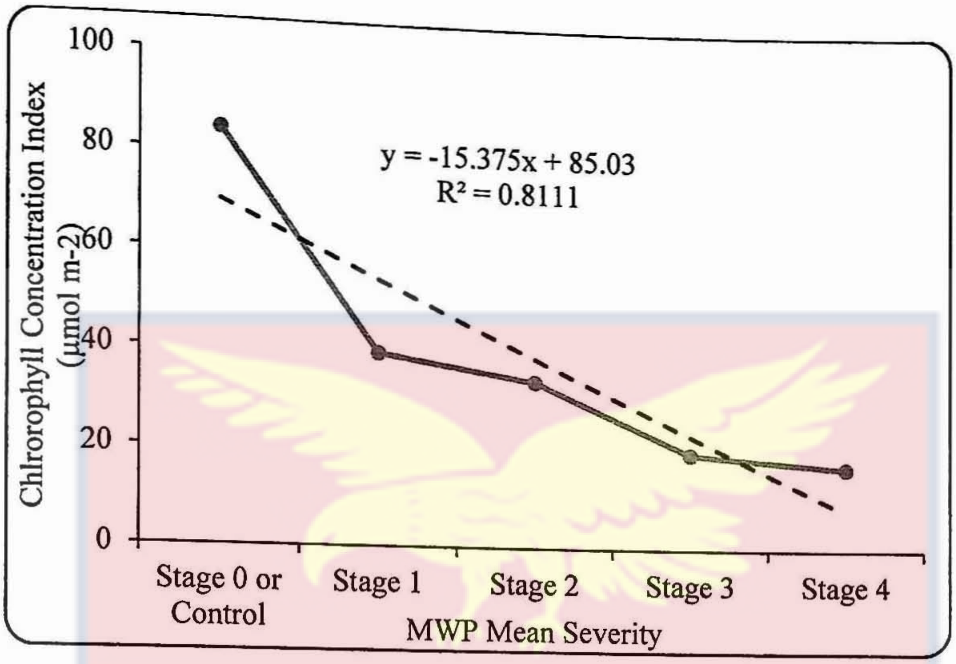

Figure 48: Chlorophyll content index of leaf samples infected with MWP in the Central region of Ghana

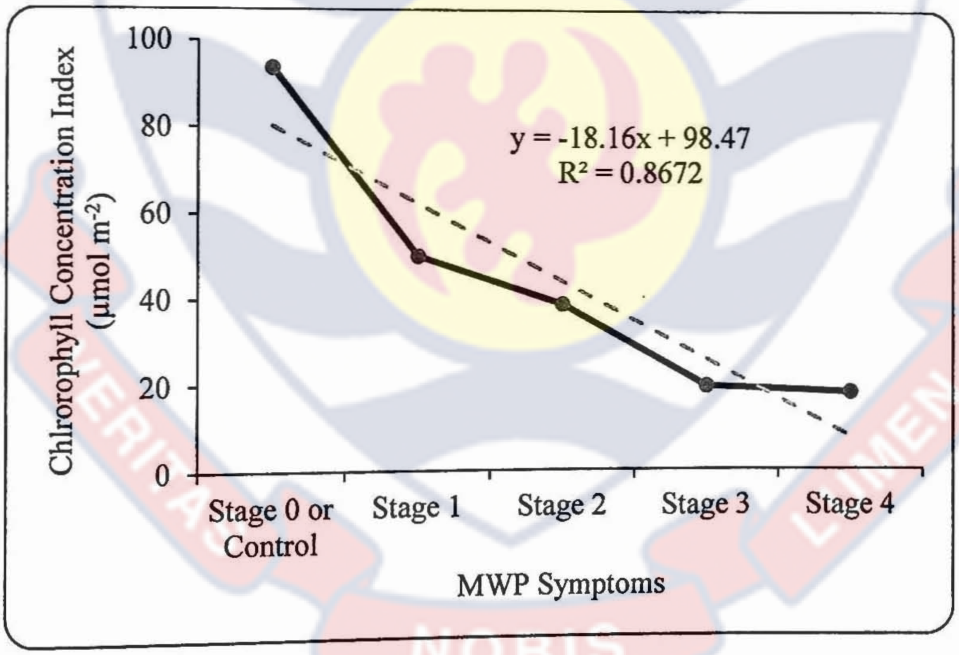

Figure 49: Chlorophyll content index of leaf samples infected with MWP in the Eastern region of Ghana

6.3.2 The Scanning Electron Microscopy (SEM) of diseased leaves of pineapples

Figures 50 to 54 are SEM images of the abaxial (lower) surfaces of leaf samples at the different disease stages of the MWP.

Stage 0- no disease symptoms seen, trichomes are intact completely covering the stomata (Figure 50).

Stage 1- a minor reddening of the leaves that runs about midway up the plant. This normally starts in small patches of plants and is referred to as the isolated wilt stage. At this stage, trichomes are beginning to weaken but have not rubbed off yet (Figure 51).

Stage 2-definite and the sudden change in colour of the leaf from red to pink. The leaf margins turn yellow and roll under, starting at the leaf tips, and trichomes begin to fall off exposing the stomata at some portions of the leaf (Figure 52).

Stage 3-the leaf tip dies back and affected leaves become limp and droop. The trichomes are completely lost exposing the location of the furrows of the leaf (Figure 53).

Stage 4- Much of the length of the affected leaves become dry., At this stage, the leaf is completely dried up so the trichomes are completely lost and a total collapse of the stomata takes place (Figure 54).

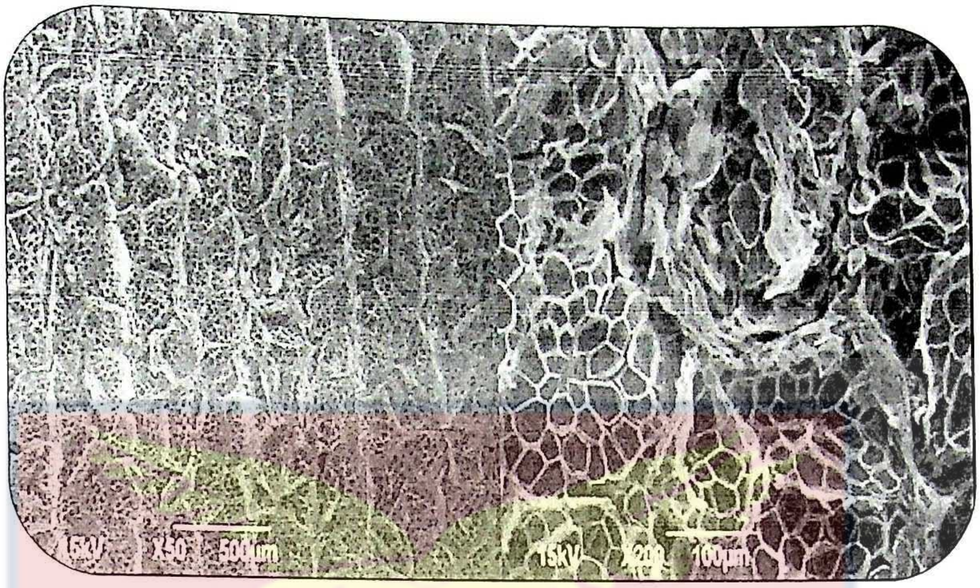

Figure 50: A SEM image of the abaxial (lower) leaf surface of stage 0 of the MWP in the study area Source: (M.T Sarpong, 2017)

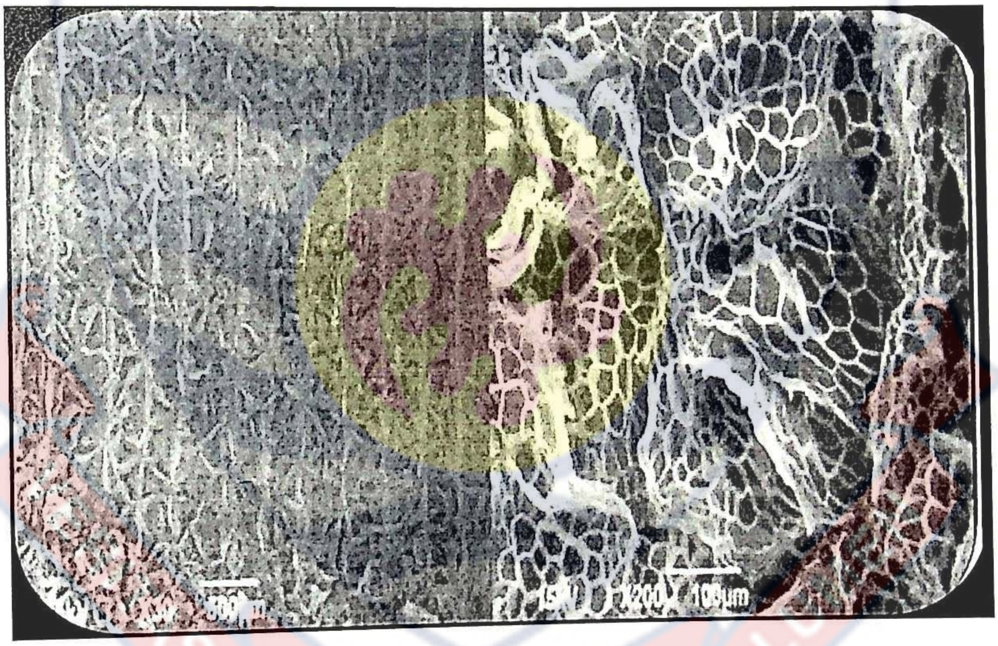

Figure 51: A SEM image of the abaxial (lower) leaf surface of stage 1 of the MWP in the study area (Photo: M. T Sarpong, 2017)

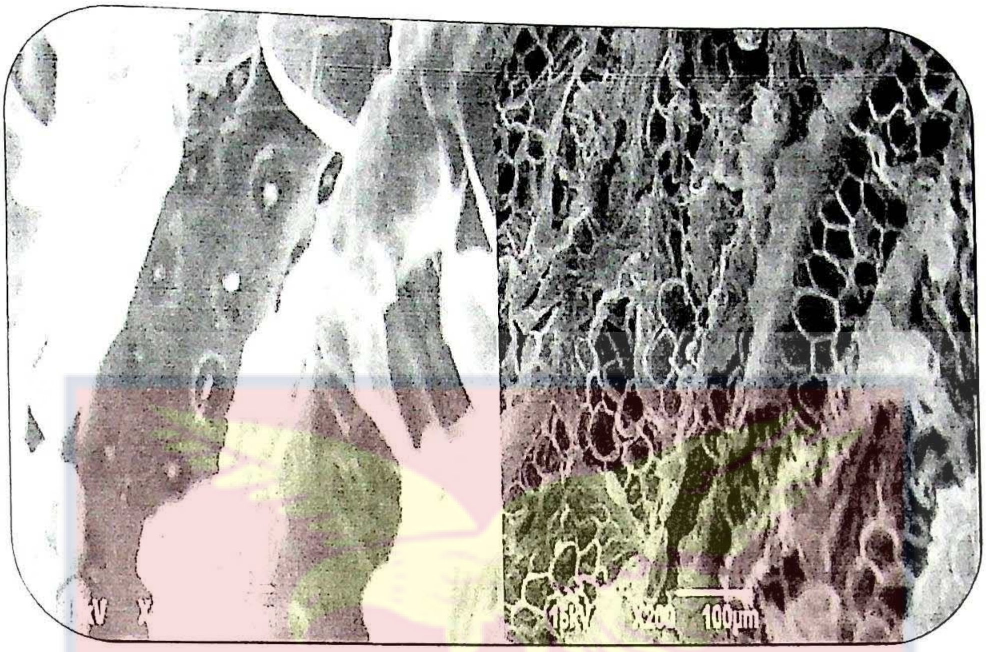

Figure 52: A SEM image of the abaxial (lower) leaf surface of stage 2 of the MWP in the study area. (Photo: M.T Sarpong, 2017)

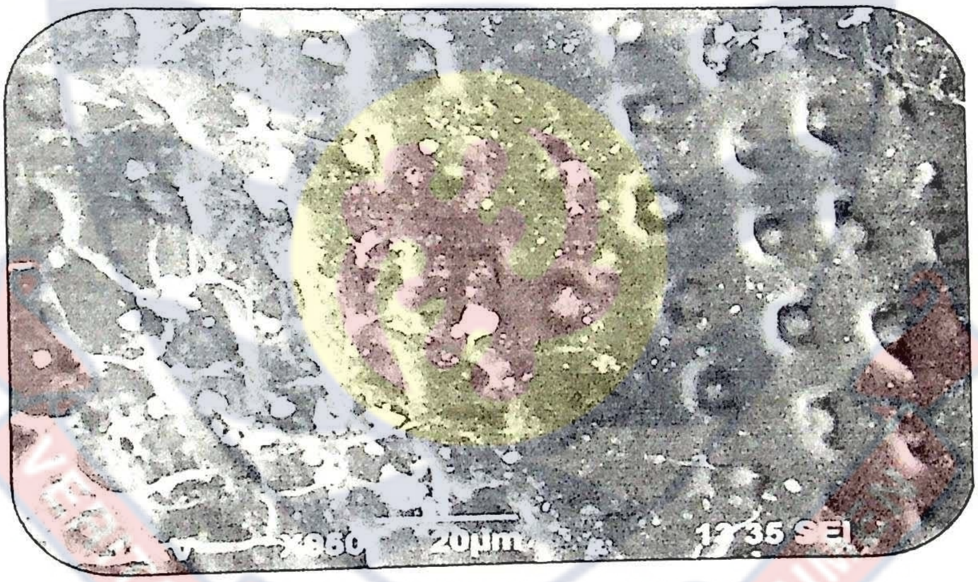

Figure 53: A SEM image of the abaxial (lower) leaf surface of stage 3 of the MWP in the study area (Photo: M.T Sarpong, 2017)

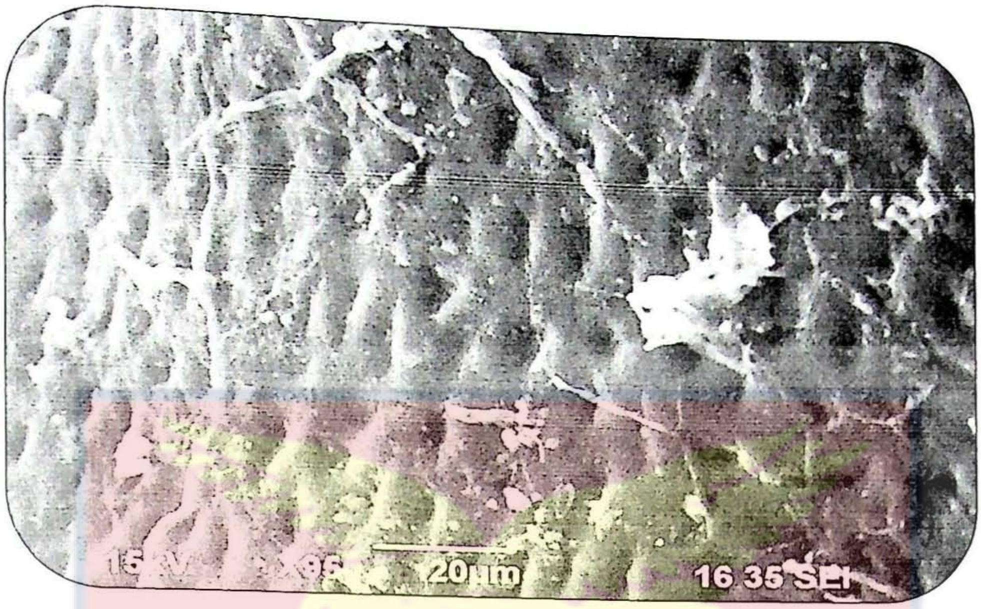

Figure 54: A SEM image of the abaxial (lower) leaf surface of stage 4 of the MWP in the study area. (Photo: M.T Sarpong 2017)

6.4 Discussion

During photosynthesis, the pineapple plant converts energy from the sun to chemical energy, which allows the pineapple to develop the tissues that support its life. It is, therefore, very important for the pineapple to continue to live and produce its food. One important aspect of its photosynthesis is the presence of chlorophyll which is responsible absorption of light for photosynthesis in the pineapple plant.

The MWP attack results in the change in colouration of the leaves a sign of the loss of the green pigmentation of the leaves. From the results of the two regions, there was chlorosis in the leaves of the pineapples as the disease progressed from one stage to the other.

For most of the pineapple varieties, the disease attack resulted in the following symptoms: a minor reddening of the leaves that runs about midway up the plant. This normally starts in small patches on the plants, and then there is a definite and sudden change in colour from red to pink. The leaf margins turn yellow and coil under, starting at the leaf tips. The leaf tip dies back and affected leaves become limp and droop and dry up for much of their length (Broadley et al., 1993; Pesticide Initiative Programme, 2005).

From a physiological standpoint, the leaf chlorophyll is a criterion of importance. The volume of solar emissions taken in by a pineapple leaf is principally a role of the foliar concentrations of photosynthetic colouration, and consequently reduced concentrations directly reduces the photosynthetic ability and later primary production (Curran et al., 1990; Fillela et al., 1995).

The change in the colouration of the leaves of the pineapple could partly be due to the feeding of the mealybug which is sap-sucking and is located on the leaves as well as in the soil within the root zones of the pineapple plant. Therefore, their feeding can lead to symptoms that will cause the roots to stop growing. The feeding of the mealybug mostly drooping of the leaves, beginning from the tips (Joy, 2010).

The feeding of the mealybug through the roots causes the plants' roots to cease growing which then results in deprivation of water for the plant. Again, when they feed on the leaves by sucking the sap leads to the plant losing moisture in both cases the prolonged deprivation of water or loss of moisture, respectively, will lead to the wilting condition. The introduction of the PMWaV into the system of the plant that make the leaves lose their turgidity results in the typical symptom of wilting in the plant. As the leaves of the plant wilts, the trichomes also gets weakened and fall off. The major function of trichomes is for absorption of water and minerals and aid in transpiration and prevent water loss the plant will transpire at a faster rate to speed the wilting of the plant which is the symptom of the MWP.

The SEM photographic images showed a continuous reduction or removal of the trichomes from the leaves of the plants as the MWP progressed from one stage to the other with an increase in severity. The final stage of the disease is the affected leaves drying up for much of their length exposing completely the stomata thereby leading to increased water loss from the leaf surfaces (abaxial and adaxial). This corroborates the findings of Yuan & Luo (2016) who reported that the trichomes located on aerial portions of pineapple leaves that surround the stomata protect the pineapple from excessive water loss, high temperature, radiation, and UV light.

6.5 Conclusions

i. The feeding by the mealybugs and infection by the PMWaV are accountable for the loss of the chlorophyll in the plant leaves thereby leading to the eventual wilting of the plants.

ii. The loss of the trichomes in the MWP attack exposes the plants to water loss due to increased transpiration, and poor supply of minerals because the trichomes aid in the absorption of the needed minerals by the plants.

6.6 Recommendations

i. The prevention of the MWP and the control of the mealybugs and symbiont ants is very important in the management of the MWP in pineapples and therefore farmers should take MWP prevention very seriously.

ii. The issue of some of the farmers finding it difficult to uproot and destroy the infected plants because of the belief that the plants could recover after some time is counterproductive and should be discouraged because there is proof that even when the plants recover, they still carry the virus and could be the source of infection in your next cropping season when you use planting materials coming from these recovered mother plants.

CHAPTER SEVEN

7 MANAGEMENT STRATEGIES FOR MINIMIZING INCIDENCES OF VIRUS SPREAD AND MWP IN THE CENTRAL AND EASTERN REGIONS OF GHANA

7.1 Introduction

In most parts of the pineapple growing parts of the world, the problem of the MWP has been a difficult one because of the role played by the mealybugs and the ants in the spread of the disease. The young and the adult mealybugs excrete the honeydew which attracts the ants and serves as a mould that causes serious smutting of the leaves and the fruits.

The frequent use of insecticides and labour in the management of the mealybugs and for that matter the MWP makes the cost of control or management to the farmer still a great one. Other recommended alternative methods such as removal of heavily infested plants with pineapple mealybug or PMWaV and burning (Mau and Kessing, 2007; Flint, 2016). This alternative method of management lead to the loss of many plants by farmers, therefore, make it a difficult decision to take by many farmers. Most farmers easily confuse the wilting from the MWP, and wilt caused by other environmental conditions such as water stress, therefore, they allow wilted plants that are because of the MWP to stay on for a long time to serve as a reservoir for the perpetuating of the disease over the years.

Approved chemicals such as ants' bait for the control of the ants that tend the mealybugs have been efficacious in controlling the mealybug population (Mau and Kessing, 2007).

It is worth noting that control of mealybugs with insecticides is a very difficult task because the waxy coatings of the mealybugs fend off most of the insecticides whose mode of action is by contact. The typical characteristic of the mealybug to aggregate in difficult to reach sites such as within the soil, at the bases of fruits, at the basal portions of the leaves make them very hard to reach with insecticides. They lay eggs that are shielded by the waxy filamentous oozing of the ovisac, and this makes it impracticable to get to with insecticides. The mealybugs again can easily develop resistance to most insecticides in a short time of continuous use (Flint, 2016).

To suppress the population of mealybugs, especially the younger nymphs which have less of the waxy coating accumulation, one can employ the use of insecticidal soaps, horticultural oil, or neem oil insecticides that is applied directly on mealybugs (Flint, 2016).

Many natural enemies of the mealybugs feed on and kill mealybugs. These beneficial insects generally can be relied upon to keep numbers at tolerable levels. Mealybugs have many natural enemies, including parasitic wasps that lay their eggs in or on developing mealybugs, then feed on and kill the mealybugs when they hatch. Species in the genera contain parasites and parasitoids for mealybugs, *Coccophagus, Leptomastix, Allotropa, Pseudaphycus,* and *Acerophagus*. Lady beetles, green and brown lacewings, spiders, minute pirate bugs, and larvae of predaceous midges are all natural predators of mealybugs. (Flint, 2016).

Auspiciously, the ants that tend the mealybug and serve as an important source for the protection of the mealybug population could also be targeted to be eliminated and by so doing the mealybugs are exposed to their natural enemies who will suppress their population naturally. Rather than actively handling mealybugs, the physical and cultural methods used to manage mealybug wilt have been aimed at decreasing the number of ants. Since insecticides are used most effectively and selectively in this form, bait preparations are heavily used in pineapple fields to control ants (Jahn et al., 2003).

It is vital to note that, since ants play such an important role in the spread of the mealybug from one plant to the next, ant management is a critical approach.

7.2 Materials and Methods

In developing the appropriate strategies aimed at the effective management of the MWP in the Central and Eastern regions of Ghana two experiments were set up: an experiment to evaluate the pre- and post-planting activities on three planting materials -crowns, slips and suckers over 58 weeks of growth was conducted. 9 treatments and 4 replications was established on a 0.1-hectare land with 5,000 plants and an estimated 550 plants per treatment. The nine treatments were as follows:

T_1. crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_2. slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_3. suckers dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_4. farmers practice with crowns (no dipping and one foliar application of cypermethrin solution)

T_5. farmers practice with slips (no dipping and one foliar application of cypermethrin)

T_6. farmers practice with suckers (no dipping and one foliar application of cypermethrin)

7. Control with crowns (no insecticide application)
8. Control with slips (no insecticide application)
9. Control with suckers (no insecticide application)

Except for the farmers' practice, cypermethrin treatments were repeated on a bi-monthly basis. Choice of the treatments was based on whether they were approved for use on pineapples (The European Commission, 2018) as either organic or inorganic/conventional. Monitoring for the presence of ants and wind-borne mealybugs were combined with an actual visual assessment of the individual plants. The extent of the mealybug and ant infestation, the number of the pesticide applications, percentage incidence and severity of MWP and ant species data were recorded at bi-weekly intervals for fifty-eight weeks after planting.

An experiment designed with seven treatments and five replications was established on a 0.10 hectare land with a total of five thousand plants and an estimated seven hundred and fifteen plants per treatment. The sucker was the planting material used as it is the standard and preferred planting material by most farmers. The seven treatments were as follows:

T_1. suckers with up to three foliar applications of neem oil

T_2. suckers with up to three foliar applications of white vinegar

T_3. suckers with up to three foliar applications of cypermethrin

T_4. suckers with up to three foliar applications of deltamethrin

T_5. suckers with up to three amdro ant bait applied as a broadcast

T_6. farmers practice (one foliar application of cypermethrin)

7. Control (application of water only)

Except for the farmers' practice and the control, all other treatments were repeated on a bi-monthly basis. Choice of the treatments was based on whether they are approved for use in organic or conventional pineapple production. Deltamethrin and cypermethrin are two of the insecticides commonly used and available for farmers that are approved by the European Commission for use on pineapples (The European Commission, 2018).

Monitoring the presence of ants and mealybugs were conducted with an actual visual assessment of the individual plants within the various treatments.

The extent of the mealybugs and ants infestation, the number of the treatments applications, incidences and severity of MWP and ant species data were recorded at bi-weekly intervals up to the fruiting stage that was 58 weeks after planting.

At the maturity of the fruits at week 58, Fisher's protected least significant difference test for the yield of the pineapples was conducted to determine the treatment with the best yield in terms of managing the MWP.

7.3 Results

7.3.1 Percentage Incidence of MWP on pineapple plants after treatments

Figure 55 is a bar chart of the percentage incidence of MWP on pineapple plants after treatments. At week 4 there was an incidence of the MWP in all the treatments except treatments 1 and 2. Incidence was highest (1.5%) of planting materials that had no treatment. There was a significant difference between treatment 6 and treatments 4 and 5. In week 12 the control with suckers had a higher percentage incidence of 2.5. There were significant differences between treatment 4 and treatment 3 and the controls with suckers and slips. There was no incidence of the MWP in treatment 1 from week 4 to week 20. In week 28 incidence of the MWP first showed in treatment 1 with the lowest percentage of 0.25. There was a significant difference between treatment 4 and 3 in week 28 only while a higher percentage of incidence in the control was found in slips with 2%.

It is seen that there was a decrease in the incidence of the control with slips and control with suckers from 2.25% and 2.75% to 2% from week 20 to week 28 respectively. However, both the control with slips and control with suckers still recorded the highest incidence in week 28. There was no significant difference among the treatments in week 36 to week 58 with the highest incidence in the control (12%) followed by the control with slips (9%). The lowest incidence was observed on treatment 1 (1%) followed by the second lowest in treatment 2 (2%) (Figure 55)

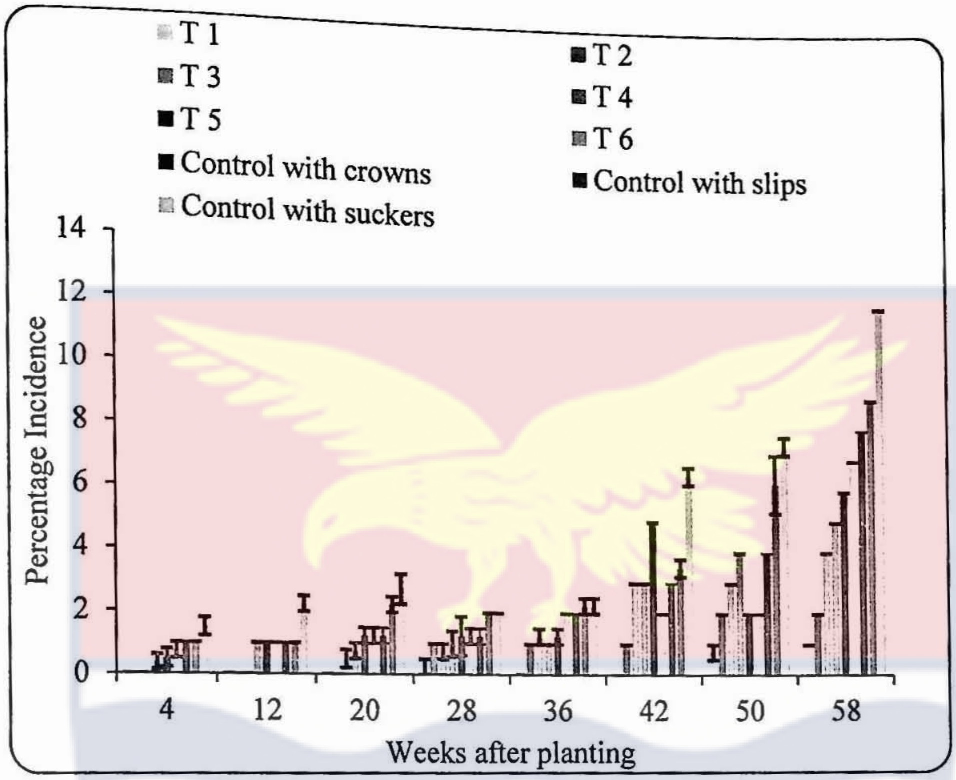

Figure 55: Percentage incidence of MWP on pineapple plants after treatment

T_1. crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_2. slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_3. suckers dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_4. farmers practice with crowns (no dipping and one foliar application of cypermethrin solution)

T_5. farmers practice with slips (no dipping and one foliar application of cypermethrin)

T_6. farmers practice with suckers (no dipping and one foliar application of cypermethrin)

7. Control with crowns (no insecticide application)
8. Control with slips (no insecticide application)
9. Control with suckers (no insecticide application)

7.3.2 Percentage incidence of MWP in the planting materials

Figure 56 is a representation of the percentage incidence observed in the different planting materials. Percentage incidence was high in plants produced by suckers throughout the period of growth (7.67%), the incidence was lowest (4.67%) in plants produced by crowns. There were significant differences between suckers and slips and suckers and crowns in week 4 and between suckers and slips in week 20. In weeks 42-58, there were significant differences between the slips and the crowns.

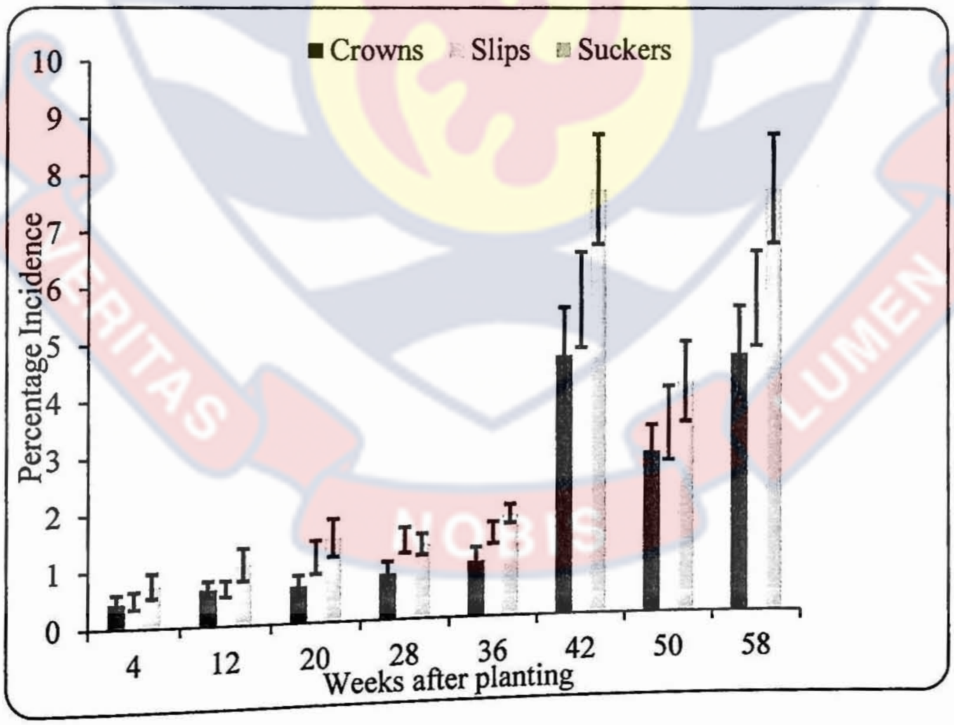

Figure 56: Percentage incidence of MWP of the planting materials weeks after planting

For planting materials that were drenched up to three times after planting at two-monthly intervals the lowest percentage incidence of 2% was observed at week 58 compared to the other two –no pre-planting dipping and only once drenching with insecticide solution after planting with 9% and 6%, respectively, at week 58. There were no significant differences among the three treatments in all the weeks. It can be seen that the MWP incidence occurred at 20 weeks after planting, when the planting materials were drenched 3 times after planting, compared to the other two treatments where the disease occurred at week 4 (Figure 57).

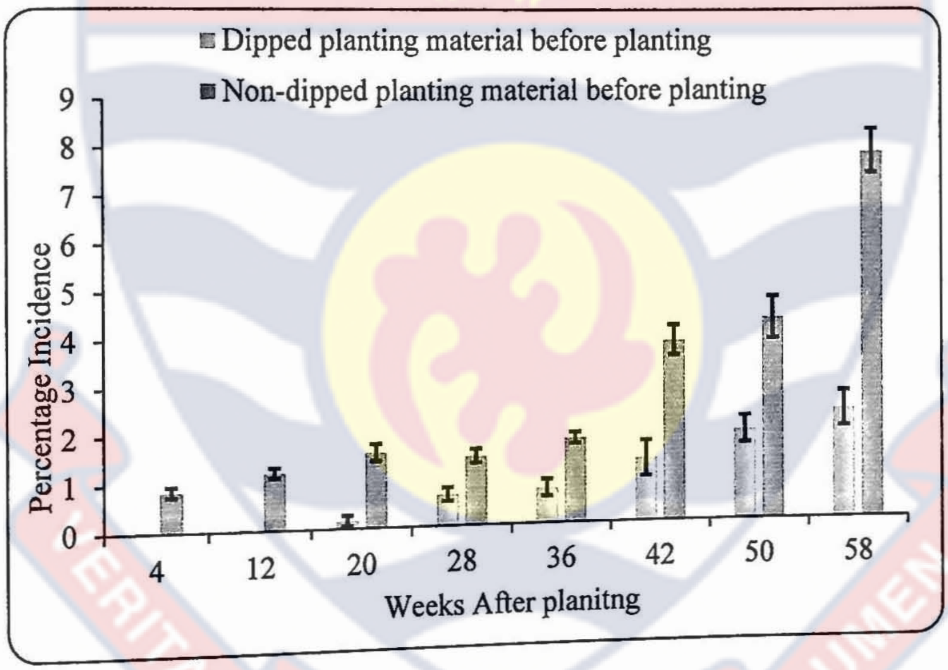

Figure 57: Percentage incidence of MWP after post-planting insecticide application weeks after planting

There was no disease incidence of disease in the pre-planting dipping before post-planting application from weeks 4 to 12. Percentage incidence for the un-dipped planting materials before planting generally increased from week 4 except in week 28 where there was a drop from 1.58% to 1.46% compared to week 20.

There was no significant differences between the two treatments throughout the 58 weeks (Figure 58).

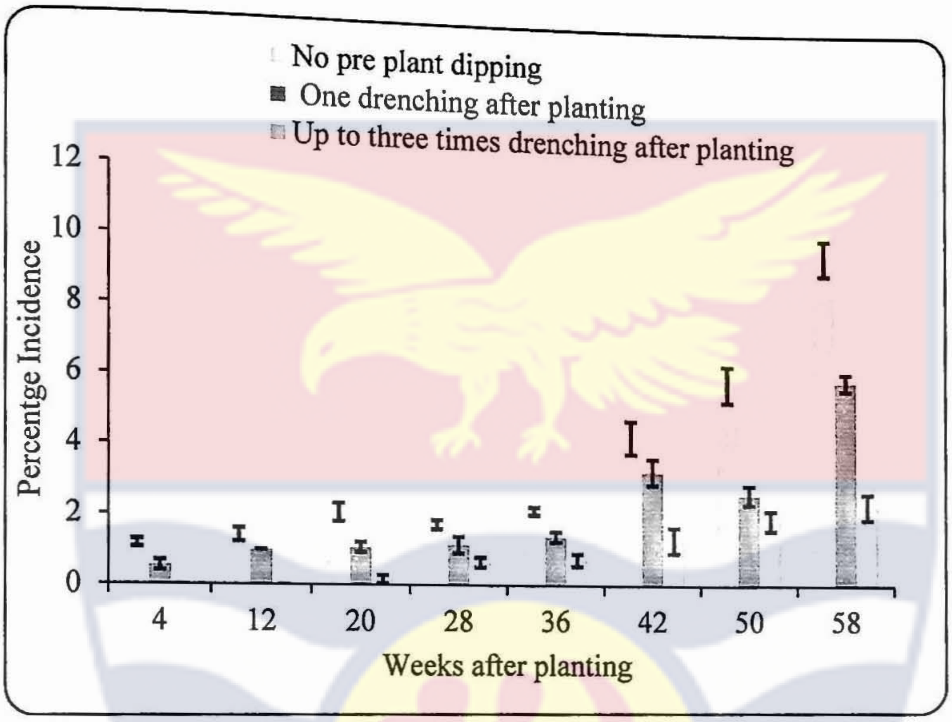

Figure 58: Percentage incidence of MWP among planting materials that were dipped in insecticide solution before planting

7.3.3 Mean severity of the MWP under the nine treatments combinations

Figure 59 is a bar chart of the mean severity of the MWP by influencing various treatment combinations over the period of growth, 58 weeks. From the chart, at four weeks after planting the mean severity of the MWP had started to rise in all the treatments except treatments 1 (crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin) and 2 (slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin). The severity in these two situations was zero. Controls with crowns, slips, and suckers all recorded a mean severity of 1.

There were significant differences between treatment 6 (farmers practice with suckers -no dipping and one foliar application of cypermethrin) and 4 (farmers practice with crowns -no dipping and one foliar application of cypermethrin solution) and 5 (farmers practice with slips -no dipping and one foliar application of cypermethrin).

In week 12 the control with suckers showed the highest mean of 1.5 while all the others recorded 1 except treatments 1 (crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin) and 2 (slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin) which had no sign of disease.

Treatment 4 recorded the lowest mean severity score of 0.75 in week 20 with treatments 1 and 2 showing no disease symptoms. By week 28 treatment 1 had had a severity of 0.25 while all other treatments had recorded a mean severity score of 1. It is, however, noted that the severity of the disease where nothing was applied had dropped from 1.5 to 1.

By the end of week 36 which represented the pre-flower induction growth stage of the plants, the mean severity of disease in treatment 1 had dropped to 0 and treatment 4 had risen to 1 while treatments 2, 3, 4, 5 and, 6 had maintained the mean severity score of 1. The severity score for the controls with slips and suckers had risen to 1.25. Week 42 marked two weeks into the post-flower induction growth stage of the plants and in this treatment week, 1 had 0 while treatment 2 of control with crowns maintained their mean severity of 1. The control with suckers recorded the highest mean severity of 2.5 and the control with slips still maintained the mean severity score of 1.25 from week 36. By week 58 which was the fruiting stage in the post flower induction stage of the growth of the pineapples, it was seen that mean severity for all the treatments had shown various degrees of the MWP but treatment 1 recorded the lowest mean severity of 1 and treatments 5 together with controls with crowns, slips, and suckers all recording a mean severity score of 4.4, being the highest.

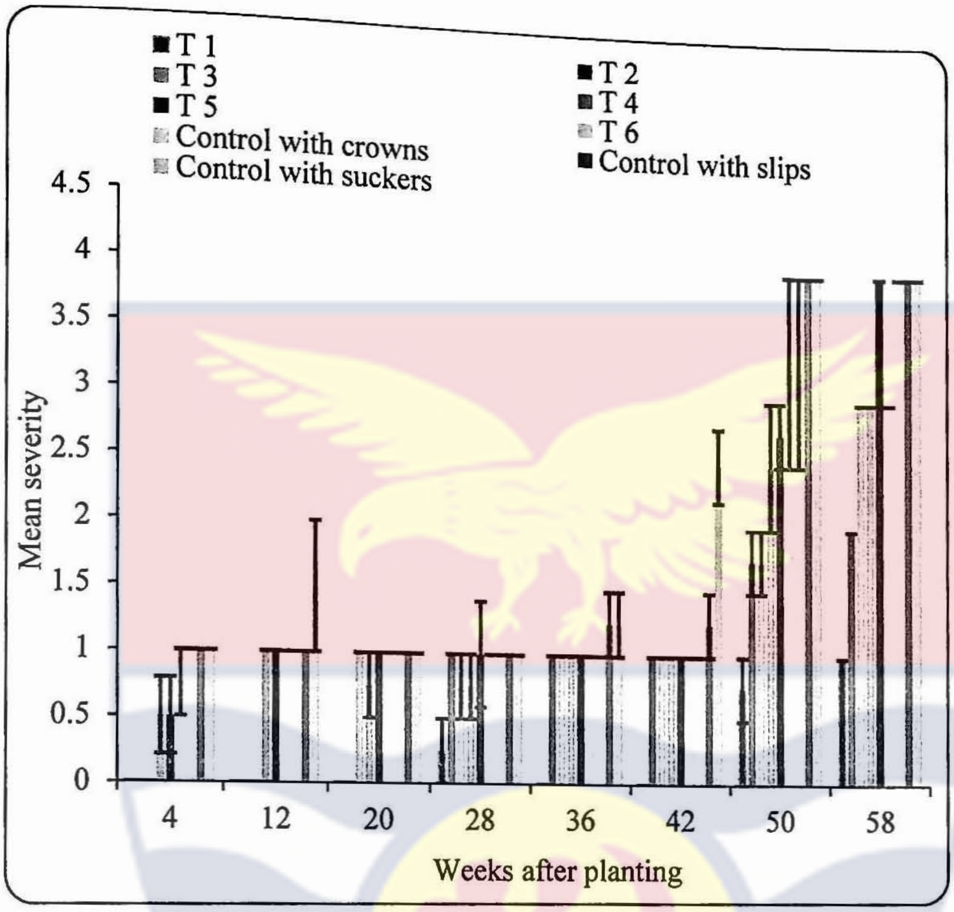

Figure 59: Mean severity of MWP of the various treatments after the weeks after planting

T_1. crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_2. slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_3. suckers dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_4. farmers practice with crowns (no dipping and one foliar application of cypermethrin solution)

T_5. farmers practice with slips (no dipping and one foliar application of cypermethrin)

T6. farmers practice with suckers (no dipping and one foliar application of cypermethrin)

7. Control with crowns (no insecticide application)

8. Control with slips (no insecticide application)

9. Control with suckers (no insecticide application)

7.3.4 Mean severity of MWP post-planting insecticide application

Figure 60 is the bar chart of the mean severity of MWP for post-planting insecticide application over the period of growth, 58 weeks. There were planting materials that were: not dipped in an insecticide solution before the planting was done, drenched only once after the planting, and those that were drenched up to three times at two-monthly intervals before the post-flower induction growth stage. From week 4 to week 36 that represented the pre-flowering stage of the plants there were no significant differences among the various treatments, however, it was noted that planting materials that were drenched in insecticide solution up to three times at two-monthly intervals showed the lowest mean severity from week 20 to week 36. The treatment in which no pre-planting dipping into insecticide solution was done showed the highest mean severity throughout the pre-flower induction stage. Weeks 42-58 represented the post-flower induction stage of the plant growth and from that stage, the treatment with no pre-plating dipping into insecticide solution had the maximum mean severity score of 4 by week 58. The planting materials that were drenched only with insecticide once after the planting recorded a mean severity score of 3.33 and planting materials with up to three times drenching with insecticide solution after planting recorded a mean severity of 2.

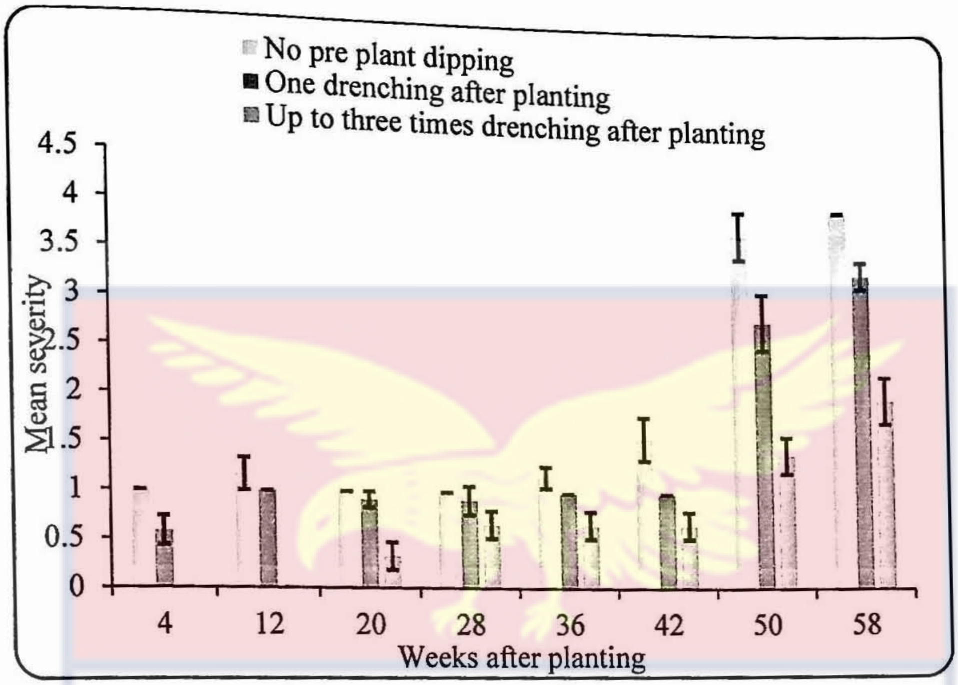

Figure 60: Mean severity of MWP after post-planting insecticide application

7.3.5 Mean severity of pineapple plants propagated from different vegetative parts

The planting materials used were the crowns, slips, and suckers. The mean severity generally increased from week 4 to week 58 for all the propagating materials. By the end of the pre-flowering stage (week 36) the crowns had recorded the lowest mean severity of 0.67 and this was significantly lower than the suckers and the slips. At fruit maturity (week 58), the mean severities for both suckers and slips were at 3.33 each whereas that for the crowns was still the lowest at 2.6. This difference was, however, not significant (Figure 61).

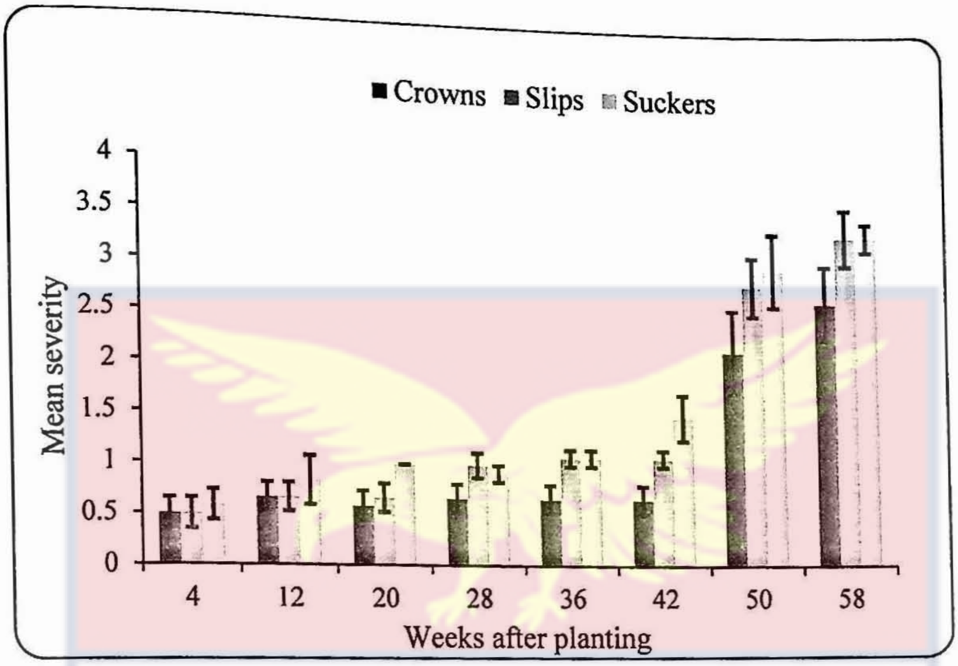

Figure 61: Mean severity of MWP of planting materials weeks after planting

7.3.6 Mean severity of MWP on pineapple planting materials dipped in insecticide solution before planting

The disease began to increase at week 4 for planting materials that were not dipped in an insecticide solution before planting with a severity score of 0.79 progressing to 3.67 at week 58 (Figure 62).

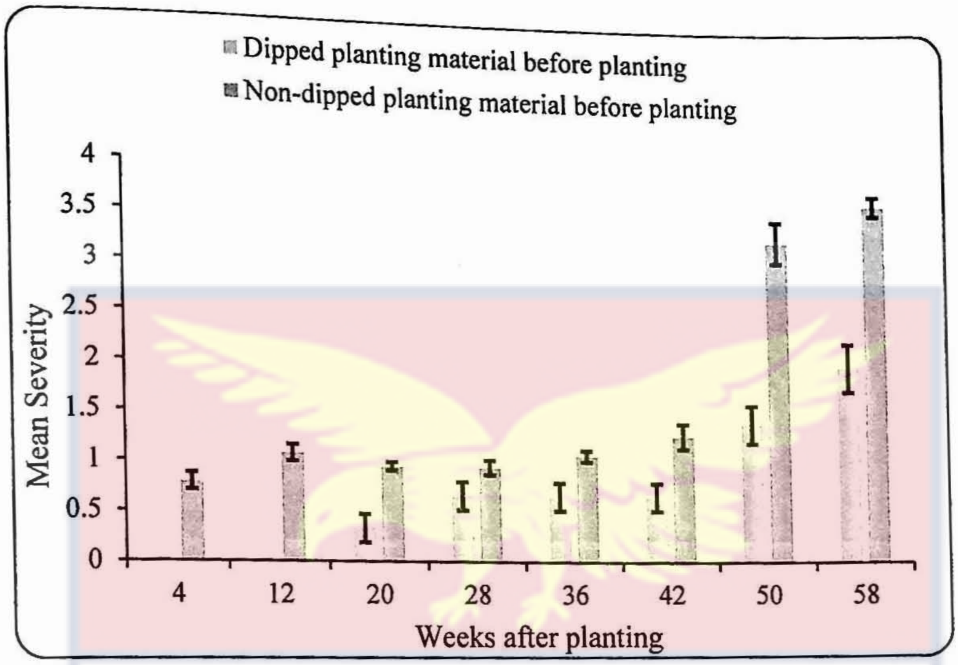

Figure 62: Mean severity of MWP of planting materials following insecticide applications before planning

7.3.7 Mean ant population per treatment

The mean ant population per each treatment of the pineapples is presented in Figure 63. The highest mean population of ants per plant was in treatment 4 in week 50 where a record of 19 ants was found to be present per plant. There was no significant difference among the treatments from week 4 to 58. There was no record of the presence of the ants on plants in treatment 1 from week 4 to 50. It was in week 58 that an average of 5 ants per plant in treatment 1 was observed.

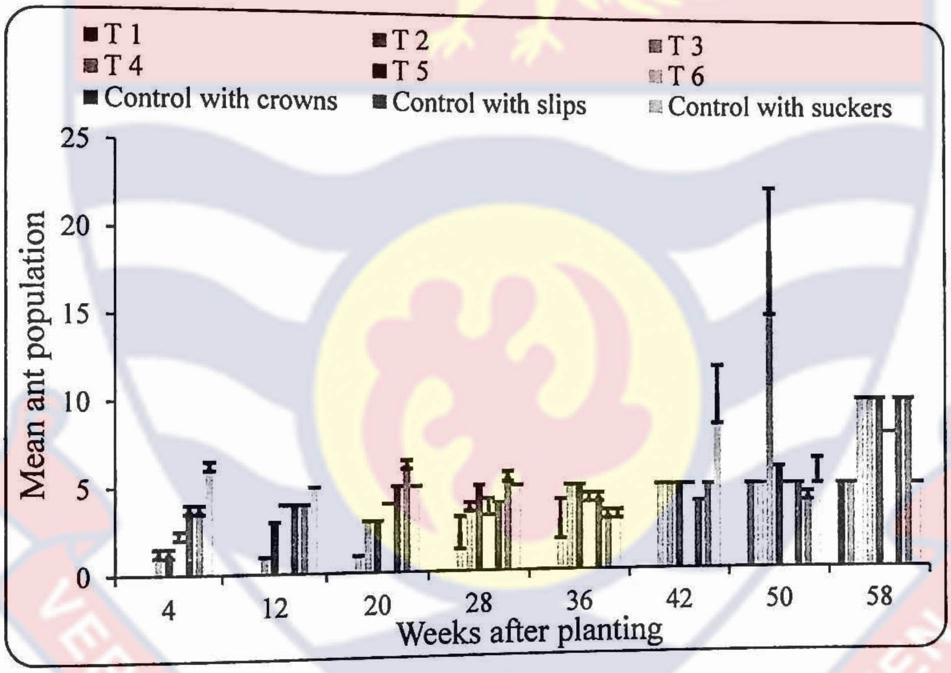

Figure 63: Mean of the ant population per treatment after weeks after planting

T_1. crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_2. slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_3. suckers dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_4. farmers practice with crowns (no dipping and one foliar application of cypermethrin solution)

T_5. farmers practice with slips (no dipping and one foliar application of cypermethrin)

T_6. farmers practice with suckers (no dipping and one foliar application of cypermethrin)

7. Control with crowns (no insecticide application)
8. Control with slips (no insecticide application)
9. Control with suckers (no insecticide application)

7.3.8 Mean ant population on the planting materials

The mean ant population recorded per the three different planting materials is graphically represented in Figure 64. In week 4 there was a significant difference between the population of ants on suckers and those on crowns and slips. Through the 58 weeks of planting, it is seen that there was a steady rise in the population of the ants on the sucker planting material until week 50 where the population dropped from 6.75 to 5.25 and rose again to 7.67 in week 58 but was still lower than those on crowns and slips. There was no significant difference in mean ant population on suckers and crowns, crown and slips but a highly significant difference between mean ant population on crowns and suckers in weeks 12, 20 and 28 respectively. There was high significant differences in mean ant population between suckers and crowns and suckers and slips but no significant difference between population on crowns and slips in week 42. In week 50 and 58 there was significant differences in the mean ant population among the three planting materials.

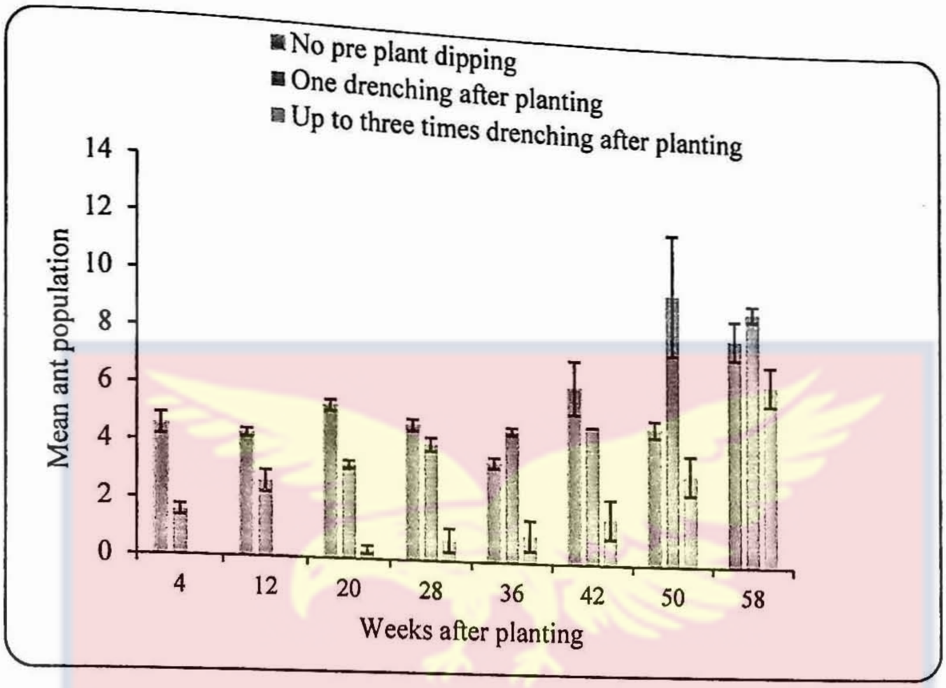

Figure 65: Mean ant population after insecticide application post

7.3.10 Mean ant population on planting materials dipped in insecticide solution before planting

There were no significant differences between the two treatments throughout the 58 weeks of the growth of the plants as seen in Figure 66. At weeks 4 and 12, there were no ants on planting materials that were dipped in the insecticide solution before planting. On the other hand, the presence of ants was recorded from the week after planting while planting materials that were not dipped started recoding presence of the ants from week 1 and kept rising with each week of observation until week 36 where there was a drop in the population from 4.5 to 4.17 per plant and rose again to 5.71 in week 42 up to 8.83. By week 58 the planting materials that were dipped in the insecticide solution before planting recorded 6.67.

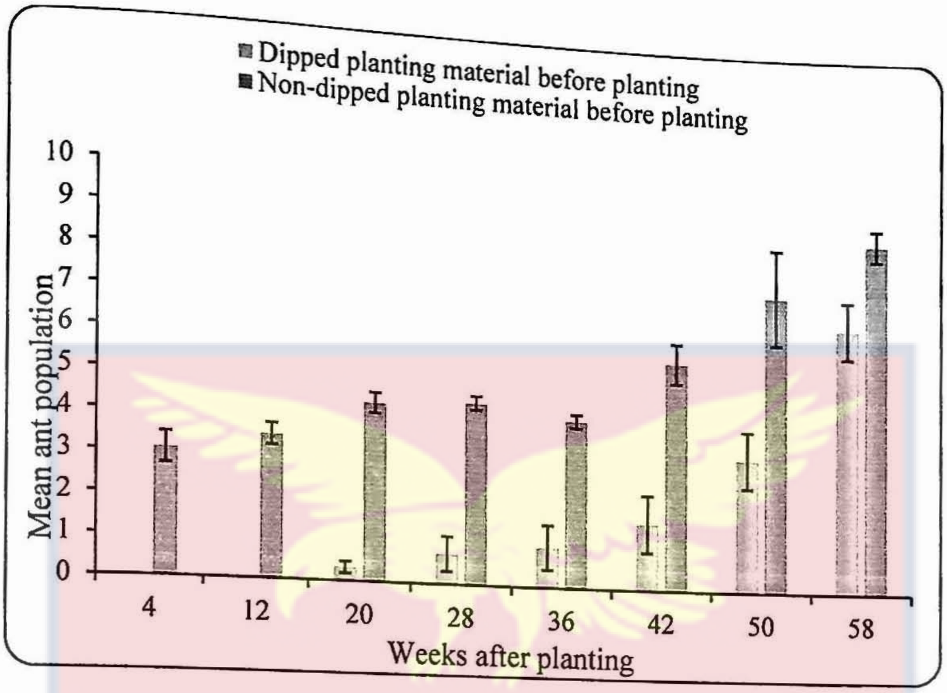

Figure 66: Mean ant population for dipped and non-dipped planting materials before planting

7.3.11 Mean mealybug population per plants weeks post-planting

In Figure 67, the mean mealybug population in week four was high in the control with slips and suckers. There was a significant difference between the mean mealybug population in treatments 5 and 6 but there were no significant differences among all the other treatments. In week 12 and week 20, there were no significant differences among all the treatments. However, it was seen that the mean mealybug population was higher in the control with slips than the control with suckers in week 20.

In week 28, significant differences were observed between treatments 5 and 4, 5 and 3, and 4 and 3, and the population in the control with slips was again higher in week 28 than all the other treatments. Week 36 which marked the end of the pre-flower induction stage of growth of the plants saw treatment 6 with the highest mean population of 6 mealybugs per plant while treatment 3 had the lowest mean population of the mealybug.

Week 42 which is two weeks into the post flower induction stage of growth of the pineapple registered the highest mealybug population in the control (7) while treatment 5 recorded the lowest mean population of 4. There was, however, no significant difference among all the treatments. Treatment 4 had the highest mean mealybug population with 16.25 followed by treatment 3 and control with suckers (Figure 67).

In week 58, treatment 1 and treatment 2 had the lowest mean mealybug population of 5 per plant. The highest mean mealybug population of 18.5 per plant was recorded on the control with suckers and there was a significant difference between the control with suckers and the control with slips and the control with crowns (Figure 67).

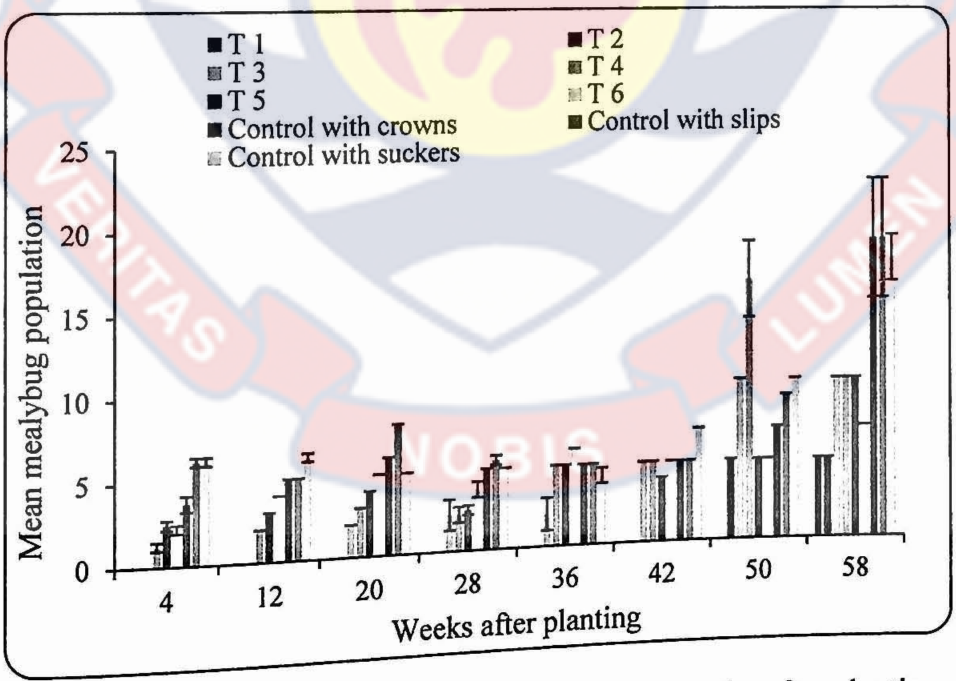

Figure 67: Mean mealybug population per treatment weeks after planting

T_1. crowns dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_2. slips dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_3. suckers dipped in solution of cypermethrin before planting and with up to three foliar applications of the cypermethrin

T_4. farmers practice with crowns (no dipping and one foliar application of cypermethrin solution)

T_5. farmers practice with slips (no dipping and one foliar application of cypermethrin)

T_6. farmers practice with suckers (no dipping and one foliar application of cypermethrin)

7. Control with crowns (no insecticide application)
8. Control with slips (no insecticide application)
9. Control with suckers (no insecticide application)

7.3.12 Mean mealybug population on the three planting materials

Mealybug population generally increases in the 3 different planting materials from week 4 to 58. A significantly higher population was observed at weeks 50 to 58 compared to the population at weeks 4 to 42. While generally population did not vary among plants cultivated with the 3 planting materials at week 28 there was a significantly higher population on plants cultivated with suckers than with crowns and slips. The population was, however, like those observed on plants cultivated with crowns and slips ate week 50 (Figure 68).

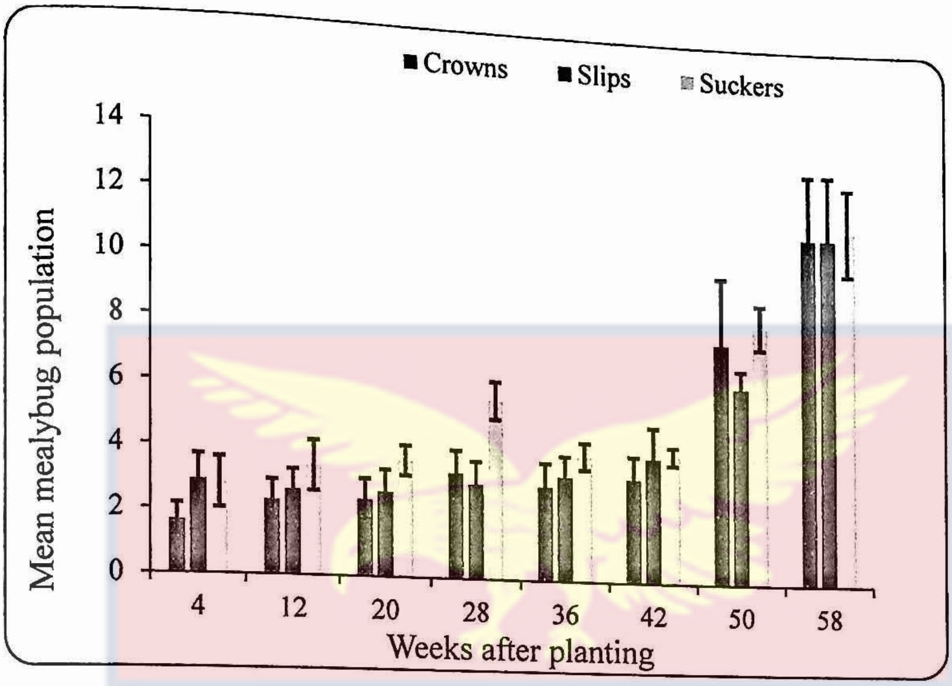

Figure 68: Mean mealybug population per planting material the weeks after planting

7.3.13 Mean mealybug population after insecticide application after planting

By the end of the pre-flower induction stage (week 36) planting materials that were drenched three times recorded the least mealybug population of 0.67. There were no significant differences among the no pre-plant dipping, once drenching and three times drenching after planting. At the fruiting stage (week 58) the planting materials that were not dipped in insecticide solution before planting recorded the highest mean mealybug population of 18.33 (Figure 69).

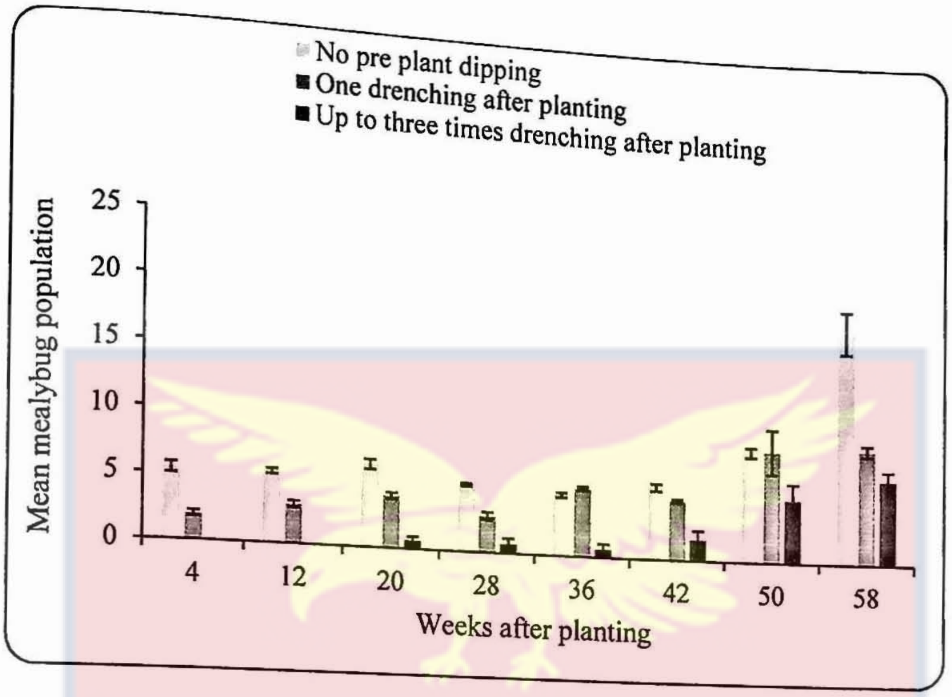

Figure 69: Mean mealybug population after insecticide application post-planting weeks

7.3.14 Mean mealybug population on dipped and non-dipped planting materials

There was no mealybugs on planting materials that were dipped in insecticide solution in week 4 and 12. By week 36 mealybug population on planting materials that were dipped in insecticide solution before planting was 0.67. Generally, the population of mealybug on planting materials that were not dipped in insecticide solution were high compared to those that were dipped. At fruit maturity (week 58), a mean population of 13.67 per plant was recorded in the plants that were not dipped in insecticide solution before planting while plants that were dipped in insecticide solution before planting had a mean population per plant of 6.67 per plant (Figure 70).

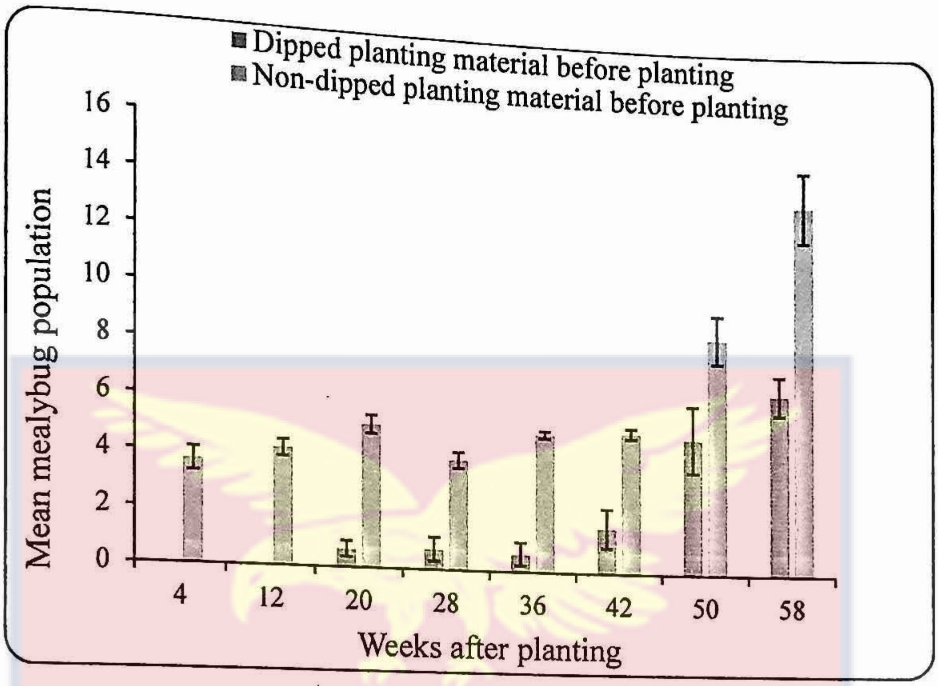

Figure 70: Mean mealybug population on dipped and non-dipped planting materials before planting

7.3.15 Percentage incidence of MWP after the treatments

Figure 71 represent data on the incidence of the MWP after the treatments. It can be seen that that was a high variation among treatments to disease incidence. The least incidence occurred on suckers with up to three foliar applications of deltamethrin (T_4) over the 58 weeks and was significantly different from the rest. T_1 (suckers with up to three foliar applications of neem oil) and T_2 (suckers with up to three foliar applications of white vinegar) were similar but significantly different from treatment three (suckers with up to three applications of cypermethrin). T_5 (suckers with up to three amdro ant bait applied as a broadcast) and T_6 [Control (application of water only)] were not significantly different with the control recording the highest percentage incidence 5.25% followed by treatment 5 with 3.44%.

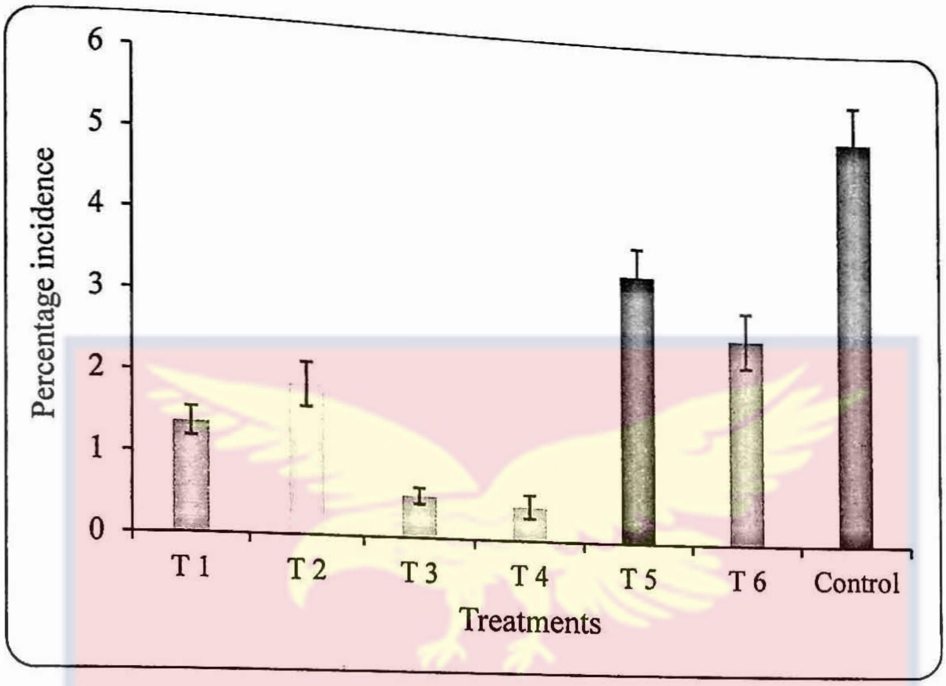

Figure 71: Percentage incidence of MWP after the treatments

T_1. suckers with up to three foliar applications of neem oil

T_2. suckers with up to three foliar applications of white vinegar

T_3. suckers with up to three foliar applications of cypermethrin

T_4. suckers with up to three foliar applications of deltamethrin

T_5. suckers with up to three amdro ant bait applied as a broadcast

T_6. farmers practice (one foliar application of cypermethrin)

7. Control (application of water only)

7.3.16 Mean severity of MWP after the treatments

Figure 72 presents the representation of the data on mean severity after the treatment of pineapple plants grown from the different planting materials. Treatment 4 (suckers with up to three foliar applications of deltamethrin) performed better in managing the disease. Severity score was 0.375 Treatment 5 (suckers with up to three Amdro ant bait applied as broadcast) was the second-worst performer with a severity score of 2.594 apart from the control which scored with a severity score of 3.094.

There was high variation among the treatments. The least severity occurred on suckers with up to three foliar applications of deltamethrin (T_4) over the 58 weeks and was significantly different from the rest of the treatments. T_1 (suckers with up to three foliar applications of neem oil) and T_2 (suckers with up to three foliar applications of white vinegar) were similar but significantly different from treatment three (suckers with up to three applications of cypermethrin).

T_5 (suckers with up to three amdro ant bait applied as a broadcast) and T_6 [Control (application of water only] were not significantly different.

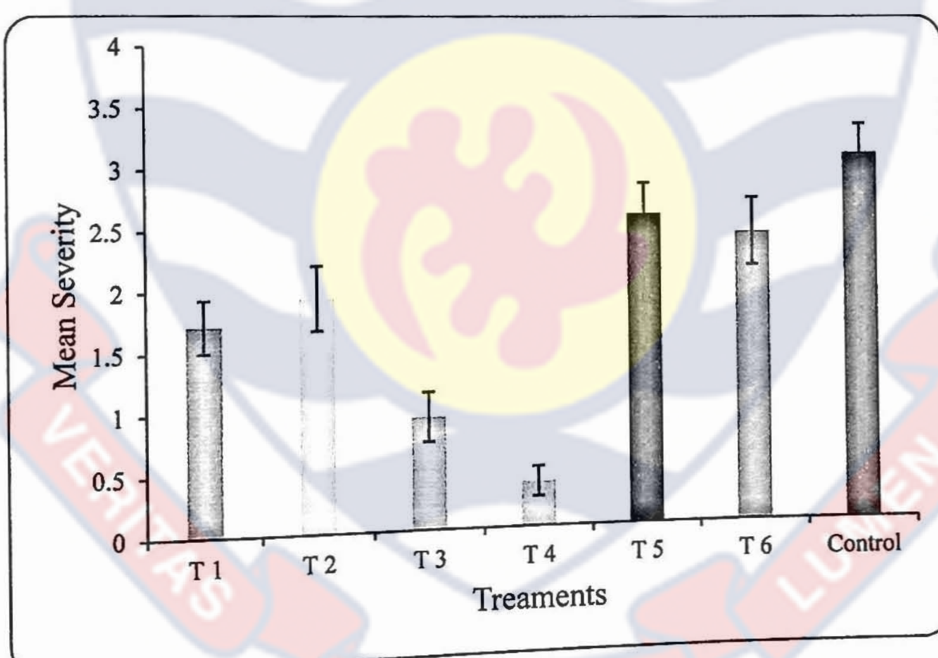

Figure 72: Mean severity of MWP after the treatments

T_1. suckers with up to three foliar applications of neem oil

T_2. suckers with up to three foliar applications of white vinegar

T_3. suckers with up to three foliar applications of cypermethrin

T_4. suckers with up to three foliar applications of deltamethrin

T_5. suckers with up to three amdro ant bait applied as a broadcast

T_6. farmers practice (one foliar application of cypermethrin)

7. Control (application of water only)

7.3.17 Mean ant population after the treatments

Figure 73 presents the chart for the mean ant population on the pineapple plants after the application of the treatments, there was high variations in the mean ant population.

Treatment 2 (suckers with up to three foliar applications of white vinegar) had the highest mean ant population of 4.469 apart from the control. Treatment 4, however, recorded the least mean population of ants per plant of 0.5. There were, however, significant differences among treatment 1 (suckers with up to three foliar applications of neem oil), treatment 2 (suckers with up to three foliar applications of white vinegar), treatment 5 (suckers with up to three Amdro ant bait applied as broadcast) and 6 (farmers practice -one foliar application of cypermethrin) (Figure 73).

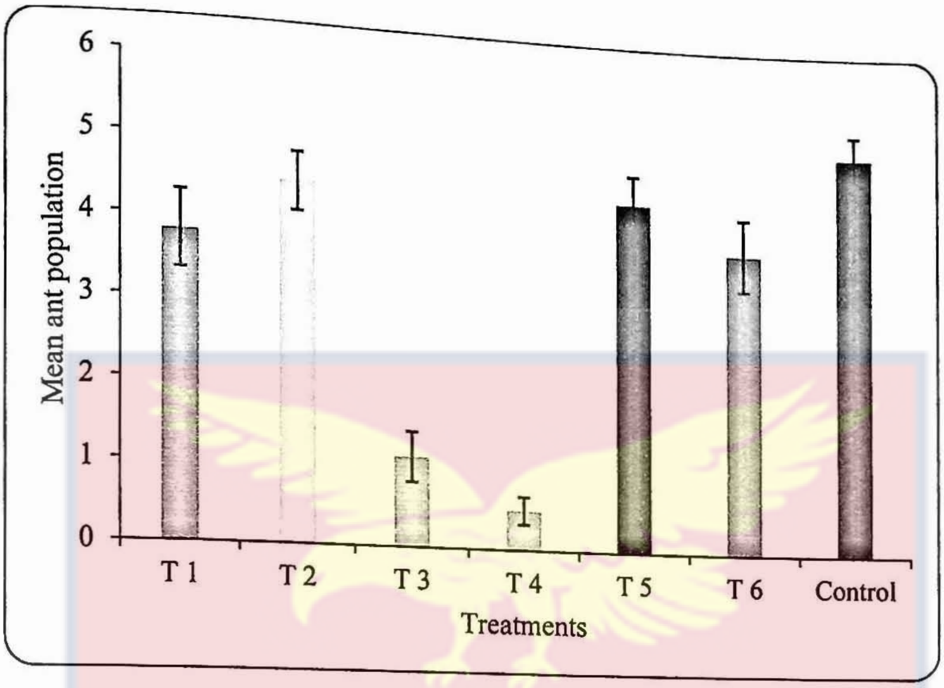

Figure 73: Mean ant population after the treatments

7.3.18 Mean mealybug population after the treatments

Treatment 4 (suckers with up to three foliar applications of deltamethrin) had the lowest mean mealybug population per plant of 1.78 followed by treatment 3 (suckers with up to three foliar applications cypermethrin) with 1.91 mean mealybugs per plant. Treatment 5 with a mean population of 4.53 per plant was the treatment with the highest mealybug population.

Treatments 1 and 2 were not significantly different but significantly different from treatments 3 and 4. There were significant differences between treatments 4 and 3 and among treatment 1 (suckers with up to three foliar applications of neem oil) and treatments 2 (suckers with up to three foliar applications of white vinegar) and 5 (suckers with up to three Amdro ant bait applied as broadcast). There was also a significant difference between treatment 5 and the control but not similar to treatment 6 [farmers practice (one foliar application of cypermethrin] (Figure 74).

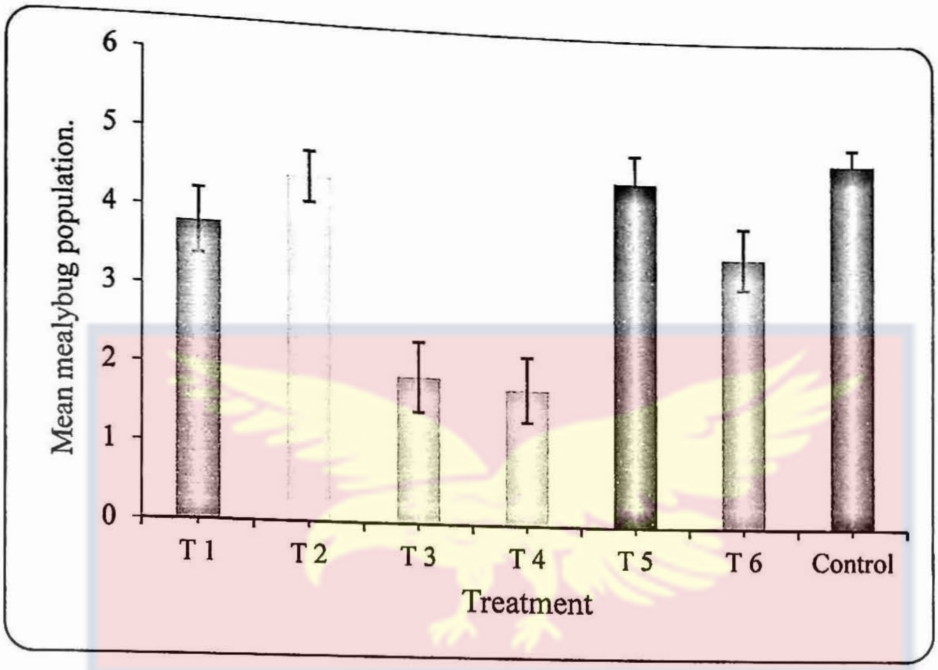

Figure 74: Mean mealybug population after the treatments

7.3.19 Fisher's protected least significant difference test for pineapple fruit weight

Treatments 4, 3, 6 and the control are statistically significantly different from each other with the average yield for treatment 4 being the highest with 2.731 kg per fruit. Treatments 2, 1 and 5 are statistically not significantly different. Treatment 5 with a mean fruit weight of 1.710 was the lowest among the various treatments apart from the control (Table 19).

Table 19: Fisher's Protected Least Significant Difference Test for Yield of Pineapples

Treatments	Mean (kg/ha)
T_4 (sucker with up to three foliar applications of deltamethrin)	2.713a
T_3 (sucker with up to three foliar application cypermethrin)	2.288b
T_6 [farmers practice (one foliar application of cypermethrin]	1.950c
T_2 (sucker with up to three foliar applications of white vinegar)	1.728d
T_1 (sucker with up to three foliar applications of neem oil)	1.725d
T_5 (sucker with up to three Amdro ant bait applied as broadcast)	1.710d
Control	1.263e

7.4 Discussion

7.4.1 Pre-plant dipping of planting materials before planting and post-planting drenching of plants with insecticides

The dipped planting materials into insecticide solution before the planting and the post-planting applications of insecticide through drenching of the planting materials performed better concerning the severity and incidence of the MWP and for planting materials that were drenched up to three times at two-monthly intervals also showing the least severity and incidence of the MWP. This is in confirmation of the recommended practice as proposed by the Pesticide Initiative Programme (2004) which recommends that irrespective of the planting material type to be used, a total treatment should be applied materials before planting to avoid the risk of contamination and distribution of pests and diseases. Insects such as mealybugs, symphylids, snails, borers, mites must be eradicated in the planting material through treatment with recommended and approved insecticides.

Sulaiman (2000) had also reported that pre-treatment of planting materials of pineapple was effective in decreasing the mealybug population and could protect the pineapples from the occurrence of MWP.

Joy, Anjana, & Soumya (2016) and Sanewski, Bartholomew, & Paull (2018) had stated the need for and importance of post-planting insecticide application for the control of mealybugs. They also stated that when ants are controlled through insecticide application by drenching the nests of the ants are destroyed and therefore expose the mealybugs to their natural enemies or the mealybugs are affected by the insecticides that are targeted at them.

Application of insecticides targeting the mealybugs should be done as the plant grows and through the vegetative growth stage of the pineapple plant because of emerging crawlers of the mealybugs that happen with new growth parts of the plant and this period usually last only for some few days, so timing is critical. It is instructive to note that it is important to cover the insect thoroughly with the insecticide to kill the very young ones referred to as the crawlers. Additionally, foliar spraying at a determined interval is important in a successful or practical control program.

7.4.2 The ability of planting materials to withstand the MWP over the fifty-eight-week period of growth of the pineapples

The crowns as planting material did better with the disease incidence and severity after the fifty-eight-week period of growth than the slips and the suckers.

This situation could be due to fact that the suckers and the slips which were the other planting materials used could have had some latent infection with the PMWaV before planting since the mealybugs are commonly found hiding in soils from where the suckers emerge from or from beneath the fruits where the slips are attached. Sether et al. (2010) had mentioned that although pineapple plants can recuperate when mealybugs are detached from the plants the plant will go on as a PMWaV infected, therefore, when these planting materials which are usually the suckers and slips are used for planting, they provide the source of later virus acquisition by mealybugs in freshly planted suckers setting the stage for future MWP development. Also, the suckers and slips are usually bigger and have a higher weight of about 200 g more than the crowns, therefore, the suckers and slips establish faster after planting and making available new leaves with much sap to feed on by the mealybugs is higher than the crowns which are usually slow-growing (Reinhardt et al., 2018).

7.4.3 Mealybug and ant population and the incidence and severity of the MWP

The lower mean population of ants and mealybugs on the crowns compared to the suckers and the slips could be the reason for the crowns performing better in respect of the onset of the MWP. The possible reason for the suckers and slips attracting higher ants and mealybugs population could be because the crowns have a less fresh weight compared to the suckers and slips which establish faster after planting and provide more fresh and juicy leaves for mealybug to feed on. (Reinhardt et al., 2018). However, Dey et al. (2018) have indicated that contact of the plant by large numbers of mealybugs on plants did not always lead to MWP symptoms, and that healthy plants can become diseased when you transfer mealybugs to them from symptomatic plants, strongly making a case for the presence of a "transmissible factor" in MWP aetiology. Sether and Hu (2002a) on the other hand had earlier suggested that there was a direct association between high occurrences of MWP and high mealybug numbers with abilities to transmit PMWaVs.

7.4.4 Incidence, severity ants and mealybugs population on the pants after the treatment

The efficacy of deltamethrin has been confirmed by Johnson, Luukinen, Buhl, and Stone (2010) They reported that deltamethrin has very broad-spectrum control and ingestion and direct contact of insecticide on the insects is effective and generally has low toxicity to mammals and other animals and birds. These possibly would be the reason why the performance of the deltamethrin in the experiment proved superior in reducing the disease incidence and severity because it possibly was effective against the ants and the mealybugs. It, however, should be noted that deltamethrin is highly poisonous to honeybees (Johnson et al., 2010). Although the insecticide deltamethrin proved to be the most superior in terms of the MWP management, the concerns of consumers with regards to food safety issues is a matter that should not be glossed over, therefore, the possible combination with other alternative control methods should be adopted.

7.4.5 Effect of the treatments on the weight of the fruits after harvest

The use of deltamethrin in no doubt not only controlled the ants and mealybug populations it also showed in the yield data at the harvest stage showing an impressive average fruit weight of 2.713 kg putting them in the category 'A' of pineapple fruits as they are classified on the international market (Centre for the Promotion of Imports from developing countries (CBI), 2018). It, however, be noted that the use of neem oil, white vinegar and the Amdro ant baits also recorded fruits with an average weight between 1.71-1.72 kg which is accepted by consumers (Centre for the Promotion of Imports from developing countries (CBI), 2018).

7.5 Conclusions

i. Pre–planting dipping of planting materials into insecticide solution and drenching after planting up to three times at two-monthly intervals resulted in better management of the incidence and severity of the MWP in pineapples in the study area.

ii. The crowns proved a superior planting material in terms of the presence of the MWP.

iii. Mealybug and ant populations were lower on the crowns than those of the suckers and the slips.

iv. Pre-plant dipping and drenching after planting at regular intervals have proven to be the best way of controlling the ants and the mealybug and by extension the MWP.

v. The management of the MWP incidence and severity and the ants and mealybugs indicated the effectiveness of insecticides- deltamethrin and cypermethrin that were used in the experiment.

vi. White vinegar and neem oil worked best in reducing the incidence and severity of the MWP and the mealybug and ants after the insecticides and could be a useful alternative

7.6 Recommendations

i. As a way of getting planting materials for the next planting season that can be better in managing the MWP the use of the crowns could be adopted as the first planting materials. The crowns are slow-growing and take a long time to come into maturation thus their suckers and slips could then be used for the second season of planting. By so doing the suckers and slips that will be emanating from the mother plant that is coming from a crown will be "healthy" and therefore show less incidence of the disease. It should be noted that in handling the crowns during transportation care should be taken in order not to damage the hearts of the crowns.

ii. Since it has been stated that proper pre-treatment of pineapple planting materials is a sure way of decreasing the mealybug population and probably protecting the pineapple from incidence of MWP, it should be accompanied by adhering to a pattern of application of insecticides to control the ants and the mealybugs infestation before planting and after planting. However, because of the concerns of many consumers on the excessive use of pesticides in conventional production, the use of other alternatives such as insecticidal soaps, horticultural oil, neem oil insecticides, Amdro baits, could be considered in combination with the insecticides to reduce the frequency of the use of insecticides.

iii. Roguing of fields with the disease should be strictly enforced so that farmers do not bank their hopes on the plants recovering after an attack, since the recovered plants become added sources of the wilt virus for the next planting field.

iv. Insecticide control of the mealybugs and the ants that tend the mealybugs have been the first choice for many pineapple farmers. The application of deltamethrin up to three times was seen to be the most effective against the mealybugs and the ants and in the reduction of the severity and incidence of the MWP in this study.

v. Adoption of an integrated control where a combination of insecticides and organic means –neem oil and vinegar could be used in conjunction with each other.

CHAPTER EIGHT

8 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

The thesis set out to investigate the occurrence of mealybug wilt disease in major pineapple growing areas of the Central and Eastern regions of Ghana. This was achieved by conducting a questionnaire survey; assessed the distribution and severity of disease; identified the species of mealybug that transmit the disease and the symbiont ant species that protected the mealybugs; determined the extent to which the effect of the disease infection affect the photosynthetic abilities of the plant as well as management strategies for curbing the disease.

Farmers did not harvest suckers from infected mother plants or from within a 1 m^2 perimeter of an infected plant, and they had a high degree of MWP knowledge on their farms.

Many of the farms surveyed across the Central and Eastern regions of Ghana had MWP incidences of 10-20% which was above the 3% threshold, indicating that the disease presents a serious threat to pineapple production in the two regions of Ghana.

The patterns of spread or distribution of the MWP across the various districts surveyed in the Central and Eastern regions of Ghana is more of clustering than random or even distribution on the field.

The Pink pineapple mealybug (*Dysmicoccus brevipes*) was found in the seven districts across the two regions that were studied.

Three ant species, *Camponotus pennsylvanicus*, *Solenopsis invicta*, and *Pheidole* spp., were discovered in the four districts (Awutu Senya-West, Gomoa-East, Gomoa-West and Ekumfi) of the Central region of Ghana whereas in the Eastern region of Ghana, only the *Pheidole* spp. were found in all three districts (Akuapem-North and South and Upper-West-Akyem), while *Solenopsis invicta* and *Camponotus pennsylvanicus* were only found in Akuapem-South and Upper-West-Akyem Districts.

Propagation with crowns as planting material gave a lower incidence of the MWP disease and a lower population of ants and mealybugs compared to the slips and the suckers.

The feeding by the mealybugs and attack by the PMWaV in the MWP are responsible for the loss of the chlorophyll in the leaves that eventually lead to wilting of the plants.

White vinegar and neem oil as an alternative to pesticides worked best in reducing the incidence and severity of the MWP and the mealybug and ant population.

8.2 Conclusions

From the findings of the study the following conclusions are drawn:

i. All the respondents who partook in the questionnaire survey had adequate knowledge of MWP. They were able to identify the major symptoms of MWP and could distinguish between MWP and other wilting conditions such as water stress and agrochemical burns that had similar wilt symptoms like the MWP.

ii. The incidence and severity of MWP were high during the pre-flowering stage of the growth of pineapple than the post-flowering stage.

iii. The study showed that MD2 was resistant to MWP while Smooth Cayenne was the most susceptible variety.

iv. Respondents employed different strategies to manage the disease. Some of the management strategies included the keeping of fallow plots to break the life cycle of the disease-causing pathogens, treating mother plots and soil with insecticides especially plots with the history of MWP incidence, as well as avoiding infected mother plots for planting materials, flagging of affected plots and destruction of affected plants.

v. Most of the farms surveyed in the Central and Eastern regions of Ghana had disease incidence scores of 10-20%, indicating that the disease had become more prevalent over time and beyond the minimum economic threshold of 3%.

vi. The progression of the disease continued after the attack because conditions that favour the disease was always available during the period of study.

vii. The recording of the incidence levels above 3% in Awutu-Senya-West, Gomoa, East, Gomoa-West and Ekumfi in the Central region and Akuapem-North, Akuapem-South and Upper-West-Akyem in the Eastern region at both before and after flower induction stages of the pineapples surveyed was indicative of the fact that the prevalence of the disease was high and serious than may have been estimated.

viii. In general, the MWP pattern of spread or distribution across the various districts in the Central and Eastern regions of Ghana that were studied are more clustered than random or even on the field.

ix. The sum of diseased or symptomatic pineapple plants suggested pathogen transfer from one plant to another at the time of observation.

x. Due to the active movement of planting materials between farmers in the two locations, there was a high percentage incidence, mean severity, and ant and mealybug populations in the two regions. Mealybug activity may well increase during the rainy season because of the abundance of leaves and root sap to feed on, increasing the incidence of the MWP.

xi. The Pink mealybug, *D. brevipes*, was found to be present and dominant in the Central and Eastern regions of Ghana. Three ant genera, *Camponotus*, *Pheidole*, and *Solenopsis*, were found in the study areas.

xii. The feeding by the mealybugs and infection by the PMWaV are accountable for the loss of the chlorophyll in the plant leaves thereby leading to the eventual wilting of the plants.

xiii. The loss of trichomes during the MWP infection exposes the plants to water loss due to increased transpiration, and poor supply of minerals because the trichomes aid in the absorption of the needed minerals by the plants

xiv. Pre–planting dipping of planting materials into insecticide solution and drenching after planting up to three times at two-monthly intervals resulted in better management of the incidence and severity of the MWP in pineapples in the study area.

xv. Pre-plant dipping and drenching after planting at regular intervals have proven to be the best way of controlling the ants and the mealybug and by extension the MWP.

xvi. The management of the MWP incidence and severity and the ants and mealybugs indicated the effectiveness of insecticides- deltamethrin and cypermethrin that were used in the evaluation.

xvii. White vinegar and neem oil worked best in reducing the incidence and severity of the MWP and the mealybug and ants after the insecticides and could be a useful alternative

8.3 Recommendations

i. The (MoFA) of Ghana through the agricultural extension agents should extend extension advisory and support on good agronomic practices services to pineapple farmers in Ghana.

ii. Farmers should be educated on factors that affect the epidemiology of MWP in pineapple farms and effective disease management strategies.

iii. MWP management and control should be taken seriously by the farmers to prevent the increasing incidence and severity of the disease.

iv. Farmers must be encouraged to destroy suckers or plants that show symptoms of the MWP earlier enough than the usual practice of waiting for diseased plants to stay on fields for a long time with the hope of pineapples recovering from the disease, this allows for diseased plants to serve as a reservoir for the PMWaV and the mealybugs.

x. If possible, the government of Ghana working through the MoFA should embark on an intensive clean planting material multiplication and distribution to farmers at subsidized prices to encourage farmers to rogue out all the diseased mother plants that give rise to planting materials that are infected and carrying latent infections.

xi. Effective treatment of the mother plots that is the source of the planting materials should be given equal attention like the main crop to control the ants and the mealybugs that are normally not controlled on the mother plots. Farmers often think these mother plots are not producing fruits and so treating and taking care of the mother plots is usually seen as a waste of resources.

xii. Mother plots are usually overgrown with weeds and look abandoned with all the alternate hosts of the mealybugs in there. Therefore, the destruction of the harvested and unmanaged pineapples fields is important. Planting materials selection should always be from non-infected fields.

xiii. Farmers should put in place and sustain suitable ants and mealybug control regimes and develop good planting material selection and treatment.

xiv. Controlling the ants that tend the mealybug exposes the mealybugs to their natural enemies that significantly suppress the population of the mealybugs.

xv. It is important to clear fields and the boundaries of fields of weeds especially the alternate hosts for mealybugs that could serve as a reservoir for the ants and the mealybugs.

xvi. Dipping of planting materials rootstock in insecticide solution before planting, control of ants and mealybugs in especially the Smooth Cayenne variety of pineapple is a must for all producers to reduce the incidence of the MWP.

xvii. A lot of control measures and precautionary measures need to be employed in the cultivation of the highly susceptible varieties of pineapple to the MWP.

xviii. Although the Pink mealybug was the common mealybug seen in the study areas, it is also likely that the Grey mealybug could be occurring within the study area and so further work should be geared towards finding the Grey mealybug and its association with the ants.

xix. Other ant genera could be present in the study districts or from other districts not surveyed that could be introduced to the study area, therefore, further work in identifying other ant genera associated with the mealybugs and the MWP should be done.

xx. Further work on molecular characterization of the PMWaV in the study area must be conducted to detect all the virus species causing the MWP in the study area.

xxi. The prevention of the MWP and the control of the mealybugs and symbiont ants is very important in the management of the MWP in pineapples and therefore farmers should take MWP prevention very seriously.

xxii. As a way of getting planting materials for the next planting season that can be better in managing the MWP the use of the crowns could be adopted as the first planting materials. The crowns are slow-growing and take a long time to come into maturation thus their suckers and slips could then be used for the second season of planting. By so doing the suckers and slips that will be emanating from the mother plant that is coming from a crown will be "healthy" and therefore show less incidence of the disease. It should be noted that in handling the crowns during transportation care should be taken in order not to damage the hearts of the crowns.

xxiii. Proper pre-treatment of pineapple planting materials is a sure way of decreasing the mealybug population and probably protecting the pineapple from incidence of MWP, it should be accompanied by adhering to a pattern of application of insecticides to control the ants and the mealybugs infestation before planting and after planting. However, because of the concerns of many consumers on the excessive use of pesticides in conventional production, the use of other alternatives such as insecticidal soaps, horticultural oil, neem oil insecticides, Amdro baits, could be considered in combination with the insecticides to reduce the frequency of the use of insecticides.

xxiv. Roguing of fields with the disease should be strictly enforced so that farmers do not bank their hopes on the plants recovering after an infection, since the recovered plants become added sources of the wilt virus for the next planting field.

xxv. Insecticide control of the mealybugs and the ants that tend the mealybugs have been the first choice for many pineapple farmers. The application of deltamethrin up to three times was seen to be the most effective against the mealybugs and the ants and in the reduction of the severity and incidence of the MWP in this study.

xxvi. Adoption of an integrated control where a combination of insecticides and organic means- neem oil and white vinegar could be used in conjunction with each other.

REFERENCES

Ablordepey, D. S. (2006). Pineapple Farmers lose $11 million Due to Lack of Market. *15(149783)*. Accra: The Graphic communications group limited.

Agricultural Cooperative Development International and Volunteers in Overseas Cooperative Assistance (2015). *Renewing Smooth Cayenne Pineapple Production in Ghana.* ACDI/VOCA. Retrieved April 16, 2017, from http://52.0.15.52/our-programs/success-story/renewing-smooth-cayenne-pineapple-production-ghana

Afari-Sefa, V., Asare-Bediako, E., Kenyon, L., & Micah, J. A. (2015). Pesticide use practices and perceptions of vegetable farmers in the cocoa belts of the Ashanti and Western Regions of Ghana. *Advances in Crop Science and Technology*, *3* (174), 1-10.

Aiyeloja, A. A., & Bello, O. A. (2006). Ethnobotanical potentials of common herbs in Nigeria: A case study of Enugu state. *Educational Research and Review*, *1*(1), 16-22.

Akobundu, I. O. (1987). *Weed Science in the Tropics: Principles and Practices.* New York: John Wiley and Sons.

Anaeto, F. C., Asiabaka, C. C., Nnadi, F. N., Ajaero, J. O., Aja, O. O., Ugwoke, F. O. & Onweagba, A. E. (2012). The role of extension officers and extension services in the development of agriculture in Nigeria. *Wudpecker Journal of Agricultural Research*, *1*(6), 180-185. Retrieved May 19, 2018, from http://www.wudpeckerresearchjournals.org

Antwi, E. K., Boakye-Danquah, J., Asabre, S. B., Yiran, G. A., Loh, S. K., Gyekye, K., & Owusu, K. (2014). Land use and landscape structural changes in the ecoregions of Ghana *Journal of Disaster Research*. *9*(4), 452-467.

Apantaku, S. O., Aromolaran, A. K., Shobowale, A. A., & Sijuwola, K. O. (2016). Farmers and extension personnel view of constraints to effective agricultural extension services delivery in Oyo State, Nigeria. *Journal of Agricultural Extension*, *20*(2), 202-214.

Asare-Bediako, E., Addo-Quaye, A., Boakye, B., Sarbah, J. M., Asante, P. & Dorm, E. (2015). Incidence and severity of viral and fungal diseases of chilli pepper (*Capsicum frutescens*) in some districts in Ghana. *International Journal of Plant and Soil Science*, 7(3), 147-159.

Bartholomew, D.P, Kenneth G. Rohrbach, K.G, & Dale O. Evans, D.O.(2002). *Pineapple Cultivation in Hawaii.* College of Tropical Agriculture and Human Resources (CATRH), Hawaii.The University of Hawaii at Manoa.

Bartholomew, D. P., Paull, R. E., & Rohrbach, K. G. (2003). The pineapple: botany, production and uses. Wallingford, UK: CABI Publishing.

Bayer Environmental Science. (2010). *An ant identification guide*. North Carolina, US. Bayer Crop Science LP, Environmental Science Division.

Beardsley, J. W. (1959). On the taxonomy of pineapple mealybugs in Hawaii, with description of a previously unnamed species (Homoptera: Pseudococcidae). *Proceedings of Hawaiian Entomological Society, 17*(1), 29-37.

Beardsley, J. W. (1965). Notes on the pineapple mealybug complex, with descriptions of two new species (Homoptera: Pseudococcidae). *Proceedings of the Hawaiian Entomological Society, 19*(1), 55-68.

Beardsley, J. W., Su, T. H., McEwen, F. L., & Gerling, D. (1982). Field investigations on the interrelationships of the bigheaded ant, the grey pineapple mealybug and the pineapple mealybug wilt disease in Hawaii. *Proceedings of the Hawaiian Entomological Society, 24*, 51-67.

Beardsley, J. W. (1993). The pineapple mealybug complex; taxonomy, distribution. *International Society for Horticultural Science, 334*, 383-386.

Bell, A. D. (1991). *Plant Form: An Illustrated Guide to Flowering Plant Morphology*. Oxford, UK: Oxford University Press.

Ben Dov, Y. (1994). *A Systematic Catalogue of the Mealybugs of the World (Insecta: Homoptera: Coccoidea: Pseudococcidae and Putoidae) with data on Geographical Distribution, Host plants, Biology and Economic Importance*. Andover, UK: Intercept.

Bencini, M. C. (1991). Post-harvest and processing technologies of African staple foods. *Technical Compendium. 89*, pp. 131-134. FAO Agricultural Services Bulletin.

Benzing, H. D. (1976). Bromeliad trichomes: structure, function, and ecological significance. *Selbyana, 1*, 330-348.

Bijzet, Z., & Sippel, A. D. (2001). Rootstocks. In E. D. Villare (Ed.), *The cultivation of pineapple*. Nelspruit, South Africa: Institute for Tropical and Subtropical Crops.

Bishop, D., & Bristow, C. (2001). Effect of Allegheny mound ant (Hymenoptera: Formicidae) presence on homopteran and predator populations in Michigan jack pine forests. *Annals of the Entomological Society of America, 94*, 33-40.

Brightwell, R. J., & Silverman, J. (2010). Invasive Argentine ants reduce fitness of red maple via a mutualism with an endemic coccid. *Biological Invasions, 12*, 2051-2057.

Broadley, R. H., Wasserman, R. C., & Sinclair, E. R. (1993). *Pineapple Pests and Disorders.* Brisbane, Australia: Department of Primary Industries.

Bruce, P. A., & Oku, S. (2000). *Survey on Non-traditional Crops in Ghana.* Policy Planning Monitoring and Evaluation Directorate, Ministry of Agriculture, Accra.

CABI (2015) *Dysmicoccus brevipes* (pineapple mealybug). Crop Protection Compendium. Retrieved January 20, 2022, from https://www.cabi.org/cpc/datasheet/20248

CABI. (2015). *Invasive Species Compendium: Dysmicoccus neobrevipes (Grey pineapple mealybug).* Wallingford, UK: CABI Publishing. Retrieved October 30, 2018, from https://www.cabi.org/isc/datasheet/20251

CABI. (2017). *Invasive Species Compendium.* Wallingford, UK: CABI Publishing. Retrieved October 30, 2018, from https://www.cabi.org/isc/datasheet/5392

CABI. (2018). Invasive Species Compendium: Detailed coverage of invasive species threatening livelihoods and the environment worldwide. Wallingford, UK: CAB International. Retrieved January 1, 2019, from https://www.cabi.org/isc/

Carter, W. (1933a). The pineapple mealybug, *Pseudococcus brevipes*, and wilt of pineapples. *Phytopathology, 23*, 207-242.

Carter, W. (1933b). The spotting of pineapple leaves caused by *Pseudococcus brevipes*, the pineapple mealybug. *Phytopathology, 23*, 243-259.

Carter, W., & Schmidt, C. T. (1935). Mass action phenomena in mealybug wilt. *Annals of the Entomological Society of America*, *28*, 396-403.

Carter, W. (1945a). Some etiological aspects of mealybug wilt. *Phytopathology*, *35*, 305-315.

Carter, W. (1945b). The influence of plant nutrition on the susceptibility of pineapple plants to mealybug wilt. *Phytopathology*, *35*, 316-323.

Carter, W., & Collins, J. L. (1947). Resistance to mealybug wilt of pineapple with special reference to a Cayenne-Queen hybrid. *Phytopathology*, *37* 332-348.

Carter, W. (1963). Mealybug wilt of pineapple; a reappraisal. *Annals of New York Academy of Sciences*, *105*, 741-764. Retrieved October 20, 2017, from https://doi.org/10.1111/j.1749-6632.1963.tb42961.x

Carter, W. (1967). Insects and related pests of pineapple in Hawaii: a manual for fieldmen. Pineapple Research Institute, Honolulu.

Central Coastal Agricultural Research Institute (2013). Pineapple. Retrieved January 5, 2015, from http://www.ccari.res.in/dss/pineapple.html

Centre for the Promotion of Imports from developing countries (CBI). (2018). *Exporting fresh pineapple to Europe.* The Hague: CBI. Retrieved April 21, 2019, from https://www.cbi.eu/market-information/fresh-fruit-vegetables/pineapple

Collins, J. L., & Carter, W. (1954). Wilt resistant mutations in Cayenne variety pineapple. *Phytopathology*, *44*, 662-666.

Coppens d'Eeckenbrugge, G., & Leal, F. (2001). *An ethnobotanical inventory.* Retrieved April 25, 2016, from: http://www.ciat.cgiar.org/ipgri/fruits_from_americas/frutales/Ficha%20Ananas%20comosus.htm;http://www.ciat.cgiar.org/ipgri/fruits_from_americas/frutales/more%

Coppens d'Eeckenbrugge, G., & Leal, F. (2003). Morphology, anatomy, and taxonomy. In: Bartholomew, D.P., Paull. R.E., & Rohrbach, K.G. (Eds.) *The Pineapple: Botany, Production and Uses.* Wallingford, UK: CABI Publishing.

Cudjoe, A. R., Neuenschwander, P., & Copela, M. W. (1993). Interference by ants in biological control of the cassava mealybug *Phenacoccus manihoti* (Hemiptera: Pseudococcidae) in Ghana. *Bulletin of Entomological Research, 83*, 15-22.

Curran, P. J., Dungan, J. L., & Gholz, H. L. (1990). Exploring the relationship between reflectance red edge and chlorophyll content in slash pine. *Tree Physiology, 7*, 33-48.

Davidson, D. W., Cook, S. C., & Snelling, R. R. (2004). Liquid-feeding performances of ants (Formicidae): ecological and evolutionary implications. *Oecologia, 139*, 255-266.

De La Cruz Medina, J., & García, H. S. (2005). *Pineapple: Post-harvest Operations.* Rome: Food and Agricultural Organisation of the United Nations.

den Dass, J. L. (1993). *Producing pineapple in the Atlantic zone of Costa Rica: Agronomic and Marketing aspects.* Turrialba, Costa Rica. The Atlantic Zone Programme.

Dey, K. K., Borth, W. B., Melzer, M. J., Wang, M., & Hu, J. S. (2015). Analysis of pineapple wilt associated virus-1 and -2 for potential RNA silencing suppressors and pathogenicity factors. *Virus, 7*(3), 969-995.

Dey, K. K., Green, J. C., Melzer, M., Borth, W., & Hu, J. S. (2018). Mealybug Wilt of Pineapple and Associated Viruses. *Horticulturae*, *4*(4), 52.

Donkoh, F; Agboka, D. (1997). Constraints to pineapple production in Ghana. *425*, 83-88. *Acta Horticulturae*. Retrieved January 3, 2022, from https://doi.org/10.17660/ActaHortic.1997.425.8

Duncan, B. A. (2004). *Women in Agriculture in Ghana* (Second ed.). Accra, Ghana: Fredrich Ebert Foundation.

Ecocrop (FAO). (2011). *Feedipedia.* Retrieved April 18, 2019, http://ecocrop.fao.org/ecocrop/srv/en/home

Egelie, A. A., & Gillett-Kaufman, J. L. (2015). *Dymiscoccus brevipes (Cockrell)(Insecta :Hemiptera: Pseudococcidae).* Retrieved April 21, 2017, http://entnemdept.ufl.edu/creatures/FRUIT/MEALYBUGS/pineapple_mealybug.htm

Ehler, J. T. (2018). *The MD2 Pineapple.* Retrieved October 30, 2018, from http://www.foodreference.com/html/artmd2pineapple.html

Environmental Systems Research Institute (ESRI). (2013). *ArcGIS Help 10.1: Spatial Autocorrelation (Global Moran's I) (Spatial Statistics*). Retrieved August 28, 2017, from: http://resources.arcgis.com/en/help/main/10.1/index.html#//

Faber, B. A., & Ohr, H. D. (1999). UC Pest Management Guidelines: Pineapple. California Davis, USA: University of California.

Fillela, I., Serrano, L., Serra, J., & Peñuelas, J. (1995). Evaluating wheat nitrogen status with canopy reflectance indices and discriminant analysis. *Crop Science*, *35*, 1400-1405.

Flint, M. L. (2016). *Mealybugs: Pests Notes*. Retrieved April 19, 2019, from The University of California Statewide IPM Program (UC IPM): http://ipm.ucanr.edu/PMG/PESTNOTES/pn74174.html

Food Market Exchange. (2004). *Fruit market Report*. Retrieved November 19, 2016, from http://www.foodmarketexchange.com/datacenter/product/fruit/pineapple/detail/

Frenken, K. (2005). *Irrigation in Africa in figures: AQUASTAT Survey*. Food and Agricultural Organisation, FAO Land and Water Development Division. Rome: Publishing Management Service, Information Division. Retrieved August 28, 2017, from https://catalogue.nla.gov.au/Record/3673377

Gambley, C. F., Steele, V., Geering, A. D., & Thomas, J. (2008). The genetic diversity of ampeloviruses in Australian pineapples and their association with mealybug wilt disease. *Australasian Plant Pathology*, *37*, 95-105. doi:10.1071/AP07096

Gil, C. R. (2017). *Ananas comosus*. Retrieved October 30, 2018, from http://www.colegiobolivar.edu.co/garden/wp-content/uploads/2017/06/Crosas-Ananas-comosus-2017.pdf

González-Hernández, H., Johnson, M. W., & Rei, N. J. (1999a). Impact of *Pheidole megacephala* (F.) (Hymenoptera: Formicidae) on the biological control of *Dysmicoccus neobrevipes* (Cockerell) (Homoptera: Pseudococcidae). *BioControl*, *15*(2), 145-152.

González-Hernández, H., Reime, N. J., & John, M. W. (1999b). Survey of the natural enemies of *Dysmicoccus* mealybugs on pineapple in Hawaii. *BioControl*, *44*, 47-58.

Haines, W. (2008). *Discover Life.* Retrieved January 1, 2017, from http://pick18.discoverlife.org/mp/20q?act=new_hostandguide=Ants

Hale, L. P., Greer, P. K., Trinh, C. T., & Gottfried, M. R. (2005). Treatment with oral bromelain decreases colonic inflammation in the IL-10 deficient murine model of inflammatory bowels disease. *Clinical Immunology, 116*, 134-142.

Helms, K. R., & Vinson, S. B. (2002). Widespread association of the invasive ant *Solenopsis invicta* with an invasive mealybug. *Ecology*, *83*, 2425-2438.

Illingworth, J. F. (1926a). A study of ants in their relation to the growing of pineapples in Hawaii. *Experiment Station of the Association of Hawaiian Pineapple Canners Bulletin No. 7*. Honolulu: University of Hawaii.

Illingworth, J. F. (1926b). Pineapple insects and some related pests. *Experiment Station of the Association of Hawaiian Pineapple Canners Bulletin No. 9*. Honolulu: the University of Hawaii at Manoa.

Illingworth, J. F. (1931). Preliminary report on evidence that mealybugs are an important factor in pineapple wilt. *Journal of Economic Entomology*, *24*, 877-899.

Infonet Biodivision. (2019). *Mealybug.* Retrieved August 2, 2020, from https://www.infonet-biovision.org/PlantHealth/Pests/Mealybugs

International Tropical Fruits Network. (2011). Pineapple- common varieties. Retrieved April 16, 2017,

from: www.itfnet.org/v1/2016/05/pineapple/

International Tropical Fruits Network. (2016). Pineapple – Introduction. Retrieved from https://www.itfnet.org/v1/2016/05/pineapple-

Ito, K. (1938). Studies on the life history of the pineapple mealybug, *Pseudococcus brevipes* (Ckll.). Journal of Economic Entomology, *31*, 291-297.

Jackson, G. (2017). *pestnet. org-pacific Pests and Pathogens - Fact Sheets, Pineapple mealybug.* Retrieved April 19, 2019, from pestnet website: http://www.pestnet.org/fact_sheets/pineapple_mealybug_282.htm

Jahn, G. C., & Beardsley, J. W. (2000). Interactions of ants (Hymenoptera: Formicidae) and mealybug (Homoptera: Pseudococcidae) on pineapple. *Proceedings of the Hawaiin, Entomological Society, 34*, 181-185.

Jahn, G. C., Beardsley, J. W., & Gonzalex-Hernandez, H. (2003). A review of the association of ants with the mealybug wilt disease of pineapple. *Proceedings of the Hawaiin, Entomological Society, 36*, 9-28.

Jahn, G. C., Sanchez, E. R., & Cox, P. G. (2001). The Quest for Connections: Developing a research agenda for integrated pest and nutrient management. *International Rice Research Institute (IRRI) Discussion Paper No. 42*, 18 pp. Los Baños, Philippines.

Jallow, M. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Thomas, B. M. (2017). Pesticide knowledge and safety practices among farmworkers in Kuwait: Results of a survey. *International Journal of Environmental Research and Public Health, 14*(340), 1-15.

Johnson, M., Luukinen, B., Buhl, K., & Stone, D. (2010). *Deltamethrin Technical Fact Sheet*. Oregon State University Extension Services. Oregon: National Pesticide Information Center. Retrieved April 18, 2015, from http://npic.orst.edu/factsheets/archive/Deltatech.html

Joy, P. P. (2010). Pests and diseases: plant protection- Kew. Retrieved April 27, 2019, from http://prsvkm.tripod.com/Html/Pests.htm

Joy, P. P., & Sindhu, G. (2012). Diseases of Pineapple (*Ananas comosus*): Pathogen, Symptoms, Infection, Spread and Management. Kerala, India: Pineapple Research Station, Kerela Agricultural University. Retrieved April 18, 2017, from prsvkm.kau.in/sites/default/files/documents/diseases

Joy, P. P., Anjana, R., & Soumya, K. K. (2016). Insect Pests of Pineapple and their Management. In A. K. Panday, P. Mall, A. K. Pandey, & P. Mall (Eds.), *Insect Pests Management of fruit crops* (pp. 471-492). New Delhi, Delhi, India: Biotech books. Retrieved April 18, 2017, from http://prsvkm.kau.in/sites/default/files/documents/pests_of_pineapple_and_thier_management.pdf

Kamble, P. N., Giri, S. P., Mane, R. S., & Tiwana, A. (2015). Estimation of chlorophyll content in young and adult leaves of some selected plants. *Universal Journal of Environmental Research and Technology, 5*(6), 306-310.

Kaudo, H. O. (2014). *Modern crop production.* Retrieved January 20, 2015, from http://hellenomondikaudo.blogspot.com/2014/12/pineapple-production.html

Knoema Corporation. (2020). The production of pineapples in Ghana. Retrieved December 29, 2021, from https://knoema.com/data/ghana+agriculture-indicators-area+pineapples

Krauss, B. (1949). Anatomy of the Vegetative Organs of the Pineapple, *Ananas comosus* (L.) Merr. (Continued) II. *The Leaf. Botanical Gazette, 110*(3), 333-404. Retrieved July 28, 2018, from http://www.jstor.org/stable/2472619

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement, 30*, 607-610.

Macabe. (2017). *Districts of the Eastern Region (2012).* Retrieved August 26, 2017, from en.Wikipedia.org:https://en.wikipedia.org/wiki/File:Districts_of_the_Eastern_Region_(2012).svg

Malezieux, E., Cote, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull, & K. G. Rohrbach (Eds.), *The Pineapple: Botany, Production and Uses* (pp. 69-107). Wallingford, UK: CABI Publishing.

Mamoon, R., Bushra, S. and Tarig, M. (2014). Use and impact of insecticides in mealybug control. *International Journal of Advances in Biology, 1*(2), 1-11.

Manandhar, H K; Timila, R D; Sharma, S; Joshi, S; Manandhar, S; Gurung, S B; Sthapit, S; Palikhey, E; Pandey, A; Joshi, B K; Manandhar, G; Gauchan, D; Jarvis, D I & Sthapit, B R (2016) A field guide for identification and scoring methods of diseases in the mountain crops of Nepal. Retrieved January 10, 2022, from https://www.bioversityinternational.org/e-library/publications/detail/a-field-guide-for-identification-and-scoring-methods-of-diseases-in-the-mountain-crops-of-nepal/

Manicom, B. (2011). Diseases. In E. A. de Villers (Ed.), *The Cultivation of Pineapple* (pp. 214-230). Nelspruit, South Africa: Institute for Tropical and Subtropical Crops.

Mau, R. L., & Kessing, J. L. (2007). *Dymicoccus neobrevipes (Beardsley).* Retrieved November 21, 2010, from Crop Knowledge Master: http://www.extento.hawaii.edu/kbase/crop/Type/d_brevip.htm

Messenger-Routh, B. J. (1996). The effect of gypsum soil on Phytophthora root rot of pineapple. *PhD Dissertation.* The University of California Riverside.

Miller, D., Rung, A., Parikh, G., Venable, G., Redford, A. J., Evans, G. A., & Gill, R. J. (2014). *Scale Insects. Identification Tool for Species of Quarantine Significance, Edition 2.* Retrieved June 12, 2015, from idtools.org

Ming, R., Vanburen, R., Wai, C. M., & Tang, H. (2015). The pineapple genome and the evolution of CAM photosynthesis. *Nature Genetics, 47*(12). doi:10.1038/ng.3435

Ministry of Food and Agriculture (2013). *Agriculture in Ghana Facts and Figures.* MoFA, SRID. Accra, Ghana: Statistics, Research and Information Directorate (SRID) of the Ministry of Food and Agriculture.

Ministry of Local Government and Rural Development of Ghana and Maks Publications and Media Services. (2006). *Ghana Districts: A repository of all Local Assemblies in Ghana.* (ghanadistricts.com) Retrieved August 28, 2017, from ghanadistricts.com: http://www.ghanadistricts.com/About-District-Details.aspx?distID=65anddistName=Awutu-Senya-West

Minitab Ltd. (2021). Minitab 20 support. Retrieved February 2, 2022, from https://support.minitab.com/en-us/minitab/20/help-and-how-to/statistics/basic-statistics/how-to/store-descriptive-statistics/interpret-the-statistics/all-statistics/

Montinola, L. R. (1991). *Pina.* Metro Manila, Philippines: Amon Foundation.

Moran, J. A., Mitchell, J. A., Goodsmanson, G., & Stockburger, K. (2000). Differentiation among effects of nitrogen fertilization treatments on conifer seedlings by foliar reflectance: a comparison of methods. *Tree Physiology, 20*, 1113-1120.

Morton, J. (1987). *Fruits of Warm Climates.* North Carolina, USA: Creative Resource Systems Inc.

Mynott, T. L., Ladhams, A., Scarnato, P., & Engwerda, C. R. (1999). Bromelain, from Pineapple Stems, Proteolytically Blocks Activation of Extracullar Regulated Kinase-2 in T-cells. *The Journal of Immunology, 163*, 2568-2575.

Nabila, J. S., & Kofie, R. (Eds.). (2001). *Unimax Macmillan Senior Secondary Atlas.* Accra North, Ghana: Macmillan Education Ltd.

National Bank For Agriculture and Rural Development. (2006). *Pineapple Cultivation.* Strategic Relationship Solutions (SRS). Mumbai: Lintas Personal.

Nichols, L. M. (2013). *Common ants ID infographic-Pictorial Key to the Common Urban Ants of North Carolina*. Retrieved April 24, 2017, from School of ants: http://schoolofants.org/content/common-urban-ants-key

Nixon, G. E. (1951). *The Association of Ants with Aphids and Coccids*. London, UK: Commonwealth Institute of Entomology.

Owusu, E. O., Billah, M. K., Davies, H. E., Amponsah, J. Y., Akoto, S. H., & Kettingbasepa, P. (2011). *Nation-wide Survey of Mealybugs, with a special reference to the invasive papaya mealybug, Paracoccus marginatus in Ghana.*

Peñuelas, J., & Filella, I. (1998). Visible and near-infrared reflectance techniques for diagnosing plant physiological status. *Trends in Plant Science*, *3*, 151-156.

Petty, G. J., & Tustin, H. (1993). Ant (*Pheidole megacephala* F.)-mealybug (*Dysmicoccus brevipes* Ckll.) relationships in pineapples in South Africa. First International Pineapple Symposium. *Acta Horticulturae*, *334*, 387–395.

Phillips, J. S. (1934). *The biology and distribution of ants in Hawaiian pineapple fields*. Experiment Station of the Pineapple Producers Cooperative Association Bulletin 15, Honolulu.

Pierce, S., Maxwell, K., Griffiths, H., & Winter, K. (2001). Hydrophobic trichome layers and epicuticular wax powders in Bromeliaceae. *The American Journal of Botany*, *88*(8), 1371-89.

Pesticide Initiative Programme. (2004). MD2 Pineapple Variety Production Guide: a handbook for farm managers and technicians. *Technical Itinerary*. Bruxelles, Belgium: COLEACP/PIP.

Pesticide Initiative Programme. (2005). Guide to good crop protection practices for pineapples (*Ananas comosus*) In Organic farming in ACP countries 11. Bruxelles, Belgium: COLEACP/PIP.

Pesticide Initiative Programme. (2008a). PIP Technical Itinerary: Pineapple Cayenne 52. (CIRAD, Ed.) Bruxelles: COLEACP.

Pesticide Initiative Programme (2008b). Guide to good crop practices for pineapple (*Ananas comosus*) in organic farming in ACP countries. 39. Bruxelles: COLEACP/PIP.

Pesticide Initiative Programme. (2011). Guide to good crop practices for pineapple (*Ananas comosus*) in organic farming in ACP countries. 1-39. COLEACP/PIP.

Plantwise. (2011). *Plantwise Knowledge Bank-pineapple mealybug wilt (PMBW) (Pineapple mealybug wilt-associated viruses)*. Retrieved April 29, 2018, from https://www.plantwise.org/KnowledgeBank/Datasheet.aspx?dsid=41335

Produce for Better Health Foundation. (2018). South African Baby Pineapples: nutrition, selection and storage. Retrieved April 16, 2018, from: https://fruitsandveggies.org/fruits-and-veggies/pineapple/

Punjab National Bank. (2007). *Pineapple Basic.*, New Delhi. Punjab National Bank (PNB).

Purseglove, J. W. (1984). *Tropical Crops. Monocotyledons*. London: Longman.

Py, C., Lacoeville, J. J., & Teisson, C. (1987). *The Pineapple, Cultivation and Uses*. Paris, France.

Queensland Department of Primary Industries (2005). *Pineapple best practice manual*. Retrieved June 04, 2017, from https://www.daf.qld.gov.au/__data/assets/pdf_file/0007/66247/Ch 20-The-Pineapple.pdf

Réal, P. (1959). The annual cycle of the cochineal *Dysmicoccus brevipes* Ckll. vector of a "wilt" of pineapple in lower Côte d'Ivoire; its determinism. *Journal of Plant Pathology and Agricultural Entomology, 38*, 3-111.

Reimer, N. J., & Beardsley, J. W. (1990a). Effectiveness of hydramethylnon and fenoxycarb for the control of big-headed ant (Hymenoptera: Formicidae), an ant associated with mealybug wilt of pineapple in Hawaii. *Journal of Economic Entomology, 83*, 74-80.

Reinhardt, D. R., Bartholomew, D. P., Souza, F. V., de Carvalho, A. P., de Pádua, T. R., Junghans, D. T., & de Matos, A. P. (2018). Advances in pineapple plant propagation. *Revista Brasileira Fruticultura, 40*(6), doi:DOI: http://dx.doi.org /10.1590/0100-29452018302

Rice, R. P., Rice, L. W., & Tindall, T. D. (1990). *Fruits and Vegetable Production in Warm Climates.* London: Macmillan Edu. Ltd.

Rohrbach, K. G., Beardsley, J. W., German, T. L., Reimer, N., & Sanford, W. G. (1988). Mealybug wilt, mealybugs and ants on pineapple. *Plant Disease, 72*, 558-565.

Rohrbach, K. G., & Johnson, M. W. (2003). Pests, diseases and weeds. In D. P. Bartholomew, R. E. Paull, & K. G. Rohrbach, *Pineapple: Botany, Production and Uses* (pp. 1-12). New York: CABI Publishing.

Sanewski, G., Bartholomew, B., & Paull, R. E. (2018). *The Pineapple: Botany, Production and Uses* (Second edition). Wallingford, Oxfordshire, UK: CABI Publishing.

Sarpong, G. A. (2006). *Improving tenure security for the rural poor, Ghana - country case study.* Rome: Food and Agriculture Organisation of the United Nations.

ScaleNET. (2007). *Dysmicoccus brevipes.* Retrieved November 21, 2010, from http://www.sel.barc.usda.gov/scalekeys/mealybugs/key/mealybugs/med

Scharffetter, J. B., Korsberg, A., & Bickford, C. (2015). Role of abaxial trichome density in regulating optical properties and photosynthesis in glycine max. Kenyon College. Retrieved August 11, 2016, from biology.kenyon.edu/HHMI/posters_2015/scharfetterj.pdf

Sea-Freight Pineapple Exporters of Ghana. (2007). Inventory of pineapple processors in Ghana. Accra, Ghana.

Secor, E. R., Jr., Carson, W. R., Cloutier, M., Guernsey, L. A., Schramm, C. M., Wu, C. A., & Thrall, R. S. (2005). Bromelain exerts anti-inflammatory effects in an ovalbumin-induced murine model of allergic airway disease. *Cellular Immunology, 237*, 68-75.

Sether, D. M., & Hu, J. S. (1998). Corollary analyses of the presence of pineapple mealybug wilt associated virus and the expression of mealybug wilt symptoms, growth reduction, and/or precocious flowering of pineapple (Abstr.). *Phytopathology, 88*, S80.

Sether, D. M., Ullman, D. E., & Hu, J. S. (1998). Transmission of pineapple mealybug wilt-associated virus by two species of mealybug (*Dysmicoccus* spp.). *Phytopathology, 88*, 1224-1230.

Sether, D. M., & Hu, J. S. (2001). The impact of Pineapple mealybug wilt-associated virus-1 and reduced irrigation on pineapple yield. *Australas. Plant Pathology, 30*, 31-36.

Sether, D. M., & Hu, J. S. (2002). Yield impact and spread of pineapple mealybug wilt associated virus-2 and mealybug wilt of pineapple in Hawaii. *Plant Disease*, *86*, 867-874.

Sether, D. M., & Hu, J. S. (2002a). Closterovirus infection and mealybug exposure are both necessary factors for the development of mealybug wilt disease. *Phytopathology*, *92*, 928-935.

Sether, D. M., Melzer, M. J., Busto, J., Zee, F., & Hu, J. S. (2005a). Diversity and mealybug transmissibility of ampeloviruses in pineapple. *Plant Disease*, *89*, 450-456.

Sether, D., Borth, W. B., Melzer, M. J., & Hu, J. (2010). Spatial and temporal incidences of pineapple mealybug wilt-associated viruses in pineapple planting blocks. *Plant Disease*, *94*(2), 196-200.

Shahbandeh, M. (2022). Global pineapple production by leading countries 2020. Retrieved December 28, 2021, from https://www.statista.com/statistics/298517/global-pineapple-production-by-leading-countries/

Sulaiman, S. F. (2000). Effect of pesticidal pre-treatments of pineapple plants on the incidence of mealybug wilt disease. *Acta Horticulturae*, *529*, 273-288. doi:10.17660/ActaHortic.2000.529.33

Systematic Entomology Laboratory (SEL). (n.d). *Scales and mealybugs.* Retrieved January 15, 2016, from https://www.ars.usda.gov

The Central Regional Coordinating Council. (2015). *Central Region of Ghana.* Retrieved August 27, 2017, from http://www.centralregion.gov.gh

The European Commission. (2018). The EU Pesticides Database. Retrieved July 25, 2018, from https://ec.europa.eu/food/plants/pesticides/eu-pesticides-database_en

The Pineapple Working Group. (2010). Pineapple News: Newsletter of the Pineapple Working Group. *International Society for Horticultural Science, 17*, 2.

The United Nations Conference on Trade and Development.(2021). Shipping during COVID-19: Why container freight rates have surged. Retrieved January 31, 2022, from https://unctad.org/news/shipping-during-covid-19-why-container-freight-rates-have-surged

Torres, R. A., & Garcia, J. O. (2005). Diagnosis of pineapple crop (*Ananas comosus* L.) cultivation in Nayarit, Mexico. *Acta Horticulturae, 666*, 43-49.

Trade and Markets Division-FAO. (2009). *Increasing incomes and food security of small farmers in West and Central Africa through exports of organic and fair-trade tropical products.* Rome: Food and Agriculture Organization of the United Nations. Retrieved September 12, 2017, from http://www.fao.org/tempref/docrep/fao/field/009/ak799e/ak799e00.pdf

Ullman, D. E., German, T. L., Gunasinghe, U. B., & Ebesu, R. H. (1989). Serology of a closterovirus-like particle associated with mealybug wilt of pineapple. *Phytopathology, 79*, 1341-1345.

United States Agency for International Development. (2006). *Success Story Pineapple: Introduction of a new variety.* Retrieved December 15, 2011, from http://www.fintrac.com/docs/red/06_03_USAID_RED_SS_Pineapple_MD2_ENG.pdf

van Santen, A., & Stice, K. (2017). *Pineapple Production in Vanuatu: Training Guide*. Vanuatu: ISSUU.

Wakman, W., Teakle, D., Thomas, J. E., & Dietzgen, R. G. (1995). Presence of clostero-like virus and a bacilliform virus in pineapple plants in Queensland. *Australian Journal of Agricultural Research, 46*, 947-58.

Wikiversity contributors. (2018). *Pineapple production.* Retrieved October 01, 2018, from https://en.wikiversity.org/w/index.php?title=Pineapple_productionandoldid=1876036

Williams, D. J., & Watson, G. W. (1988). *The scale insects of tropical South Pacific.* Wallingford, UK: CABI Publishing.

Williams, D. J., & Willink, M. G. (1992). *Mealybugs of Central and South America.* Wallingford, UK: CABI Publishing.

Wolfenbarger, D. O., & Westgate, P. J. (1949). Dipping pineapple planting stock for mealybug control. Retrieved October 12, 2018, from https://journals.flvc.org/fshs/article/download/102159/98092

Yayock, J. Y., Lombin, G., & Owunobi, J. J. (1998). *Crop Science and Production in Warm Climates.* London, UK: Macmillan.

Yuan, S., & Luo, H. (2016). Negative regulators of messenger RNA and the role of microRNA for plant genetic engineering. In R. R. Watson and V. R. Preedy, *Genetically Modified Organisms in Food* (p. 516). Elsevier Inc. doi:https://doi.org/10.1016/C2014-0-01928-4

Zentmyer, G. A., Menge, J. A., & Ohr, H. D. (1998). Phytophthora root rot. In R. C. Ploetz (Ed.), *Compendium of Tropical fruit diseases* (pp. 77-79). St Paul, Minnesota., USA: American Pathological Society.

Zhang, J., Liu, J., & Ming, R. (2014). Genomic analyses of the CAM plant pineapple. *Journal of Experimental Botany, 65*(13), 3395-3404.

Zhou, A., Zeng, L., Lu, Y., Xu, Y., & Liang, G. (2012). Fire Ants Protect Mealybugs against Their Natural Enemies by Utilizing the Leaf Shelters Constructed by the Leaf Roller *Sylepta derogata*. *PLoS One*, *7*(11). Retrieved January 10, 2022, from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0049982

Zou, A. M., Lu, Y. Y., Zeng, L., Xu, Y. J., & Liang, G. W. (2012). Effects of honeydew of *Phenacoccus solenopsis* on foliar foraging by *Solenopsis invicta*. *Sociobiology*, *59*, 71–79.

APPENDIX

Appendix A: Questionnaire used for the interview

UNIVERSITY OF CAPE COAST

SCHOOL OF AGRICULTURE

DEPARTMENT OF CROP SCIENCE

QUESTIONNAIRE ON STUDIES OF PINEAPPLE MEALYBUG ASSOCIATED WILT VIRUS IN GHANA

This research is for Academic purposes and as such the information you provide will be treated with the confidentiality it deserves

Please check (☒) the boxes and supply response where applicable

A. Farmer Characteristics

1. Name of Farm/Farm: ………………………………………………………………
2. Age of the farmer in years
3. Gender Male ☐ Female ☐
4. Number of years growing/producing pineapples
5. Educational level

Primary ☐ JHS/JSS☐ Middle School☐

SHS/SSS ☐'O' Level ☐'A' Level ☐

Bachelor ☐Masters ☐Doctorate. ☐

Other, Specify……………………………………………………………………………

B. Farm Characteristics

6. Total farm size under pineapple cultivation
7. Size of land under cultivation with:
   a. MD2 ……………………………………………………
   b. Smooth Cayenne ………………………………………………

c. Queen Victoria ....

d. Sugarloaf..

8. Type of land ownership

a. Leasehold..

b. Own/Inherited..

c. Outright Purchase...

d. Other, Specify...

9. Source of planting materials

a. Own source ☐

b. Other farms ☐

c. Own farms and other sources ☐

10. Indicate by checking the type of labour for the following activities (select from the following to answer the question: permanent, casual/contract, contractors, family/friends)

Fruit Harvesting	Planting	Sucker Harvesting	Mother plot management

11. What is your source of information for your pineapple business?

Agricultural Extension officers ☐

MoFA ☐

Agro-input dealers ☐

Newspaper ☐

Radio ☐

Television ☐

Family and Friends ☐

other pineapple farmers

others (please specify) ………………………………………………………… ☐

12. Do you have contact with AEA? Yes ☐ No ☐

13. If yes to question 12, how many times do extension agents visit your farm in a month? …………………………………………………………

14. What service(s) do the agricultural extension agents provide for you?

a. …………………………………………………………

b. …………………………………………………………

c. …………………………………………………………

d. …………………………………………………………

C. Farmers' Knowledge on MWP

15. Do you have any knowledge of the MWP?

Yes ☐

No ☐

16. If you answered yes to question 15 above, then how you can differentiate between mealybug wilt from water stress wilt, please mark as many as you identify. Mealybug associated virus wilt show:

a. A slight reddening of the leaves about halfway up the plant ☐

b. Definite and sudden change in leaf colour from red to pink and the leaf margins turn yellow and roll under, starting at the leaf tips ☐

c. The leaf tip dies back and affected leaves become limp and droop ☐

d. The affected leaves dry up for much of their length ☐

e. New central leaf growth normal leaves emerges-the after 'recovery' ☐

f. There is the presence of mealybug /ants underneath the plants attached to the roots when uprooted ☐

17. How does the other wilting conditions present in the pineapple you grow?

Tip burn /wilt ☐

Yellowing of leaves ☐

Other, Specify ……………………………………………………………………

18. How does the wilting condition (s) indicated in question 17 above presented: Evenly distributed among the plants ☐

Appear a few days after fertilizer/agrochemical application ☐

Isolated and spotted ☐

Other, Specify ……………………………………………………………………

D. Farmers Perception of the Pineapple MWP

19. Indicate your perception about the Mealybug wilt of pineapple using the following responses 1=strongly disagree, 2= Disagree, 3= Somewhat agree, 4=Agree and 5= Strongly agree

Statement	1	2	3	4	5
The Mealybug wilt of pineapple reduces the yield of the pineapple fruits					
The Mealybug wilt of pineapple can destroy the entire farm if not treated					
Plant affected by the Mealybug wilt of pineapple needs to be destroyed together with all plants within 1 m radius around it					
The greater the mealybug population of the pineapple farm the greater the incidence and severity of the Pineapple MWP					
The mealybug associated virus disease is very serious during the rainy season					

Statement	1	2	3	4	5
The mealybug associated virus disease is very serious during the dry season					
The mealybug associated virus disease is very serious during the rainy and dry season					
The Mealybug wilt of pineapple results more in low plant density					
The mealybug wilt of pineapple results more in high plant density					
Ants are the carriers of the mealybugs from place to place					
Controlling the ants and mealybug population is a way of checking the spread of the viruses					
The mealybug wilt virus is more serious on the field that no plastic mulch is used					
The mealybug wilt virus is more serious in the field than plastic mulch is used					
The mealybug wilt virus is serious when the field is bushy					

20. If you grow more than one variety of pineapple, please rank from very high to low (by ticking the box) which of the variety suffers mealybug associated wilt virus most

Variety	Very high	High	Moderate	Low
MD2				
Smooth Cayenne				
Sugarloaf				
Queen Victoria				

21. The stage of growth of the pineapple is the ants/mealybug population is high

Variety	Pre-flower induction stage	Post –flower induction stage
MD2		

Smooth Cayenne		
Sugarloaf		
Queen Victoria		

22. Stage of growth of the pineapple where mealybug associated wilt virus disease is severe

Variety	Pre-flower induction stage	Post –flower induction stage
MD2		
Smooth Cayenne		
Sugarloaf		
Queen Victoria		

23. Is the Mealybug wilt of pineapple restricted to certain portions of the field?

a. Yes ☐

b. No ☐

24. If you answered yes to question 23, which spots/areas is the wilt restricted to, during attack ……………………………………………………………

E. Farmers' Agronomic Management Practices

25. Do you keep fallow plots?

a. Yes ☐

b. No ☐

26. What is the duration of your fallow plots?

27. How do you keep track of the diseased areas/spots of your planted field?

a. Flagging plots with diseased plants ☐

b. Tagging individual diseased plants ☐

c. Indicating on the map of the plot ☐

d. Recording in a file ☐

e. Other, Specify……………………………………………………………

28. Control of mother plots against mealybug associated virus of pineapple

a. 3 months interval ☐

b. 6 months interval ☐

c. 9 months interval

d. Other, specify.. ☐

29. By what means do you prevent Mealybug wilt of pineapple on your mother plots

a. Spraying with insecticides to destroy ants and mealybugs ☐

b. Physical destruction of infected mother plants ☐

c. Not planting at the same spot for at least two seasons ☐

d. Other, specify..

30. Do you treat the soil that has been planted in the earlier seasons before planting new suckers?

a. Yes ☐

b. No ☐

31. If you answered yes to question 30 above, then by what means do you treat the soil

a) Spraying with insecticide ☐

b) Other, Specify..

32. Do you do spot soil treatment or whole plot treatment if you are replanting on land that has been planted before with an incidence of mealybug wilt?

a) Spot treatment ☐

b) Whole plot treatment ☐

33. What is the frequency insecticide of application to prevent mealybug/ant invasion in the variety(s) of pineapple you grow?

a. MD2 ....

b. Smooth Cayenne..

c. Queen Victoria..

d. Sugarloaf...

34. Time of application

a. MD2 ....

b. Smooth Cayenne ....

c. Queen Victoria...

d. Sugarloaf...

35. Type of insecticide applied

a. MD2 ....

b. Smooth Cayenne...

c. Queen Victoria...

d. Sugarloaf...

36. What is the rate of insecticide application?

a. MD2:..

b. Smooth Cayenne ....

c. Queen Victoria...

d. Sugarloaf...

37. Do you use the same insecticide throughout the growing season?

a. Yes ☐

b. No ☐

38. Do you use the same insecticide year in year out?

a. Yes ☐

b. No ☐

39. Who recommended the type of pesticides/rate you are using?

a. Agricultural Extension Agent ☐

b. Agro products input dealer ☐

c. Friends/Other Farmers

d. Buyers/Customers ☐

e. NGOs (Agro based) ☐

f. Other, Specify: .... ☐

40. When do you do the treatment?

a. As a precaution to prevent the occurrence of disease/mealybugs/ant ☐

b. As a Curative measure to destroy the ants/mealybugs when they appear ☐

c. Other, Specify..

41. Is the treatment method you have adopted effective against the MWP?

a. Yes ☐

b. No ☐

42. Land preparation method

a. Ploughing/harrowing/Ridging/Plastic Mulching ☐

b. Ploughing/harrowing/Ridging ☐

c. Weeding/Stumping ☐

d. Weeding ☐

Other, Specify..

43. What is the Pre-harvest Interval of the insecticide you apply? ....

44. What is the re-entry interval of insecticide(s) you apply? ....

F. Effects of Disease on Farmers' Socio-Economic Status

45. What is the estimated percentage loss of plants per hectare in any of the varieties that suffers from the mealybug associated virus attack?

Variety	1-20%	21-40%	41-60%	Above 61%
MD2				
Smooth Cayenne				

Variety	1-20%	21-40%	41-60%	Above 61%
Sugarloaf				
Queen Victoria				

46. Plants that are attacked by the wilt disease can recover to bear exportable fruits

c. Yes ☐

d. No ☐

47. Describe the nature of fruits produced by wilt infected plants:

a. Small and hollow fruits (non-Marketable) ☐

b. Low brix/too acidic fruits (non-Marketable) ☐

c. Other, Specify..

48. What is the estimated loss in terms of?

a. Yield ....

b. Financial (loss of sale value if for export) ....

c. Financial (loss of sale value if sold locally) ....

d. Resources (labour, inputs, man-hours) ....

e. Cost of pesticides ....

f. Other, specify..

THANK YOU!!!