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Occurrence and distribution of Papaya Mealybug (*Paracoccus marginatus* Williams and Granara de Willink) (Hemiptera: Pseudococcidae) in the coastal area of Kenya

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Abstract

Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) was first reported in Kenya in 2016. Kenya Plant Health Inspectorate Service (KEPHIS) together with other collaborators has since continuously carried out surveillance and management initiatives to contain the pest. In November and December 2020, a delimiting survey of the papaya mealybug (PMB) was conducted in six coastal counties. The survey was aimed at determining the incidence and intensity of infestations in the farms, host range in the region and to assess the farmers' awareness on management options. Sixty-seven (67) farms were randomly sampled across the six counties. An open data kit (ODK) mobile tool generated questionnaires were administered to collect data on PMB incidence, infestation intensity and management practices applied and their effectiveness based on responses from farmers. Papaya mealybug was confirmed to occur in the six counties surveyed with incidences which ranged from 10-100%. The intensity of infestation in the counties varied from very low to medium based on the applied scale and was higher on fruits compared to the leaves, stems and flowers. The survey further revealed that PMB infested citrus, sugarcane, okra and custard apple that were initially not reported as hosts. Majority (65%) of the farmers interviewed were aware about the occurrence of PMB on their crops and could positively identify and describe it. Some farmers had tried to manage the pest and the lowest incidence (3%) was recorded from fields where farmers combined chemical and cultural practices for management. In order to contain the impact and spread PMB, authorities and research institutions in Kenya may need to consider deploying classical biological control management which has successfully been deployed in other countries.

Key words: Delimiting survey, incidence, infestation intensity, Kenya, papaya mealybug.

Introduction

Papaya mealybug (PMB) *(Paracoccus marginatus)* is a devastating pest of papaya and other crops in Kenya. It is classified in the Order Hemiptera and Family Pseudococcidae. It is native to Mexico and Central America and was first reported in Kenya in 2016 (Macharia *et al*., 2017). Papaya mealybug has been found on more than 200 host plants ranging from vegetables, fruit trees and ornamental plants many of which are of great economic value (Finch *et al*., 2021). The insect can cause great devastation to economies that depend on agriculture (Krishnan *et al*., 2016). The serious invasive pest status of PMB is enhanced by its fast growth, short life span, polyphagous feeding behavior and ease of dispersion. Papaya mealybug completes its life cycle in an average of 15-32 days (Laneesha, Suroshe, Babasaheb, & Shankarganesh, 2020). Reproduction in PMB occurs sexually and each female lays 100-600 eggs in a white waxy ovisac with several generations per year (Muniappan *et al*., 2008). Female PMB undergoes three immature larval stages before moulting into adult stage. Male PMB undergoes two immature larval stages that moult into a non-feeding pre-pupal stage and later into a short-winged adult. First instar crawlers are best suited for dispersal because they can survive for a day or even more without feeding as they locate a suitable feeding site (CABI, 2024). In favourable tropical conditions, PMB can produce as many as 15 generations in a year (CABI, 2024). The estimated optimum and maximum temperature thresholds for full development of PMB is 28.4°C and 32.1°C respectively (Amarasekare, Chong, Epsky, & Mannion, 2008).

Infestations on papaya appears as a cluster of cotton like masses on above ground plant parts. The adult is the most destructive stage of PMB which acts by sucking the sap of the plant and weakening it further. Adult colonies usually establish along the veins and midribs of older leaves and all areas of tender leaves and fruits (Walker *et al*., 2003). In severe attack, leaves turn yellow and necrotic, a characteristic

feature of PMB attack (Krishnan *et al.*, 2016). Infested tender leaves get bunched up and distorted. Heavy infestations and feeding on the phloem sap produces honey dew, which cause formation of the black sooty moulds on the infested fruits and vegetation (Meyerdirk *et al.*, 2004). The honey dew excreted attract ants that form mutual associations with the PMB. Sooty mould formation on the surface of leaves impairs photosynthetic efficiency which further affects the yield of the host crop (Schneider & LaPolla, 2010). Papaya mealybug also attack fruits causing discoloration and shriveling (Sarma, 2013). It is projected that PMB has the potential to cause much damage in the future (Laneesha *et al.*, 2020).

Spread of PMB to new areas is largely aided by animals, ants and human activity. Animals and humans accidentally pick up crawlers of PMB as they brush past infested plants thus transferring them to new host plants (Sarma, 2013). Farm machinery and vehicles passing through crops and fields during pruning and harvesting activities also aid in spreading crawlers to new hosts. Crawlers move from one plant to another and are also dispersed by wind, rain and irrigation water. In trade, transport of infested fresh fruits and plants for planting can transmit PMB over long distances and potentially between countries (Krishnan *et al.*, 2016).

Management of PMB has posed a great challenge for various reasons. Effectiveness of chemical products is limited due to the waxy and cotton coverings on the body of PMB (Tanwar, Jeyakumar, & Vennila, 2010). However, application of profenophos, chlorpyriphos, buprofezin, dimethoate, imidacloprid, thiametoxam, acetampride in appropriate concentrations has been observed to be effective (Krishnan *et al.*, 2016). Biological control is gaining popularity as the most effective management tool against PMB. Classical biological control has been applied successfully in some countries in the Caribbean, Pacific Islands, the state of Florida and Hawaii in the USA and India

(Muniappan *et al*., 2008; Myrick, Norton, Selvaraj, Natarajan, & Muniappan, 2014). Eight host specific parasitoids have so far been reported to give effective control of PMB (Laneesha *et al*., 2020). The parasitoids *Anagyrus loecki* Noyes, *Acerophagus papayae* Noyes and Schauff and *Pseudleptomastrix mexicana* Noyes and Schauff (Hymenoptera: Encyrtidae) have been deployed against PMB in classical biological control in various parts of the world. *Acerophagus papayae* is so far rated the most effective having shown 75-81% suppression of PMB (Laneesha *et al*., 2020). Other natural enemies exploited in biological control include, the mealybug destroyer (*Cryptolaemus montrouzieri*), ladybird beetles, lacewings, hover flies and beetles in the family Coccinellidae (*Scymnus sp*.) (Krishnan e*t al*., 2016).

In Kenya, the first report of PMB was in the coastal region; in Kwale, Mombasa and Kilifi counties (Macharia *et al*., 2017). The pest was detected on papaya (*Carica papaya*), cassava (*Manihot esculenta*), chili pepper (*Capsicum annuum*), guava (*Psidium guajava*), mango (*Mangifera indica*) and eggplant (*Solanum melongena*) with losses of up to 91% on papaya (Macharia *et al*., 2017). The survey underscored the threat posed by PMB on food security and loss of livelihoods in the region. In recommendation, Macharia *et al,* (2017) pointed out the need for further delimiting surveys covering a wider area including examination of potential hosts and natural enemies. It is against this background that this delimiting survey was carried out to determine the incidence and intensity of PMB infestations, the host range and to create awareness among farmers on management options of PMB.

Materials and Methods

This survey was carried out between November and December 2020 in six counties in the coastal region of Kenya; Mombasa, Kilifi, Kwale, Taita Taveta, Lamu and Tana River. A total of 67 small and large farms were randomly sampled across the six counties. The sample size was limited as a precautionary measure

against spreading the pest during surveillance. An open data kit (ODK) mobile tool generated questionnaires that were administered to collect data on name of farm, location, GPS coordinates, farm acreage, host crop, age of the crop, symptoms of PMB expressed, pest incidence, pest infestation intensity, management method(s) applied in control of PMB and their effectiveness based on responses from farmers interviewed. The percentage incidence was determined based on a formula developed and applied by Kennedy *et al*. (2017) while the intensity of infestation was estimated based on a grade chart adopted by Regupathy and Ayyasamy (2010) on tapioca plant. To determine the incidences, 5 spots were selected in each field sampled and, in each spot, 20 plants were selected at random. A total of 100 plants per field were examined. The percentage incidence of infested plants was computed from the number of plants affected and total number of plants observed: Percentage incidence (%) = Number of plants affected / Total number of plants observed X 100.

The intensity of infestation on the whole plant and specific plant parts was estimated using visual parameters based on grades provided (table 1). Besides papaya, other crops infested by PMB were recorded. Destructive sampling was done where necessary for PMB extraction in the laboratory and further identification of the host plants. Farmers were also interviewed and responses recorded on checklist embedded in ODK questionnaire on their knowledge of PMB, management options applied and their efficacy. Chi-square test of independence was carried out to determine whether there was a relationship between the following parameters: presence of PMB and the cropping system, farmers' knowledge and PMB infestations in the farms, frequency of scouting and presence of PMB in the fields, and the management practice and average incidences of PMB.

Table 1: Grade chart for estimating the intensity of infestation of papaya mealy bug

Intensity	Infestation levels
Very Low (1)	i. Few individuals of PMB found casually
Low (2)	i. PMB found in low numbers
	ii. No adverse symptoms e.g. deformation of leaves observed on affected plants
Medium (3)	i. Almost 75-100% coverage of leaves /fruits/ inflorescence
	ii. Yellowing of leaves
	iii. Shedding of infested leaves and fruits
High (4)	i. Almost all plant parts (stem, leaves, flowers and fruits) covered with PMB showing white appearance
	ii. Leaves, fruits and inflorescences are covered with honey dew excretion and sooty mould
Very High (5)	i. All plant parts (stem, leaves, flowers and fruits) are covered with PMB showing white appearance
	ii. Honey dew rain under the tree
	iii. Crinkling of leaves
	iv. Drying and death of plants

Source: © Regupathy and Ayyasamy (2010)

Results and Discussion

Incidence and intensity of infestations of PMB on papaya

A total of 67 farms were surveyed in the 6 counties (figure 1). More farms were sampled in Lamu due to the vastness of the county while Mombasa was least

sampled because it is largely urban with limited farming activities.

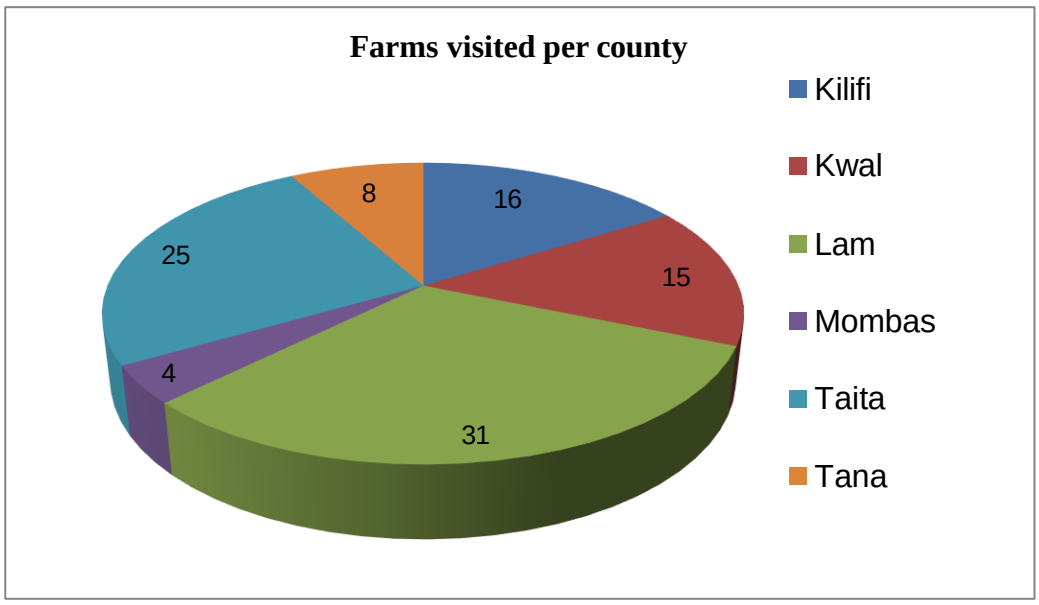

Figure 1: Distribution of farms as sampled across the counties

The findings confirmed that PMB occurred in all the six counties surveyed: Kilifi, Kwale, Lamu, Mombasa, Taita Taveta and Tana River. In the first report which only covered four counties, PMB was detected to occur in Kwale, Kilifi and Mombasa but absent in Taita Taveta county (Macharia *et al.*, 2017). The survey demonstrated that PMB had spread to the entire coastal region in less than three years. Papaya mealybug is physiologically at its optimum in temperature range of 25±5 ºC (Krishnan *et al.*, 2016). Further, in temperatures above 25ºC, females exhibit highest fecundity producing an average of 300 eggs per cycle. Papaya mealybugs have the ability to develop and establish successfully in areas with temperature range of between 18 ºC and 30 ºC (Amarasekare *et al.*, 2008). Coastal Kenya is generally warm with

temperatures mostly above 20ºC throughout the year. This is considered suitable for reproduction of PMB and with increased reproduction, came spread in order to explore food sources.

The survey also revealed varying levels of infestations in the counties (Table 2). The intensity of infestation ranged from very low to medium based on the scale applied on tapioca (Regupathy & Ayyasamy, 2010). Tana River County showed very low infestation while Kwale, Lamu and Taita Taveta showed low infestation. Kilifi and Mombasa showed medium infestations. The varying infestation intensities could be attributable to varying PMB management practices applied across the counties.

Table 2: Overall infestation across the six counties

County	Intensity of infestation
Kilifi	3
Mombasa	3
Kwale	2
Lamu	2
Taita Taveta	2
Tana river	1

Where; 1- Very low, 2- Low, 3- Medium, 4- High, 5- Very high

Incidences of PMB across the surveyed sub-counties ranged from 10% to 100% (Table 3). Kaloleni Sub-County in Kilifi County and Chewani Sub-County in Tana River County recorded the lowest incidences of 10% and 20% respectively. Mwatate and Taveta Sub-Counties in Taita Taveta recorded the highest incidences of 100% (table 3). Macharia *et al* (2017) observed that about 7.2% of farmers in the region applied various management options ranging from traditional, cultural to chemical methods to manage PMB. The various management practices applied together with the varying weather conditions across the sub counties could explain the PMB incidences observed.

Table 3: Incidence and infestation intensity of PMB on papaya in the different coastal sub counties.

County	Sub-County	PMB Incidence (%)	PMB Intensity
Kilifi	Kilifi North	80%	3
	Magarini	75%	3
	Kilifi South	67.50%	3
	Malindi	50%	3
	Ganze	64%	2
	Kaloleni	10%	2
Kwale	Msambweni	90%	3
	Kinango	95%	2
	Kwale	95%	2
	Lungalunga	68%	2
	Matuga	55%	2
	Kubo	40%	2
Lamu	Lamu East	70%	2
	Lamu West	41%	2
	Mpeketoni	32.50%	2
Mombasa	Changamwe	92%	3
Tana river	Tana River Delta	60%	2
	Chewani	20%	1
Taita Taveta	Mwatate	100%	2
	Taveta	100%	2
	Voi	26%	2

Where; 1- Very low, 2- Low, 3- Medium, 4- High, 5- Very high

The intensity of infestation was high on fruits (14%) compared to other parts of papaya plant (Table 4). Stems were the second highly infested plant parts (3%) followed by leaves and flowers (2%). Papaya mealybug like other mealybugs has a piercing-sucking mouth parts. They feed by inserting their mouthparts into plant tissues to suck the sugary sap from the phloem and other cells. The high preference for fruits compared to other papaya plant parts can be attributed to the softness of fruits and high concentration of sugars as the fruit ripens.

Table 4: Intensity levels of infestation on plant parts

Part of the plant	Intensity infestation by PMB	No. of counts	Percentage
Leaves	Low	45	68%
	Medium	20	30%
	High	1	2%
Stem	Low	58	89%
	Medium	5	8%
	High	2	3%
Flowers	Low	53	85%
	Medium	8	13%
	High	1	2%
Fruits	Low	28	43%
	Medium	28	43%
	High	9	14%

Host range of Papaya Mealy Bug

From the survey, papaya emerged as the most preferred host of PMB at 65% incidence followed by cassava (18%), mango and sugarcane (5%), citrus (3%) with castor plant, guava and okra at 2% (figure 2). In Kenya, PMB had previously been detected on papaya (*Carica papaya*), cassava (*Manihot esculenta*), chili pepper (*Capsicum annuum*), guava (*Psidium guajava*), mango (*Mangifera indica*), and eggplant (*Solanum melongena*) by Macharia *et al.* (2017). This survey revealed an expansion in the host range to include citrus, sugarcane, okra and custard apple. This may be because of the polyphagous nature of PMB. PMB has been reported to infest plants from 22 families of economic importance including weeds (Finch *et al.*, 2021; Muniappan *et al.*, 2008). It is therefore important to continue monitoring surveys in order to detect any further expansion in host range.

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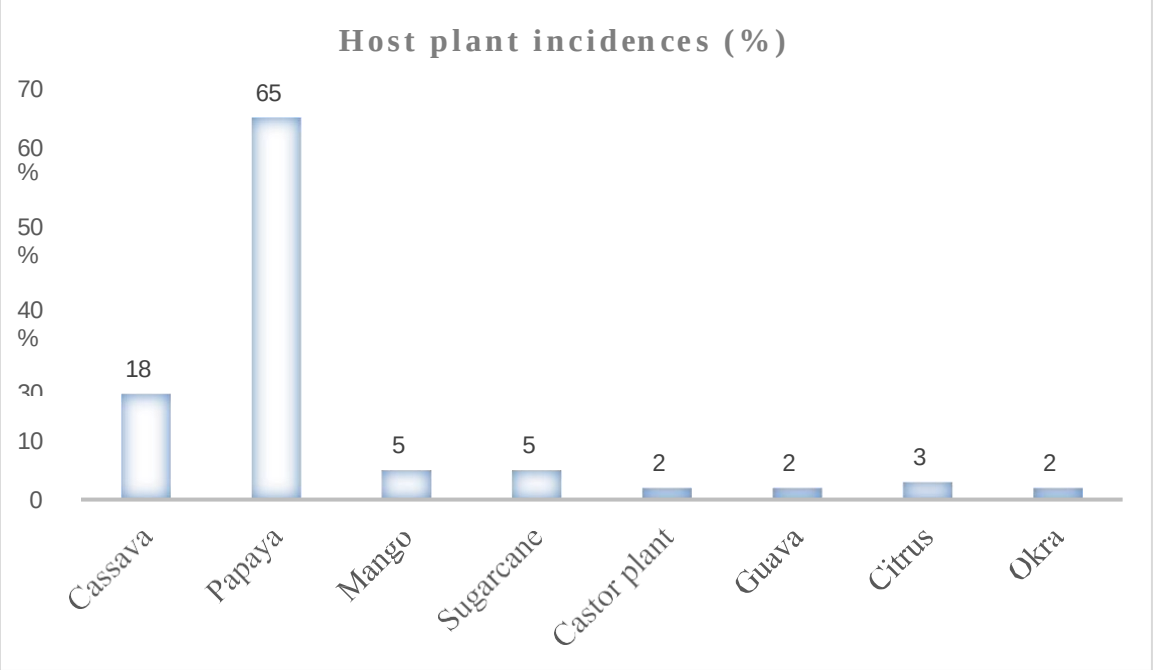

Figure 2: Infestation incidences of PMB on various hosts plant

During the survey, it was also observed that farmers intercropped papaya with other crops. The analysis revealed that there was a statistically significant relationship between cropping system and PMB infestations in the farms ($X(2) = 7.487$, $p=0.024$). Papaya mealybug was observed to be more dominant in intercropped farms than in monocrops. Famers in the surveyed area mostly intercropped fruit trees (papaya, mango, citrus, guava and castor plant) with cassava, sugarcane and vegetables like okra. Being a polyphagous pest, PMB may have preferred the intercrops as alternative hosts. Undefined farms were generally poorly managed, weed infested and neglected therefore could not be clearly defined as monocrop or intercrop system.

Farmer awareness and management of Papaya Mealy Bug

During the survey, farmers were interviewed to assess their level of knowledge of PMB. Majority (65%) of the farmers were aware about the occurrence of PMB on their crops and

could positively identify and describe it while 35% were not aware about PMB neither could they positively identify the pest. A section (2%) of the interviewed farmers did not respond to the question.

Further analysis revealed that there was a significant relationship between farmer's knowledge on PMB and the infestations in the farms (X (1) = 13.367 p<0.000). Knowledgeable farmers applied some management measures on PMB in the farms and this led to the reduced infestations in such farms. Farmers were also interviewed on the frequency of scouting for pests and diseases, particularly for PMB in their farms. The results showed that PMB was more dominant in farms where no scouting was undertaken. Scouting for pests and diseases results in early detection and initiation of intervention measures.

On whether there occurred a relationship between frequency of scouting and presence of PMB in the fields, a chi-square test of association was conducted. A significant relationship between the frequency of scouting and the presence of PMB in the fields was detected (X (3) = 51.330, p<0.05). This could imply that farmers who scouted their farms consequently applied control measures more as compared to those who never carried out any scouting and that may have led to the low incidences of infestation.

Average incidences of PMB in the farmers' fields was evaluated in relation to the management practices that farmers used. A significant relationship between the pest management practice and PMB incidences was detected in the farmer fields (X (3) = 61.916, p<0.05). The highest average incidence was recorded in farms where no management practice was applied (figure 3). This finding could be supported by the biology of PMB which has shown that in favourable environmental conditions and plenty of food, PMB can reproduce up to 15 generations in a year (CABI, 2024). The lowest average incidence (3%) was recorded in fields where farmers combined chemical and cultural practices

in the control of PMB. Therefore, a single approach may not effectively work in managing PMB. The combination is a partial integrated approach which may have contributed to increased susceptibility of PMB life stages therefore a better approach as compared to a single management approach. It is important therefore to increase the awareness of farmers on various management options and the best combinations to achieve an effective integrated management.

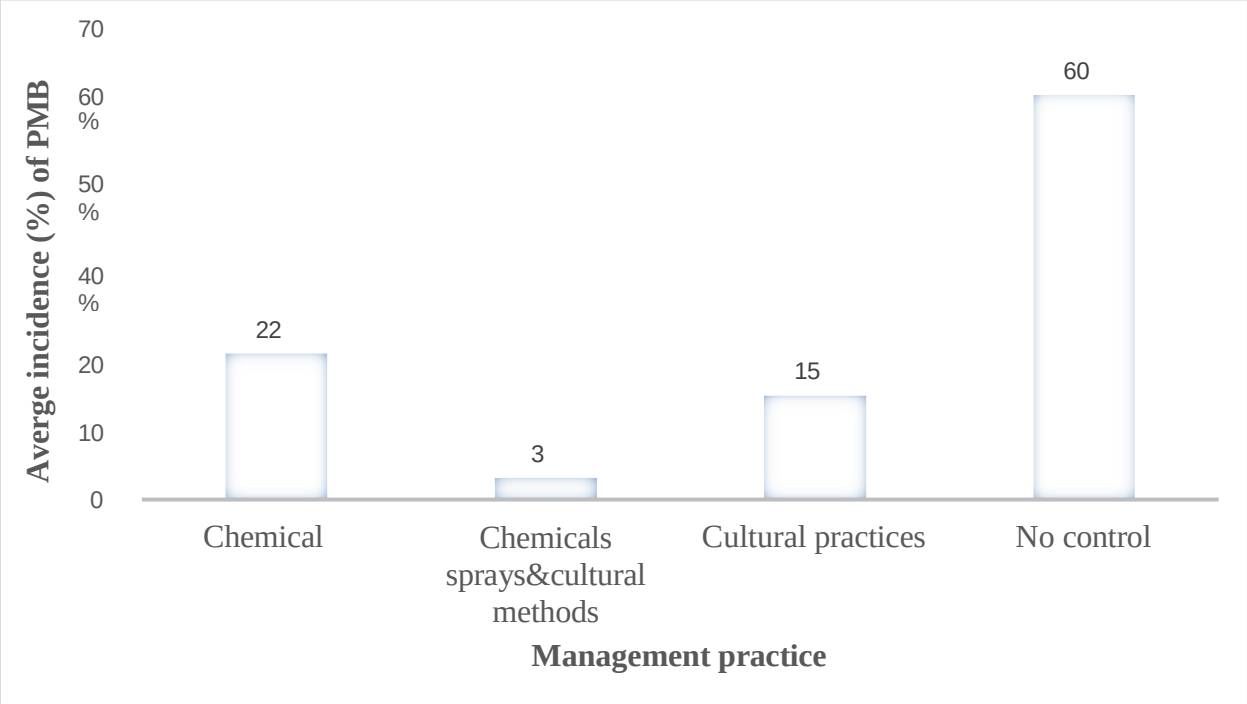

Figure 3: Percentage Incidences of PMB in different management practices

Conclusion and recommendations

During this survey, PMB was confirmed to occur in Taita Taveta, Mombasa, Kwale, Kilifi, Tana River and Lamu counties. In the first report, PMB had only been detected in Kwale, Kilifi and Mombasa Counties. This survey showed that PMB had spread to all the coastal counties in less than three years. The intensity of infestations ranged from very low to medium as per the applied scale and was higher on fruits compared to other plant parts. The survey also revealed that PMB had expanded its host range to include citrus, sugarcane, okra and castor that were not initially reported. The quick spread to other hosts demands effective management, regular scouting, monitoring and control. Increased awareness amongst farmers, agricultural extension workers and other stakeholders needs to be sustained to support effective management efforts in the region. To contain the spread, authorities and research institutions in Kenya should consider classical biological control which has successfully been deployed in other countries.

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