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Original article

Characterization of Farmer's knowledge and management practices of papaya mealybug *Paracoccus magnatus* (Hemiptera: Pseudococcidae) in Tanzania

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ABSTRACT

Papaya mealybug (PMB) is a serious insect pest for papaya production in Sub-Saharan Africa, limiting production potential in farming communities. We did a household survey to evaluate the Characteristics of farmers' knowledge, challenges, and current (PMB) control practices in four papaya growing regions of Tanzania namely, Tanga, Dodoma, Pwani, and Katavi involving 100 papaya farmers. The study found that 96% of farmers reported PMB, as a major challenge in papaya production. Very few (0.8%) of the farmers were knowledgeable on insect pest identification. Chemical pesticides were the only option for PMB control, and 43.0% of farmers were able to access and apply. We also found that 36.4% of the farmers were aware of the adverse effects of chemical pesticides. Furthermore, the study observed that 0.3% of farmers use botanical pesticides. Additionally, the study observed that 44.1% of farmers use control measures against PMB, the remaining 55.9% did not practice any control measure, thus leading to low papaya yields observed in the study regions. Our findings provide insights to farmers into the use of plant-based pesticides, mainly plant essential oils, and its benefits that may promote farmers' attitudes towards increasing papaya yield and reducing chemical pesticide use to avoid pest resistance.

1. Introduction

Papaya (*Carica papaya*) is a significant crop within the Caricaceae family characterized by softwood, cultivated as a perennial plant worldwide (Carvalho, 2015). The crop originated from South Mexico and Costa Rica (Vitoria, 2011). Currently, the global production of papaya is estimated to be 13.05 million metric tonnes in 2017, led by India with 44% of the world total. In Tanzania, the crop is grown mainly in Coastal, Dar Es Salaam, Morogoro, Tanga, Katavi, Dodoma, and Zanzibar, with a total production of 8,244 tonnes (F.A.O., 2012).

Papaya fruits can be eaten raw or processed into drinks, jams, candies and consumed as a vegetable when green fruits and leaves are cooked (Tulamandi et al., 2016). It is high in vitamin A, D, and C, and fibre, also contains papain enzyme used for meat tenderization and reduces constipation problems, as well as several secondary metabolites important for pharmaceutical and industrial applications (Shoaib et al., 2020; Bitto et al., 2009, Ramachandran & Nagarajan, 2014). However, having antioxidants lowers the incidence of several diseases including, cancer, heart disease, arteriosclerosis inflammation, arthritis, and brain dysfunction (Otsuki et al., 2010). In Tanzania, papaya is grown in lower to mid altitudinal zones, which experience high temperature, humidity, and moderate rainfall. The highly papaya-producing regions in Tanzania include Pwani, Dodoma, Tanga, Katavi, Morogoro, and Zanzibar, and are dominated by mainly smallholder farmers (Muzemu, 2013). Despite the favourable climatic conditions for papaya production in the above regions, yields are primarily low, ranging from 20 to 50 fruits /plant/year, contrary to products obtained under suitable climatic conditions, ranging from 200 up to 500 fruits/-plant/year (Prishanthini & Vinobaba, 2014).

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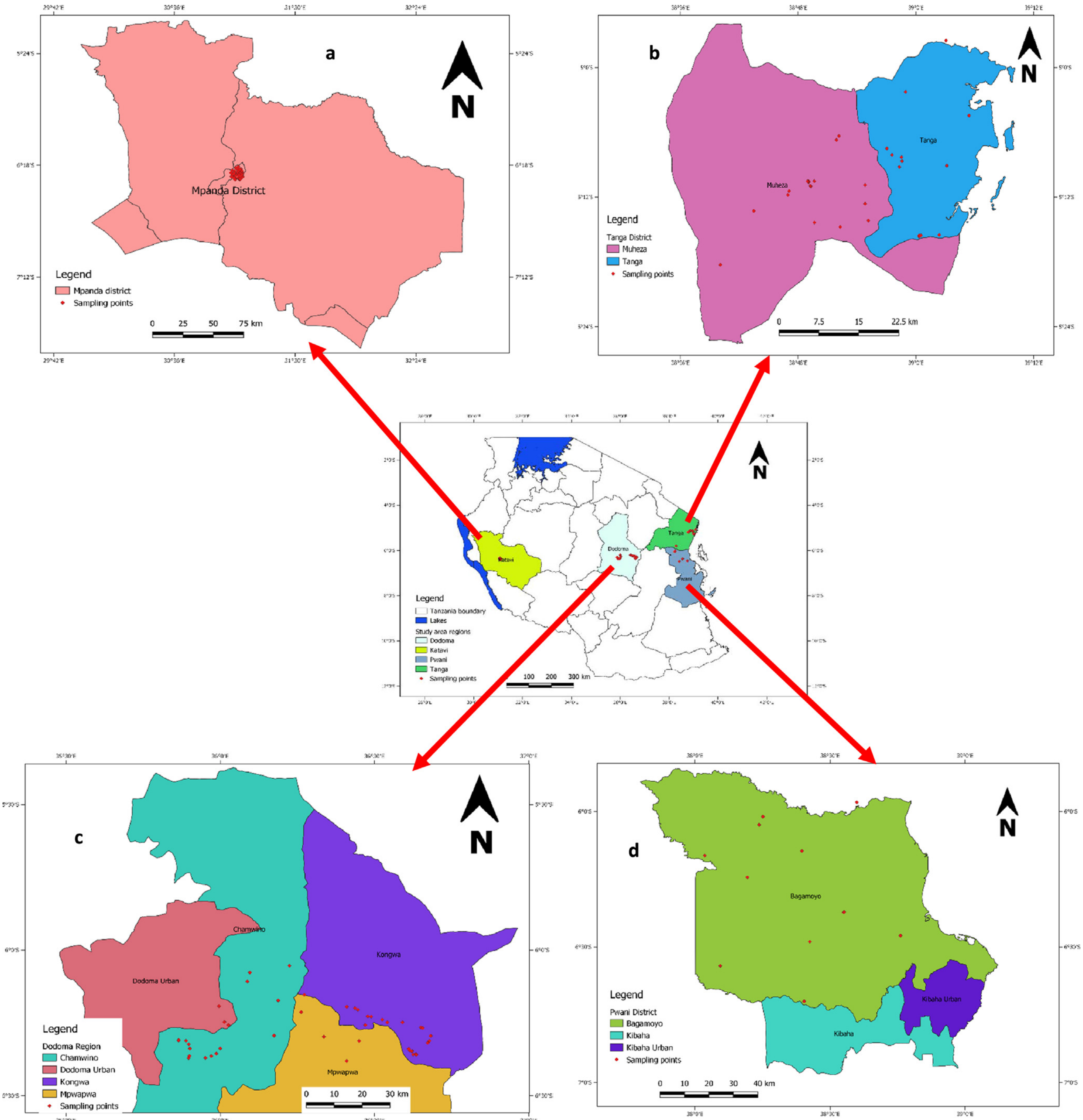

Fig. 1. The map showing regions in the study area and sampling points from October 2020 to January 2021 in four regions of Tanzania (a = Katavi, b = Tanga, c = Dodoma and d = Pwani).

Fruit production is affected by various factors, among which are pest and diseases infestation which have been a challenge to Tanzanian papaya farmers. Insect pests are reported to attack papaya three weeks after emergence. The destructive insect pests of papaya are the papaya mealybug (*Paracoccus marginatus*), aphids (*Aphis fabae*), and whiteflies (*Bemisia tabaci*). However, the most devastating insect pest is papaya mealybug which causes a severe economic loss of about 75–100%, especially in Sub-Saharan African countries if not well managed. The heavy wax covering the PMB body and the high diversity of host plants have made it very difficult to control the insect in a sustainable manner (Otsuki et al., 2010). Chemical pesticides have been reported as the only available method preferred by most farmers against papaya insect pests (Fatima et al., 2016). However, The Environmental concerns have been well addressed, and the negative impacts have been identified.

Furthermore, chemical pesticide alone is not a suitable approach for controlling this pest due to the challenge of affordability and access to smallholder farmers (Wilson et al., 2018). As a result, fewer farmers are practising other control measures such as cultural practices that have been followed by few farmers to control papaya mealybug.

Despite the papaya production challenges, very little information on identification, knowledge, perception, and reliable control measures is available in Tanzania. Therefore, proper identification, and sustainable development of new and adaptable control measures, indigenous farmers' learning, and perception of insects to be fully exploited and incorporated in papaya production processes. Therefore, this study was conducted to assess farmers' knowledge and management practices of papaya mealybug in Tanzania toward improving papaya production via insect pest management based on plant-based pesticides.

2. Materials and methods

2.1. Study site and farming description

The survey study was conducted in four main papaya growing regions of Tanzania, namely Tanga (Latitude 5°08′88.75″ S Longitude 39° 10′ 23″ E), Pwani (Latitude 7° 32′ 37.71″ S Longitude 38°82′ 05″ E), Dodoma (Latitude 6° 16′18.40″ S Longitude 35° 74′ 54″ E) and Katavi (Latitude 6°40′ 00.00″ S Longitude 31° 33′ 33″ E) during October 2020 to January 2021. The study area selection was based on their ecological and geographical location, with numerous papaya production farms and increasing papaya mealybug control challenges. The surveyed regions are at an altitude of 24.98 m, 258 m, 1120 m, and 966 m, respectively, above sea level; the annual mean rainfall is 982 mm, 1116 mm, 447 mm, and 250 mm, with a mean temperature of 26 °C, 32 °C, 22.6 °C, and 32 °C, respectively. The main crops grown in these regions are maize, cassava, common bean, groundnuts, and fruit crops such as papaya, mango, oranges, watermelon, pineapple, and guava. Among fruit crops, papaya is widely grown for home consumption and as a cash crop (Fig. 1).

2.2. Field survey and data collection

A semi-structured questionnaire was used to evaluate farmers' perception, knowledge, and practices on papaya mealybug insect control. The household selection was purposive sampling targeting every fifth household from the list created in each region until we attained the required number of respondents. The permission for participation in the survey was approved by the respective agriculture officers and village leaders before the survey question administration. The researcher enlightened the reason for doing the survey. The farmer's list provided by the village leader was used to sample the respondents randomly. We interviewed 100 farmers' households, twenty-five (25) papaya growing farmers from each region. Before the interview, a consent form was provided to the respondent, introducing the researcher's aim and asking for approval to continue with the discussion. The pre-tested questionnaire obtained from the pilot study was used to develop a final version for data collection. During the interview, Kiswahili as a national language was used and occasionally local language for farmers who do not understand Kiswahili.

After that, the local language translators were used to arbitrate communication between interviewers and respondents. Finally, the answers were all written down in English. The time taken for interviewing a farmer was between 30 and 40 min. During the survey, three areas of information were captured; i) Personal farmers data, economic profile, and farms characteristics, ii) current knowledge of papaya mealybug, and iii) papaya mealybug management practices by farmers. Other information on papaya and management challenges most farmers face was obtained through focus group discussion through community meetings in all villages.

Finally, to assess the infestation of insect pests, the researcher showed pictures of all possible papaya insect pests. Then, farmers were allowed to score for the level of infestation caused by each problem identified. The study used 1 to 4 scales by Nagrare et al. (2011).

Grade I: the scattered appearance of a few mealybugs on the plant (<25%). **Grade II** is a severe mealybug infestation on any branch or less than half of the plant (25 49%). **Grade III**: a severe infestation of mealybug on more than one branch or half portion of the plant (50–75%). **Grade IV**: a severe mealybug infestation on the whole plant (>75%). Data were collected through face-to-face interviews with farmers using a questionnaire programmed on the Open Data Kit (O.D.K.) platform administered on a computer via the O.D.K. to manage the application.

2.3. Data analysis

The summarized, collected data were analysed using descriptive statistics (means, standard deviation, and percentages) were obtained using the Statistical Package for Social Sciences (SPSS) version 25. Comparative statistical tools, such as Chi-square and one-way analysis of variance (ANOVA), were conducted to assess differences regarding socio-demographic, farm characteristics, knowledge, perceptions, and management practices of papaya pests. We set the level of significance at 5% and means separation by Tukey's HSD (honestly significant difference) test**.**

3. Results

3.1. Socio-Economic characteristics of the farmers

Most farmers surveyed in the four regions were male (79.3%). The average age of the farmers across the explored areas did not vary ($p < 0.49$), ranging from a mean of 44.4 years in Tanga, 45.13 years in Pwani, 46.4 years in Katavi, and 46.8 years in Dodoma. The mean age for all regions was 45.6 years, comprising 3–5 individuals per household. 59.5% of the respondents had primary education standard 7, whereas 12.4% had no formal education, and only 5% had higher education (Table 1). The level of education varied significantly in the surveyed regions. The highest number of respondents with formal education was in the Tanga and Dodoma regions, which also had a high papaya yield (Table 1).

3.2. Papaya cultivation practices

In all the surveyed regions, most farmers' average area for papaya production was 0.86 ha, and it varied significantly $P = 0.001$) across the regions. The area of production range from 1.19 ha in the Tanga, 1.08 ha in Pwani, 0.76 ha in Katavi, and 0.44 ha in Dodoma. Only 28.1% of the respondents were growing improved varieties, of which 79% do not know improved papaya varieties. Most of the surveyed farmers, 71.9%, use local papaya varieties, which are highly variable in cropping and fruit characters. Only 28.1% of the respondents are growing improved varieties, of which 79% did not know the name of the varieties. At the same time, most (71.9%) of the surveyed farmers cultivated local papaya varieties. About 91.7% of farmers reported intercropping papaya mostly with cassava, maize, groundnut, pineapple, and beans, and sometimes with vegetables such as African eggplants. However, 81% of the respondents were not satisfied with the yield due to insect pests.

3.3. The prevalent of papaya pests

During the survey, 96% of farmers reported insect pests as a primary challenge to current papaya production. Farmers mentioned numerous insect pests attacking papaya in their local languages, such as papaya mealybug (*P. marginatus*) = "wadudu mafuta",

Table 1
Characteristics of respondent households (values are mean ± sd, n = 136) during November 2020 to January 2021.

Regions	Tanga	Dodoma	Katavi	Pwani	Mean (S.D.)	Chi-Square (X^2)
Respondent Age	44.4 ± 13.1	45.13 ± 14.7	46.8 ± 15.0	46.4 ± 12.7	45.6 ± 13.8	X^2 = 11.38, P = 0.4
Education	2.26 ± 0.7	2.43 ± 1.0	1.8 ± 0.1**	1.7 ± 0.9**	2.04 ± 0.67	X^2 = 34.3, P = 0.001
Household size	4.95 ± 2.2	4.19 ± 2.0	4.40 ± 1.3	4.39 ± 1.3	4.48 ± 1.7	X^2 = 27.6, P = 0.42
Total farm size	4.27 ± 21.	6.56 ± 0.3	3.28 ± 1.5	4.52 ± 2.1	4.65 ± 1.5	X^2 = 42.4, P = 0.2
Yield	185.6 ± 48.1	179.4 ± 106.8	146.8 ± 98.1	108.1 ± 41.0**	154.9 ± 75.3	X^2 = 174.7, P = 0.001

Mean values with an asterisk are statistically significant at $p < 0.01$

aphids (*Aphis fabae*) = 'kimamba" and whiteflies (*Bemisia tabaci*) "buhuka". Additionally, 98.3% of farmers mentioned the papaya mealybug (*Paracoccus marginatus*) as the key insect pest of papaya, followed by whiteflies (*Bemisia tabaci*) (32.2%) of farmers and aphids (*Aphis fabae*) (6.6%) of farmers (Fig. 2). Other pests (not insects) mentioned by farmers were birds, underground rodents, livestock, and thieves. Apart from that, 76.9% of farmers reported yellowing as the significant symptom of papaya mealybug infestation, followed by leaf curling 67.8%.

3.4. Knowledge of papaya mealybug identification

Based on the survey conducted, 99.2% of respondents could not identify and differentiate papaya mealybug species observed in other host plants. Furthermore, only 0.8% of farmers were able to describe by their local names and colour, which was the prominent gap to be considered. Similarly, most farmers were confused about differentiating papaya mealybug from other insects, particularly aphids, claiming morphologically the same. During a survey, 69.7% of respondents mentioned that they saw the papaya mealybug during 2015, with significant variations across regions (x^2 = 99.2, df = 48, p = 0.001) and primarily affected papaya during the vegetative stage and that the infestation is worse than in the past 5-8yrs. On average, farmers had minor to moderate (4.5–39.5%) knowledge of insect pests' identification and management.

3.5. The economic role of papaya mealybugs infestation in papaya yields and production

In the study regions, farmers reported insect pests, particularly papaya mealybug, as the significant constraints to papaya production in their farms varied in infestation rate across the regions (x^2 = 41.4, df = 15, p = 0.001), with the most infestation in Pwani region followed by the Tanga region (Fig. 3). Furthermore, we conducted a Chi-square analysis to understand the effects of papaya mealybug infestation on papaya yield. The results were significant (p = 0.001) across regions, having a mean yield of 185.6 fruits/-plant/year in Tanga, 179.4 fruits/plant/year in Dodoma, 146.8 fruits/plant/year Katavi 146.8 fruits/plant/year and 108.1 fruits/-plant/year in Pwani (Table 1 and Fig. 3).

3.6. Papaya mealybug control practices

The study found that 43.0% of respondents use chemical pesticides, 0.8% use ashes as a local control method, and 0.3% use botanicals, while 55.9% do not apply any control measure. Currently, papaya production in study areas is for subsistence, and due to the ineffectiveness of chemical pesticides, farmers have abandoned papaya production by not applying any insect control measure. However, papaya production in the study areas is starting to gain commercialization due to the increased fruits (particularly papaya) consumption demand in major cities.

Moreover, 93.4% of farmers reported chemical pesticides Profenofos as the most preferred and effective by 50%. Besides, only 36.4% of the respondents were aware of the harmful effects of chemical pesticides. Among those, 15.5% reported the toxicity effects to humans, and others (67%) complained about the high price. On the other hand, 79.3% of the farmers reported that chemical pesticides are easy to obtain and 34% easy to use. Additionally, 31.6% of the respondent know the advantages of using botanical pesticides though none of them (0.3%) use it against papaya mealybug. Apart from that, 25.6% reported that botanical pesticides are nontoxic, and 85% of respondents reported easy to process, while 96.7% reported that botanical pesticides are easy to obtain. Despite the chemical pesticides being the only available control measure

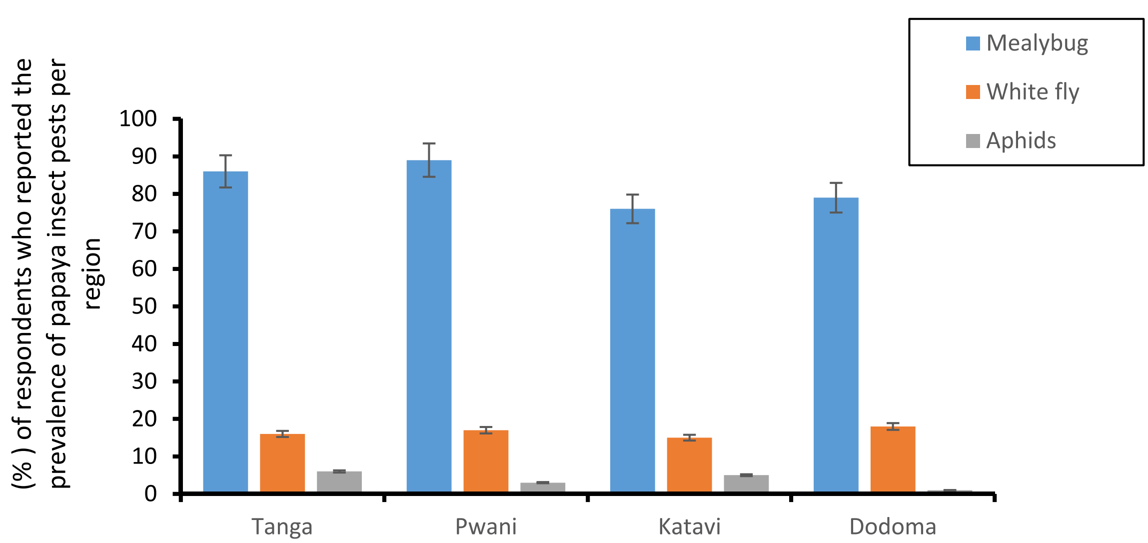

Fig. 2. Major papaya insect pests in papaya farming as reported by farmers during the survey in four regions of the study area.

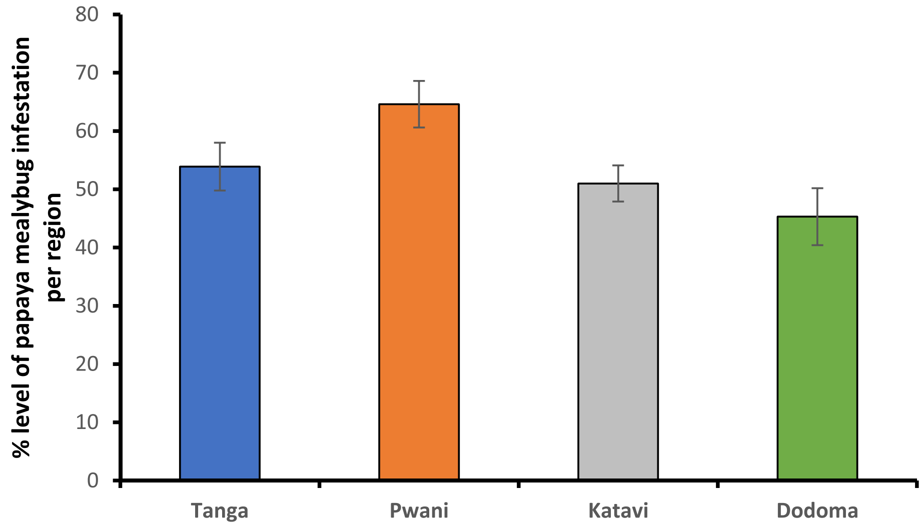

Fig. 3. Level of papaya mealybug infestation as reported by farmers during study survey in four regions during 2020–2021.

for most farmers, only 43.0% apply it against papaya mealybug in the field.

Furthermore, the respondents reported that they were not aware of which control measure is effective. A few of them, 0.3%, mentioned neem extract as another method against papaya mealybug but complained about the accessibility and preparation rates which also was a gap in this study. In the survey, most farmers got the chemical pesticides application instructions from agro-dealers. However, we noticed that 43% of these dealers have only achieved primary education and no formal pesticide application and security training.

4. Discussion

Most of the surveyed farmers in this study were male heads of the families, who are likely to influence and affect the management of pest and farming practices. A high number of male farmers in papaya production could be a potential way forward to pest management as the head of the family have veto power on the farming decision. Most farmers engaged in papaya farming were at the middle age, with a low family workforce contributing to the low yields observed as the production did not engage productive young age. The highest number of respondents with formal education found in the Tanga and Dodoma regions could be the source of the high papaya yield observed in those regions as most educated farmers are aware of agricultural managerial practices, particularly insect pests control practices.

On the other hand, most farmers used local papaya varieties, which are highly variable in cropping and fruit characteristics. The productivity and quality of fruits from such plants are not as good as those of improved cultivars, probably associated with low papaya yield in surveyed regions (Singh & Sharma, 2016). Growers need to know the suitable varieties because some studies show that good varieties are resistant to insect pests, particularly papaya mealybug, which can be very profitable to growers. However, the illiteracy on papaya varieties to most surveyed farmers might contribute to the low yield, indicating most planted non-insect-resistant varieties. In all the surveyed areas, the insects were severe in papaya plants due to the crops intercropped with, as those intercropped crops found in papaya plants are the primary papaya mealybug host plants. In line with this study, Zucca et al. (2010) observed papaya mealybug on cassava, eggplant, beans, and mangoes. However, for the papaya yield to be satisfactory to farmers, awareness training must be done on the suitable crops to be intercropped with papaya.

The study discovered the gap in the knowledge on insect pest identification and specific control measure. For example, despite farmers identifying the insect morphologically, they were not aware of the particular control measure for the specific insect; as a result, some of the wax coating insects, particularly the papaya mealybug, remained uncontrolled, leading to more severe challenges in papaya production. However, most farmers were confused about differentiating papaya mealybug from other insects such as aphids, claiming morphologically the same. Furthermore, this kind of identification falls under field observation based on morphological characters, which are inefficient as many mealybug species look similar and lead to a wrong title. Besides, farmers observed yellowing as the main symptom of papaya mealybug attack, but unfortunately, they could not differentiate with plant nutrient deficiency symptoms. These pieces of information drive researchers to form farmers - extension officers- researcher's networks for better and more reliable agriculture information flow.

During the survey, farmers believed that the presence of mealybug was just punishment from ancestral and that only ancestral could remove it, which is a significant hindrance perception toward insect pest management (Personal communication). This study information was in line with the study by Gebregergis et al. (2018). The common knowledge of insect identification observed in all surveyed regions could be due to the loss of traditional knowledge, resulting from the slight transmission of agricultural information from one generation to another. In addition, the lack of extension services from agriculture officers, N.G.O.s, and other agricultural stakeholders could be another source of low and unreliable information flow to farmers.

In addition, most of the farmers in this study mentioned insect pests, particularly papaya mealybug, as the major threats to papaya production and primarily affected papaya during the vegetative stage. In line with these results, Ramachandran and Nagarajan (2014) observed and reported low papaya yield due to a high infestation of papaya mealybug in the field. The current study indicated that papaya mealybug attacks other host plants attributed to higher infestation and favourable weather factors in the surveyed regions. The second reason for the high infestation in the areas surveyed could be poor farm sanitation, such as leaving infested plant residues and intercropped host plants observed in the surveyed areas. The study recommended that unmanaged papaya mealybug can cause a loss of up to 75% with a profound impact on smallholder farmers.

Despite a large area under papaya cultivation in Katavi and Pwani region, these regions have a low papaya yield due to the high mealybug infestation observed in the study area. Thus, papaya mealybug infestation is a significant driver in papaya yield loss in most papaya-growing regions in Tanzania. The findings of this study are in line with those reported by Kansiime et al. (2020) that the papaya mealybug has emerged as a significant threat to the papaya production industry in Kenya and India.

The most common method used by farmers in all the study areas was chemical pesticides, which was effective only by 50%, implying that the reported methods were not adequate. In line with the current study, most contact chemical pesticides are less effective to control papaya mealybug due to heavy wax coating insect's bodies. While pesticide use dominated as the only available and known papaya mealybug control measure, the study revealed a challenging gap in chemical pesticide usage. For instance, most visited farmers usually did not know the names and rates of the chemical pesticides. Similarly, the study observed unregistered pesticides farmers use to control papaya mealybug.

Additionally, noticed the misuse and handling of the spray equipment during the survey similarly to Wilson et al. (2018), Kapeleka et al. (2019), and Devine and Furlong (2007). Plant-based products especially plant essential oils, are a safe alternative but have not been developed and practised to control papaya mealybug in all the surveyed regions. To not rely on the chemical pesticide in the long run, the study discovered a gap in using plant-based pesticides, mainly plant essential oils. During the survey, we noticed that most dealers have only achieved primary education and no formal pesticide application and security training, which might be the reason for the unawares and improper pesticides application that most farmers face. Devine and Furlong (2007) explained the effects of chemical pesticide misuse, particularly in smallholder farmers in sub-Saharan Africa.

The knowledge gap discovered in this study alert the capacity building on proper insect identification and management using plant-derived products, particularly the plant essential oils containing chemical compounds that can dissolve the mealybug wax coating body and eventually inflict them (Prishanthini & Vinobaba, 2014). Lastly, to develop a new good and insect control program/ technology, farmers' indigenous knowledge is essential for easy and rapid adoption in the deployed areas.

5. Conclusion

The present study has revered insect pests, particularly papaya mealybug being the major drawback to papaya growing farmers in Tanga, Pwani, Katavi, and Dodoma regions in Tanzania. Farmers mentioned Chemical pesticides as the leading available method for papaya mealybug management. However, most farmers were not able to apply its cost affordability. In all surveyed study areas, most farmers could not identify and differentiate papaya mealybug observed in other host plants. Additionally, the use of plant-based pesticides, specifically plants essential oils, in papaya mealybug management among most farmers was not addressed that brought a gap in this study.

Furthermore, the study suggests different capacity-building training for farmers, such as developing farmers' field schools. In addition, creating awareness to farmers on using plant-based pesticides, mainly plant essential oils, might benefit farmers by reducing chemical pesticides usage. Finally, the findings from this study urge the need to integrate extension officers and other agricultural stakeholders as critical players in the formation of research-farmers-networking programs contributing to developing an efficient, low-cost, and environmentally friendly pest management strategy. Resource-constraint farmers can quickly adopt toward sustainable papaya production.

Author Contributions

Concept, R.W.M., P.B.V., and P.A.N. Methodology, R.W.M., P.B.V. and P.M.K., Formal analysis, R.W.M. Original draft preparation, R.W.M. Review and editing, P.B.V., P.A.N., and P.M.K. All co-authors contributed to finalizing the manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author upon request.

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