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Evaluation of host plant species for a trap cropping strategy in integrated pest management of pineapple mealybug (*Dysmicoccus brevipes*)

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Selecting the right crop management strategy is crucial for agricultural success, particularly for pineapple [*Ananas comosus* (L.) Merr.] growers battling the pineapple mealybug [*Dysmicoccus brevipes* (Cockerell 1893)], a pest causing significant harm worldwide. Mealybugs are small, soft-bodied insects that can cause severe crop damage by secreting a sticky liquid known as honeydew, which promotes mold growth and inhibits photosynthesis (Palma-jiménez and Blanco-meneses 2018). The pineapple mealybug is notorious for stunting growth and even killing plants by sucking sap and spreading viruses (Lisnawita *et al*. 2023). They are challenging to control due to their wide host range. Traditionally, the management of pineapple mealybug infestation in plants primarily relies on chemical control methods, involving the administration of synthetic pesticides such as organophosphates (e.g. malathion), neonicotinoids, and chitin-biosynthesis inhibitors (Wallingford *et al*. 2015, Lembaga Perindustrian Nanas Malaysia 2020). Though effective at first, excessive use of these chemicals poses environmental and health risks, including potential harm to humans and animals. However, repeated usage of these compounds may lead to insect resistance, which over time may decrease the efficiency of these pesticides (Leong *et al*. 2020).

To reduce dependence on chemical pesticides, alternative strategies are being explored. Recent research has focused on leveraging mealybugs' host selection behaviour for control. Trap cropping involves growing other non-crop species plants in a selected area to attract pests away from main crops and has emerged as an effective, sustainable solution (Sarkar *et al*. 2018). This method, which exploits pests' preferences for certain plants, has proven successful in reducing pest populations and minimizing damage without the downsides of chemical use (Popp *et al*. 2013, Dara 2019). However, there's a need for further research to identify specific plants that effectively attract pineapple mealybug. Understanding these preferences can help refine trap cropping strategies, offering the global pineapple industry a way to combat pests more sustainably (Cotes *et al*. 2018). Our study aims to fill this gap by investigating the selection and preference of pineapple mealybug for different host plant species, contributing to the development of more effective and environmental friendly pest management techniques.

Host plants: Nine host plant species, namely banana (*Musa* spp.), pumpkin [*Cucurbita moschata* (Duchesne) Duchesne ex Poir.], roselle (*Hibiscus sabdariffa* L.), hibiscus (*Hibiscus rosa-sinensis* L.), ground fig (*Euphorbia hirta* L.), okra [*Abelmoschus esculentus* (L.) Moench], java grass (*Cyperus rotundus* L.), goose grass [*Eleusine indica* (L.) Gaertn.] and rhodes grass (*Chloris gayana* Kunth) has been used in this study. The selection of the host plant species is based on reports of Mani and Shivaraju (2016), O'Hearn and Walsh (2018), Lopes *et al*. (2019). All the host plants were planted on 16 inch × 16 inch polybags with a mixture of soil consisting of 3:2:1 topsoil, sand, and organic matter as the plant medium. The plant was irrigated following usual operating standards until the growth of 2–3 feet tall.

Insects: The pineapple mealybug were reared on sweet pumpkins (Carabali-Banguero *et al*. 2013). The rearing was done in an insect cage with a fine mesh net covering the entire enclosure in an environment maintained at 27°C (Mani and Shivaraju 2016). Thirty adults of the pineapple mealybug were reared on the pumpkin for two months to establish its population before the host plant experiment began (O'Hearn and Walsh 2018).

Host plant experiments: Host plant preference for pineapple mealybug was evaluated from August 2022 to January 2023. Three research plots of 9 m^2 were established. Each plot was made open at the top and black netting (which allows 50% light penetration) covers the plot edge to reduce the pest attacks on the host plant, particularly grasshoppers and leaf-eating beetles. The distance between each plot is approximately 10 m. Experiments were set up in a completely

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randomized design (CRD) with three replicates (plot). No-choice settling experiments were used to evaluate the efficacy of all the chosen trap crops (Schoeny *et al*. 2019). To inhibit the growth of additional weeds in the area, plastic mulch, also known as silvershine, is applied to the ground part of the plot. Nine host plant species (banana, pumpkin, roselle, hibiscus, okra, ground fig, java grass, sambau grass and rhodes grass) were readily planted (2–3 feet tall) before the experiment began. The host plant species were arranged in a circle. The pumpkin that serves as the pineapple mealybugs' reservoir is placed at the center with a 1 m distance from the host plant species (Schoeny *et al*. 2019). The distance of the host plant species from one another is 60 cm. All plants were watered and fertilized following standard operating procedures and plant requirements. No herbicides or pesticides were applied throughout this study. The pineapple mealybug and the host plant have been monitored biweekly for 6 months, and the population of the pineapple mealybug was calculated on each of the host plants. The host plant crops that attract the greatest number of pineapple mealybug are considered to be the most effective and will be used in subsequent field studies.

Data analysis: The data analysis was performed using the One-way Analysis of Variance (ANOVA) method in Minitab version 20.0 software. A heatmap was constructed utilizing the Origin Pro 2022 programme to graphically represent the relative abundance of pineapple mealybug attracted to individual trap crops. In addition, a bar graph was employed to assess and contrast the overall abundance of pineapple mealybug across several trap crops. The bar graph was analyzed using Microsoft Excel.

Host preference and performance: Our findings reveal a pronounced preference of pineapple mealybug for bananas over other tested plant species (Table 1). Statistical analysis via ANOVA confirms a significant variance in mealybug distribution across different plants (F=26.87, P<0.00), highlighting the impact of host species on mealybug attraction. Subsequent analysis through Tukey's Pairwise Comparisons delineates the plants into categories based on average mealybug counts. Bananas, with an average of 621.7 mealybug, are distinguished as the top attractor in category A. Category B is initiated by pumpkin (average 237.0) and includes roselle, hibiscus, and ground fig, with averages of 155.0, 120.0 and 81.3, respectively. The lowest averages, constituting category C, are seen in okra (27.0), java grass (20.0), goose grass (10.0) and rhodes grass (2.0).

The grouping letters signify statistical significance. The host plants sharing a letter do not significantly differ in their ability to attract mealybug. Therefore, banana significantly outperforms all other crops. Conversely, crops like okra and various grasses exhibit minimal attraction. This research underscores the importance of host plant selection in the strategic management of pineapple mealybug populations, identifying bananas as the prime candidate for effective trap cropping strategies.

The variance in pineapple mealybug populations among diverse host plants, with bananas exhibiting the highest level of infestation (Fig. 1). This indicates a pronounced preference of mealybug for bananas over other tested plants, whereas rhodes grass is markedly less attractive to these pests.

Table 1 Pineapple mealybug adults observed on plants; mean no. of adults observed on all 9 host plant species

Species of host plant	Mean ± SD
Banana	621.7 ± 172.7^{a}
Pumpkin	237.0 ± 45.6^{b}
Roselle	155.0 ± 22.5^{bc}
Hibiscus	120.0 ± 70.0^{bc}
Ground fig	81.3 ± 17.5^{bc}
Okra	27.0 ± 17.3^{c}
Java grass	20.0 ± 27.2^{c}
Goose grass	10.00 ± 12.49^{c}
Rhodes grass	2.00 ± 2.65^{c}

Note: Means that do not share a letter are significantly different.

The variability in mealybug presence on ground fig and hibiscus, as evidenced by larger error margins, suggests their efficacy may fluctuate based on environmental or situational factors. In contrast, plants like pumpkin and banana show more stability in mealybug populations, indicated by narrower error bars.

Through Tukey's method, bananas are uniquely classified in Group A for their superior attractancy, while pumpkin is placed in Group B. Roselle, hibiscus and ground fig share a grouping in BC, suggesting their attractiveness to mealybug might be equivalent to that of pumpkin but less so than bananas. Less preferred species, including okra and various grasses, fall into Group C, highlighting their lower mealybug densities.

These outcomes highlight the strategic potential of selecting specific host plants for mealybug management in agriculture. Bananas' appeal to mealybug positions them as a promising trap crop option. However, the inconsistency observed in certain species points to the necessity for further investigation to validate their reliability under different circumstances.

Fig. 2 heatmap elucidates the dynamics between pineapple mealybug and an array of host plants across biweekly intervals, using colour intensity to signify mealybug abundance. Predominantly light colours across the heatmap suggest limited appeal of most plants to mealybug. In contrast, *Musa* spp. consistently exhibit dark tones, marking them as the most frequented by mealybug, with *Cucurbita moschata* trailing as a close second due to its numerous darker segments. The variation in colour intensity among other plants highlights their fluctuating appeal, with some showing sporadic dark areas, indicating temporary heightened attractiveness. The vertical gradient change across the heatmap denotes shifting attraction levels over time, potentially due to environmental changes, mealybug lifecycle stages, or other factors.

This study investigates the efficacy of various trap crops in managing pineapple mealybug, with bananas emerging as the most effective attractant. These results

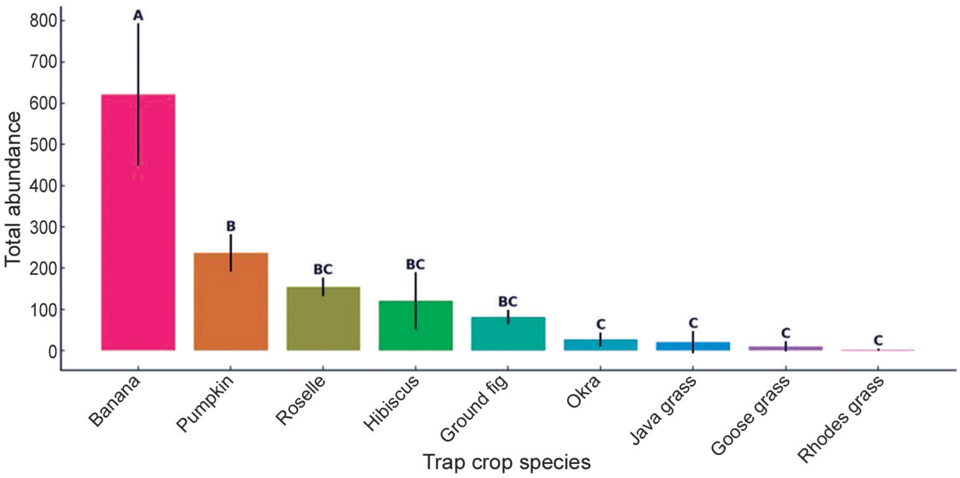

Fig. 1 Total abundance of pineapple mealybug for each host plant species.

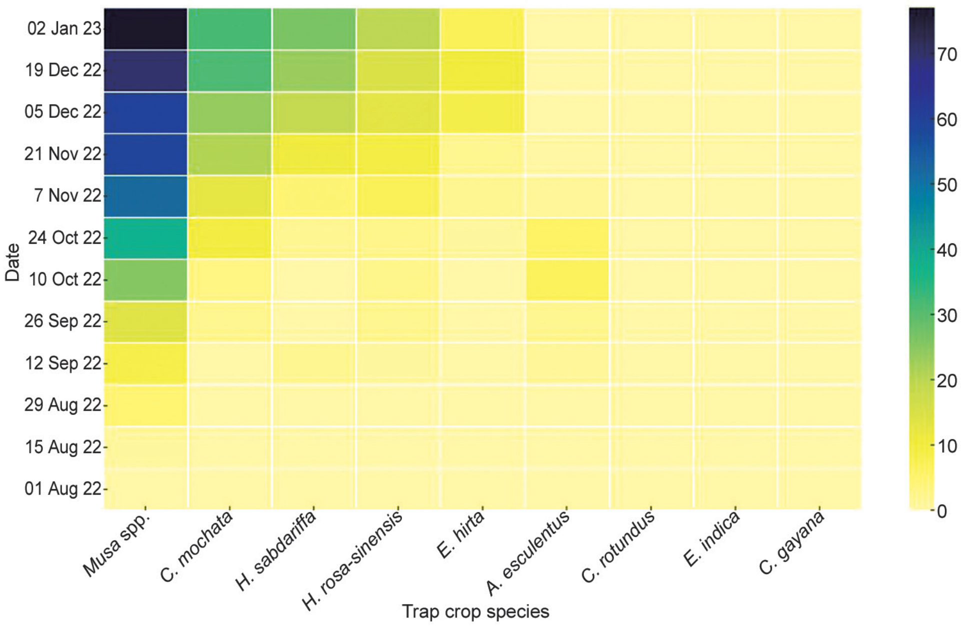

Fig. 2 Heatmap of pineapple mealybug attracted to each host plant species.

are in accordance with the findings of Kabi *et al.* (2016) who reported the reduced mealybug population densities in pineapple-banana intercrops than in a sole pineapple crop across seasons. In New Caledonia, the strategy of placing banana alongside other crops to divert the Common Fruit-Piercing Moth (*Eudocima phalonia*) away from the main crop, showcasing the versatility of banana as trap crops in diverse agricultural settings (Leroy *et al*. 2021). Also, a study by De Graaf *et al*. (2008) has demonstrated that susceptible banana cultivars and residues can indeed serve as trap crops in multi-cultivar stands. The allure of banana could stem from their distinct characteristics, such as aroma, which Schiestl (2010) notes as crucial for pollinator attraction, or the visual appeal of bright colours as Long *et al*. (2011) discuss, and even leaf texture, which Salerno *et al*. (2020) suggest may influence insect preferences. Yet, the complete effectiveness of bananas also requires evaluating cultivation aspects and local adaptability (Kumar and Singh 2023).

Additionally, crops like pumpkin, roselle, hibiscus, and ground fig have been identified as moderately effective (Mani and Shivaraju 2016, Lopes *et al*. 2019), suggesting a potential for combined use with banana to enhance the overall effectiveness of mealybug management strategies. In situations when banana is not a feasible trap crop, this may be useful. This study supports earlier findings showing trap cropping efficacy varies by species (Sarkar *et al*. 2018). Conversely, okra, java grass, goose grass, and rhodes grass showed minimal attraction (Lopes *et al*. 2019), hinting at their limited utility as primary trap crops but possible roles in broader pest management frameworks. The study emphasizes the need for strategic selection based on crop effectiveness, pest resistance, and environmental compatibility, alongside considerations for managing crop-weed dynamics to mitigate pest harborage (Hooda and Chauhan 2023, Maybery-reupert *et al*. 2023). This comprehensive strategy highlights the varying performance of trap crops, as well as the significance of integrated pest management measures.

The present investigation stresses the importance of trap crop selection for regulating pineapple mealybug infestations. Notably, banana were identified as the most efficacious in attracting mealybug, outperforming other evaluated crops. Conversely, certain crops like okra and various grasses showed minimal effectiveness. This evidence supports the efficacy of trap cropping as a mealybug management approach. Future inquiries should examine the specific attributes of these crops that attract mealybug, with a focus on exploring the influence of sensory factors such as scent, colour, and texture. Moreover, the potential simultaneous effect of implements a combination of trap crops merits investigation. While less effective crops may not serve as primary attractants, their role in a holistic pest management framework, possibly as secondary options or within crop rotation practices, remains valuable. This study propels forward the quest for more sustainable pest control methods, highlighting the importance of ongoing research in agricultural pest management strategies.

SUMMARY

Pineapple mealybugs are responsible for the emergence of pineapple wilt disease and the subsequent transmission of the pineapple disease virus. This study aimed to evaluate the alternate host plants as potential trap crops for pineapple mealybug. A total of nine host plant species, banana, pumpkin, roselle, hibiscus, ground fig, okra, java grass, goose grass and rhodes grass were selected for the study. Thirty adult females of pineapple mealybug were reared on a pumpkin for two months. Three replicates of a plot (area covered with black netting measuring 3 m × 3 m) were set up. Nine host plant species, approximately 2–3 feet in a 16 inch × 16 inch polybag were arranged in a circle around the pumpkin. The effectiveness of the host plant species was determined by calculating the infestation of each plant species for six months (with two-week observations). Our findings revealed that the pineapple mealybug prefers banana with the greatest mean and SD value (621.7±172.7), followed by pumpkin (237.0±45.6) and the lowest one is rhodes grass (2.00±26.5). ANOVA results show that there is a significant difference between host plant species (F-value of 26.87 and a P-value < 0.00). The observations suggest that banana has the potential to be utilized as trap crops for pineapple mealybug, and can be considered in IPM strategy to control pineapple mealybug.

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