Study Brief 47: Impact

Biocontrol for papaya mealybug: lessons learnt from Kenya

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Summary

The invasive pest papaya mealybug (PMB) (*Paracoccus marginatus*) results in high yield losses and increased production costs for smallholder farmers. In Kenya, PMB was first recorded in Mombasa in 2016 and has since spread to become a serious pest, resulting in severe yield losses of between 57% and 91% and household economic losses of £2,224/ha (USD 2,809) annually.

For years, farmers have primarily depended on chemical pesticides to control PMB, but these are associated with concerns around environment and health. Instead, integrated pest management (IPM), including classical biological control (biocontrol), offers high potential as an alternative for controlling PMB. For example, the parasitic wasp *Acerophagus papayae* has proven very efficacious in managing PMB in countries where it has been released, including Ghana.

In December 2020, *A. papayae* was evaluated under laboratory conditions and subsequently approved as a classical biocontrol agent by the Kenya Technical Standing Committee on

Imports and Exports (KSTCIE). Following mass rearing and subsequent small-scale field releases at six research sites around Mombasa, Kwale, and Kilifi coastal counties, the parasitoid was effectively established at papaya farms, confirming *A. papayae*'s potential as a valuable form of PMB biocontrol in Kenya and elsewhere in Africa.

Prior to any field releases of *A. papayae* in Kenya, a study was also conducted to determine smallholder farmers' knowledge, attitudes, and practices (KAP) towards biocontrol. Obtaining their perceptions was key, as farmers are often overlooked despite being recognised as hugely important players in decision-making on pest management practices. Subsequently, following initial field releases of *A. papayae*, a follow-up study took place in 2022 to determine any changes in farmers' KAP towards biocontrol, as well as any changes in papaya yield and subsequent farmer income.

Key highlights

- The highest parasitism rate of PMB (73%) was recorded after more than 1,000 parasitoids were released on farm, and parasitism was still observed four months after release.
- In all the research sites, PMB population counts reduced significantly after releases, to a level where it was difficult to find the pest.
- Farmers' perception of biocontrol was very positive across KAP survey years, with a 12% increase in awareness of biocontrol observed from 2021 to 2022.
- Farmers carried out activities that enhanced pest natural enemies, e.g. intercropping and crop diversification, and demonstrated some initial uptake of natural enemy field reservoirs to support *A. papayae* population establishment and spread.
- On average, treatment farms achieved approximately 196 kg higher harvest than control farms, and the control farms lost a higher amount of income (USD 94) than the treatment farms across the survey years.

Background

The invasive pest papaya mealybug (PMB) (*Paracoccus marginatus*) results in high yield losses and increased production costs for smallholder farmers. Native to Mexico and Central America, PMB was first recorded in sites around Mombasa, Kenya, in 2016. It has since rapidly spread and established in suitable areas in 21 counties across the country, becoming a serious pest. PMB causes severe yield losses of between 57% and 91% and household economic losses of £2,224/ha (USD 2,809 as of March 2024 exchange rate) annually.

In Kenya, PMB control primarily relies on synthetic pesticides, which pose serious health risks to humans and animals, as well as detrimental environmental risks. Effectively targeting and controlling PMB using synthetic insecticides is also challenging, due to the pest's protective waxy exterior and wide host range. Chemical insecticide resistance, as reported in other parts of the world, is also an increasing concern in Africa.

Alternatively, integrated pest management (IPM), including biocontrol, offers high potential for PMB management. For example, the parasitic wasp *Acerophagus papayae* has been very efficacious in controlling PMB in countries where it has been released, including Ghana.

Following this success, *A. papayae* was imported into Kenya from Ghana in December 2020 and evaluated under laboratory conditions as a potential agent for a classical biocontrol program for PMB in Kenya. The parasitoid was subsequently approved by KSTCIE for field release.

Mass rearing and subsequent small-scale field releases of the adult parasitoid took place between December 2021 and November 2022 at six research sites in the counties of Kilifi, Kwale, and Mombasa. Effective establishment of the parasitoid in papaya farms in Kenya confirmed the potential of *A. papayae* as a good candidate for PMB biocontrol in Kenya and elsewhere in Africa.

Farmer views are hugely important in decision-making on pest management practices but are often overlooked. Therefore, a study was also conducted to determine smallholder farmers' knowledge, attitudes, and practices (KAP) towards biocontrol prior to release of *A. papayae*. This baseline study was followed by a further KAP study in 2022, after the initial field releases of *A. pa*payae, to determine whether any change in farmers' KAP had occurred. Consideration was also given to papaya harvest and income on treatment and control farms pre and post *A. papayae* release.

What we did

Determining the most suitable host instar for parasitisation is essential for efficient mass rearing and optimal timing of parasitoid field release. For the laboratory assessment of *A. papayae*, three-week-old potato plants were used as host plants to rear PMB. An initial PMB culture was field collected from papaya plantations in Mwala, Machakos County. The parasitoid colony was established from adult *A. papayae* obtained from CABI-West Africa, in Ghana.

Six papaya farms, two in each of the three counties – Kilifi, Kwale, and Mombasa – were selected as study release sites. Each site had at least 100 papaya trees with no chemical insecticides used. From December 2021 to November 2022, parasitoids were released in two rounds at all six farms and monitored for their establishment.

To assess any change in smallholder farmers' KAP towards biocontrol, a follow-up KAP study was conducted at the end of September 2022 after the release of *A. papayae*. The objective was to revisit as many as possible of the 295 (195 men, 100 women) farmers who were randomly selected and interviewed during the initial 2021 KAP study in Kilifi, Kwale, and Mombasa counties. However, it was only possible to locate 141 (103 men, 38 women) farmers who had previously been interviewed in the 2021 survey for the comparative analysis. Where participants from the 2021 survey had lost their papaya trees, new farmers (38 men and 21 women) were selected to take part in the parasitoid mass releases. These farmers were interviewed with an explanation of the project work to date, but not included in the comparative analysis across years.

The 2022 KAP study was linked with the parasitoid releases and, in each county, around half of the respondents were supplied with parasitoid mummy cards (i.e. cards with parasitoid eggs) between July and September 2022. These respondents were considered 'treatment' sites, while the other half, who did not receive parasitoid cards, were considered 'control' sites, with farms selected based on their distance from each other. Household data was

collected via Open Data Kit (ODK), an online data collection tool, and supplemented by focus group discussions. A difference-in-difference (DD) approach was also used to provide an initial estimate of the potential impact of the biocontrol intervention on papaya harvest and income across the survey years.

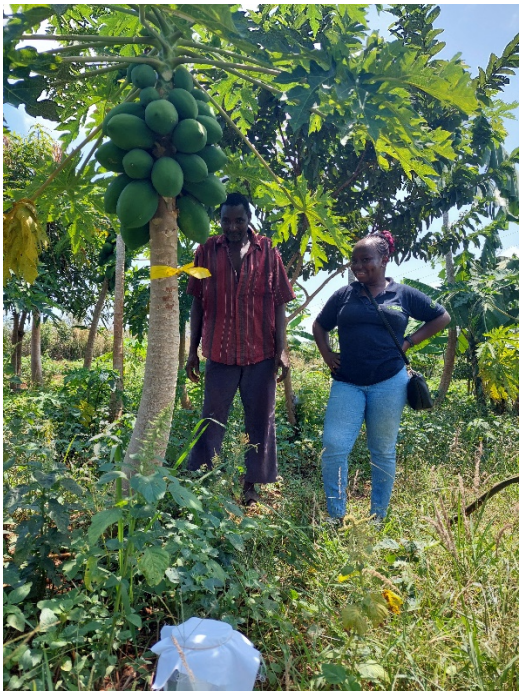
What was achieved?

Parasitoid release and establishment

The initial laboratory assessment of *A. papayae* observed that, whilst parasitism occurs at all developmental stages, a higher level of parasitism occurred in the third instar and adult female stages. The host stage also influenced the sex ratio of *A. papayae*, with a higher proportion of female parasitoids emerging from third and adult female instars, and more male parasitoids from the second instars. This confirmed the results of previous studies, which showed that female parasitoids in larger hosts live longer and have higher reproduction rates than in smaller hosts. This is particularly crucial as the sex ratio can impact the success of a biocontrol programme: a female-biased sex ratio is generally more advantageous than a male-biased ratio because male parasitoids primarily focus on mating and do not contribute directly to pest mortality. Female parasitoids also play a pivotal role in pest control through host feeding or oviposition (laying eggs), leading to reductions in pest populations.

Within a month of field release, *A. papayae* had established in all six research sites, with a parasitism rate of 30% or higher. The highest parasitism rate of PMB (73%) was recorded after more than 1,000 parasitoids were released on a farm, and parasitism was still observed four months after release. This outcome provided strong evidence of the exceptional efficiency of *A. papayae* in reducing PMB populations. In all the research sites, PMB population counts significantly reduced five months after releases to a level where it was difficult to find the pest at the research sites.

Before *A. papayae* parasitoid release in December 2021



After 3 releases, October 2022

For the successful establishment of *A. papayae* and to conserve the parasitoid population, papaya farmers in the three regions were encouraged to reduce their pesticide use. Greater engagement in activities to enhance natural enemies was evidenced by the results of the 2022 KAP survey, which showed an increase in farmers reporting use of intercropping; crop diversification (growing various crops or different varieties); agroforestry and windbreaks; cover crops; natural or planted fallows around fields and flowering hedges along field edges; and more careful use of chemical pesticides across survey years (Fig. 1).

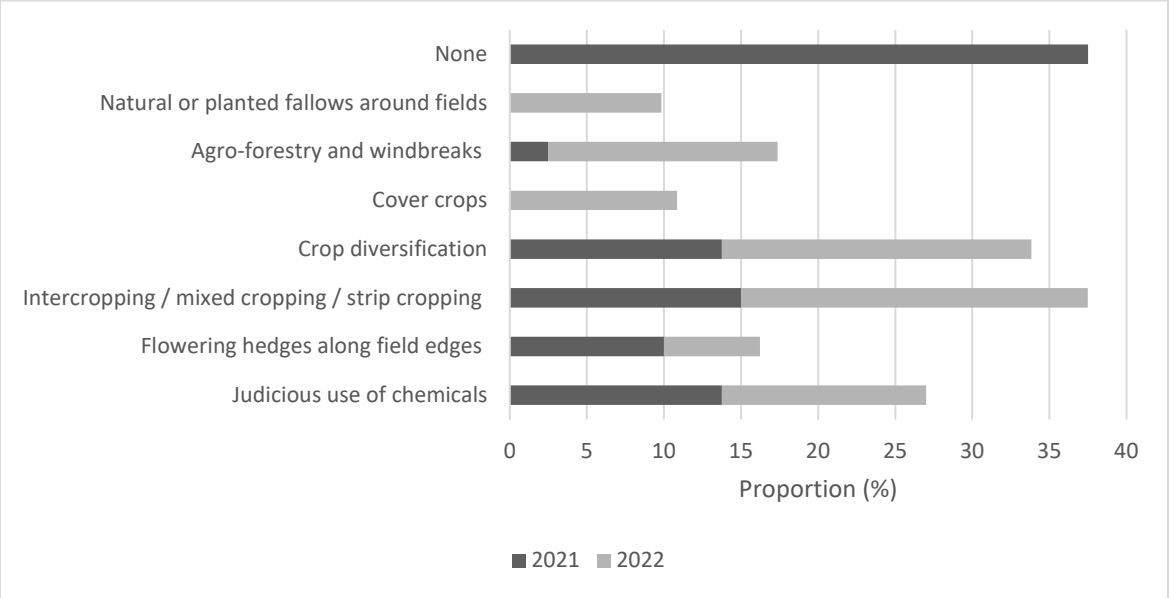


Figure 1. Activities undertaken to enhance natural enemies across survey years

Awareness and use of biocontrol

In 2021, half of the surveyed farmers had heard of biocontrol, which increased to 62% in 2022. There was increased perception of biocontrol as effective, requiring specialised training, and contributing to increased crop productivity. Farmers' response rate outlining challenges in use of biocontrol (conserving natural enemies) was much higher in 2022 than 2021, likely due to increased awareness of the biocontrol concept. However, two critical issues remained the same across both surveys: 1) lack of knowledge and experience of using natural enemies, and 2) lack of technical support (Fig. 2).

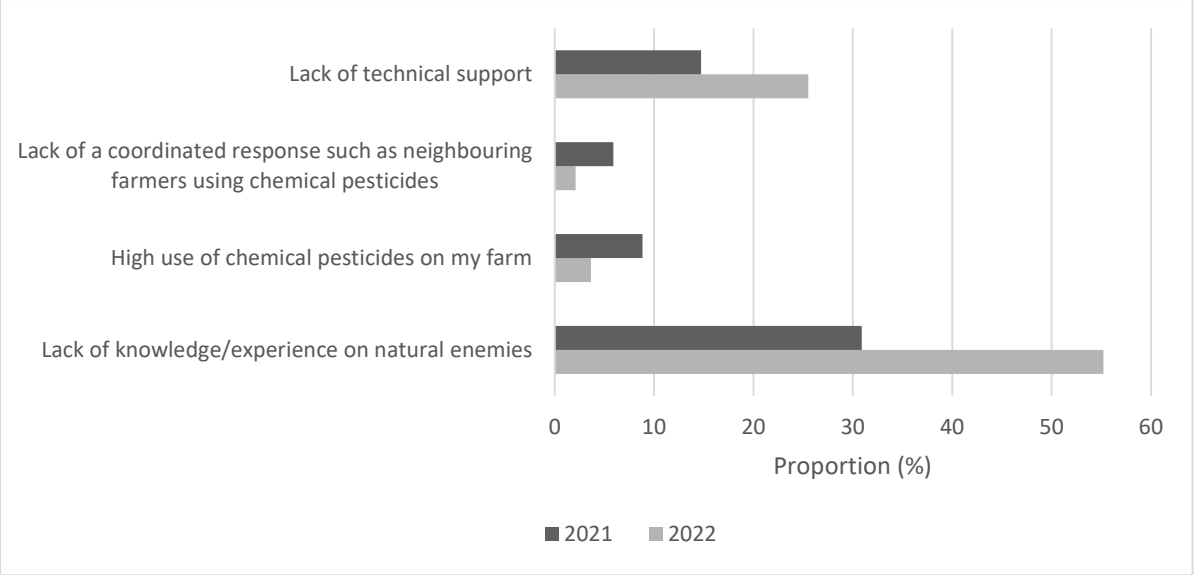


Figure 2. Challenges in using biocontrol (conserving natural enemies)

Although at an early stage, the following harvest and income data across years on treatment and control farms provides some positive preliminary results. However, the small sample size and other factors (such as high rainfall or drought) must also be considered before making assumptions about the biocontrol agent leading to this change.

Overall, there was a reduction in papaya harvest in 2022 compared to 2021 for both treatment and control farms. On average, the treatment farms achieved approximately 196 kg higher harvest than the control farms. (Table 1).

Table 1: Papaya yield (kg/ha) for treatment and control farms

County	**Treatment** (kg/ha)		**Control** (kg/ha)		**Diff-in-diff** (kg/ha)
	2022	**2021**	**2022**	**2021**	
Mombasa	234.9	683.5	656.4	713.5	-391.4
Kilifi	245.1	655.1	188.2	914.8	316.5
Kwale	811.0	1158.1	281.3	1087.8	459.4
Mean	**498.4** (1,002.7)	**886.4** (1,532.2)	**313.6** (564.8)	**897.1** (1,270.7)	**195.5**

n=138 (mean figures presented in parentheses are standard errors)

In 2022, over half of farmers (54%) in the treatment areas reported increases in harvest, which were attributed to a range of factors including increased availability of rains/favourable climatic conditions (rainfall at the beginning of 2022 was good); greater implementation of good agricultural practices, i.e. adding manure; irrigation and soil fertility improvement; and seedlings maturing into productive trees. Some farmers also mentioned the introduction of the parasitoid and, in some instances, the effect of the parasitoid on papaya crops was mentioned:

"[I …] carried out good agriculture practices; introduction of parasitoid in the farm" (farmer in Kilifi)

"Low pest infestation, due to parasitoid brought into the farm, enhanced the pawpaw productivity" (farmer in Kilifi)

"Control of pest by use of parasitoids" (farmer in Kwale)

"Had received mummy cards which had the parasitoid which helped to control pest infestation" (farmer in Mombasa)

Income from papaya was also lower in 2022 compared to 2021 for both treatment and control farms (Table 2). On average, the control farms lost USD 94 more income than the treatment farms.

Table 2: Average income (USD) for treatment and control farms in 2021 and 2022

County	**Treatment** (USD/ha)		**Control** (USD/ha)		**Diff-in-diff** USD/ha)
	2022	**2021**	**2022**	**2021**	
Mombasa	39.5 (88.1)	98.4 (189.8)	187.5 (424.3)	501.3 (1251.3)	254.9
Kilifi	54.1 (163.6)	76.3 (172.8)	34.4 (75.4)	131.1 (268.1)	74.5
Kwale	86.3 (145.2)	140.7 (291.7)	36.9 (76.5)	72.5 (98.4)	-18.7
Mean	**66.2** (145.1)	**109.0** (235.8)	**70.6** (218.2)	**207.8** (641.4)	**94.4**

n=138 (mean figures presented in parentheses are standard errors)

Across KAP surveys, most farmers (95%) expressed willingness to cooperate with neighbours to control pests, such as PMB. This included conducting cooperative scouting for pests; area-wide efforts to rotate crops; coordinated actions in the release of biocontrol agents, the application of chemical pesticides, and the planting of beneficial plants to support natural enemies.

Encouragingly, most respondents (>77%) were aware that biocontrol works best at a community level, where, although there is individual responsibility, the community is engaged in an area-wide approach. Over time, there was an increase in awareness of area-wide management and high levels of willingness to support biocontrol. Respondents were also keen to become more involved in monitoring natural enemies, not only on their own farms but across their community, and to engage in mass rearing.

In the 2021 survey, a small number of respondents reported they did not support biocontrol (n=9) due to uncertainty around its effects; not knowing how it works; its perception as ‘risky’; and the need to wait a long time before an effect is seen on the PMB population. However, in the follow up survey in 2022, these concerns appear to have been resolved, with all respondents (except one, due to not being a permanent resident in the area) responding that they would support a PMB biocontrol programme in their community.

In the 2022 KAP study, 18% (n=35) of farmers interviewed (n=200) had received natural enemy field reservoir (NEFR) training and six male farmers had subsequently set these up on their farms. Establishing NEFRs in farmers' fields is a technique that helps support parasitoid populations. The methodology recommends maintaining a 2 ha pesticide-free farm area and building an open shed containing trays that are open from above, in the centre of the field. Debris (PMB-infested dying plant parts) is placed and kept in the trays for 15 days to attract parasitoids. Within 15 days, the host plants dry out and the mealybugs are either preyed upon or die of starvation. The parasitoids that subsequently develop leave the trays and disperse naturally into the surrounding environment.

The way forward

Establishing *A. papayae* in the field and subsequent parasitisation of the mealybug to undetectable levels in the six test sites has demonstrated the parasitoid to be an effective control strategy It is recommended that *A. papayae* biocontrol is implemented more widely in Kenya and other African countries for control of PMB. The high parasitism rates and female-biased sex ratios obtained with third and adult female host instars indicate that mass rearing of *A. papayae* should be conducted with these latter host instar stages.

It is recognised that for a biocontrol programme to be successful, farmers need to be engaged in an area-wide, integrated approach. It is therefore critical to conduct farmer training on biocontrol safety and benefits – both to the environment and human health – and to encourage farmers to reduce their chemical pesticide use. Reduced insecticide use is required if further NEFRs are to be established to support the spread and establishment of *A. papayae* populations across a large area. Farmers also need to be able to recognise and monitor parasitoid populations to help support their establishment for PMB control.

Continued awareness raising and capacity strengthening among farmers and other key stakeholders, to enhance their understanding of biocontrol and the need for a collective approach, is necessary. Farmers' willingness to be trained as lead farmers and to use their farms as demonstration plots is important, especially since face-to-face interactions are an important communication and learning method. Training for extension officers, plant doctors, and agro dealers in biocontrol is also required, since they are key information sources farmers look to for advice and provision of technical support.

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