

Understanding changes in farmers' knowledge, attitudes, and practices after releasing *Acerophagus papayae* (Hymenoptera: Encyrtidae), a biocontrol agent for papaya mealybug (*Paracoccus marginatus*) (Hemiptera: Pseudococcidae) in Kenya

K Constantine¹ , F Makale² , I Mugambi² , D Chacha² , A Ogunmodede¹ , S Opisa² , B Luke¹ ,
I Rwomushana²  and F Williams² 

¹ CABI, Silwood Park, Buckhurst Road, Ascot, Berkshire, United Kingdom.

² CABI, Canary Bird, Limuru Road, Muthaiga, Nairobi, Kenya.

Limited adoption of integrated pest management approaches including biological control is associated with lack of knowledge, experience and technical support. One of the main reasons for lack of success of biological control of arthropod pests is cited as the poor involvement of farming communities and extension in dissemination of information. This study considers changes in farmers' knowledge, attitudes and practices towards biological control of the invasive pest papaya mealybug (*Paracoccus marginatus*) following initial releases of the parasitic wasp, *Acerophagus papayae* in the coastal counties of Kilifi, Kwale, and Mombasa in Kenya. Interviews were conducted with farmers across two years: (i) in 2021, prior to release of *A. papayae*, and (ii) in 2022, following initial releases of *A. papayae*. A comparison is made between 141 farmer responses across survey years complemented by information from three focus group discussions. Results highlight a 12% increase in awareness of biological control across survey years and a positive change in perception of biological control attributes such as effectiveness and improved crop productivity. Men were more likely to perceive biocontrol as effective, safe and affordable than women. Using a Difference-in-Difference analysis, on average treatment farms achieved approximately 196kg greater harvest than the control farms and the control farms lost a greater amount of income (94USD) than the treatment farms across the survey years. The findings from this study highlight the need for continued awareness-raising and gender responsive farmer education on the use and benefits of biological control, and how to reduce the use of chemical pesticide.

INTRODUCTION

Integrated Pest Management (IPM), which includes biological control, offers an important alternative to a heavy reliance on chemical pesticides and is of particular importance for smallholder farmers (Pretty and Bharuncha 2015). However, limited adoption of IPM approaches among smallholder farmers is widely reported with reasons for limited uptake including lack of awareness and knowledge, lack of availability of locally developed packages, lack of technical support as well as lack of regulatory or policy frameworks (Parsa et al. 2014; Machezano et al. 2017). Farmer perceptions are hugely important in influencing on-farm pest management decisions but frequently farmers' knowledge, beliefs and attitudes are not considered in biological control initiatives (Heong et al. 2002; Wyckhuys et al. 2017). This lack of attention to farmers' knowledge contributes to high dependence on, and over-use of, chemical pesticides (Wyckhuys et al. 2017).

In sub-Saharan Africa, one of the main reasons for lack of success of biological control of arthropod pests is cited as the poor involvement of farming communities and extension in dissemination of information (Nyambo and Löhr 2005). Indeed, collective action towards pest management within farming communities is frequently lacking but urgently required (Parsa et al. 2014). Farmers' pest management practices have a significant role in contributing towards the establishment and effectiveness of biological control agents. This includes contributing towards the success of classical biological control where an exotic natural enemy is introduced to control an invasive pest in its invasive range. However, the use of chemical pesticides remains high despite farmers' awareness of the associated risks and negative impacts on natural enemy populations (Parsa et al. 2014; Eyhorn et al. 2015; Pretty and Bharuncha 2015; Ocho et al. 2016; Musebe et al. 2018). Indeed, 'Currently, the management of many highly mobile and very destructive invasive pests is still carried out, for the most part, by individual producers who rely on the use of chemical pesticides' (Kansiime et al. 2024).

Classical biological control for pest management is a landscape-level approach where the objective is to release high numbers of natural enemies that will subsequently spread across a landscape and control the pest. In sub-Saharan Africa, where there is a high abundance of smallholdings, individual pest management practices have an important role in supporting the establishment, and success, of biological control approaches. For example, practices that support natural enemies such as intercropping and planting insect-attracting field margins are crucial alongside careful consideration of the frequency and timing of chemical pesticide applications.

CORRESPONDENCE

K Constantine

EMAIL

k.constantine@cabi.org

DATES

Received: 10 September 2024

Accepted: 29 September 2025

KEYWORDS

agricultural extension
biological control
integrated pest management
invasive species
smallholder farmers

COPYRIGHT

© The Author(s)

Published under a Creative

Commons Attribution 4.0

International Licence

(CC BY 4.0)

In 2016, the invasive papaya mealybug (*Paracoccus marginatus*, Williams and Granara de Willink) (Hemiptera: Pseudococcidae) was reported in the Magongo and Likoni areas of Mombasa County, Kenya (Macharia et al. 2017) and has since rapidly spread and established in suitable areas across the country, becoming a serious pest. Yield losses due to papaya mealybug are estimated at 57% of production, in addition to the cost of additional labour for pest management and the purchase of chemical pesticides (Kansiime et al. 2020). In order to rapidly control a new invasive pest, chemical pesticides may be used extensively (often supported by government guidance) with associated detrimental health and environmental risks (Harrison et al. 2019). However, this approach undermines more culturally-appropriate pest management strategies that are based on agro-ecological principles and are often low-cost and easily integrated into smallholder farming systems (Harrison et al. 2019). Biological control as part of an IPM approach offers high potential for the management of papaya mealybug. The parasitic wasp, *Acerophagus papayae* Noyes and Schauf (Hymenoptera: Encyrtidae), has been very successful in rapidly controlling papaya mealybug in other countries where it has been released, including Ghana, Guam, Palau, Sri Lanka, Puerto Rico, the Dominican Republic, or where found associated with papaya mealybug, as in Pakistan (Meyerdirk et al. 2004; Walker et al. 2005; Muniappan et al. 2006; Tanwar et al. 2010; Goergen et al. 2014; Offei et al. 2015; Mahmood et al. 2018). The parasitoid lays eggs inside all papaya mealybug instars with higher levels of parasitism occurring in third instar larvae and adult females (Opisa et al. 2024). In December 2020, *A. papayae* was imported into Kenyan quarantine facilities from CABI-West Africa (Ghana) for classical biological control efficacy testing. Successful confirmation of host specificity led to the preparation of a release dossier for *A. papayae* in coastal Kenya, which was approved by the Kenya Standing Technical Committee on Imports and Exports (KSTCIE) (KALRO and CABI 2021). Mass rearing and subsequent small-scale field releases of *A. papayae* took place from December 2021 to November 2022 in the coastal counties of Kilifi, Kwale, and Mombasa in Kenya.

In support of this work, prior to any releases of *A. papayae*, a study was conducted to determine smallholder farmers' knowledge, attitudes, and practices towards biological control, farmers' willingness to reduce their chemical pesticide use, and levels of support for a classical biological control program for papaya mealybug in Kenya (Constantine et al. 2023). Subsequently, following initial *A. papayae* releases in 2022, a follow-up knowledge, attitudes, and practices study was conducted. The objective of this study was to determine whether there was any change in farmers' knowledge, attitudes and practices for managing papaya mealybug following release of the biological control agent. To determine whether any change had occurred, papaya farmers who had been interviewed in the previous study were re-interviewed, following the initiation of the classical biological control programme and the introduction of *A. papayae*. The aim was to re-interview as many as possible of the 295 farmers interviewed in the previous (2021) study in the counties of Kilifi, Kwale and Mombasa. The results reported

here are a comparative analysis of farmers' knowledge, attitudes and practices for those farmers who were possible to locate and who were still growing papaya, and willing to be interviewed in the follow-up study. A preliminary analysis was also conducted to compare average production (harvest) and income between farms where the parasitoid had been released (treatment) and farms where the parasitoid had yet to be released (control).

MATERIALS AND METHODS

Survey site selection and detail

This study follows on from a previous smallholder farmers' knowledge, attitudes and practices study to understand farmer perceptions towards biological control of papaya mealybug in Kenya. Therefore, the three focus counties Kilifi, Kwale, and Mombasa had already been selected in the previous study (Constantine et al. 2023). Survey site selection was based on these being locations where papaya is grown, papaya mealybug is present and as sites that were suitable potential release sites for *A. papayae*, considering papaya mealybug impact and yield losses (Kansiime et al. 2020).

Household surveys

The study participants had also been selected in the previous study where the study population comprised farming households within the counties. The process in each county was that at least three locations were selected for enumeration, with support from local agricultural extension agents (it is acknowledged that the sample may not necessarily be representative of the county). Selection of respondent households per enumeration area followed systematic random sampling, targeting every fifth household as enumerators walked through villages/communities. The previous study consisted of 195 men and 100 women (total 295) participants across the focus counties. Despite efforts on the part of the enumerators, it was not possible or feasible within the study timeframe to locate all 295 farmers that were interviewed in the previous study. At the end of the follow-up study reported on here, a total of 141 smallholders (103 men and 38 women) had been re-interviewed (Table 1). Face-to-face interviews were conducted with farmers by trained enumerators using a structured questionnaire that had been pre-tested for validity and used in the previous study. The questionnaire was programmed on the Open Data Kit (ODK) platform and deployed on tablet computers. Household surveys took place at the end of September 2022. The reference season for production data collected was the previous 12 months (2021/2022 cropping season). Prior to the questions on perception of biological control, enumerators read a definition of biological control to each participant: 'Biological control is a form of natural pest control through natural enemies/insect predators either present in the vegetation in or around farm fields or through the introduction of natural enemies where a pest has no natural enemies to keep it in check.' Farmers were asked whether their perception on several statements on biological control and chemical

Table 1: Number of farmers interviewed by sex across survey years (2021, 2022) in the three focus counties in Kenya for treatment (*Acerophagus papayae* agent release) and control farms in 2022.

County	Treatment/ Control	Women	Men	Total
Kilifi	Treatment	8	29	37
	Control	8	20	28
Kwale	Treatment	10	31	41
	Control	4	4	8
Mombasa	Treatment	4	11	15
	Control	4	8	12
Total		38	103	141

pesticides were true or false, e.g., ‘Biological control / chemical pesticides are effective at controlling pests’. For papaya mealybug management practices, frequency of response is reported since farmers could report using more than one practice to manage papaya mealybug, e.g., physical and chemical control, or cultural and the use of plant-based concoctions.

Focus group discussions

In this follow-up study, one focus group discussion was held with farmers in each county to ensure the quantitative surveys were supplemented with qualitative perspectives. Focus group discussion participants were purposively selected to include both men and women who were household heads, based in the respective sites, and farmers growing papaya. Despite working with the county’s respective extension agents and lead farmers (lead farmers are farmers selected to lead farmer-to-farmer extension who are often selected due to their agricultural expertise, previous training experience and/or networking skills) (Franzel et al. 2014) to select focus group participants, a lack of women papaya farmers resulted in low representation of women. Facilitators led each focus group through a set of pre-determined sub-topics. The topics were centred on papaya farming activities, pest management practices, particularly for papaya mealybug, biological control awareness and use, perceptions of biological control, opinions on the release of a biological control agent for papaya mealybug, and levels of willingness to cooperate in a biological control initiative. In total thirty-two farmers (27 men and 5 women) participated in the focus group discussions (Table 2). Informed consent was secured by the interviewer by reading a consent statement to each participant or group prior to starting the household survey or focus group discussion. Each participant was required to state if they agreed or did not wish to proceed with the activity. Consent was captured via participants signatures as evidence that the participant agreed to take part. The enumerators ensured participants were aware that they could withdraw at any time.

Parasitoids such as *A. papayae* can be easily distributed to farmers through ‘parasitoid cards’ which are a means of artificially introducing a biological control agent to an area of production. The parasitoid cards contain dead pests that have natural enemies residing within them. The cards are positioned amongst the plants and over a short time, the natural enemy will emerge and begin to search for new pests. Prior to the current study, between July and September 2022, about half of the respondents in each county were supplied with parasitoid cards, these respondents were considered ‘treatment’ sites and the other half of farmers, who had not yet received parasitoid cards by the time of this survey (October 2022), were considered ‘control’ sites. It is anticipated that all households involved in the previous (2021) study, who are still growing papaya, will have received parasitoid cards by December 2022, i.e., the

‘control’ sites will have received the parasitoid after this follow-up survey was completed. The treatment and control respondents were selected based on distance from each other within each of the three counties to ensure separation between treatment and control locations. The distance between Kilifi North (treatment) and Kilifi South (control) is approximately 48 kms and the distance between Msambweni (treatment) and Lungalunga (control) in Kwale approx. 47 kms. The distance between Kisauni (treatment) and Likoni (control) in Mombasa was reduced at approximately 9 kms but this was offset by two waterbodies between the localities. Ultimately, the distance between treatment and control sites was to ensure distinct sites with limited initial spread of *A. papayae* between them following releases. Releases of *A. papayae* took place in Mombasa in July, Kilifi in August, and Kwale in September 2022 (Table 3; Figure 1). The follow-up household surveys took place at the end of September 2022. It is acknowledged that this did not allow much time following the parasitoid releases however, the main aim of this study was to understand changes in farmer knowledge, attitudes and practices rather than impact of the biological control agent.

Data analysis

Descriptive statistics were used to summarise general information including household respondent characteristics, farming activities, presence and management of papaya mealybug, and perceptions of biological control. Farmers scored their level of agreement with three questions about chemical pesticide use on a five-point Likert scale: –2, strongly disagree; 1, disagree; 0, neutral; 1, agree; and 2, strongly agree. The Acceptance Index (mean score) and Standard Deviation (Std. Dev.) are presented. To assess differences in production and income across survey years and between control and treatment farms a Difference-in-Difference (DiD) approach was used. This approach is useful to observe before and after changes in outcomes following an intervention. Farmers were asked how much fresh papaya they produced in kilograms over the previous one year. However, if farmers also responded with number of fruits and other local measures such as crates, a conversion into kgs was made during data analysis. The mean amount of fresh papaya produced across farms was calculated. For income, farmers were asked the income they had received from papaya sales across the previous one year in Kenyan Shillings. The mean amount of income across farms was calculated. Mean production (kgs) and income (KES) were calculated and used in the DiD calculations to estimate the impact of the biological control intervention on production and income across survey years on treatment and control farms using the following formulas:

$$\text{Production: } (pt_2 - pt_1) - (pc_2 - pc_1) \quad \text{Equation 1}$$

Table 2: Number of focus group discussion participants by sex in the three focus counties in Kenya.

County	Number of participants		Total
	Women	Men	
Kilifi	1	11	12
Kwale	4	4	8
Mombasa	0	12	12
Total	5	27	32

Table 3: Treatment and control locations, distance, and month of initial *Acerophagus papayae* releases in the three focus counties in Kenya.

Treatment	Control	Approximate distance between treatment and control areas	Month of biocontrol agent release (treatment)
Kilifi South	Kilifi North	~48.3 km	August
Kwale, Msambweni	Lungalunga	~46.7 km	September
Mombasa, Kisauni	Likoni	~8.5 km	July

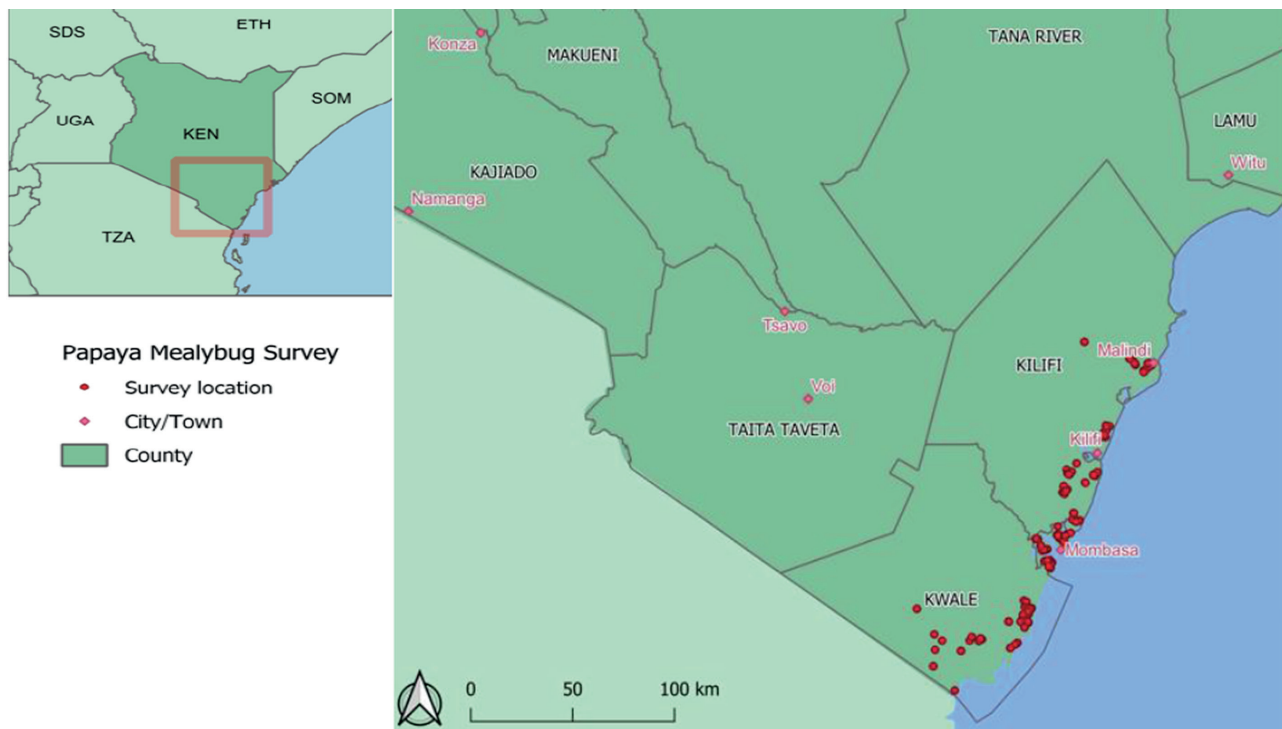


Figure 1: Survey location map showing three focus coastal counties Kilifi, Kwale and Mombasa in Kenya (red dots indicate survey farms).

$$\text{Income: } (it_2 - it_1) - (ic_2 - ic_1) \quad \text{Equation 2}$$

where pt_1 / it_1 = production or income on treatment farms 2021; pt_2 / it_2 = production or income on treatment farms in 2022; pc_1 / ic_1 = production or income on control farms in 2021; and pc_2 / ic_2 = production or income on control farms in 2022 (three outlying farms were removed from the dataset to avoid skewing the results). The data analysis was conducted using Stata version 16.1 statistical software package (StataCorp 2019). Income in 2022 was adjusted for inflation and income from both survey years converted into United States Dollars (USD). Due to the overall small sample size for those providing production and income data these results are presented without disaggregating by gender.

RESULTS

Characteristics of farmers

A high number of respondents were men (73%) and almost two-thirds (63%) were household heads. The highest proportion of respondents were from Kilifi (46%). The average age of respondents was 48 years (ranging from 22 to 86 years). Farming was the primary activity for 76% of respondents with income primarily from crop/animal farming (70%). A primary, secondary, and tertiary level of education had been achieved by 39%, 22%, and 13% of respondents, respectively. Two-thirds (66%) of various farm-level decisions are mostly made by household heads. Almost all respondents owned land (96%). The average farm size was 1.2 hectares (ha). The average amount of rented land was 0.1 ha. Most land used for growing papaya was less than 0.1 ha (71%). An average of 79 papaya trees were grown (although this was highly variable ± 206 Std. Dev.). A small proportion (29%) reported having received training on IPM (Table 4).

Papaya mealybug presence and farmers' perceptions of biological control

There was high prevalence of papaya mealybug reported by farmers in both years (97% reported seeing papaya mealybug on their farm in 2021 and 99% in 2022). However, there was a change in occurrence and severity of papaya mealybug across

survey years with a greater proportion of farmers reporting low occurrence in 2022 with this lower occurrence also found at the control sites (Figure 2). Both men and women reported similar levels of papaya mealybug occurrence across survey years (Figure 3).

There was a 12% increase in farmer awareness of the general concept of biological control from 50% to 62% across years. Overall, farmer perceptions of attributes of biological controls increased over time. For example, there was a 17% increase in the perception of biological control as effective in controlling pests; a 10% increase in perception that using biological control increases crop productivity; and an 8% increase in perception of biological control as affordable (Figure 4). There was a small decrease in the perception that biological control is slow and labour intensive. However, there were differences between women's and men's perceptions of biological control attributes (Table 5). In most instances men demonstrated more positive perceptions. For example, 14% more men than women perceived biological control to increase crop productivity, and 12% more perceived use of biological control to promote plant growth. This difference became even more marked in the follow-up study where men were 18–21% more likely to perceive biocontrol as effective, safe and affordable than women. Women's positive perceptions did however increase over time. For example, 29% of women perceived biological control as effective in 2021 which increased to 37% in the follow-up study. Men's perceptions of effectiveness increased from 35% to 55%. Women in the follow up study report biological control to be more labour intensive than men.

Farmers reported management practices for papaya mealybug across survey years (Figure 5). In 2021, a high frequency of both men (65%) and women (81%) reported using no control method for papaya mealybug. However, this frequency decreased in 2022 (16% men and 29% women). Frequency of use of biological control increased from zero to 30% for men and to 31% for women from 2021 to 2022 following the introduction of the biological control programme. For men, small increases in the frequency of use of chemical pesticides (3%), physical/mechanical controls (4%), plant concoctions (6%) and cultural controls (7%) were reported over the survey years. For women, alongside increased

Table 4: General characteristics of study respondents in the three focus counties in Kenya (n = 141, 2022).

Variable	Description	Mean	Std. Dev.
Gender	Respondent male (1 = yes)	0.73	0.44
Household head	Respondent household head (1 = yes)	0.63	0.48
County	Respondents from Kilifi (1 = yes)	0.46	0.5
	Respondents from Kwale (1 = yes)	0.35	0.48
	Respondents from Mombasa (1 = yes)	0.19	0.39
Age	Respondents average age (years)	47.6	14.26
Activity	Primary activity (1 = crop/animal farming)	0.76	0.43
Education	Education level (1 = primary)	0.39	0.49
	Education level (1 = secondary)	0.22	0.42
	Education level (1 = tertiary)	0.13	0.34
Income source	Income crop/animal farming (1 = yes)	0.7	0.46
Land owned	Amount of land owned (hectares)	1.22	2.58
Land rented	Amount of land rented (hectares)	0.14	0.43
Land size	Land area for papaya (1 = less than 0.1 hectares)	0.71	0.46
Number of trees	Average number of papaya trees grown	79.32	206.10
Decision-making	Household head responsible decisions (1 = yes)	0.66	0.48
Received training	Received training on IPM (1 = yes)	0.29	0.46

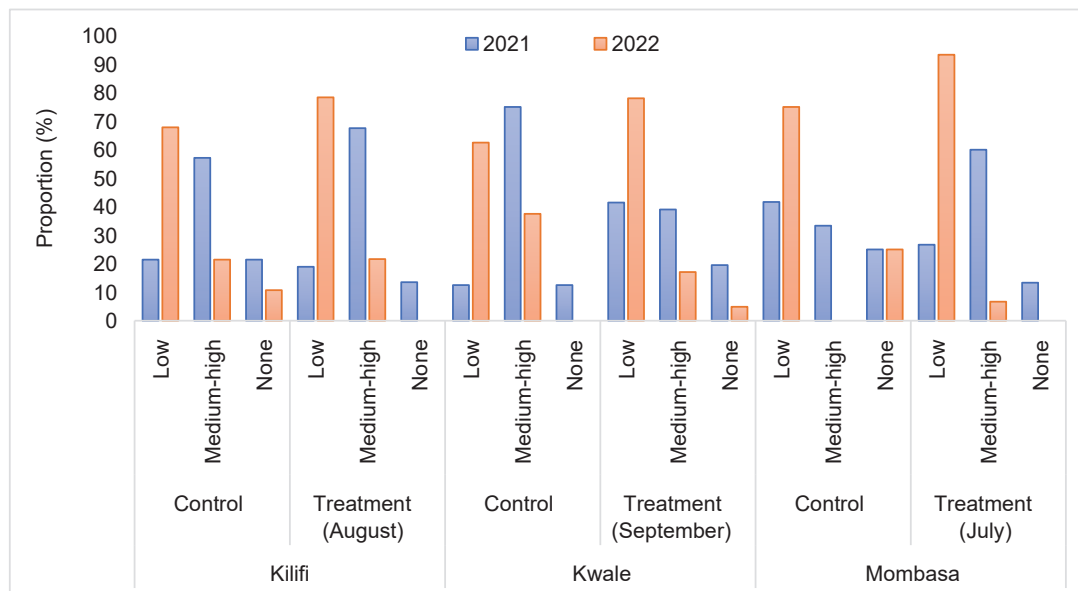


Figure 2: Farmer-reported papaya mealybug (*Paracoccus marginatus*) occurrence levels in Kilifi, Kwale and Mombasa in 2021 and 2022 for control and treatment farms. Occurrence level: none, low (under 10%), medium to high (over 10%) (n=141).

frequency of use of biological control, frequency of use increased for chemical pesticides (10%), cultural controls (8%) and plant concoctions (7%) over the survey years.

Frequency of use of cultural agronomic practices undertaken by farmers to enhance pest natural enemies increased across survey years for both women and men (Figure 6). For example, there was a 17% increase in the proportion of farmers using intercropping (4% increase for women and 13% increase for men); a 15% increase in crop diversification (growing various crops or different varieties) (4% for women and 11% for men); a 12% increase in use of agro-forestry (3% for women and 9% for men) and a 9% increase in judicious use of chemical pesticides (2% for women and 7% for men). Some practices not seen in the previous study were also reported in the current study such as use of cover crops (9%) and natural or planted fallows around fields (8%), and marginal use of crop rotation (2%) and push-pull techniques (0.2%). It is acknowledged that this change in practices may not be directly due to the papaya mealybug

biological control programme however, it is hoped that the information farmers have received through the programme may have contributed towards highlighting alternative practices.

The frequency of responses outlining challenges to the use of biological control increased over survey years, likely due to increased awareness of the concept of biological control following the initiative (Table 6). However, the two main issues remained the same for both women and men: (1) lack of knowledge and experience of using natural enemies and (2) lack of technical support.

Most respondents (> 77%) were aware that biological control works best at a community level where, although there is individual responsibility, the community is engaged in the area-wide approach. In the previous (2021) study, a small number of respondents did not support biological control (6%), due to reasons that included uncertainty of the effects of biological control; not knowing how it works; the perception of biological as risky; and the need to wait a long time before an effect is seen

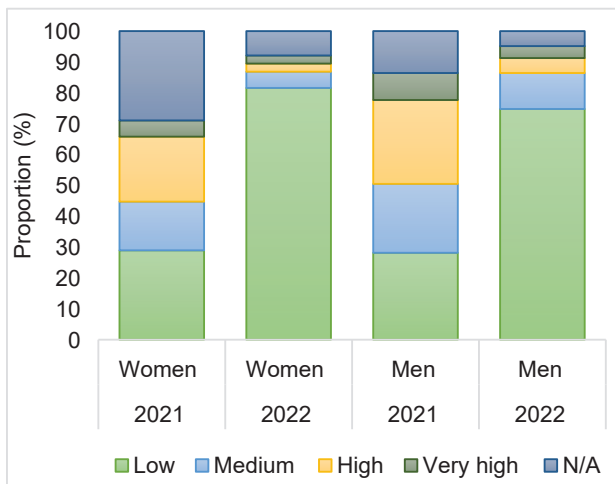


Figure 3: Papaya mealybug (*Paracoccus marginatus*) occurrence levels in 2021 and 2022, reported by women and men farmers. Occurrence level: low (0–10%), medium (11–30%), high (31–50%), and very high (over 51%) ($n = 141$).

on the papaya mealybug population. However, these concerns appear to have been addressed, with all respondents (except one, due to not being a permanent resident in the area) in the follow-up study responding that they would support a biological control programme for papaya mealybug in their community.

Overall, support for biological control was very positive across both years. In most instances, there were increases in the proportion of farmers who were ‘very likely’ to support papaya mealybug biological control (Table 7). For example, there was an average increase of 15% for those very likely to monitor natural enemy populations and papaya mealybug infestation levels more widely (i.e., ‘across my community’), and a 14% increase in those who would support mass rearing and release of biological control agents. A noticeable finding was women’s increase in likeliness to support biological control across survey years. For instance, women demonstrated a 32% increase in willingness to become involved in mass rearing and releases of biological control agents, a 26% increase in willingness to donate physical facilities, and a 24% increase in likeliness they would monitor natural enemy populations and papaya mealybug infestation levels more widely.

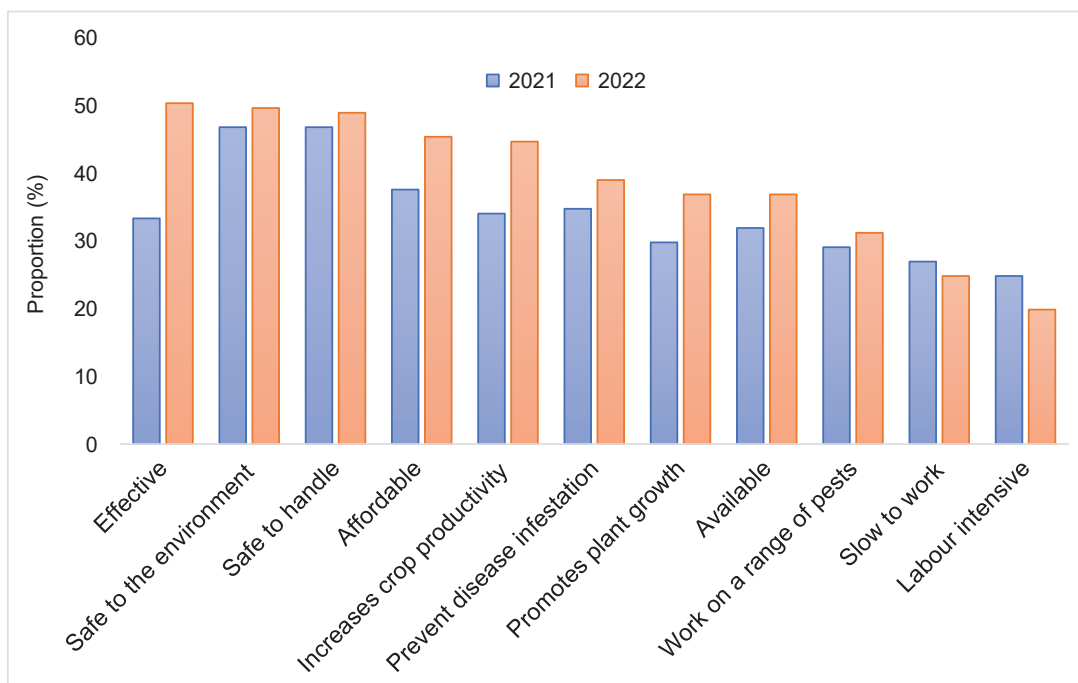


Figure 4: Farmers’ perceptions of biological control across survey years (2021, 2022) across the three focus counties in Kenya ($n = 141$).

Table 5: Farmers’ perceptions of biological control by sex across survey years (2021, 2022) in the three focus counties in Kenya (%) ($n = 141$).

Perception of biological control	2021		2022	
	Women	Men	Women	Men
Safe to handle	45	48	34	55
Safe to the environment	42	49	34	54
Affordable	34	39	32	50
Prevent disease infestation	29	37	26	44
Increases crop productivity	24	38	37	48
Effective	29	35	37	55
Available	29	33	29	40
Promotes plant growth	21	33	34	38
Work on a range of pests	34	27	32	31
Slow to work	24	28	16	28
Labour intensive	24	25	21	19
Requires specialised training	11	22	24	37

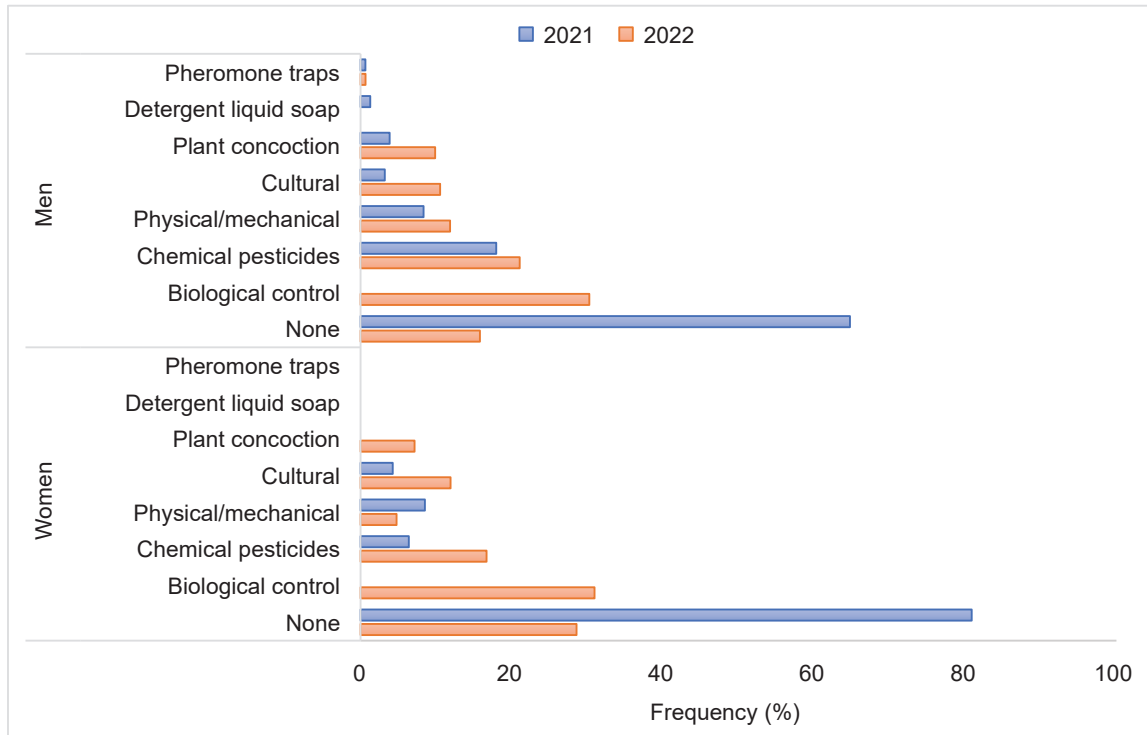


Figure 5: Frequency of use of management methods for papaya mealybug (*Paracoccus marginatus*) reported by sex across survey years (2021, 2022) ($n = 141$).

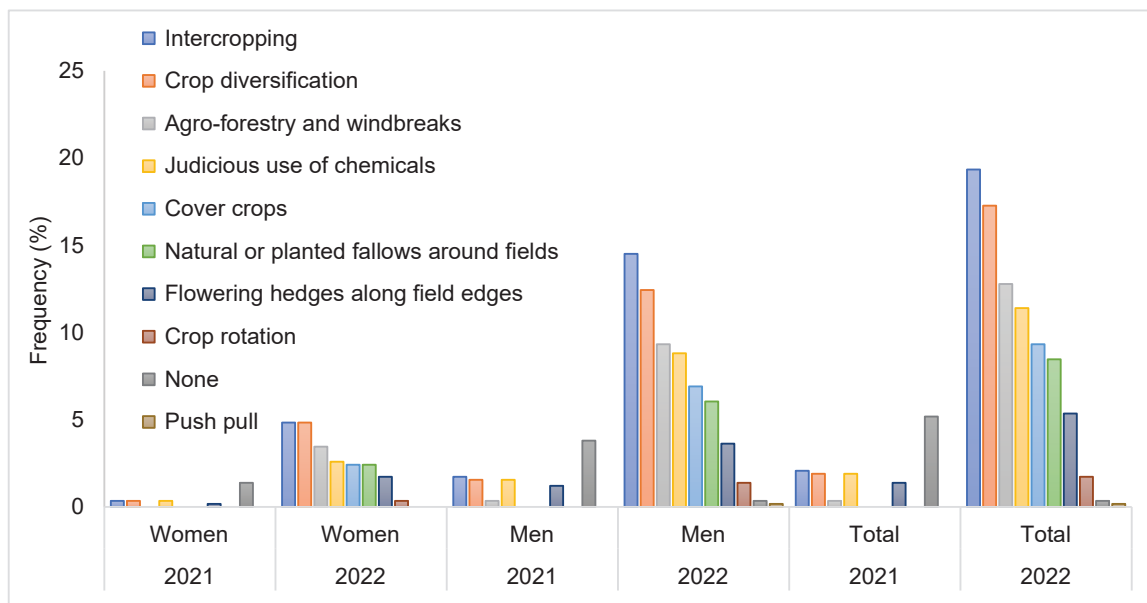


Figure 6: Reported frequency of use of cultural agronomic practices implemented by women and men farmers to enhance pest natural enemies across survey years (2021, 2022) across the three focus counties in Kenya ($n = 141$).

Table 6: Farmers' identified challenges to the use of biological control by sex across survey years (2021, 2022) in the three focus counties in Kenya ($n = 141$).

Challenge to biological control use	Frequency (%)					
	2021			2022		
	Women	Men	Mean	Women	Men	Mean
Lack of knowledge/experience	33	30	31	56	55	55
Lack of technical support	7	17	15	25	26	26
High use of chemical pesticides	20	6	9	5	3	4
Lack of a coordinated response	7	6	6	0	3	2

Table 7: Proportion of farmers 'very likely' to support each method in the papaya mealybug (*Paracoccus marginatus*) biocontrol programme by sex across survey years (2021, 2022) in the three focus counties in Kenya ($n = 141$).

Activity	Women		Men		Total	
	2021	2022	2021	2022	2021	2022
Attend community meetings	79	92	93	92	89	92
Reduce my pesticide use	79	92	89	93	87	93
Monitor on my farm	82	89	94	95	91	94
Monitor across my community	68	92	84	96	80	95
Practices to support natural enemies	76	89	88	91	85	91
Lead farmer / use farm as a demonstration farm	50	55	73	71	67	67
Lead farmer and community coordination	53	55	73	69	67	65
Mass rearing and releases of biological control agents	53	84	73	81	67	82
Mass awareness and biological control champion	55	79	77	83	71	82
Farmer donate (physical facilities/finances)	42	68	66	68	60	68

(Note: 'farmer donate' refers to farmers willing to avail their own physical facilities/finances for training of other farmers in biocontrol)

Table 8: Proportion of farmers' aware of area-wide management by sex in 2022 in the three focus counties in Kenya (%) ($n = 141$).

Awareness of area-wide management	Women	Men	Mean
Sensitisation/awareness campaigns	11	10	10
Village-led management plans	8	2	4
Mass spraying	8	1	3
Area-wide control measures (specify)	0	1	1

Area-wide management and perception of chemical pesticides

Farmers' knowledge on area-wide management increased over survey years from none, or very little awareness in 2021, to 14% in 2022. For example, there was an average 10% increase in awareness of sensitisation/awareness campaigns, a 4% increase in awareness of village-led management plans and a 3% increase in awareness of mass spraying activities. One institution (Shimo la Tewa Prison) mentioned neighbouring farmers seeking their guidance and copying what they do, e.g., timing of land cultivation, planting, and spraying. There was very low awareness of area-wide pest management in 2021 however, in 2022 awareness increased for both men (14%) and women (26%) (Table 8).

Across survey years, most farmers (97% women and 94% men) were willing to cooperate with their neighbours to control pests such as papaya mealybug. The various ways in which farmers were willing to cooperate in pest management included conducting cooperative scouting for pests, area-wide efforts to rotate crops, coordinated release of biological control agents, coordinated application of chemical pesticides, and coordinated planting of beneficial plants to support natural enemies. Most farmers agreed that training, demonstration days/plots and incentives would encourage them to support biological control, as well as leadership from extension agents, lead farmers and traditional leaders.

For both men and women, there was a small increase in those that agreed or strongly agreed that there could be alternatives to chemical pesticides in crop production and control of papaya mealybug. However, there was also a small increase among male respondents in those who agreed or strongly agreed that chemical pesticides are necessary in crop production and control of papaya mealybug. Interestingly there was a slight decrease in agreement that chemical pesticides can be harmful to your health for both men and women (Table 9).

There was an increase in the perception of chemical pesticides as a high risk due to the build-up of pest resistance, effects on natural enemies, soil and air quality, and effects on health of farm animals. The perception that pesticides cause a high risk to food safety remained the same. Interestingly, there were decreases

in the perception of chemical pesticides as a high risk to plant diversity, water quality, health of wildlife, the health of other farmers and the health of applicators (Figure 7).

In the follow-up study, 78% reported they had reduced their chemical pesticide use on papaya ($n = 111$). This is related to the fact that farmers had received biological control training and were requested to refrain from using chemical pesticides on their farm, and as such, is expected. Over time, 75% reported that the effectiveness of chemical pesticides has changed. Farmers reported having to increase the concentration of the chemical product they use (40%), and 72% said they had to change the product they use due to ineffectiveness, which is an indication of the build-up of insect resistance to chemical pesticides over time.

Papaya production and income

There was a reduction in papaya production in 2022 compared to 2021 for both treatment and control farms. The production in treatment farms reduced from 886 kg in 2021 to 498 kg in 2022, compared with a reduction from 897 kg in 2021 to 314 kg in 2022 for the control farms. Using a DiD approach (Equation 1) this means that on average the treatment farms achieved approximately 196 kg higher production than the control farms, or in other words production loss in control farms was 196 kg higher than in the treatment farms. Differences between treatment and control production by county indicates that in Kilifi and Kwale treatment farms achieved approximately 317 and 459 kg higher harvest respectively, than the control farms in each county. In Mombasa however, on average control farms achieved greater production (391 kgs) than treatment farms (Table 10).

Over half of farmers (54%) in the treatment areas in 2022 reported increases in production which were attributed to a range of factors including 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

Table 9: Farmers' perceptions of chemical pesticides indicating levels of agreement with questions on chemical pesticide use by sex across survey years (2021, 2022) in the three focus counties in Kenya ($n = 141$).

Question	Acceptance index					
	2021			2022		
	Women	Men	Mean	Women	Men	Mean
1. Do you think that pesticides are necessary in crop production / to control papaya mealybug?	0.5 (0.2)	0.7 (0.1)	0.6 (0.1)	0.5 (0.3)	0.8 (0.1)	0.7 (0.1)
2. Do you think the use of chemical pesticides can be harmful to your health?	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	1.3 (0.2)	1.4 (0.1)	1.4 (0.1)
3. Do you think that there could be alternatives to pesticides for use in crop production/control of papaya mealybug?	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	1.1 (0.2)	1.0 (0.1)	1.0 (0.1)

Average farmer rating for perceptions of chemical pesticides (Acceptance Index) are shown. Values are given as mean (Std. Dev)

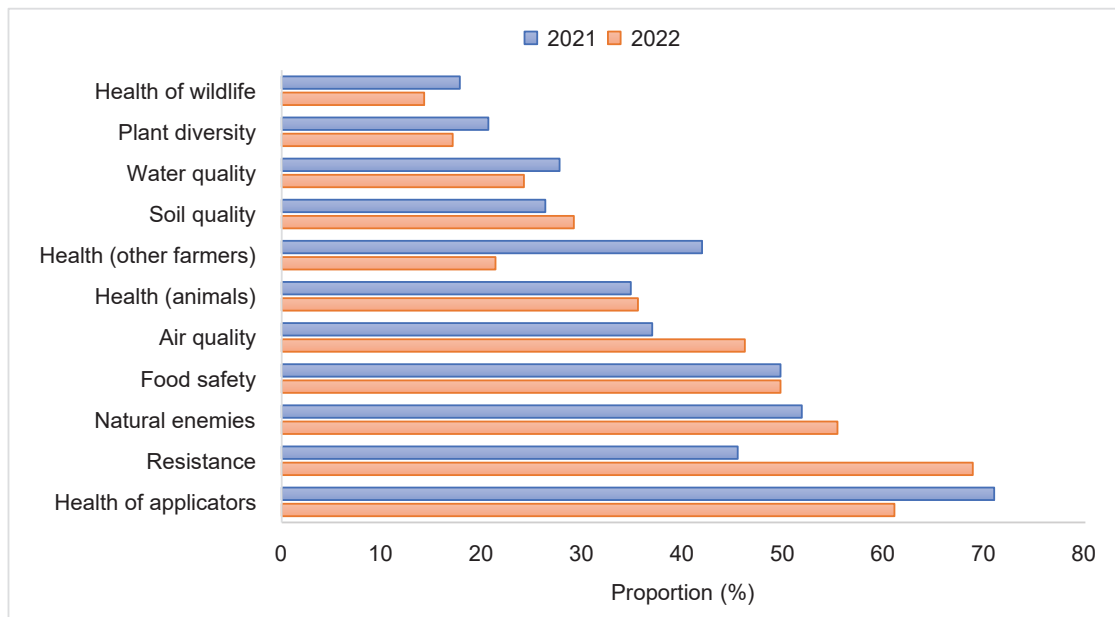


Figure 7: Farmers' high-risk perception of chemical pesticides across survey years (2021, 2022) across the three focus counties in Kenya ($n = 141$).

Table 10: Average production (kg) for treatment and control farms in 2021 and 2022 and Difference-in-Difference (DiD) calculation across farms in the three focus counties in Kenya ($n = 138$).

County	Treatment			Control			DiD
	Sample size (n)	2021	2022	Sample size (n)	2021	2022	
Kilifi	35	655 (1 188)	245 (465)	28	914 (1 370)	188 (362)	317
Kwale	41	1 158 (1 898)	811 (1 345)	8	1088 (1 260)	281 (545)	459
Mombasa	15	684 (988)	235 (501)	11	714 (1 088)	656 (855)	391
Mean	91	886 (1 532)	498 (1 003)	47	897 (1 271)	314 (565)	195

(mean figures presented in parentheses are Std. Dev.)

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 [parasitoid] cards which had the parasitoid which helped to control pest infestation' (farmer in Mombasa)

'Less pest effects due to introduction of parasitoids' (farmer in Mombasa)

In the treatment areas, a decrease in production was reported by 46% of farmers with the most frequent reasons including

drought (despite good rainfall at the beginning of 2022 drought was experienced from July to February 2023) and severe pest/papaya mealybug infestation. More farmers in the treatment areas reported losses due to papaya mealybug infestation specifically, particularly in Kwale.

By contrast, an increase in production was reported by 35% of respondents in control areas who attributed favourable climatic conditions as contributing to decreased pest infestation (including papaya mealybug). Farmers also reported ensuring good irrigation of papaya trees, maturing seedlings now producing fruits, and the adoption of good practices including regular weeding, application of manure, use of 'proper' fertiliser and organic manure. However, in the control areas 65% reported a decrease in production with the main reasons cited as prolonged drought alongside pest infestation, which included papaya mealybug. Two farmers also mentioned salty water from a borehole, ageing trees and animal attack.

Table 11: Average income (USD) for treatment and control farms in 2021 and 2022 and Difference-in-Difference (DiD) calculation across farms in the three focus counties in Kenya ($n = 138$).

County	Sample size (n)	Treatment		Sample size (n)	Control		DiD
		2021	2022		2021	2022	
Kilifi	35	76 (173)	54 (164)	28	131 (268)	34 (75)	75
Kwale	41	141 (292)	86 (145)	8	73 (98)	37 (77)	-19
Mombasa	15	98 (190)	40 (88)	11	501 (1251)	188 (424)	255
Mean	91	109 (236)	66 (145)	47	208 (641)	71 (218)	94

(mean figures presented in parentheses are Std. Dev.)

Income from papaya was found to have reduced in 2022 compared to 2021 for both treatment and control farms. The income for treatment farms reduced from 109 USD in 2021 to 66 USD in 2022, compared with a reduction from 208 USD in 2021 to 71 USD in 2022 for the control farms. Using a DiD approach (Equation 2) this means that on average, the control farms lost 94 USD more income than the treatment farms. Differences between control and treatment farm income by county indicates that the control farms in Mombasa lost a higher amount of income relative to the treatment group (the control group lost 255 USD more than the treatment group across the two periods). Similarly, in Kilifi, the control group lost a higher amount of income relative to the treatment group (75 USD). In Kwale, on average treatment farms lost a higher amount of income (19 USD) relative to the control farms (Table 11).

DISCUSSION

Biological control offers a low risk, sustainable pest management option that is often highly complementary to traditional agro-ecological farming practices and can be readily integrated into smallholder farmers' existing practices (Harrison et al. 2019). However, in many low-income countries, one of the main reasons cited for poor success of biological control efforts is the lack of engagement of farming communities and extension agents in sharing information, as well as lack of consideration of farmers' knowledge, perspectives, beliefs, and attitudes (De Groote et al. 2001; Nyambo and Löhr 2005; Wyckhuys et al. 2017). This is even though farmers' knowledge and perceptions are hugely important in determining farm level pest management decisions (Heong et al. 2002). Low adoption of biological control is associated with concerns over effectiveness, speed of action, spectrum of activity, availability and affordability (Al-Hassan et al. 2010; Constantine et al. 2020).

In 2021, a knowledge, attitude and practice survey was conducted with smallholder papaya farmers prior to the release of the classical biological control agent *A. papayae* for control of papaya mealybug. The results reported here followed up with 141 of the farmers involved in this biological control programme with the aim to determine whether any change in smallholder farmers' knowledge, attitudes and practices had occurred following the initiation of the biological control programme. The results highlight a 12% increase in awareness of biological control across survey years. There was also a positive change in perception of biological control attributes such as its effectiveness and contributions towards improved crop productivity. Additionally, perceptions of the labour intensiveness and slow speed of action of biological control decreased. These findings suggest farmers' knowledge has been enhanced by their inclusion in the early stages of a biological control initiative.

A key challenge identified by farmers to the uptake of biological control was a lack of knowledge and technical support. Lack of knowledge and access to information is a serious limiting factor in the uptake of biological control (Mkenda et al. 2020). Farmer perceptions are shaped by both their local ecological knowledge informed through daily farming experience as well as through

external sources (Martínez-Sastre et al. 2020). To enhance farmer knowledge, learning through experience and peer-to-peer learning is important. Engaging farmers in an area-wide biological control programme that promotes shared learning on a common problem supports effective diffusion of information (Rebaudo and Dangles 2013). Lead farmers play an important role in information dissemination and supporting others' understanding and use of biological control approaches (Wyckhuys et al. 2017). Additionally, there were differences between men and women's perceptions of biological control. For example, men were more likely to perceive biocontrol as effective, safe and affordable than women. Although women's positive perceptions increased over the survey years, findings highlight disparities linked to socio-cultural norms which are common in patriarchal societies. Indeed, motivations for adoption of biological control are often different for men and women. For example, among Iranian rice farmers men's motivations for adoption of biological control more frequently related to economic benefit and social acceptance, whereas women's motivations related to health maintenance (defined as: 'maintenance or improvement of the current level of health of people, animals, and plants') (Abdollahzadeh et al. 2016). Women also reported biological control to be more labour intensive than men. These results are important to acknowledge since not only do women frequently have reduced access to information and resources, including training and extension advice, but they often hold responsibility for routine farm tasks including spending a considerable amount of time scouting for and managing pests (Van de Fliert and Proost 1999; World Bank 2010; Kawarazuka et al. 2020). Therefore, it is essential that gender-based constraints (e.g., time, mobility, and social norms etc.) are addressed to ensure increased engagement of women in training and access to information. Reduced health risk associated with *Trichogramma* (Hymenoptera: Trichogrammatidae) as a biological control was important for women farmers in Pakistan although adoption increased the demand on women's time and labour (Terefe et al. 2023). The results from the current study suggest the biological control initiative has already begun to increase women's awareness of biological control and contributed to their increased levels of support, e.g., women wanting to be involved in activities such as mass rearing and monitoring of natural enemy and papaya mealybug populations. As an area-wide approach it is anticipated that over time, once *A. papayae* is established, population maintenance would not increase women's time and labour burdens.

Both men and women's use of biological control increased through the provision of parasitoid cards on treatment farms. This was complemented by men and women farmers also increasing the use of other management practices for papaya mealybug including use of cultural methods (e.g., intercropping, crop rotation etc.) and plant concoctions. Although there was some reported increase (3–10%) in the use of chemical pesticides to manage papaya mealybug in the follow-up study (by farmers yet to receive parasitoid cards) overall, 78% of respondents reported reduced use chemical pesticides. However, some farmers reported that they had stopped using chemical pesticides on their farm to support

the biocontrol programme but that this has resulted in increased pest levels on other crops. This may be reflected in the findings, for instance, there was a slight decrease in the perception of biocontrol as affordable — farmers did not have to pay for parasitoid cards — but perhaps they felt losses were being experienced through loss of other crops due to limiting their pest management options and refraining from using chemical pesticides. Despite this there was an increase in recognition that there are alternatives to chemical pesticides for use in crop production and for the control of papaya mealybug. This is important since it challenges the frequently-held perception that chemical pesticides are the only viable pest control option (Khan and Damalas 2015). Although farmers demonstrated some awareness of the negative health and environmental impacts of chemical pesticides, the decrease in these perceptions over survey years suggest there is a need for increased awareness raising and education. Increasing recognition of the negative effects of chemical pesticides has been found to influence adoption of biological pest control (Abdollahzadeh et al. 2015). The increase in the proportion of farmers reporting awareness of insect resistance to chemical pesticides across survey years also highlights farmer awareness of the need for alternatives. In support of this, farmers demonstrated high levels of willingness to cooperate with fellow farmers to control pests. This is essential in the sub-Saharan African context where small farms are in close proximity to each other and the actions of one farmer impacts their neighbours (e.g., application of chemical pesticides killing off natural enemies). Indeed, management of highly mobile and destructive pests in an uncoordinated, field-by-field basis is ineffective and unsustainable (Kansiime et al. 2024). The biological control initiative for papaya mealybug adopts an area-wide approach, where actions are coordinated over a broad landscape, and it is anticipated that *A. papayae* will establish a self-sustaining population. However, success depends on farmers working together to reduce their chemical pesticide use and implementing measures to support natural enemies such as intercropping or planting flower strips. Another key obstacle to IPM adoption is a lack of collective action (Parsa et al. 2014). Therefore, continued awareness-raising and capacity-strengthening to enhance farmers', and other key stakeholders', understanding of biological control is crucial to ensure a consistent approach.

There was a reduction in harvest and income in 2022 compared to 2021 for both treatment and control farms. This continuation of papaya production decrease is no surprise since papaya mealybug was found to be causing yield losses of 57% in an earlier study, following which there have not been any specific interventions (Kansiime et al. 2020). The introduction of *A. papayae* at the time of the follow-up study was only in its early stages with relatively low numbers of parasitoids being provided to farmers, therefore limited conclusions can be reached. Nevertheless, the preliminary results provided in this study indicate that on average higher papaya harvests were achieved in the treatment compared to the control farms, and control farms lost more income than treatment farms. However, it is also likely other factors should be considered before making assumptions. For example, weather conditions including heavy rains and flooding followed by severe drought (UNDRR 2024) will impact pest populations. In addition, the small sample size means that it is not possible to prove causality.

Although it is not possible to comment on the effectiveness of the parasitoid at this early stage, communication with colleagues who have been working with trial farmers who received the parasitoid since the beginning of the year (January 2022) indicate that papaya mealybug control has been achieved on these trial farms (S. Opisa, CABI, pers. comm.). This is positive and in accordance with other countries where *A. papayae* has been released for papaya mealybug control (Meyerdirk et al. 2004; Walker et al. 2005; Offei et al. 2015; Muniappan et al. 2006; Tanwar et al. 2010; Goergen et al. 2014; Mahmood et al. 2018). For instance, Munippan et al.

(2006) reported rapid establishment of *A. papayae* within a month of release at sampling sites. Another study reports excellent control of papaya mealybug within five months post release of the parasitoids (Myrick et al. 2013). Through the continued engagement with farmers affected by papaya mealybug their biological control knowledge and capacity will be strengthened. As such, biological control of papaya mealybug using *A. papayae* could provide a much-anticipated example of the value of biological control and the importance of engaging with farmers. Thereby addressing one of the key challenges to the success of biological control in sub-Saharan Africa. The findings from this study also highlight the need for attention to gender-responsive approaches towards farmer education and engagement.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the critical contributions of all farmers, community leaders and extension agents in facilitating and contributing to this work. We gratefully acknowledge the enumerators who worked tirelessly in the data collection. Gratitude to Justice Tambo for guidance on data analysis. Thanks to Linda Likoko for administration and organisation of the fieldwork and to Tim Beale for provision of the survey locality map. Gratitude to Senior Regional Director, CABI Africa, Dr Morris Akiri for supporting this work.

FUNDING STATEMENT

This research was funded by the CABI-led PlantwisePlus programme, which is financially supported by the Directorate-General for International Cooperation, Netherlands (DGIS); European Commission Directorate General for International Partnerships (INIPA); UK International Development from the UK government; and the Swiss Agency for Development and Cooperation (SDC).

ORCID IDS

K Constantine: <http://orcid.org/0000-0001-9053-3537>
 F Makale: <http://orcid.org/0000-0002-6454-7705>
 I Mugambi: <http://orcid.org/0000-0001-9895-0618>
 D Chacha: <http://orcid.org/0000-0002-0607-5973>
 A Ogunmodede: <http://orcid.org/0000-0001-6388-2870>
 S Opisa: <http://orcid.org/0000-0001-8289-8085>
 B Luke: <http://orcid.org/0000-0003-4055-5185>
 I Rwomushana: <http://orcid.org/0000-0001-5840-8058>
 F Williams: <http://orcid.org/0000-0002-6772-0753>

REFERENCES

- Abdollahzadeh G, Sharifzadeh MS, Damalas CA. 2015. Perception of the beneficial and harmful effects of pesticides among Iranian rice farmers influence the adoption of biological control. *Crop Protection*. 75:124–131. <https://doi.org/10.1016/j.cropro.2015.05.018>.
- Abdollahzadeh G, Sharifzadeh MS, Damalas CA. 2016. Motivations for adopting biological control among Iranian rice farmers. *Crop Protection*. 80:42–50. <https://doi.org/10.1016/j.cropro.2015.10.021>.
- Al-Hassan R, Jatoo JBD, Egyir IS. 2010. Biopesticides in Ghana: vegetable farmers' perception and willingness to pay. *The IUP Journal of Agricultural Economics*. VII(4):17–32. https://www.researchgate.net/publication/227439859_Biopesticides_in_Ghana_Vegetable_Farmers_Perception_and_Willingness_to_Pay.
- Constantine KL, Kansiime MK, Mugambi I, Nunda W, Chacha D, Rware H, Makale F, Mulema J, Lamontagne-Godwin J, Williams F, Edgington S, Day R. 2020. Why don't smallholder farmers in Kenya use more biopesticides? *Pest Management Science*. 76(11):3615–3625. <https://doi.org/10.1002/ps.5896>.
- Constantine K, Makale F, Mugambi I, Rware H, Chacha D, Lowry A, Rwomushana I, Williams F. 2023. Smallholder farmers' knowledge, attitudes and practices towards biological control of papaya mealybug in Kenya. *CABI Agriculture and Bioscience*. 4(1):18. <https://doi.org/10.1186/s43170-023-00161-7>.

- De Groot H, Douro-Kpindou OK, Ouambama Z, Gbongboui C, Muller D, Attignon S, Lomer C. 2001 Assessing the feasibility of biological control of locusts and grasshoppers in West Africa: Incorporating the farmers' perspective. *Agriculture and Human Values*. 18(4):413–428. <https://doi.org/10.1023/A:1015266432589>.
- Eyhorn F, Roner T, Specking H. 2015. Pesticide reduction in agriculture – What action is needed? Briefing paper, (August). 1–19.
- Franzel S, Sinja J, Simpson B. 2014. Farmer-to-farmer extension in Kenya: the perspectives of organizations using the approach. ICRAF Working Paper No. 181. Nairobi: World Agroforestry Centre. <http://dx.doi.org/10.5716/WP14380.PDF>.
- Goergen GE, Ajuonu O, Kyofa-Boamah ME, Umeh V, Bokonon-Ganta AH, Tamo M, Neuenschwander P. 2014. Classical biological control of papaya mealybug in West Africa. *Biocontrol News and Information*. 35(1):2–4. <https://biblio1.iita.org/handle/20.500.12478/991>.
- Harrison RD, Thierfelder C, Baudron F, Chinwada P, Midega C, Schafner U, van den Berg J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*. 243:318–30. <https://doi.org/10.1016/j.jenvman.2019.05.011>.
- Heong KL, Escalada MM, Sengsouliwong V, Schiller J. 2002. Insect management beliefs and practices of rice farmers in Laos. *Agriculture, Ecosystems & Environment*. 92(2–3):137–45. [https://doi.org/10.1016/S0167-8809\(01\)00304-8](https://doi.org/10.1016/S0167-8809(01)00304-8).
- KALRO & CABI. 2021. Application for the importation of *Acerophagus papayae* Noyes and Schauff (Hymenoptera: Encyrtidae). Dossier compiled upon request of the Kenya Standing Technical Committee on Imports and Exports (KSTCIE).
- Kansiime MK, Rwomushana I, Mugambi I, Makale F, Lamontagne-Godwin J, Chacha, D, Kibwage, P, Oluyali, J, Day R. 2020. Crop losses and economic impact associated with papaya mealybug (*Paracoccus marginatus*) infestation in Kenya. *International Journal of Pest Management*. 69(2):150–163. <https://doi.org/10.1080/09670874.2020.1861363>.
- Kansiime MK, Makale F, Duncan C, Nunda W, Karanja D, Durocher-Granger L. 2024. Area-wide pest management and prospects for fall armyworm control on smallholder farms in Africa: a review. *Sustainable Environment*. 10(1):2345464. <https://doi.org/10.1080/27658511.2024.2345464>.
- Kawarazuka N, Damtew E, Mayanja S, Okonya JS, Rietveld A, Slavchevska V, Teeken B. 2020. A Gender perspective on pest and disease management from the cases of roots, tubers and bananas in Asia and sub-Saharan Africa. *Frontiers in Agronomy*. 2:1–5. <https://doi.org/10.3389/fagro.2020.00007>.
- Khan M, Damalas CA. 2015. Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan. *Crop Protection*. 77:45–51. <https://doi.org/10.1016/j.cropro.2015.07.014>.
- Macharia I, Kimani E, Koome F, Kosiom T, Heya H, Otipa M, Oronje M. 2017. First Report and distribution of the papaya mealybug, *Paracoccus marginatus*, in Kenya. *Journal of Agricultural and Urban Entomology*. 33(1):142–150. <https://doi.org/10.3954/JAUE17-02.1>.
- Machekano H, Mvumi BM, Nyamukondiwa C. 2017. Diamondback moth, *Plutella xylostella* (L.) in southern Africa: research trends, challenges and insights on sustainable management options. *Sustainability* (Switzerland). 9(2):91. <https://doi.org/10.3390/su9020091>.
- Mahmood R, Keerio ID, Rehman A, Rashid K. 2018. Role of natural enemies field reservoir (NEFR) in farmer fields for controlling papaya mealybug *Paracoccus marginatus* at Karachi. *Pakistan Entomologist*. 40(1):7–11.
- Martínez-Sastre R, García D, Miñarro M, Martín-López B. 2020. Farmers' perceptions and knowledge of natural enemies as providers of biological control in cider apple orchards. *Journal of Environmental Management*. 266:110589. <https://doi.org/10.1016/j.jenvman.2020.110589>.
- Meyerdirk DE, Muniappan R, Warkentin R, Bamba J, Reddy GVP. 2004. Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. *Plant Protection Quarterly*. 19(3):1–6.
- Mkenda PA, Ndakidemi PA, Stevenson PC, Arnold SEJ, Darbyshire I, Belmain SR, Priebe J, Johnson AC, Tumbo J, Gurr GM. 2020. Knowledge gaps among smallholder farmers hinder adoption of conservation biological control. *Biocontrol Science and Technology*. 30(3):256–277. <https://doi.org/10.1080/09583157.2019.1707169>.
- Muniappan R, Meyerdirk DE, Sengebau FM, Berringer DD, Reddy GVP. 2006. Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. *Florida Entomologist*. 89(2):212–217. [https://doi.org/10.1653/0015-4040\(2006\)89\[212:CBCTP\]2.0.CO;2](https://doi.org/10.1653/0015-4040(2006)89[212:CBCTP]2.0.CO;2).
- Musebe R, Bundi M, Mugambi I, Akundabweni S, Nambiro E, Chege F. 2018. Effects of plant clinics on pesticides usage by farming households in Kenya. *Journal of Economics and Sustainable Development*. 9(12):36–45.
- Myrick S, Norton GW, Selvaraj KN, Natarajan K, Muniappan R. 2013. Economic impact of classical biological control of papaya mealybug in India. *Crop Protection*. 56:82–86. <https://doi.org/10.1016/j.cropro.2013.10.023>.
- Nyambo B, & Löhr B. 2005. Biocontrol-based ipm for Brassica crops in East Africa. *Second International Symposium on Biological Control of Arthropods*. 290–301.
- Ocho FL, Abdissa FM, Yadessa GB. 2016. Smallholder farmers' knowledge, perception and practice in pesticide use in South Western Ethiopia. *Journal of Agriculture and Environment for International Development*. 110(2):307–323.
- Offei MK, Thiombiano L, Solal-Céline. 2015. Economic impact assessment of the classical biological control of papaya mealybug in Ghana. *Research Journal's Journal of Agriculture*. 2(5):1–18.
- Opisa S, Makale F, Nyasani JO, Muvea A, Kabole M, Chacha D, Agboyi LK, Asudi GO, Rehman A, Luke B, Rwomushana I. 2024. Prospects of classical biological control of papaya mealybug in Kenya. Performance of its exotic parasitoid, *Acerophagus papayae*, under laboratory and field conditions. *Crop Protection*. 175:106476. <https://doi.org/10.1016/j.cropro.2023.106476>.
- Parsa S, Morse S, Bonifacio A, Chancellor TCB, Condori B, Crespo-Pérez V, Hobbs, SLA, Kroschel, J, Ba MN, Rebaudo F, Sherwood, SG, Vanek SJ, Faye E, Herrera MA, Dangles O. 2014. Obstacles to integrated pest management adoption in developing countries. *Proceedings of the National Academy of Sciences of the United States of America*. 111(10):3889–3894. <https://doi.org/10.1073/pnas.1312693111>.
- Pretty J, Bharucha ZP. 2015. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects*. 6(1):152–182. <https://doi.org/10.3390/insects6010152>.
- Rebaudo F, Dangles O. 2013. An agent-based modeling framework for integrated pest management dissemination programs. *Environmental Modelling and Software*. 45:141–149. <https://doi.org/10.1016/j.envsoft.2012.06.014>.
- StataCorp. 2019. Stata: Release 16. Statistical Software. College Station, TX: StataCorp LLC.
- Tanwar RK, Jeyakumar P, Vennila S. 2010. Papaya mealybug and its management strategies. *Technical Bulletin 22*. NCIPM. *Technical Bulletin*. (22):3–5. <https://icar.org.in/files/Papaya%20MealybugNCIPM.pdf>.
- Terefe B, Danish, M, Faisal S, Holmes KA, Luke B, Williams F. 2023. Gender analysis of uptake of *Trichogramma chilonis* to control *Helicoverpa armigera* on tomato crops in Pakistan. *Sustainability*. 15:2214. <https://doi.org/10.3390/su15032214>.
- UNDRR. 2024. Horn of Africa floods and drought, 2020–2023 – Forensic analysis. United Nations Office for Disaster Risk Reduction, Case Study. <https://www.undrr.org/quick/88888>.
- Van de Fliert E, Proost J. 1999. Women and IPM: Crop protection practices and strategies. Royal Tropical Institute. The Netherlands: Intermediate Technology Publications. <https://edepot.wur.nl/319156>.
- Walker A, Hoy M, Meyerdirk D. 2005. Papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae). University of Florida, IFAS Extension. EENY-302:1–5. <https://doi.org/10.32473/edis-in579-2003>.
- World Bank. 2010. Gender and governance in rural services. insights from India, Ghana, and Ethiopia. Washington, DC: World Bank. <http://hdl.handle.net/10986/2410>.
- Wyckhuys KAG, Bentley JW, Lie R, Nghiem LTP, Fredrix M. 2017. Maximizing farm level uptake and diffusion of biological control innovations in today's digital era. *BioControl*. 63(1):133–148. <https://doi.org/10.1007/s10526-017-9820-1>.