Constantine *et al.*
CABI Agriculture and Bioscience (2023) 4:18
https://doi.org/10.1186/s43170-023-00161-7

CABI Agriculture and Bioscience

RESEARCH

Open Access

Smallholder farmers' knowledge, attitudes and practices towards biological control of papaya mealybug in Kenya

Kate Constantine[1*], Fernadis Makale[2], Idah Mugambi[2], Harrison Rware[2], Duncan Chacha[2], Alyssa Lowry[3], Ivan Rwomushana[2] and Frances Williams[2]

Abstract

Background Farmer perceptions are highly important in influencing on-farm pest management decision-making. Biological control is extremely sustainable in the smallholder production context, but in Sub Saharan Africa (SSA) few attempts using this pest control method for arthropod pests have been successful, with one of the key reasons cited as poor involvement of farming communities and extension in the dissemination of information. Although farmers' knowledge and attitudes are hugely important for the successful implementation of biological control, they are often disregarded. Papaya mealybug (*Paracoccus marginatus*) (PMB) has rapidly spread and established in suitable areas across Kenya becoming a serious pest. The objective of this study is 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 initiative for PMB management.

Methods Household surveys were conducted covering 383 farming households (148 women) in four papaya producing counties in Kenya alongside key informant interviews with eight extension agents and thirty agro-dealers, and eight focus group discussions.

Results Although some farmers demonstrated awareness of the concept of biological control they lacked knowledge, experience and technical support from extension or agro-dealers. Reasons for not using biological control included inadequate awareness and concerns over efficacy and safety. Farmers expressed high levels of interest and willingness to support biological control, and were willing to reduce their chemical pesticide use to help conserve, and support the establishment of natural enemies. County, perception of biological as safe, training in IPM and gender were all highly significant factors determining farmers willingness to support biological control.

Conclusions Previously, poor attention has been paid to farmer perceptions and participation in biological control, which has resulted in limited success in developing countries. With high levels of interest and willingness to support biological control, the next step is to engage with farming communities impacted by PMB. By building awareness and capacity, and developing a management plan with farmers that will support the release and establishment of the biological control agent, *Acerophagus papayae*, long-term, sustainable control of PMB in Kenya is possible.

Keywords Farmer perceptions, Knowledge, Attitudes and practices (KAP), Classical biological control, Papaya mealybug, Kenya

*Correspondence:
Kate Constantine
k.constantine@cabi.org
Full list of author information is available at the end of the article

Background

There are various reasons cited for the limited adoption of Integrated Pest Management (IPM), which includes biological control, including a lack of locally-developed packages, lack of awareness and/or knowledge of the concepts of IPM/biological control, limited available alternatives to chemical controls, as well as poor research expertise and lack of funding (Machekano et al. 2017). Studies of farmer perceptions have found high awareness of the risk presented by chemical pesticides but there is a lack of information on available alternative pest control options (Eyhorn et al. 2015; Musebe et al. 2018; Ocho et al. 2016; Parsa et al. 2014; Pretty and Bharucha 2015). The majority of biological control research also overlooks smallholder farming systems, even though smallholders are central to global food security and biological control is highly suitable in this production context (Steward et al. 2014).

In Sub Saharan Africa (SSA), few attempts at biological control of arthropod pests have been successful, with one of the key reasons cited as poor involvement of farming communities and extension in the dissemination of information (Nyambo and Löhr 2005). Parsa et al., (2014) report the lack of collective action within a farming community as the top obstacle to IPM adoption. Although farmers' knowledge, beliefs and attitudes are hugely important for the successful implementation of biological control, they are often disregarded (Wyckhuys et al. 2017). A Web of Knowledge search conducted by Wyckhuys et al. (2017) from 1990 to 2016, highlights that the incorporation of social science perspectives in arthropod biological control research is extremely low (only 1.4% of research in the past 25 years has referred to farmers or other stakeholders). This is despite the fact that farmer perceptions are highly important in influencing on-farm pest management decision-making (to an even greater extent than economics) (Heong et al. 2002). It has been demonstrated that improving farmers' knowledge of pest management and pesticide use significantly reduces the amount of chemical pesticides sprayed in cotton production (Chen et al. 2013). As such, lack of attention to farmers' ecological knowledge and the social science facets of biological control only contributes to greater dependence on, and over-use of, chemical pesticides (Wyckhuys et al. 2017). An increasing number of socio-ecological studies demonstrate how the adoption of biological control and agronomic management practices by smallholders can support and improve the establishment and effectiveness of biological control agents, especially when coordinated area-wide among farmers.

When a new invasive pest arrives and an urgent response is needed, the use of broad-spectrum insecticides is often promoted and, in a desperate attempt to protect their crop, farmers can become highly dependent on chemical pesticides (Harrison et al. 2019). This is particularly the case with invasive species since there is no prior experience, or pre-existing local knowledge, of dealing with the pest (Rebaudo and Dangles 2013). However, this approach undermines agro-ecological pest management strategies that are often low-cost, culturally appropriate and readily integrated into smallholder farmers' existing practices (Harrison et al. 2019).

Horticulture is an important sub-sector in Kenya, contributing to livelihoods, accounting for 60% of export earnings, and engaging a high concentration of women and youth in the value chain (Kansiime et al. 2020). Papaya (*Carica papaya* L.), commonly referred to as pawpaw in Kenya, is a very important horticultural crop grown in coastal areas of Kenya, ranked the 5th most important fruit crop in 2017 (HDC 2017). In 2016, the invasive papaya mealybug (*Paracoccus marginatus*, Williams and Granara de Willink) (Hemiptera: Pseudococcidae) (PMB) was reported in the Magongo and Likoni areas of Mombasa and has since rapidly spread and established in suitable areas across the country becoming a serious pest (Heya et al. 2020; Macharia et al. 2017). Yield losses due to PMB 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). It should also be noted that PMB not only attacks papaya but is highly polyphagous with a host range of over 200 plants, including many economically important crops such as *Manihot esculenta* (cassava), *Citrus* spp. L. (citrus) and *Persea americana* P. Mill (avocado) (Finch et al. 2021). Kansiime et al., (2020) found that some of the chemical pesticides being used to control PMB by farmers were not registered for the control of this pest which, alongside poor handling and disposal practices, can have serious environmental and health implications. Indeed, organophosphates and neonicotinoids, known to negatively affect pollinators, were the most commonly used pesticides by the farmers in this study (Kansiime et al. 2020).

In PMB's native range (Central America) naturally occurring parasitoids and predators help keep numbers in check. However when introduced to areas outside of their country of origin a lack of natural enemies can result in serious outbreaks (Oluyali 2020). Under such conditions, the use of biological control can be highly appropriate. "Biological control is the use of parasitoid, predator, pathogen, antagonist, or competitor populations to suppress a pest population, making it less abundant and thus less damaging than it would otherwise be." (Driesche and Bellows 1996). Of the various forms of biological control, the focus in this study is classical biological control (CBC). "Classical biological control (CBC)

is the introduction of a biological control agent (BCA), usually from a pest's area of origin, to permanently control a target pest in an area where it has become invasive." (Cock et al. 2015). The intention is that once the BCA has been introduced it will establish, reproduce and spread, resulting in a self-sustaining effect on the target pest (Cock et al. 2015). Classical biological control therefore offers an environmentally-sustainable, cost-effective technology that can contribute to fortifying agroecosystems and livelihood security and is entirely suitable for smallholder production contexts (Burra et al. 2021; Wyckhuys et al. 2017). Reduced chemical pesticide dependence will benefit the establishment of the BCA as well as any potential native natural enemies. A recent meta-analysis highlights that when natural enemies are present, and chemical pesticide use reduces their densities, pest densities can actually resurge to greater levels (Janssen and Rijn 2021). The potential of increasing populations of natural enemies to tackle arthropod pests is high (Landis et al. 2000).

An IPM strategy is highly recommended for the sustainable management of PMB where collaborative research, with farmers, is needed to determine the efficacy of indigenous practices and botanicals (Kansiime et al 2020). Biological control offers high potential in the management of PMB. As such the parasitoid *Acerophagus papayae* Noyes and Schauff (Hymenoptera: Encyrtidae) was imported from Ghana to Kenya for CBC efficacy testing in quarantine facilities. A release dossier was subsequently prepared and approval granted by the Kenya Technical Standing Committee on Imports and Exports (KSTCIE) for the release of *A. papayae* in Kenya. The success of *A. papayae* as a CBC agent for PMB has been reported in Ghana (Goergen et al. 2014; Offei et al. 2015); Guam, Palau and Sri Lanka (Meyerdirk et al. 2004; Muniappan et al. 2006; Tanwar et al. 2010); Puerto Rico and the Dominican Republic (Walker et al. 2005).

The objective of this study was to determine smallholder farmers' knowledge, attitudes and practices (KAP) towards biological control in selected counties in Kenya where PMB is prevalent. The KAP survey aimed to understand smallholder farmers' current levels of knowledge and perceptions towards biological control, farmers' willingness to reduce their chemical pesticide use to support parasitoid establishment, and the scope for increasing the use of agronomic, physical and indigenous practices, which are complimentary to biological control. The study also sought to understand factors influencing farmers willingness to support a biological control initiative for PMB. It is important to clarify that the discussion with farmers focused on their understanding of biological control relating to invertebrate BCA's and what they could do to support establishment on their farm. This has relevance to not only CBC ('one-off' introductions of an exotic natural enemy—the focus of this study) but also to other forms of biological control such as augmentative (repeat introduction of natural enemies as needed) and conservation (protecting natural enemy refuges) biological control. The study also sought to determine use, if any, of commercial biopesticide products purchased 'off the shelf' and applied to a crop however, biopesticide products per se were not referred to in discussion of the concept of biological control with farmers.

Methods

Survey site selection and detail

The selected counties were: Mombasa (situated in the south-eastern part of the former Coast Province), Kilifi (coastal county north of Mombasa), Kwale (former Coast Province of Kenya, mainly an inland county with coastline south of Mombasa) and Machakos (Eastern inland county) (Fig. 1). These counties were selected since they were considered suitable potential release sites for *A. papayae* considering PMB impact and yield losses (Kansiime et al. 2020). The survey focused on papaya since although PMB affects a range of crops, the impact of the pest is mainly observed on papaya (Kansiime et al. 2020).

Household surveys

The study population comprised farming households within the four counties. For each county, 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. Face-to-face interviews were conducted with farmers by trained enumerators using a structured questionnaire that had been pre-tested for validity. The questionnaire was programmed on the Open Data Kit (ODK) platform and deployed on tablet computers. At the end of the exercise, 383 smallholders (148 women) had been interviewed (Table 1). Household surveys took place during October 2021. The reference season for production data collected was the previous 12 months (2020/2021 cropping season).

During the survey 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."* This was read to participants prior to the questions on perception of biological control.

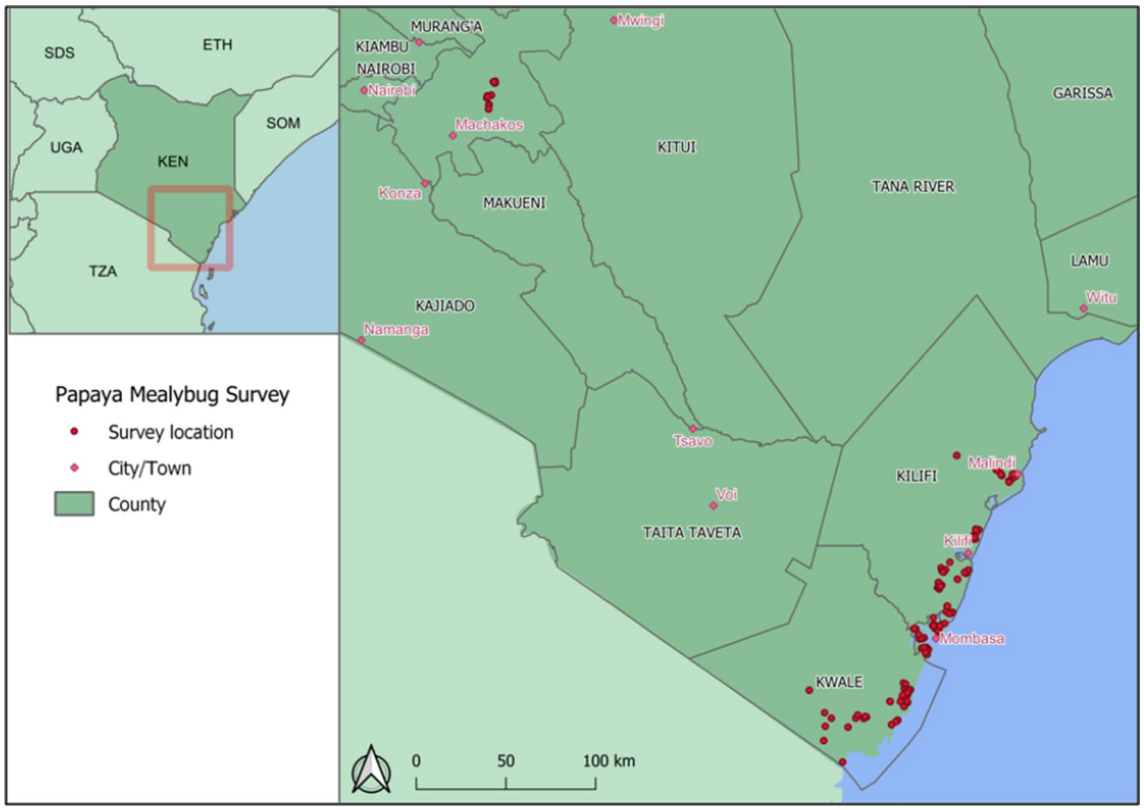

Fig. 1 Map of the survey areas in Kenya

Table 1 Distribution of respondents by gender across survey counties

County	Number of respondents		
	Men	Women	Total
Kilifi	79	33	112
Kwale	58	31	89
Machakos	40	48	88
Mombasa	58	36	94
Total	235	148	383

Table 2 Number of key informant interviews with extension agents and agro-dealers and focus group discussions (FGDs) across the survey counties

	Number of respondents		
	Agro-dealer interviews	Extension agent interviews	FGDs (number of participants)
Kwale	8	2	2 (20)
Mombasa	8	2	2 (15)
Machakos	11	2	2 (20)
Kilifi	3	2	2 (32)
Total	30	8	87

Kenya has 85 registered biopesticides for use in crop production which includes products containing natural enemies (PCPB 2022). However, this study focuses on the concept of biological control using predators and natural enemies rather than on the use of biopesticide products per se. A rating scale of perceptions of biological control in relation to various terms (positive, risky, necessary, natural, effective, useful, ethical and affordable) was used, see Turner and Caron 2021.

Key informant interviews

Interviews using pre-prepared question guides were conducted with eight extension agents and thirty agro-dealers across the survey locations (Table 2). The aim was to determine knowledge and awareness of biological control, recommendations given to farmers, farmers' awareness of, and recommendations for, any biological control products, and perceived challenges and factors that would encourage increased smallholder

uptake of biological control/support for an area-wide biological control strategy for PMB.

Focus group discussions

Eight focus group discussions were conducted across the survey localities. Focus group participants were purposively selected to include both men and women who were household heads, based in the respective sites, and farmers growing papaya. 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 PMB; biological control knowledge awareness and use (facilitators read out the definition of biological control included in the household surveys); perceptions of biological control; opinions on the release of a BCA for PMB; and levels of willingness to cooperate in a CBC initiative. In total eighty-seven farmers (36 women) participated in the focus group discussions (Table 2).

Data analysis

Descriptive statistics were used to summarise general information including household respondent characteristics, farming activities, presence and management of PMB and perceptions of biological control. Data analysis to determine factors that influenced a farmer's willingness to support a biological control program was conducted in RStudio v4.2.2 (R Core Team 2022). An ordinal logistic regression was used with farmers willingness to support a biological control program set as the dependant variable and ordered as follows; 1 = not willing; 2 = possibly willing; and 3 = very willing. The respondent's demographic factors (county, gender, age, education), farm factors (farm size, harvest quantity, occurrence of PMB), biological control perceptions (awareness of biological control, overall perception of biological control, perceived health risk of biological control to self/others), belonging to a farmer group and level of training (training in IPM, biological control specifically, or other training) were all included as independent variables. Subsequently, a stepwise removal of factors occurred to prevent model over fitting and to ensure only relevant variables were included. Following the stepwise reduction of factors, the following explanatory variables remained: county, gender, awareness of biological control, perceived health risk of biological control to others, overall perception of biological control, group belonging, and whether the respondent had received any training in IPM. An analysis of deviance was then conducted on the reduced model to determine the overall significance of each remaining independent variable, followed by a Tukey–Kramer adjusted pairwise post-hoc test to look at within factor significance.

Results

Household respondent characteristics and farming activities

The average age of respondents was 46 years, two-thirds (66%) of respondents were household heads (84% of men and 36% of women). A primary or secondary level of education had been attained by 61% of household heads interviewed, with a greater proportion of men reaching a higher education level than women ($p \leq 0.01$). Farming was the primary activity for 72% of respondents with income primarily from crop/animal farming (67%). Almost all respondents owned land (98%) with the average farm size 1.5 hectares (1.1 and 1.7 ha for women and men, respectively). The majority of respondents (85%) grew papaya on a small area of land (less than 0.05 ha). An average of 54 papaya trees were grown with women growing fewer trees than men (22 and 75, respectively) ($p \leq 0.01$). On average 0.2 hectares are set aside for growing papaya and due to small portions of land papaya is intercropped alongside other crops. Almost all respondents scouted for pests (97%) and most respondents (76%) reported rotating their crops in the last 2 years (Table 3).

Presence and management of papaya mealybug

The majority of respondents (95%) reported seeing PMB on their farm. Men were more likely than women to report PMB occurrence ($p \leq 0.01$). Prevalence of PMB was reported to have changed over time with current levels of occurrence reported to be low to medium (0–30%) by 54% of respondents and high to very high (31 to 51% and above) by 34% of respondents. A change in the amount of papaya harvested over time was reported, with a decrease in annual production and a corresponding decrease in annual income. Extension agents reported PMB as a major problem within farming communities that has been increasing over time. FGD participants reported PMB on other crops in addition to papaya, including maize, cassava, tomato, okra, pepper, mango, avocado, citrus, amaranth, capsicum, beans, kales and cowpea. In terms of management, extension agents indicated that they recommended field sanitization, use of chemical pesticides (for which they referred farmers to registered agro-dealers), high-pressure water jetting, washing leaves with warm water and selective removal of infested leaves and burning.

Chemical pesticide sprays were used by 27% (n = 105) of respondents with men significantly more likely to use chemical pesticides than women ($p \leq 0.01$). A small proportion of those using chemical pesticides also used other methods (6%). Other control practices for PMB management were used by 23% (n = 85) of respondents, including physical/mechanical methods

Table 3 Summary descriptive statistics of surveyed households

Variable	Description	Mean	Std. Dev
Household head	Respondent household head (1 = yes)	0.66	0.48
Gender	Gender of household head (1 = male)	0.61	0.49
Age	Age of household head (years)	46.14	13.49
Education level	Household head attained primary education (1 = yes)	0.4	0.49
	Household head attained secondary education (1 = yes)	0.21	0.41
Primary activity	Primary activity of household head (1 = farming)	0.72	0.45
Income source	Main income source of household head (1 = farming)	0.67	0.47
Land owned	Total land owned (acres)	3.63	7.29
Land size	Land size for growing papaya (1 = < 0.05 ha)	0.85	0.36
Papaya trees	Number of papaya trees grown (average)	54.34	164.64
Scouting	Scout for pests (yes = 1)	0.97	0.17
Rotate crops	Rotate crops (yes = 1)	0.76	0.43
PMB infestation	Seen papaya mealybug on crops (1 = yes)	0.95	0.21
Health risk	Risk chemical pesticide to applicator (1 = high)	0.71	0.45
Heard biocontrol	Heard of term biological control (1 = yes)	0.51	0.50
Perception (risky)	Perception biological control 'risky'	0.04	0.21
Perception (safe)	Perception biological control 'safe'	0.84	0.37
Support	Willing to support biological control (1 = yes)	0.94	0.23
Pesticide use	Reduce pesticide use (1 = likely)	0.88	0.32
Belong group	Belong to farmer association (1 = yes)	0.41	0.49
IPM training	Received training in IPM (1 = yes)	0.23	0.42
Cooperate area-wide	Cooperate pest management/neighbours (1 = very willing)	0.90	0.30
Kwale	Household is located in Kwale county (1 = yes)	0.23	0.42
Kilifi	Household is located in Kilifi county (1 = yes)	0.29	0.46
Machakos	Household is located in Machakos county (1 = yes)	0.23	0.42
Mombasa	Household is located in Mombasa county (1 = yes)	0.25	0.43

such as hand picking; cultural methods such as farm-level plant concoctions including neem, tobacco and hot pepper; the use of field sanitation and trap crops; and a small proportion of farmers used pheromone traps and detergents with almost a third reporting effectiveness as fair (Fig. 2). Over half of respondents (56%) did not use any control methods for PMB.

In reference to farm-level plant concoctions, 22% of respondents (n = 84) reported using, or to have previously used, these for pest management on their farm. Of these respondents, 74% primarily used neem concoctions/extracts (neem is locally referred to as 'Mkilifi' and contains the active ingredient *Azadirachtin*). One reference was made to Nimbedicine (a commercial neem-oil-based botanical insecticide containing *Azadirachtin*). Alongside neem, farmers reported using aloe vera, pepper, *Lantana camara,* and ash all of which are considered cultural controls.

Farmer perceptions of biological control and chemical pesticides

Over half of respondents (51%) reported they had heard of insects/animals/organisms as 'biological controls', that help reduce pest populations on their farm. The most frequently mentioned BCAs were birds, ladybirds/beetles, ants, bees, wasps and spiders (42%, 16%, 12%, 7%, 6% and 3%, respectively). Other BCAs mentioned included butterflies, snakes, frogs, rodents, locusts, cats, chickens, and chameleons, amongst others mentioned by a small proportion of respondents. The majority of extension agents were aware of, and had received training on, biological control. They estimated the proportion of farmers using biological control at ~ 18% however, this included use of pheromone traps and plant extracts, therefore the actual proportion is likely to be much lower.

For those respondents who stated that they had heard of biological control, a high proportion were aware that they are safe for the environment and safe to handle (94

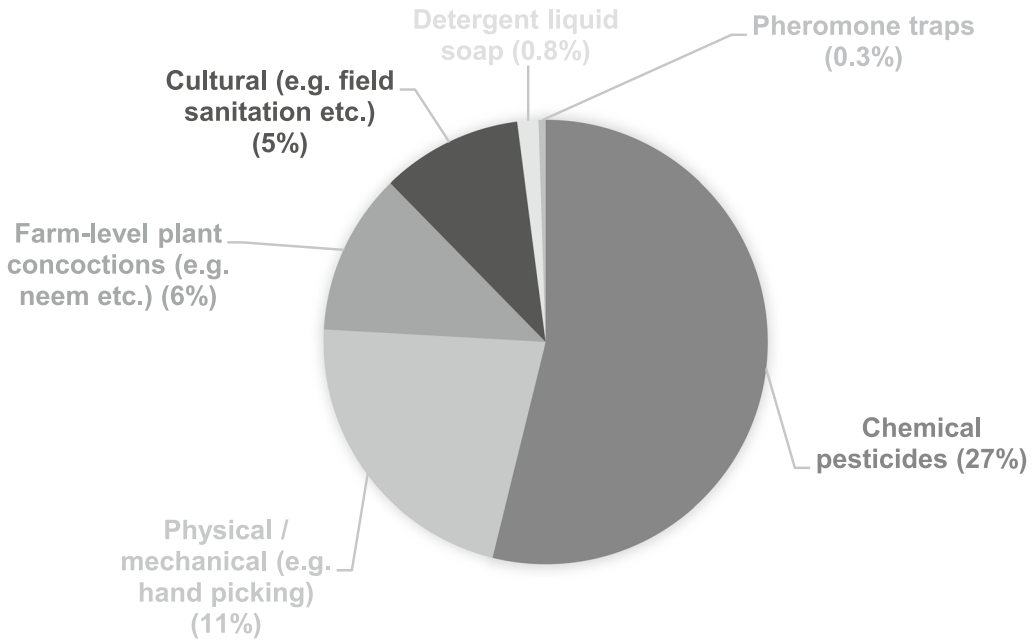

Fig. 2 Proportion of respondents using various management practices for PMB (for those farmers managing PMB)

and 93%, respectively). Biological control was also perceived as affordable (79%), effective at preventing pest infestation (72%), able to increase crop productivity (66%) and available (65%). Biological control was also perceived to work on a broad range of pests (62%) and generally perceived to not require specialised training (62%). However, biological control was perceived to be slow to work by 53% of respondents (30% reporting quick to work) and labour intensive (43%) (Fig. 2). In contrast, there were high levels of awareness of the risk of chemical pesticides and perceptions that they are not safe to handle or safe to the environment (77% and 74% of respondents, respectively), with the greatest risk perceived to be to the health of the applicator (high risk reported by 71% of respondents). There was also recognition of high risk for food safety (56%), pest natural enemies and beneficial insects (49%), and the build-up of resistance by pests to frequently used products (47%). Indeed, most respondents (81%) were aware that pests can build up resistance against chemical pesticides and the FGDs confirmed that farmers believed excessive use of chemical pesticides has resulted in the build-up of pest resistance leading to ineffectiveness. A high number of respondents did not perceive chemical pesticides as affordable (71%). However, chemical pesticides were reported to be easily available (85%), effective at controlling pests (78%), and to increase crop productivity (75%) (Fig. 3). There were some differences in perceptions by gender for example, more men than women perceived biological control to require specialist training and to be more labour intensive (Fig. 4).

For those who had heard of biological control (n = 195) the main source of information, for both men and women, were friends, neighbours and family members (39%) followed by their own knowledge and experience (21%). Both men and women reported receiving some information on biological control from extension agents. More men than women reported information from NGO's, farmer groups, and lead farmers. Very limited information on biological control came from other sources such as the internet, radio, television or newspapers. In the last 12 months, general sources of information on pests and diseases included own experience (45%), agro-dealers (37%), extension agents (34%), and neighbours/friends/relatives (30%) with less frequent sources including newspapers, pamphlets, and mobile SMS.

Following a definition of biological control respondents were asked to rate their perception on different aspects relevant to biological control. The responses indicate an understanding that biological control can offer many benefits with positive views on biological control as safe, natural and affordable (no significant differences between gender) (Fig. 5).

As there was such low use of biological control, fewer than 25% claimed to have used biological control, it is important to understand the reasons behind this lack of use. The main reason for not using biological control for both men and women was a lack of awareness (50%). The other key reasons given were that biological control is not perceived as effective or reliable (16%); unavailable (8%);

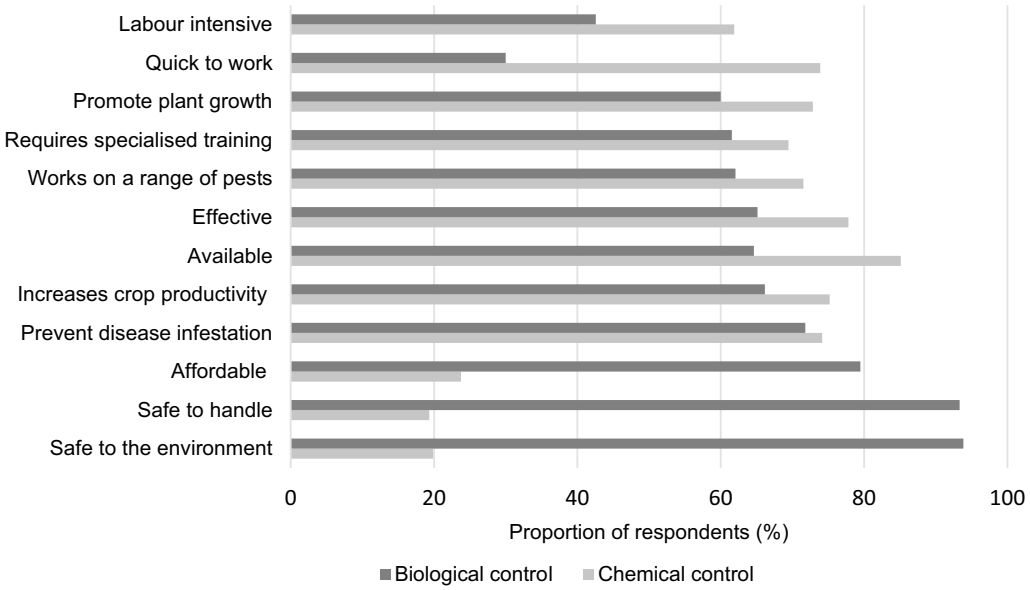

Fig. 3 Farmer perception of biological control and chemical pesticides. Note: perceptions for biological controls are based on responses from those who had heard of biological control (n = 195); those for chemical pesticides are based on all responses (n = 383)

Fig. 4 Perceptions of biological control by gender

difficult to apply/labour intensive (6%); too expensive (4%); and some respondents reported uncertainty over safety (4%) and non-target impacts (4%) (Fig. 6). Some respondents reported that biological controls were not used by, or recommended by friends or relatives (3%), or by experts, such as extension agents or agro-dealers (2%). Two women perceived biological control as a traditional method and as such perceived it to be ineffective compared to chemical pesticides. Extension agents reported not recommending biological control products due to them being unaffordable and inaccessible; they also do not like to recommend them because of low levels of success rates alongside limited general knowledge of biological control practices. Agro-dealers stated that they have low capacity and, in most instances, do not know how to use biological control (which do not have comprehensive information on the label) whilst they are also packaged in quantities favourable to large scale farms (contributing

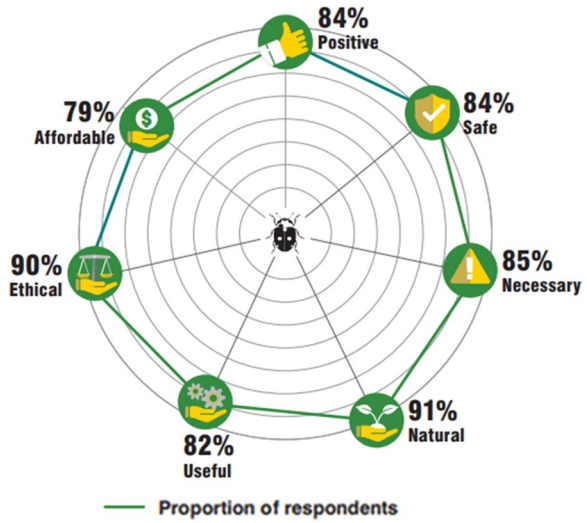

Fig. 5 Farmers' perceptions of biological control

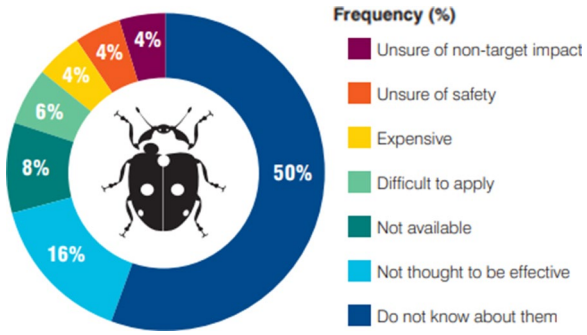

Fig. 6 Farmer identified reasons for not using biological control

to the high price which is a challenge for small-scale farmers). Agro-dealers find it hard to stock a variety of biological controls as there is no, or very little, demand compared to chemical pesticides due to their high price and farmers' lack of knowledge, with mainly large-scale tomato and mango producers embracing biological control. Indeed, of the agro-dealers interviewed just over half stocked biological control products which are mainly purchased by large-scale farmers.

The majority of respondents did not undertake any specific activities to enhance pest natural enemies (72%). The main challenges identified to conserving natural enemies was lack of knowledge, experience, and technical support, excessive use of chemical pesticides on farms, including on neighbouring farms, the small size of the plot, drought impacting flowering, and subsequent natural enemy populations, expense and availability. Further discussion revealed lack of a community approach to natural enemy conservation was a challenge. In terms of training, a third of those interviewed had received training on topics such as pesticide use and safe handling (33%), fewer had received training on IPM (23%), and more men than women had received training overall. Six out of the eight interviewed extension agents had received training on biological control methods for pest management.

Farmer's willingness to support biological control of papaya mealybug

The majority of respondents (>90%) viewed the release of a BCA to manage PMB positively and stated that they would be willing to support a biological control initiative in their community. There was an understanding that such biological control would work best at a community, or combined individual and community level. A small proportion of respondents (6%) remained cautious about biological control and expressed concerns over risk, effectiveness, and the slower speed of action of biological control compared to chemical pesticides, stating they would require more information (particularly field demonstrations) to address these concerns. The majority of respondents (90%) were willing to participate in a cooperative effort towards pest management with their neighbours. Over 80% were willing to conduct cooperative scouting with neighbours for pests, participate in area-wide efforts to rotate crops, engage in coordinated chemical pesticide applications and coordinate habitat management to support natural enemies. Extension agents confirmed that engaging with farmers in the early stages of an initiative was essential to ensuring their commitment, and ownership, of the process.

The analysis of deviance conducted on the ordinal logistic regression showed that county, gender, perceived health risk of biological control to others, awareness and overall perception of biological control, group belonging and receipt of training in IPM all significantly influenced the degree to which farmers would

Table 4 Factors influencing the degree to which farmers are willing to support a biological control initiative

Variable	LR Chi^2	Df	Pr(> Chi^2)
County	17.1679	3	0.0006527***
Gender	9.0689	1	0.0025999**
Health risk	6.0907	2	0.0475794*
Heard of biological control	3.9587	1	0.0466298*
Perception of biological control	16.3649	2	0.0002795***
Belonging to a group	4.3814	1	0.0363339*
Received IPM training	17.5039	1	2.867e−05***

Ordinal logistic regression results; analysis of deviance

Significance *** 0.001, ** 0.01, * 0.05

be willing to support a biological control initiative (Table 4).

Further post-hoc analysis using Tukey–Kramer adjusted pairwise comparisons indicated that, respondents in Mombasa were less willing to support biological control than respondents from any other county ($p < 0.01$), as were those who perceived biological control as risky ($p < 0.01$). Similarly, men were significantly more willing to support biological control than women ($p < 0.01$) and those who perceived biological control as having a high health risk to others where significantly less like to support a biological control program ($p < 0.05$). An individual's awareness of biological control (had previously heard of biological control), belonging to a farmer association and whether they had received any IPM training were all significantly positively correlated with willingness to support a biological control initiative ($p \leq 0.05$) (Table 5).

Since CBC is an area-wide pest management strategy, farmers were asked to rate their level of agreement with various statements related to this approach. The majority of respondents agreed to strongly agreed that agriculture is essential to livelihoods (90%), that PMB threatens agricultural productivity and livelihoods (93%), and that by working together with their neighbours, pests, such as PMB, could be managed more effectively (95%). There was agreement that it would be easier to control pests if farmers coordinated their crop rotations (97%), and that they could rely on neighbouring farmers/farmers within their community to implement agreed measures on their farms (81%) (Fig. 7). Related to this area-wide approach, 75% of farmers agreed that their farms were either very similar or shared some similarities, to their neighbours' farms.

Discussion

Farmer perceptions are highly influential on pest management decision-making (Heong et al. 2002). "Farmers' knowledge, beliefs and attitudes towards pests and natural enemies are of paramount importance to the practice of biological control, but are all too often disregarded." (Wyckhuys et al. 2017). From initiation, the biological control programme for PMB will have involved high-level government approval for importation of the potential BCA, host-range testing to ensure specificity in quarantine facilities through to approval for release of *A. papayae*. Subsequently, research organisations and actors such as extension agents will have begun to engage with farmers. It is therefore likely that through this institutional process perceptions of biocontrol will have been influenced (Myrick et al. 2014). Although farmers in this study demonstrated some level of awareness of the concept of biological control, they lacked knowledge, experience and technical support from extension agents and/or agro-dealers. However, biological control was generally perceived positively with its use primarily constrained by farmers' lack of awareness—half of farmers were not aware of biological control. The majority of extension agents were aware of, and had received training on, biological control however, they did not regularly recommend it to farmers citing farmers' lack of awareness and knowledge, alongside the fact that biological control is perceived as unaffordable, not locally available and to have limited effectiveness. Agro-dealers find it hard to stock a variety of biological controls as there is no, or very little, demand, reporting that they lack know-how on how to use biological controls, and that they are

Table 5 Factors influencing farmers willingness to support biological control (post-hoc pairwise comparison)

Variable	Base	Comparing factor	Coefficient	Standard error	t- value
County	Kilifi	Kwale	0.594	0.399	1.487
		Machakos	0.737	0.429	1.718
		Mombasa	−0.732**	0.347	−2.111
Gender	Female	Male	0.859**	0.286	3.001
Health risk to others	High Risk	Low Risk	0.737*	0.333	2.215
		Medium Risk	0.026	0.335	0.078
Heard of biological control	No	Yes	0.563*	0.285	1.974
Perceptions of biological control	Neutral	Safe	0.931	0.363	2.568
		Risky	−1.135**	0.633	−1.795
Belonging to a group	No	Yes	0.651*	0.309	2.109
Received IPM training	No	Yes	1.727*	0.477	3.621

Coefficients from the reduced ordinal logistic regression model (post-hoc analysis using Tukey–Kramer adjusted pairwise comparisons)

Significance *** 0.001, ** 0.01, * 0.05

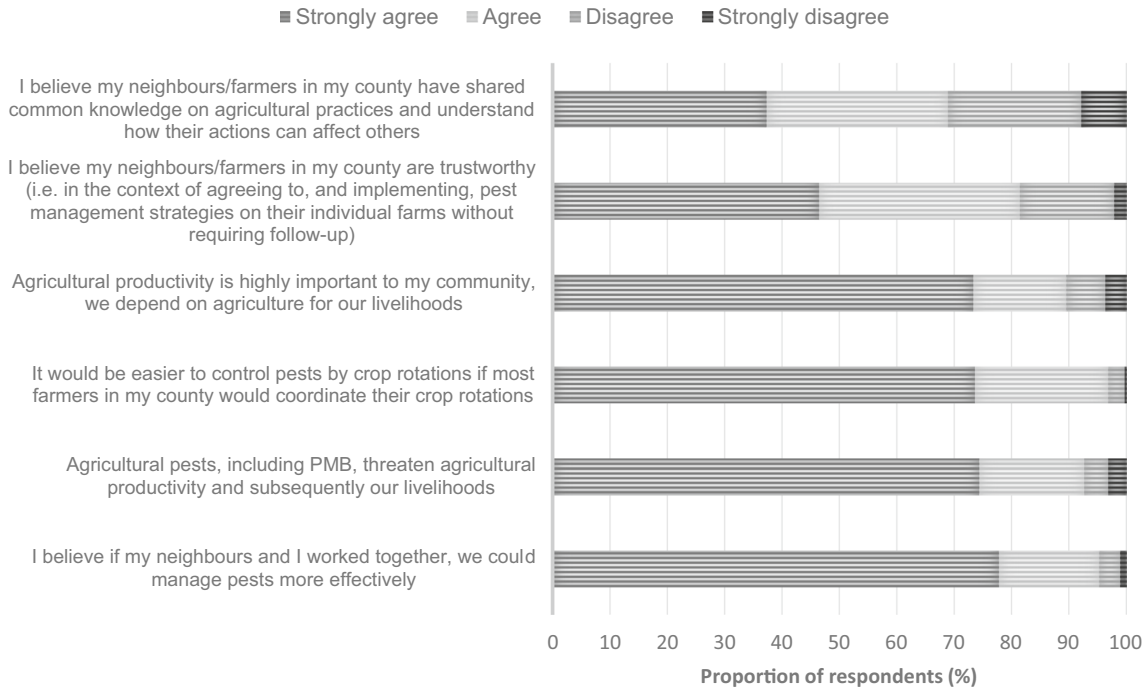

Fig. 7 Farmers' level of agreement with statements on area-wide pest management

generally targeted at large-scale farmers who can afford them. However, a recent study investigating agro-dealer's willingness to stock a new fungal-based biopesticide, reported that 82% of those interviewed were willing to stock the product, with younger and educated agro-dealers, as well as those with access to credit, social networks, and information, more willing to stock the biopesticide (Ogutu et al. 2022).

Farmers reported that traditional pest control methods, such as chemical pesticides, are not working against PMB, but they lacked awareness of, or access to, alternative options. The proposed CBC initiative for PMB is an area-wide pest management approach i.e. *A. papayae* is anticipated to establish a self-sustaining population, provided its establishment is supported by farmers. As a landscape-level approach, farmers are not expected to purchase biological controls as such, but to support natural enemy establishment by reducing their chemical pesticide use, and potentially implementing other measures to help aid the agent's establishment (i.e. planting flower strips or establishing natural enemy field reservoirs). The proposed initiative could therefore offer a number of benefits from building awareness and knowledge of biological control as a pest management approach among farmers, and more widely, through to demonstrating the benefits of classical biological control in terms of economic savings in PMB management, but also important health and environmental benefits.

Attitude toward risk can be a key impediment to the adoption of biological control (Wyckhuys et al. 2017). However, farmers in this study demonstrated low-risk perception of biological control, with high levels of agreement that biological control is safe, both to handle and for the environment, as well as natural, ethical and positive. A minority of respondents held concerns over biological control safety and efficacy which could be addressed through awareness-raising and training alongside concerns over affordability. Khan and Damalas (2015) found high-risk perception of chemical pesticides were associated with an increased probability of the use of alternative pest control practices (Khan and Damalas 2015).

A key finding was that there were very high levels of willingness to support a biological control initiative for PMB, which can be built upon going forward. For example, the majority of those interviewed were willing to participate in cooperative efforts towards pest management including coordinated scouting for pests, crop rotations and chemical pesticide applications, as well as habitat management to support natural enemies. Key factors influencing farmers willingness to cooperate in biological control included whether it was perceived as safe and previous training in IPM. Few farmers in our study had received IPM training highlighting a significant gap in farmer knowledge. Farmers who have received training in IPM have a greater awareness of alternative pest

management practices, such as natural enemies and biological control, with this training also helping farmers to modify local knowledge to better fit within their environmental context (Wyckhuys et al. 2017; Wyckhuys and O'Neil 2007).

Awareness-raising and information dissemination are essential to the success of a CBC control initiative. In Ghana for example, where farmers received training, they reduced their chemical spraying frequency and changed to *Bt*-based products which supported the establishment of the parasitoid *Diadegma semiclausum* for control of Diamondback moth (*Plutella xylostella*, DBM) resulting in significant reductions in DBM populations and damage (Nyambo and Löhr 2005). In contrast, in neighbouring areas, where the parasitoid had spread but farmers were not trained and were unaware of the parasitoid, they continued spraying with broad-spectrum insecticides, and consequently, the level of parasitism was much lower and damage from the pest remained very high (Nyambo and Löhr 2005). Extension and agro-dealers are recognised as key to the dissemination of information including on biological control however, the agro-dealers interviewed here believed that promotion of biological controls must also come from the producing companies, who need to be more proactive to ensure their products are known to farmers, as is the case for chemical pesticides. Although most extension agents had received training in biological control, they did not promote it to farmers. Clearly, going forward awareness raising and capacity building is required.

Peer pressure is reported to be highly influential in determining a person's individual pest management decisions and could be utilised to help drive the dissemination of biological control practices (Heong et al. 2002; Rebaudo and Dangles 2013; Wyckhuys et al. 2017). Respondents gave value to peer-to-peer learning both within the communities, as well as further afield in other regions, highlighting the importance of learning through sharing experiences. Rebaudo and Dangles (2013) found passive information diffusion effective at the farmer community level suggesting a need for emphasis on creating the conditions for social learning on pest control. Identification and training of lead farmers' in ecological concepts can also encourage the generation of locally-relevant biocontrol technologies (Wyckhuys et al. 2017). The identification of resourceful and innovative farmers, who have proficiency in seeking advice and information, and who are likely 'early adopters', is important for information dissemination since these farmers will be able to lead by example and support their neighbour's awareness and understanding of biological control practices (Wyckhuys et al. 2017).

Gender is important in the adoption of biological control but is often overlooked. Women and men know vastly different things about farm insects with women often reported to favour safer, more environmentally-sound practices (Christie et al. 2015; Kansiime et al. 2020; Wyckhuys et al. 2017). Most decisions on pest management in this study were made by the household head or jointly by the household head and the spouse. It is important that any future training is appropriate and accessible for those responsible for decision-making as well as those who support the decision-making process. In Vietnam, for example, women play a key role in pest management decision-making but have no or very little knowledge of biological control, therefore steering their husbands towards insecticide-based pest control (Uphadyay et al. unpublished in Wyckhuys et al. 2017). Indeed, in the current study men were more likely to support biological control than women. The gendered distribution of on-farm tasks (Iradukunda et al. 2019; Kawarazuka et al. 2020; Okonya et al. 2019) such as women playing a greater role in non-chemical control of PMB, whereas men more frequently deciding to use chemical pesticides, are also important. Gendered aspects of farm activities would be important to investigate in greater detail when considering activities related to CBC and the establishment of a BCA.

Farmers in this study were supportive of changing their practices to manage PMB due to the limited effectiveness of current control measures. Almost 30% of respondents in our study were using chemical pesticides, lower than has previously been reported however, even with chemical control measures, losses due to PMB remain high (57%) (Kansiime et al. 2020). Farmers may change their chemical pesticide use due to ineffectiveness and the build-up of pest resistance. Farmers mentioned pest resistance as an issue and it is well known that excessive use of chemical control can result in rapid resistance of pests to pesticides (Khan and Damalas 2015). In addition, some of the chemical pesticides used in the early stages of invasion may not have been appropriate as farmers desperately attempt to protect their crop (Harrison et al. 2019). Importantly, farmers in our study were willing to reduce their chemical pesticide use. Farmers have a difficult time assessing the value and relative advantages of biological control, especially of preventative measures (Wyckhuys et al. 2017). However, the costs associated with chemical pesticide application—product, labour and time—presents a significant burden to farmers. A CBC initiative offers a potential way to redirect resources towards a more sustainable and effective management plan for PMB in Kenya, with implications elsewhere. For example, a recent study on PMB in Tanzania found high reliance on chemical pesticides (or no control) with

losses of up to 75%; a CBC approach could be highly relevant here (Mwanauta et al. 2022).

It was also highlighted in our study that engaging with farmers early on is essential to ensuring the success and sustainability of any future biological control initiative. For example, there was a shared understanding of the problem being faced by the communities (PMB), the threat this poses to livelihoods and high levels of recognition that by working together and coordinating actions, this threat could be more effectively managed. Respondents also reported similarities across their farms, important for a landscape-level parasitoid release requiring a relatively homogenous landscape and coordination of activities (Wyckhuys et al. 2017).

Collective sensitization of communities and awareness creation through capacity building, as well as bringing together those stakeholders providing services to farmers, such as extension and agro-dealers, would all contribute to the success of a CBC initiative. Farmers in this study made clear recommendations for practical field training on biological control, alongside the creation of demonstration plots, whilst also highlighting the need for leadership through lead farmers supported by extension and agro-dealers. Community meetings and engaging with groups farmers already belong to is also important to establishing a collective response. Support from traditional authorities, as well as at the policy level, were also highlighted. Participatory tools could be useful in formulating agreements between farmers e.g. on reduced chemical pesticide applications and adopting practices to promote natural enemy establishment and would help to ensure clear and attainable goals from the outset. In terms of methods to engage with farmers, face-to-face interaction was highly valued by farmers in the survey localities, alongside dedicated agricultural helplines, mobile phone messaging and published materials. The use of market days, plant clinics/health rallies and radio would also be important to promote activities and ensure farmer engagement across a wide area. The results from this study also highlight significant differences in farmer perceptions between counties and gender which are helpful in focussing resources going forward. For example, more men perceived biological control to be useful and necessary than women, suggesting a need to increase women's awareness and understanding of biological control.

For long-term success of biological control of PMB in Kenya, it is essential that smallholder farmers are engaged in the process and made aware of *A. papayae* as a beneficial BCA, its ecology and the reason they need to avoid pesticide use (Bentley 2014). In Ghana, where *A. papayae* was released, even well-organized farmer groups were not aware of the parasitoid, and as such could not support its establishment, emphasising that research and extension must go hand in hand (Bentley 2014). Despite success in the introduction and establishment of parasitoid wasps to control mealybugs in Africa and Asia, farmers continue to apply insecticides, and so the establishment of the parasitoids, and their success in pest control, is reduced (Bentley 2014).

Conclusions

- There were high levels of interest and willingness to support a CBC initiative using the parasitoid *A. papayae* for the management of PMB in the survey localities.
- To ensure community ownership and long-term sustainability it is essential to engage with communities in the initial stages of a biological control initiative.
- Continued community engagement and capacity building is required to ensure increased knowledge of biological control principles by farmers in the survey localities, and nationally, as *A. papayae* spreads.

Abbreviations

BCA	Biological Control Agent
CBC	Classical Biological Control
DBM	Diamondback moth
FGD	Focus group discussion
IPM	Integrated Pest Management
KAP	Knowledge, Attitudes and Practices
KSTCIE	Kenya Technical Standing Committee on Imports and Exports
ODK	Open Data Kit
PMB	Papaya mealybug
SMS	Smart Messaging Service
SSA	Sub Saharan Africa
WHO	World Health Organisation

Acknowledgements

Sincere thanks to all farmers for giving their valuable time to participate in the study. Many thanks to the community leaders, extension agents and agro-dealers for their time and assistance in facilitating the study. We gratefully acknowledge the enumerators who worked tirelessly in the data collection. Thanks to Linda Likoko for administration and organisation of the fieldwork. Thanks to Tim Beale for provision of the survey locality maps and Sarah Hillier and Donna Smith for the infographics. Many thanks to Monica Kansiime for helpful discussion on papaya mealybug impact in Kenya and to Léna Durocher-Granger for initial discussions on the concept of collective action in relation to biological control. Thanks also to Justice Tambo and two anonymous reviewers for valuable comments on the manuscript. Gratitude also to Senior Regional Director, CABI Africa, Dr Morris Akiri for supporting this work.

Author contributions

FW, KC and IR all contributed to critical early stage thinking and conceptualisation of the study. KC, FW, FM and IM all contributed to design and development of the survey tools. FM, IM, DC and HR conducted the field survey work and trained enumerators. KC led data analysis with inputs from FW, IM, HR and FM. AL conducted statistical analysis. All authors checked and edited the final manuscript.

Funding
This study was conducted as part of CABI's PlantwisePlus programme, which is funded by the UK Foreign, Commonwealth and Development Office (FCDO), the Netherlands Ministry of Foreign Affairs (DGIS), the Swiss Agency for Development and Cooperation (SDC), and the European Commission (DG INTPA). CABI is an international intergovernmental organization, and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom (Foreign, Commonwealth and Development Office), China (Chinese Ministry of Agriculture and Rural Affairs), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), the Netherlands (Directorate-General for International Cooperation), Switzerland (Swiss Agency for Development and Cooperation) and Ireland (Irish Aid, International Fund for Agricultural Development-IFAD). See http://www.cabi.org/about-cabi/who-we-work-with/key-donors/ for full details.

Availability of data and materials
All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate
A consent statement was read to all participants prior to completing the survey and subsequent interviews were only completed with those who gave their consent.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]CABI, Bakeham Lane, Egham TW20 9TY, UK. [2]CABI, Canary Bird, 673 Limuru Road, Muthaiga, P.O. Box 633-00621, Nairobi, Kenya. [3]CABI, Nosworthy Way, Wallingford OX10 8DE, UK.

Received: 8 February 2023 Accepted: 5 June 2023
Published online: 15 June 2023

References

Bentley, J. Softly killing the mealybug. *AGRO Insight*. 2014. https://www.agroinsight.com/blog/?p=434. Accessed 14 March 2022

Burra DD, Pretty J, Neuenschwander P, Liu Z, Zhu ZR, Wyckhuys KAG. Human health outcomes of a restored ecological balance in African agro-landscapes. Sci Total Environ. 2021;775:145872. https://doi.org/10.1016/j.scitotenv.2021.145872.

Chen R, Huang J, Qiao F. Farmers' knowledge on pest management and pesticide use in Bt cotton production in China. China Econ Rev. 2013;27:15–24. https://doi.org/10.1016/j.chieco.2013.07.004.

Christie ME, Van Houweling E, Zseleczky L. Mapping gendered pest management knowledge, practices, and pesticide exposure pathways in Ghana and Mali. Agric Hum Values. 2015;32(4):761–775. https://doi.org/10.1007/s10460-015-9590-2.

Cock MJW, Day RK, Hinz HL, Pollard KM, Thomas SE, Williams FE, Witt ABR, Shaw RH. The impacts of some classical biological control successes. CAB Rev. 2015. 10, No. 042 https://doi.org/10.1079/PAVSNNR201510042.

Van Driesche RG, Bellows TSJ. Biological control: Section 1 Origins and Scope of Biological Control. New York: Chapman and Hall; 1996. p. 1–31.

Eyhorn F, Roner T, Specking H. Pesticide reduction in agriculture—What action is needed? Briefing paper, 2015; 1–19. https://doi.org/10.13140/RG.2.2.17146.80324.

Finch EA, Beale T, Chellappan M, Goergen G, Gadratagi BG, Khan MAM, Rehman A, Rwomushana, I, Sarma AK, Wyckhuys KAG, Kriticos DJ. The potential global distribution of the papaya mealybug, *Paracoccus marginatus*, a polyphagous pest. Pest Manag Sci. 2021;77(3):1361–70. https://doi.org/10.1002/ps.6151.

Goergen GE, Ajuonu O, Kyofa-Boamah ME, Umeh V, Bokonon-Ganta AH, Tamo M, Neuenschwander P. Classical biological control of Papaya mealybug in West Africa. Biocontrol News Inf. 2014;35(1):5–6. https://hdl.handle.net/10568/75899.

Harrison RD, Thierfelder C, Baudron F, Chinwada P, Midega C, Schaffner U, van den Berg J. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: providing low-cost, smallholder friendly solutions to an invasive pest. J Environ Manag. 2019;243(August 2018):318–30. https://doi.org/10.1016/j.jenvman.2019.05.011.

HDC. Horticulture validated report 2016–2017. Nairobi (Kenya): Agriculture and Food Authority, Horticultural Crops Directorate. 2017. http://kilimodata.developlocal.org/dataset/3534b0b9-e49e-4c72-a90a-e423844a83a2/resource/c7758a80-9102-481e-a6c2-fa983081221d/download/horticulture-validated-data-2016-2017.pdf

Heong KL, Escalada MM, Sengsoulivong V, Schiller J. Insect management beliefs and practices of rice farmers in Laos. Agr Ecosyst Environ. 2002;92(2–3):137–45. https://doi.org/10.1016/S0167-8809(01)00304-8.

Heya HM, Khamis FM, Onyambu GK, Akutse KS, Mohamed SA, Kimathi EK, Ombura FLO, Ekesi S, Dubois T, Subramanian S, Tanga CM. Characterization and risk assessment of the invasive papaya mealybug, *Paracoccus marginatus*, in Kenya under changing climate. J Appl Entomol. 2020;144(6):442–58. https://doi.org/10.1111/jen.12748.

Iradukunda F, Bullock R, Rietveld A, van Schagen B. Understanding gender roles and practices in the household and on the farm: implications for banana disease management innovation processes in Burundi. Outlook Agric. 2019;48(1):37–47. https://doi.org/10.1177/0030727019831704.

Janssen A, Van Rijn PCJ. Pesticides do not significantly reduce arthropod pest densities in the presence of natural enemies. Ecol Lett. 2021. https://doi.org/10.1111/ele.13819.

Kansiime MK, Rwomushana I, Mugambi I, Makale F, Lamontagne-Godwin J, Chacha D, Kibwage P, Oluyali J, Day R. Crop losses and economic impact associated with papaya mealybug (*Paracoccus marginatus*) infestation in Kenya. Int J Pest Manag. 2020. https://doi.org/10.1080/09670874.2020.1861363.

Kawarazuka N, Damtew E, Mayanja S, Okonya JS, Rietveld A, Slavchevska V, Teeken B. 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. 2020;2(July):1–5. https://doi.org/10.3389/fagro.2020.00007.

Khan M, Damalas CA. Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan. Crop Prot. 2015;77:45–51. https://doi.org/10.1016/j.cropro.2015.07.014.

Landis DA, Wratten SD, Gurr GM. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu Rev Entomol. 2000;45(February):175–201. https://doi.org/10.1146/annurev.ento.45.1.175.

Macharia I, Kimani E, Koome F, Kosiom T, Heya H, Otipa M, Oronje ML. First report and distribution of the Papaya Mealybug, *Paracoccus marginatus*, in Kenya. J Agric Urban Entomol. 2017;33(1):142–50. https://doi.org/10.3954/JAUE17-02.1.

Machekano H, Mvumi BM, Nyamukondiwa C. Diamondback moth, *Plutella xylostella* (L.) in Southern Africa: research trends, challenges and insights on sustainable management options. Sustainability. 2017;9(2):91. https://doi.org/10.3390/su9020091.

Meyerdirk DE, Muniappan R, Warkentin R, Bamba J, Reddy GVP. Biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in Guam. Plant Prot Q. 2004;19(3):110–114.

Muniappan R, Meyerdirk DE, Sengebau FM, Berringer DD, Reddy GVP. Classical biological control of the papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in the Republic of Palau. Florida Entomologist. 2006;89(2):212–7. https://doi.org/10.1653/0015-4040(2006)89[212:CBCOTP]2.0.CO;2.

Musebe R, Bundi M, Mugambi I, Akundabweni S, Nambiro E, Chege F. Effects of plant clinics on pesticides usage by farming households in Kenya. J Econ Sustain Dev. 2018;9(12):36–45. https://core.ac.uk/download/pdf/234648387.pdf

Mwanauta RW, Ndakidemi PA, Venkataramana PB. Characterization of farmer's knowledge and management practices of Papaya Mealybug *Paracoccus magnatus* (Hemiptera: Pseudococcidae) in Tanzania. Saudi J Biol Sci. 2022. https://doi.org/10.1016/j.sjbs.2022.02.037.

Myrick S, Norton GW, Selvaraj KN, Natarajan K, Muniappan R. Economic impact of classical biological control of papaya mealybug in India. Crop Protect. 2014. https://doi.org/10.1016/j.cropro.2013.10.023.
Nyambo B, Löhr B. The role and significance of farmer participation in biocontrol-based IPM for brassica crops in East Africa. In Proceedings of the Second International Symposium on Biological Control of Arthropods, Davos, Switzerland, 12-16 September 2005:290–301.
Ocho FL, Abdissa FM, Yadessa GB. Smallholder farmers' knowledge, perception and practice in pesticide use in South Western Ethiopia. J Agric Environ Int Dev. 2016;110(2):307–23. https://doi.org/10.12895/jaeid.20162.484.
Offei MK, Thiombiano L, Solal-Céligny A. Economic impact assessment of the classical biological control of Papaya Mealybug in Ghana. J Agric. 2015;2(5):1–18. https://researchjournali.com/view.php?id=1582
Ogutu F, Muriithi BW, Mshenga PM, Khamis FM, Mohamed SA, Ndlela S. Agro-dealers' knowledge, perception, and willingness to stock a fungal-based biopesticide (ICIPE 20) for management of *Tuta absoluta* in Kenya. Agriculture. 2022. https://doi.org/10.3390/agriculture12020180.
Okonya JS, Mudege NN, Rietveld AM, Nduwayezu A, Kantungeko D, Hakizimana BM, Nyaga JN, Blomme G, Legg JP, Kroschel J. The role of women in production and management of RTB crops in Rwanda and Burundi: do men decide, and women work? Sustainability. 2019;11(16):1–15. https://doi.org/10.3390/su11164304.
Oluyali J. Papaya Mealybug: a technical brief—description, identification and sustainable management strategies in Kenya. 2020. https://www.cabi.org/cabi-publications/papaya-mealybug-a-technical-brief-description-identification-and-sustainable-management-strategies-in-kenya/
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. Obstacles to integrated pest management adoption in developing countries. Proc Natl Acad Sci USA. 2014;111(10):3889–94. https://doi.org/10.1073/pnas.1312693111.
PCPB. Pesticide Control Product Board (PCPB). 2022. https://www.pcpb.go.ke/biopesticides-on-crops/. Accessed 24 Mar 2022
Pretty J, Bharucha ZP. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. InsEcts. 2015;6(1):152–82. https://doi.org/10.3390/insects6010152.
R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
Rebaudo F, Dangles O. An agent-based modeling framework for integrated pest management dissemination programs. Environ Model Softw. 2013;45(May):141–9. https://doi.org/10.1016/j.envsoft.2012.06.014.
Steward PR, Shackelford G, Carvalheiro LG, Benton TG, Garibaldi LA, Sait SM. Pollination and biological control research: are we neglecting two billion smallholders. Agric Food Secur. 2014;3(1):1–13. https://doi.org/10.1186/2048-7010-3-5.
Tanwar RK, Jeyakumar P, Vennila S. Papaya Mealybug and its management strategies. Technical Bulletin 22. NCIPM. Technical Bulletin, 2010(22), 3–5. https://icar.org.in/files/Papaya%20MealybugNCIPM.pdf
Turner B, Caron V. Perception of Biocontrol (Biological Control) research project. Survey on dung beetles. Canberra: University of Canberra and CSIRO; 2021.
Walker A, Hoy M, Meyerdirk D. Papaya Mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Insecta: Hemiptera: Pseudococcidae). University of Florida, IFAS Extension. EENY-302. 2005;1–5. https://doi.org/10.32473/edis-in579-2003
Wyckhuys KAG, O'Neil RJ. Local agro-ecological knowledge and its relationship to farmers' pest management decision making in rural Honduras. Agric Hum Values. 2007;24(3):307–21. https://doi.org/10.1007/s10460-007-9068-y.
Wyckhuys KAG, Bentley JW, Lie R, Nghiem LTP, Fredrix M. Maximizing farm-level uptake and diffusion of biological control innovations in today's digital era. Biocontrol. 2017;63(1):133–48. https://doi.org/10.1007/s10526-017-9820-1.

Publisher's Note