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A non-linear approach to the establishment of local biological control agent production units: a case study of fall armyworm in Bangladesh

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Abstract

Background: Strides have been made in Bangladesh to promote the utilisation of biological control agents (BCAs), however farmer utilisation remains sub-optimal. The establishment of local BCA production hubs, although touted as a panacea to this problem, has no proven business case. This study makes the case for a non-linear business model.

Methods: Qualitative and quantitative data from maize growing areas in Bangladesh was collected via telephone interviews from key informants representing four key stakeholders—national research institute, regional research stations, farmer producer organisations and agro-dealers.

Results: Farmer uptake of BCAs in Bangladesh for FAW management is hindered by several factors—lack of BCAs availability in local markets, negative farmer and agro-dealer perceptions, poor input industry linkages for the supply of BCAs products to agro-dealers and inadequate institutional finances for capacity building of and technical support by research scientists and extension agents. Given these challenges to BCAs uptake, an innovation systems-based business model that links researchers, extensionists, agro-dealers and farmer producer organizations in a non-linear pathway is proposed for Bangladesh. This translates into the establishment of local BCA production hubs owner-managed by farm entrepreneurs, with scientists providing them with nucleus culture, while extension services provide technical support for quality assurance. The interaction between all stakeholders is non-linear with all actors intellectually consulted and engaged, with technical capacity on BCAs available for any actor requiring it. Multi-disciplinary research, that takes into account feedback from stakeholders, complements the process thus generating robust and relevant knowledge for feedbacking to improve the business model, capacity building initiatives and farmer engagement.

Conclusions: Mentoring and capacity building leveraged via engagement of research institutions; and demonstration of technology use and guidance utilising extension services and agro-dealer networks, will promote the utilisation of BCAs for FAW management and enable local farm entrepreneurs to meet the increased demand via establishment of local BCA production hubs.

Keywords: Integrated pest management, Biocontrol agents, Agro-dealer networks, Research-extension linkages, Innovation systems

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Background

Invasive species are animal or plant species that deliberately or inadvertently, arrive in new areas and cause



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serious damage to the environment, human health and economic activities (Keller et al., 2011). Often introduced by humans, they include microbes, weeds, insects, vertebrates and other organisms. Apart from causing major direct losses, invasive species also result in indirect losses, including large management costs.

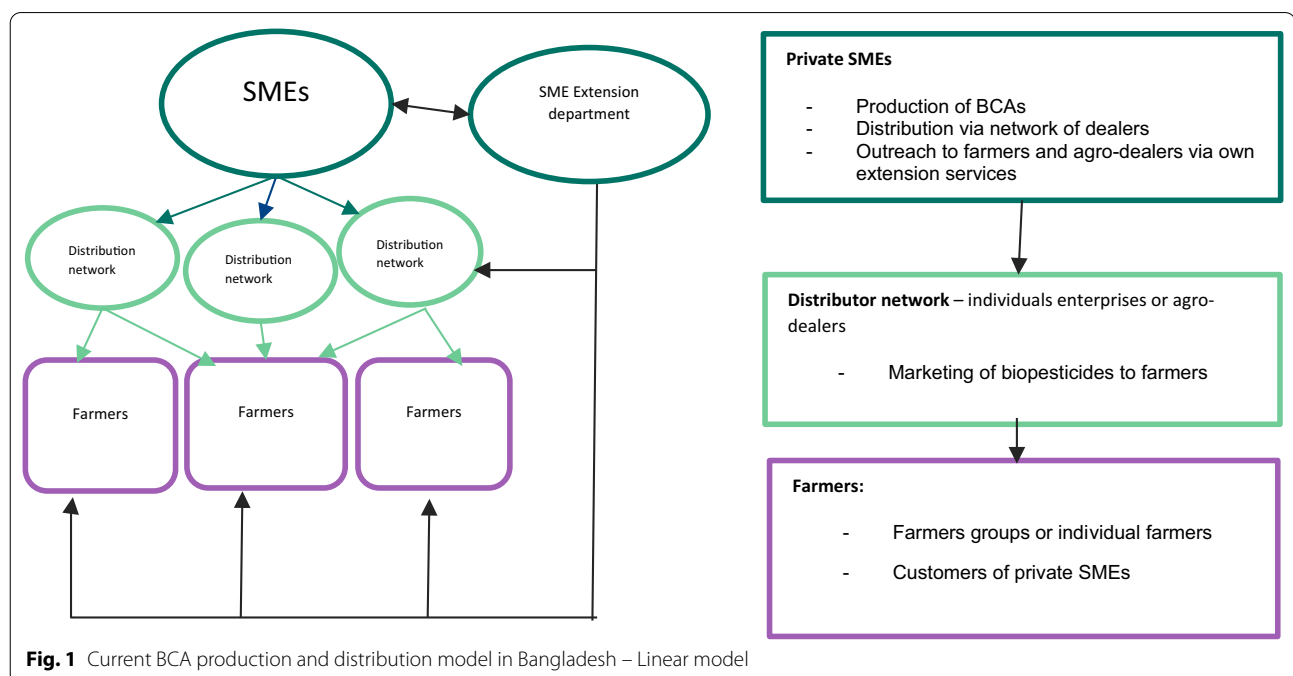
The global agriculture sector has not been spared from the significant impacts of invasive species (Paini et al., 2016). A recent example is the fall armyworm (FAW), *Spodoptera frugiperda*, native to the Americas, which was first detected in maize crops in Africa in early 2016 (Day et al., 2017) and in South Asia and Southeast Asia in late 2018 (Deole and Paul, 2018). In Bangladesh, FAW was detected in November 2018 (Lamsal et al., 2020). Fall armyworm is of concern, as globally evidence of yield loss and economic injury from the pest in various crops including maize, cotton, sorghum and others has been documented (Overton et al., 2021; Day et al., 2017). In Bangladesh, maize cultivation has grown in importance since the 1980s and is now currently amongst the top three important crops in the country (Uddin et al., 2017; Rahman and Rahman, 2014).

Biological control for FAW management

Biological control (BC) is seen as a potential management strategy for FAW as it can provide long-term control without harming the environment and human health (Tian et al., 2020). Biological control, with the appropriate effort levels and resources, can be effective for the management of FAW in maize as well as other at-risk

crops (Tefera et al., 2019). Although BC has been widely advocated and researched (van Lenteren et al., 2020; van Lenteren and Cock, 2020; van Lenteren et al., 2018; Stevenson, et al., 2017; Chandler et al., 2011) farmer uptake and usage globally is less than optimal (Zhanga and Chaudhary, 2021; Constantine et al., 2020; Barratt et al., 2018; van Lenteren, 2012). This is also the case in Bangladesh generally (Alam et al., 2021; Alam, 2013) and also for FAW management specifically (McGrath et al., 2021).

In recent years, Bangladesh has made strides in terms of BC research, product development and farmer outreach (Rashid et al., 2021; Mian et al., 2016; Rahman et al., 2012, 2018; Mamun and Ahmed, 2011). Furthermore concerns about the toxicity of synthetic pesticides to humans and the environment and issues of resistance to pesticides are making the use of BCAs increasingly attractive (Chandler et al., 2011; Glare et al., 2012). Commercialisation of BCAs in Bangladesh is spearheaded by private enterprises, who have central production premises, with distribution via a network that includes but is not limited to established agro-dealers. Most of these enterprises popularise BCAs via promotion activities which include having an extension department that engages with farmers and agro-dealers (Fig. 1). This business model is linear in nature with BCAs produced by the manufactures in a centralised location. This entails that BCAs with short shelf life would not be available as they need to be produced closer to the farmer to avoid spoilage (Teixidó et al., 2020).



Low BCAs uptake is attributed to many factors which include non-availability of BC products in local markets and farmer scepticism about their efficacy (Glare et al., 2016). The latter is due to lack of understanding of their use, lack of knowledge on application rates and methods, and high cost of the products (Ayedun et al., 2017; McGrath et al., 2021). In addition, cumbersome regulatory processes and fragmented strategies; inadequate access and poor communication of the economic benefits of BCAs with farmers and policy makers further limits BCAs uptake (Barratt et al., 2018). Finally, limited distribution networks (McGrath et al., 2021; Sola et al., 2014) and short shelf life of some BCAs (Teixidó et al., 2020), entails that some products are not within easy reach of farmers. These factors reduce the product range of BCAs available to farmers, and ultimately perpetuate over reliance on chemicals. The establishment of local BCAs production hubs, owned and operated by farm entrepreneurs or women groups, has been touted as a means to overcome these challenge.

Cases of local BCAs production are few but emerging globally (Kadzamira et al., 2022). In Bangladesh there is no clear guidelines on the profitability and costs of establishing local BCAs production hubs by farm entrepreneurs for FAW infested areas. This study contributes to this as it provides insights for practitioners, governments and funders on a type of business model that can be used for establishing local BCAs production hubs.

Methods

An assessment was conducted to determine the feasibility of establishing local BCA production hubs at community level for FAW management in Bangladesh. Telephone based key informant interviews, to collect qualitative and quantitative data, were carried out with four stakeholder groups (refer to Fig. 3) that were identified as key for increasing the uptake of BCAs for FAW management in Bangladesh. Information collected from Farmer Producer Organisations (FPOs) included general information (membership, type of crops under cultivation, total acreage under cultivation), type of products used for FAW control by their members, costs and constraints associated with BCA usage vs chemical usage, farmers awareness, acceptability and perceptions of BCAs, availability of BCAs in the local market and interest in trainings on BCAs. This information has been used to establish the feasibility of establishing local BCA production hubs. In addition, information on farmers willingness-to-pay for BCAs was also gathered. Information collected from agro-dealers included information on type and level of products being stocked for FAW management and future stocking plans, perceptions of the market for and challenges with stocking BCAs, farmers

knowledge of and demand for different types of BCAs, their own knowledge of different types of BCAs and willingness to be trained in BCAs.

From the research institutes, information was collected pertaining to their financial and technical capacity for setting up and maintaining nucleus culture and laboratories for continuous experiments. In addition, a mini training assessment was conducted which aimed at establishing the financial and technical requirements that would be optimal to establish a critical mass of qualified researchers and extension agents needed for continuous production and maintenance of culture for supporting local BCA production hubs. Cost estimates gathered from FPOs and research scientists, were triangulated to provide information on financing of the proposed business model—see section on Financing.

Research scientists interviewed were purposively selected from the Entomology Department of the Bangladesh Agricultural Research Institute (BARI) headquarters, and four regional BARI stations in maize growing areas. The Bangladesh Agricultural Research Institute (BARI) is the largest multi-crop research institute in the country conducting research on a wide variety of crops, including maize. By far the largest research institute amongst the National Agricultural Research System (NARS) in the country, BARI is mandated to carry out research and development (R&D) activities focusing on development of new crop varieties, conducting socio-economic research and generating knowledge for improving farm management practices, pest control methods, post-harvest techniques and farm machinery (Stads et al., 2019; Beintema and Kebir, 2006). Its extensive network of regional and sub-regional research stations allows BARI to translate any research knowledge generated into local context for farm level application.

Six agro-dealers and six FPOs, were randomly selected from the farming area under each of the selected regional research stations. FPOs included in the assessment represent a total of 317 farmers. Data collected was analysed using descriptive statistics. Data used for conceptualising the business model proposed in this paper, can be found in the Additional file.

Results and discussion

Business model concepts

A business model is a way of doing business and represents a firm's money-earning logic (Beattie and Smith, 2013; Rappa, 2004). It is a means via which any given enterprise markets its products and sources inputs and finance (Kelly et al., 2015). Business models are varied, ranging from linear to circular business models. A review of 45 journal articles on business models published between 2000 and 2020, show that all business

models have four generic features—value proportion, target customer, value/supply chain and financial model (Geissdoerfer et al., 2018; Bocken et al., 2014; Amit and Zott, 2012; Chesbrough, 2007). Value proposition is the kind of value that is inherent in a firm's product or service. It can be of value economically, socially and/or environmentally. The target customer is the primary target market for a business's products and services. These are the clients who require and purchase the products and services on offer. The value or supply chain is the precise actions and actors that are utilised to create value and to deliver it to the target customer. The financial model of an enterprise refers to the primary cost drivers and profit prospects for a company and it shows how economic gains are distributed across partners and stakeholders.

The way in which these four generic features are organized and managed, provides the basic distinction between business models. A linear business model is one in which a product is commercialized with a manufacturer selling the product outright to suppliers/middle-men, who then take the product and market them to the target customer. The linear business model is characterized mainly by a one-way communication from manufacturer to their marketing networks to the end customer. There is often no backward linkages or a platform for the suppliers/middle-men and the manufacturer to engage and discuss customer needs and/or feedback on the product.

On the other end of the spectrum is the circular business model, which is centred on creating products and delivering value to its broader range of stakeholders while considering ecological and social impacts (Guldmann and Huulgaard, 2020). Circular businesses are

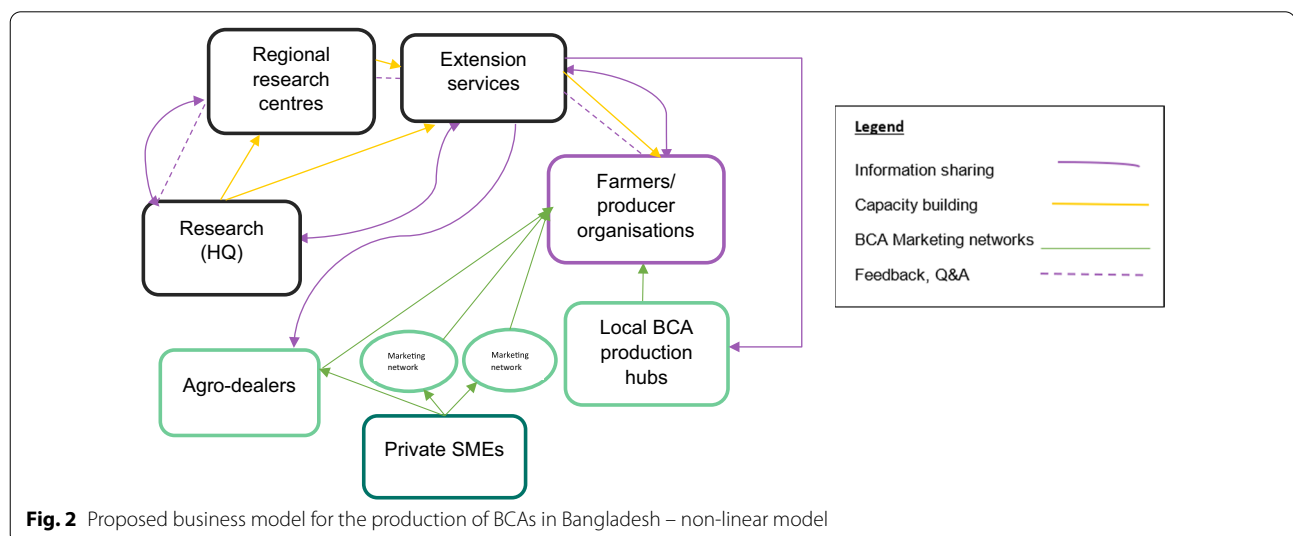
focused on sustainability via the designing of products, production processes and marketing strategies that consider future generations. The value proposition of a circular business model is centred around enabling collaboration between diverse and independent actors along the value chain.

Proposed business model for setting up local BCA production hubs for Bangladesh

In order to establish local BCA production hubs in Bangladesh, we envision a parallel system to the prevailing linear business model in use by private enterprises (Fig. 1). The parallel system would be a non-linear business model (Fig. 2) premised on innovation systems thinking (World Bank, 2007) with local BCA production hubs owned and managed by farm entrepreneurs or women's groups. It is a type of a circular business model, with regional scientists providing nucleus culture for BCAs to farm entrepreneurs/women's groups operating local BCA production hubs while local extension services provide technical support to ensure quality of the end products.

In turn, regional scientists and local extension services will be capacitated by the national research institute via training on all matters pertaining to BCAs. Extension agents will also be responsible for engaging local agro-dealers to ensure they stock products that are complementary to BCAs and provide them with information needed for point-of-sale advice. Extension services is also responsible for ensuring farmers use BCAs appropriately and that they are aware of various sources of BCAs in their area including their local BCA production hubs.

The interaction between farm entrepreneurs, regional and national scientists, extension services and farmers/FPOs is non-linear with all actors networking and



communicating freely, with technical capacity available for any actor requiring it, to fully participate and play their role (Jones, 2008 cited by Mapila et al., 2012). In addition, the business model is non-linear as FPOs and agro-dealers are involved intellectually from the on-set of conceptualising the intervention (Fig. 2). Throughout this process, multi-disciplinary research, that takes into account feedback from farm entrepreneurs, farmers, FPOs and agro-dealers, will be designed and conducted to better understand challenges and opportunities of locally producing BCAs.

The ultimate goal of this non-linear approach is to establish local BCA production hubs thus increase the

availability of BCAs that are effective for FAW management in local markets, while concurrently creating employment for farm entrepreneurs. Public research institutes will initiate this process and engage all actors that are relevant, thus ensuring effective biopesticide research-for-development.

What the non-linear business model for local BCA production looks like in practice in Bangladesh

Practically the non-linear business model for local BCA production will, in Bangladesh, primarily engage four stakeholder groups (Fig. 3).

Nodal Research Institute - capacity building, maintenance of culture, quality assurance:

Bangladesh Agricultural Research Institute (BARI), Gazipur

- Capacity building for BCAs nucleus culture production for scientists & extension agents
- Setting up & keep bioassays/ trials in progress to bring improvement in culture strains
- Quality assurance by Entomology department

Field support - BCA production, farmer training and field engagement:

Regional research centers and extension agents

- Mass multiplication and supply of nucleus culture to FPOs
- Training of farmers in production and use of BCAs for FAW management
- Training of field extension officers in community mobilisation of FPOs
- Supporting farmers in field application of BCAs for FAW management

Markets, point of sale advisory:

Agro-dealers and input suppliers

- Marketing and selling of BCAs for FAW management and complementary products, along with other inputs in local area
- Sharing information to farmers about the use and application of particular products via oral advice, posters, pamphlets and sometimes short videos
- Inform farmers where they can source BCAs not stocked by the agro-dealer i.e. from farm entrepreneurs or self-help groups in the area

BCAs production, utilisation, awareness creation, farm entrepreneurship:

Farmer producer organisations (FPOs)

- Use and adoption of BCAs for FAW management
- Raise awareness about the effectiveness of BCAs for FAW management
- Ensure adequate supply [from research] of nucleus culture for FAW management to farmers and the community
- Ensure adequate supply of BCAs by establishing production facilities at the farm level
- Support interested self-help groups and entrepreneurs to set up local BCA production units

Fig. 3 Value proposition of key stakeholders—non-linear BCA production model in Bangladesh

Research scientists and extension services

The Research Wing of BARI, executes and monitors all research programmes and other research activities through six special crop research centres, 17 research divisions, eight regional research stations and 28 sub-stations. Four of the eight regional research centres under BARI, are in maize growing areas, where BCAs for the control of FAW are highly relevant. All these centres have some laboratory facilities in place. In addition, only 20% of the staff working in the Entomology Department at BARI have been formally trained in BCA production and usage for FAW management. Other staff are knowledgeable about BCAs but have not received any formal training. The institute has a short-term capacity building plan in place, which requires financial support to become operational. The plan will result in training of just under 1000 research scientists and extension agents over a five-year period. It is envisaged that the capacity building scheme will consist of formal academic training and process-oriented research training. This type of

scheme will result not only in knowledge production and scientific rigour but also ensure that the training results in societal relevance and value (Velho, 2006). The capacity building plan will be complimented by continuous improvement of the culture strain via natural enemy surveys, laboratory bioassays and integrated pest management trials. These factors combined, provide a clear value proposition for BARI and its regional centres to lead in the production of the BCA nucleus culture, improve and maintain the strain by constant evaluation for use at the community level.

Key informants from both BARI Headquarters and the five regional research centres, in maize growing areas, are optimistic of the use of BCAs for the management of FAW and see it as an integral component of integrated pest management (Table 1). This however will only be possible, with the right training (for farmers, extension agents and research scientists) and financial support for the research centres to produce, improve and maintain BCA nucleus culture.

Table 1 Capacity assessment for BCAs—regional research stations

	Regional research centres				
	Bogura	Jashore	Rangpur	Jamalpur	Rajshahi
Farmer practices and knowledge					
# of maize growing farm households in region	250	140	120	5000	40
Current level of farmer knowledge on BCAs	Poor	Very Poor	Poor	Medium	NA
Farmers acceptability of BCAs	Acceptable	Not acceptable	Acceptable	Only acceptable if low cost	Acceptable
Existence of FPOs to take up production of BCAs as income source	Available	Available	Available	Possible with technical support	Not available
Staffing & resources					
Total # of scientists working in division	2	2	2	1	3
# of staff with formal training on BCAs	1	1	1	1	1
Current infrastructure	Lab building—2,500 sq ft and mass rearing chamber	Lab building—3,000 sq ft	Lab building -2000 sq ft and Mass rearing chamber	Lab building is to be set up	NA
Type of linkages with extension staff	<ul style="list-style-type: none"> • Trainings and field days • Demonstrations on farmer fields and mass gathering of farmers • Personal contacts between extension staff and research scientists • Contact via district and local level department of agricultural extension office 				
Mechanisms to provide training to farmers/ self-help groups/ farmer association in regional stations	<ul style="list-style-type: none"> • Classroom training combined with demonstrations on fields • Classroom training with laboratory bioassay and field demonstrations • Group wise training schedule • Individuals and farmer association representatives to attend trainings 				
Kind of support needed to maintain host culture & provide nucleus culture of BCAs on consistent basis	<ul style="list-style-type: none"> • Training and capacity building for staff • Infrastructure development support (i.e. to establish laboratory facilities) • Funding for consumables • Financial and technical support in all areas of BCAs production and management 				

All regional centres also agreed that farmer trainings should be carried out in collaboration with the local extension agents, as is the current practice. This will require dedicated financing and capacity building of extension agents to enable them to support farmers in day-to-day use of BCAs within farm settings. Funds are also needed to establish a troubleshooting ‘help-desk’ to help farmers and farm entrepreneurs with any challenges with BCA usage and production, respectively. These troubleshooting ‘help-desks’ would resolve local BCA production challenges as needed.

Agro-dealers

Agro-dealers provide various inputs for the management of FAW and they can provide complementary BCA products for farmers, FPOs and farm entrepreneurs. In Bangladesh there are about 300 agro-dealers who have been trained in basic agronomics as well as safe use and handling of pesticides. Key informant interviews with agro-dealers in the maize growing areas of Bogura, Jashore, Rangpur, Jamalpur and Rajshahi indicate that their BCA stocking behaviour is affected mainly by a perception that there is no farmer demand for BCAs and/or complementary products (Fig. 4a). This lack of demand, agro-dealers believe, is due to lack of farmer awareness of the market availability of BCAs and lack of knowledge about BCAs in general (Fig. 4b).

Currently, all agro-dealers interviewed stated that they stock various chemical products for the management of FAW, with a third of sampled agro-dealers stocking five different types of chemical products. On the other hand, BCAs for FAW management are stocked by only half of the interviewed agro-dealers, with each stockist having only two different types of BCA products. This is attributed to the limited number of BCA products for FAW

management available in the country as well as inconsistent supply from the input industry.

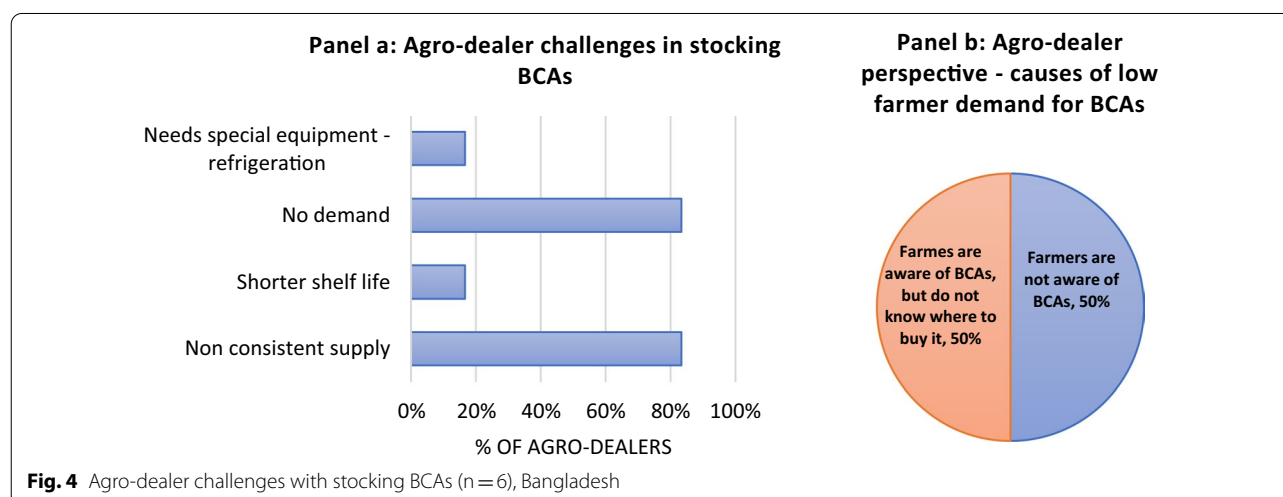
The challenges hindering agro-dealer stockage of BCAs and complementary products need to be overcome in order to enable agro-dealers to become effective supply chain actors that complement local BCA production hubs. This would require consultation and engagement with the agri-input industry in the country to collaboratively develop strategies for overcoming the mis-match between BCA demand and supply by agro-dealers and the industry, respectively. Second, there is need to create awareness of farmers’ demand for BCAs amongst agro-dealers, as a means to incentivise them to consistently stock BCAs and/or their complementary products.

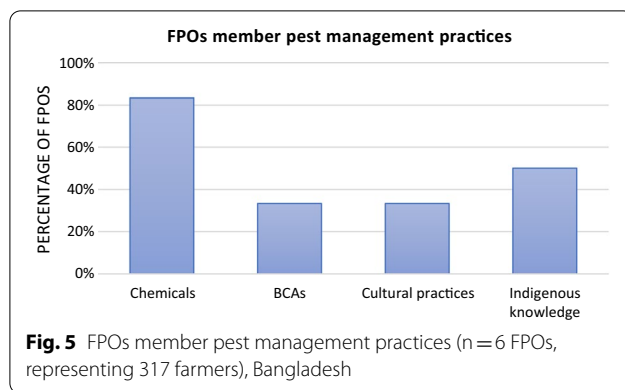
Farmer producer organisations (FPOs)

Bangladesh has well organised and long standing FPOs, trained in integrated pest management that includes biological control. In the proposed business model, the farm entrepreneurs or women’s groups that will operate local BCA production hubs must be affiliated to a functional FPO, thus ensuring a steady flow of customers. Non-FPO farmers in the area will also be able to purchase BCAs from the local production hub.

Key informant interviews with six FPOs in the maize growing areas of Bogura, Jashore, Manikgonj, Rangpur, Jamalpur and Rajshahi (see Additional file 1: Annex S3b for more details) show that currently their members have different pest management practices with BCAs ranking amongst the least used methods (Fig. 5). This is the case despite that most of the interviewed FPOs state that half of all their members are aware of BCAs (Fig. 6a).

Awareness translates into usage, with over 60% of those that know about BCAs using them for plant protection (Fig. 6b). This agrees with numerous other studies





which show that awareness raising is positively correlated with agricultural technology use (Gebreziher et al., 2020; Mkenda et al., 2020; Wyckhuys et al., 2018; Simtowe et al., 2016; Randhawa et al., 2015; Lambrecht et al., 2014). Therefore it is key that local extension services in collaboration with BARI work to further raise awareness on BCAs for FAW management for all members of FPOs. Key informants stated that currently agro-dealers are the main source of BCAs for farmers with most farmers purchasing BCAs when they have a FAW infestation in their field.

Key informants further stated that FPOs believe that the lack of BCAs in the local market is the greatest challenge to its uptake amongst their members. Other factors hindering farmer uptake include limited knowledge about BCAs, lack of a subsidies for BCAs, and the belief by farmers that BCAs are not as effective as chemicals in the management of FAW.

Despite low farmer uptake and poor market availability, most FPO key informants indicate that their members

believe that BCAs can be cost effective, are open to receive training and are willing to spend some of their money on BCAs (Table 2).

To better understand the farmers willingness-to-pay for BCAs we employed a stated preference approach. We used the FPO key informants as expert judges who provided responses to the survey on behalf of their members. The use of expert judgements is common in estimating clients' willingness-to-pay for a product and is a useful tool for providing rough estimates of expected demand for a product (Breidert et al., 2006; Hanna and Dodge, 1995). We employed the monadic test approach (Breidert et al., 2006) in which price preference information is elicited from representatives of the FPOs without considering a competitive context (i.e., in which there are no options of various vendors of the same or similar BCAs with differing prices on the market). The lack of a competitive pricing context was overcome by ensuring that the representatives from the FPOs are those in leadership and thus are aware of the competitive structure of the market for BCAs in their area and are fully knowledgeable of the trends in farmer demand for BCAs.

The majority of FPO key informants (67%) indicated that their members are willing-to-pay for BCAs for FAW management, while the remaining 33% were unable to indicate if their members would be willing-to-pay for BCAs. We consider the latter as unwilling to pay and hence are excluded from the analysis going forward. Figure 7 shows that BCAs priced below BDT 500/hectare (USD 6/hectare) would be considered of poor quality, thus not purchased by farmers. BCAs priced above BDT 10,000/hectare (USD 118/hectare) are too expensive and FPO members would be unwilling to pay this price. This

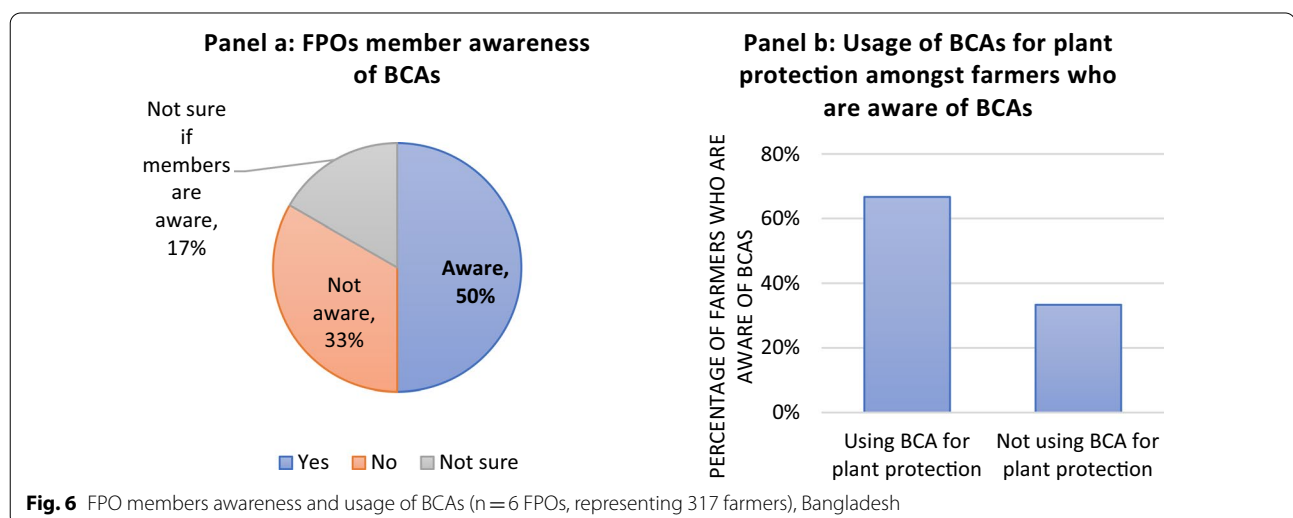
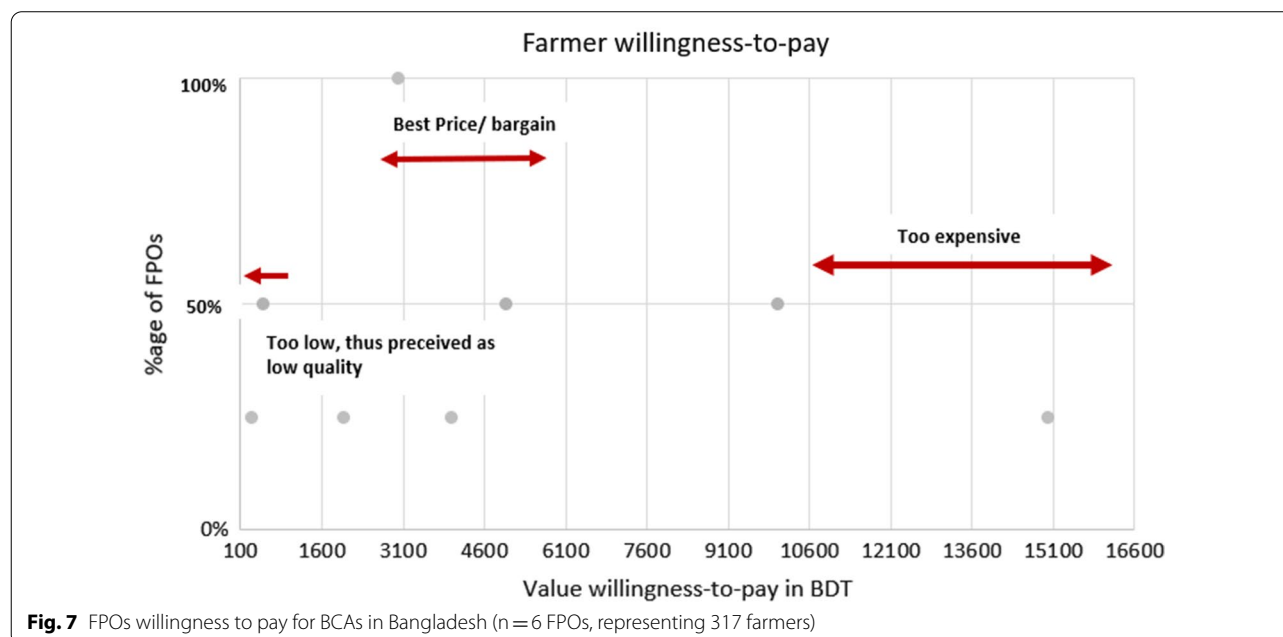


Table 2 FPOs perceptions of BCAs

FPOs	Farmers believe BCAs are cost effective	Farmers received BCAs training	Farmers have received guidance BCA usage	Farmers interested in being trained in BCA	Farmers willing to pay for BCAs	FPOs ready to support use of BCA amongst farmers	Availability of self-help groups to engage in BCA enterprise
Germplasm centre farmer group, Bogura	•	•	•	•	•	•	•
krishi projukti bastobayan kendra, Jashore	•			•	•	•	•
Vegetable crops farmer group, maniganj	•			•			•
East Nobonidas vegetable crops farmer group, Rangpur	•	•	•	•	•	•	•
SB IPM club, Jamalpur	•		•	•	•	•	•
Bijoy nagor CIG purush fasal dal, Rajshahi		•		•	•	•	•



implies that pricing BCAs either too low or too high disincentivizes farmers from purchase them.

Figure 7 further shows the best price range for farmers is between BDT 2,000/hectare (USD 24/hectare) and BDT 5,000/hectare (USD 60/hectare). This is the price range within which most FPO members would be

willing to purchase BCAs for FAW management with the best price being BDT 3,000/hectare (USD 35/hectare). Further research is needed to understand at what point the cost of producing BCAs matches farmers' willingness-to-pay, thus providing better dynamics of the supply side and the demand side linkages.

Table 3 Financing for setting up BCAs production units

	Capital costs (USD)*	Annual costs (USD)#
BARI—HQ (Gazipur)	236,186	21,779
BARI—regional centres	236,186	88,738
FPOs	35,078	18,861
Total	507,450	129,378

* Capital costs include lab buildings, mass rearing chambers and rearing units

Annual costs include BCA rearing consumables, strain improvement work, IPM trials and training costs

Financing

Globally the financing of activities for FAW management has been a mix of national budgets, with funding from United Nation agencies, development partners, development banks and the private sector. Sustainability will however only be achieved with economically effective business models. Rough estimates of the financing needed by BARI, regional centres and the FPOs to initially set up appropriate infrastructure for mass rearing of 250 million *Trichogramma* sp. is approximated at just over USD 500,000 (capital costs) (Table 3). *Trichogramma* sp has been chosen as it is considered one of the BCAs for the management of FAW, with evidence from Latin America and Africa (Ballal et al., 2021; Figueiredo et al., 2015). The funding would finance permanent infrastructure in the form of laboratory space to enable sufficient production of *Trichogramma* sp. to cover between 1,200 to 1,500 hectares of farmland per year. In addition, the finances would cover the costs for investment in culture mass rearing chambers, chemicals for diet and other non-consumables (i.e., plastic tubs and wire mesh). This will lead to consistency in production batches and help scientists to develop a standardised protocol for further relay. Further consultation with government and donors is required to determine sources of development financing for BARI to set up a sustainable plan for the production of nucleus culture for BCAs. Scaling up FAW management to other regions, will incur additional costs.

Conservative estimates for operationalising BARI's training plan, implementing the support for local BCA production, dissemination to farmers and enabling FPOs in all aspects are approximated at just under USD130, 000 annually. This includes natural enemy surveys which are continuously required to collect more potential strains and to help restore vigour by their integration in the cultures reared under laboratory conditions. Funds will also be utilized in screening field specimen and to validate bioassay results via integrated pest management field trials.

For the farm entrepreneurs or women groups, space is required to set up a dedicated production facility. For this to work, all the equipment utilised for production and consumables for diet and mass rearing needs to be low-cost. Annual recurring costs should be included in the final product price, while non-recurring costs may have to be funded from elsewhere. Other costs such as depreciation costs, costs of consumables, wages of rearing workers and 'salary' for the farm entrepreneurs will also need to be factored into the final product price. At this juncture, these are difficult to estimate, but they must be estimated upon initiation of the intervention. Once the product price is developed, it will need to be compared to farmers' willingness-to-pay, to see whether the business model is viable, or at what scale it becomes viable.

Conclusions

This study proposes the establishment of local BCA production hubs via a business model that links researchers, extensionists, agro-dealers and FPOs in a non-linear pathway with production of nucleus culture at the regional research center level. For this to succeed, capacity building must be provided at all levels to maintain, produce and utilise a viable strain of the parasitoid that will be effective in the field. In this process, different stakeholders should be mentored to better deliver on their role, with the mentoring leveraged via engagement of research institutions and demonstration of technology use and guidance through the current agricultural extension system and existing agro-dealer networks. Furthermore any efforts to build capacity for BCA production amongst research scientists, must ensure the inclusion of field-based extension staff. This will ensure continued day-to-day support for farmer producer organisations and farm entrepreneurs. This should go hand-in-hand with strengthening the linkages between the national research institute and the public agricultural extension arm at each level to ensure collaboration in engagement of farmers and local agro-dealer networks.

To fully operationalise this business model, there is need for long term financial and technical support for the Bangladesh Agricultural Research Institute (BARI), extension services as well as farmer producer organisations. Further research is however needed to understand and quantify the timelines when the proposed business model would become self-sustaining and the type of support that would be needed for relevant stakeholders during this time. This research should include understanding the type of policy actions required for incentivizing the growth of local BCA production hubs that are patterned around this business model. In addition, there is need for consultation with the input industry in the country to better understand

the supply side bottlenecks and to collaboratively develop strategies for overcoming the current mis-match between agro-dealer demand for and the input industry supply of BCAs and their complementary products.

The business model is proposed for Bangladesh for the management of FAW based on stakeholder mapping and key informant interviews. Further work is still needed to understand the full supply side and demand side constraints and costs to determine the viability of local BCA production hubs at the community level, while leveraging the support of research and agro-dealer networks. In future, such assessments should include a Gender Equality and Social Inclusion analysis, to capture gendered differences in terms of farmer perceptions, usage and knowledge of BCAs as well as farmer-willingness-to-pay. This will contribute towards understanding how best women's groups within FPOs can be supported to effectively operate local BCA production hubs.

Abbreviations

BCA: Biological control agent; FAW: Fall armyworm; IPM: Integrated pest management.

Supplementary Information

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Additional file 1: Annex S1. Data collected from Agricultural Research Institute (BARI) regional research stations. **Annex S2.** Baseline data – BARI research station – headquarters. **Annex S3. a** Baseline data for FPOs included in study. **b** Summary statistics of FPOs included in study.

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Author contributions

MC and ND designed the research with contributions from MK; MC and ND implemented the research and lead in the data collection; MK and MC analysed data; MK and MC jointly led the writing with contributions from FW. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and analysed during the current study are available from the authors upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Consent for publication of this article was received from the Bangladesh Agricultural Research Institute (BARI).

Competing interests

The Authors declare no conflict of interests.

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