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Lessons Learned and Challenges of Biopesticide Usage for Locust Management—The Case of China

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Abstract: Using qualitative methods, this study assessed the stakeholders and management processes involved in locust outbreaks in China, including factors influencing the use of biopesticides. Study findings show that China has an integrated national locust response protocol, which involves various institutions from all administrative levels of the government. The process is inherently highly complex but efficient, with multisectoral agencies working closely together to prevent and/or manage locust outbreaks. In addition, the process has been successful in combating recent outbreaks, due to dedicated government funding, decisive administrative and technical actions, and the empowerment of local government administration. This is the case with the county level acting as a 'first-responder' that is capacitated financially and technically to respond to a locust invasion in their jurisdiction. Additionally, study findings show that despite the availability of biopesticides in local markets, their use is dampened by inadequate information about market availability, negative perceptions by decision makers about their efficacy, and concerns about their costs, as well as limited knowledge of their application techniques. Actions are therefore needed by relevant authorities to enhance stakeholder awareness of biopesticide market availability, efficacy, and field application processes. Future areas of research should focus on modelling the expected impact and cost effectiveness of chemicals vs. biopesticides, thus increasing the evidence base for promoting biopesticide use.

Keywords: biopesticides; qualitative methods; Yunnan Province; efficacy; locusts

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1. Introduction

Locusts are migratory pests that have caused significant financial loss and ecological damage in many parts of the world [1]. In China, locust outbreaks have a 3000-year history, and along with floods and droughts, they are considered one of the three biggest natural disasters for the country [2–4]. Due to the recurrence of devastating locust outbreaks, the government has historically mandated treatment programmes. Under the Tang Dynasty in the eighth century, full-time locust control officers were appointed [5]. During the eleventh and fifteenth centuries, local rulers executed locust control measures, which included paying workers to catch and bury locusts. Since the 1960s, locust populations in China have been well-controlled; however, since the 1990s, locust outbreaks have become increasingly commonplace largely due to the escalation of droughts and warm winters.

The Chinese government has committed significant resources to the deployment of new pest management strategies to combat pest outbreaks [5]. Preventive management via monitoring of locust breeding grounds and use of biopesticides in the case of an outbreak are garnering increasing attention from the government [6]. As a result of improved knowledge of pest biology and ecology, coupled with more efficient monitoring and control procedures, more effective preventive management plans have been established. Successes in preventing most locust outbreaks and in controlling infestations have been attributed to emerging technology that includes spraying using drones, use of digital tools that enable practitioners to quickly gather, share, analyse, and manage data (i.e., GPS tracking, GIS mapping, satellite data imagery, and tracking applications) and the use of green technologies [7–9]. Similar successes of locust management using green technologies have also been documented in Africa [10,11]. Despite these successes, chemical pesticides are the primary control method used in many countries for the management of locust outbreaks [12–15]. Such excessive use of pesticides can cause devastating effects on the environment, human health, and nontarget species [16–22]. These concerns have reignited global interest in biological control methods.

Uptake of biopesticides remains low due to various factors, including inconsistent field results, shorter product shelf life, high costs, and effectiveness on a smaller range of pests as compared to chemical products [23–25]. Despite this, there is increasing evidence of the benefits of biopesticides for pest management in general, including for locusts [11,25–33]. China has been at the forefront in the production and use of biopesticides [34], including their use in the country's locust management and response process. Understanding how such processes are set up and operated is key for replication in other countries, such as those in Africa, where devastating locust plagues have recently been experienced [35,36]. This study contributes to this goal by analysing the locust outbreak management process currently engaged in China and the key factors influencing stakeholder willingness/unwillingness to use biopesticides in the control of locusts. Study findings will aid governments as well as private and public pest managers to implement more effective management strategies for responding to and managing locust outbreaks while concurrently promoting integrated pest management through the use of biopesticides.

2. Materials and Methods

2.1. Selection of Sampled Institutions

A three-stage purposive sampling approach was used to select key Chinese institutions involved in and mandated with: locust and grasshopper response, management, and extension services. In the first stage, nine provinces of China that had a recent locust outbreak were selected, namely: Beijing, Tianjin, Hebei, Shandong, Hunan, Yunnan, Sichuan, Hainan, and Inner Mongolia. In the second stage, we purposively selected all institutions that are mandated with, or have been known to engage in, locust outbreak response and management. Within these institutions, purposive sampling was again used at the third stage to select key informants working on locust outbreak response and management. Interviews were carried out between November 2021 and January 2022, with data collected either virtually or in person as per the availability of the respondents and depending on the COVID-19 pandemic restrictions. A total of twenty institutions responded to the survey from four different administrative levels: national, provincial, municipal, and county, representing 5% (one institution), 20% (four institutions), 30% (six institutions), and 45% (nine institutions) of the respondents in the sample, respectively.

2.2. Types of Data Collected and Analytical Approach

A structured questionnaire was used to collect data from survey respondents, including information on: the stakeholders involved, their roles, and steps taken in locust outbreak response and management at various levels; use of biopesticides and chemical pesticides; and ideas for improving the current locust outbreak response and management strategy. A mixed methods approach was used to analyse the data; the method included descriptive statistics and process mapping. Descriptive statistics included percentages and frequencies, which were used to understand various aspects of stakeholder engagement in locust management and outbreak response.

Process mapping was used to visualize the processes involved in the event of a locust outbreak, using Yunnan Province as a case study. Current state process mapping is a tool that helps in visualizing the as-is status of a process, analysing strengths and weaknesses, and can be used in developing plans for desirable future states and/or viable solutions to identified problems [37,38]. Process mapping allows organizations to better understand how knowledge is generated, where it resides, how it is used, and who its users are [39,40]. Yunnan Province was selected for two reasons. Firstly, it was one of the worst-affected areas in the 2020 locust invasion [41]. Secondly, efforts to control the locusts during this invasion were relatively successful [41], and thus understanding the processes could inform future management of the pest, for China as well as for other countries. Based on the process mapping exercise, we draw and present lessons of the factors involved in successful locust control in cases of outbreaks.

3. Results

Key respondents had on average 16 years of experience in dealing with seasonal locust outbreaks in the country. Respondents stated that China has been plagued by different locust species, specifically *Ceracris kiangsu*, *Locusta migratoria manilensis*, *L. m. tibetensis*, *Oedaleus decorus asiaticus*, *Dasyhippus barbipes*, *Bryodema luctuosum*, *Pararcyptera microptera meridionalis*, *Myrmeleotettix palpalis*, *Angaracris barabensis*, and *A. rhodopa*. However, according to the survey, among these, *L. m. manilensis*, *C. kiangsu*, *O. d. asiaticus*, and *D. barbipes* represented 32%, 26%, 11%, and 11% of all the locusts, respectively, with *L. m. manilensis* as the most active and thus most problematic nationally. However, recent outbreaks have been of *C. kiangsu*.

3.1. Stakeholder Roles and Responsibilities in Locust Response

The majority of key informants (85%) had personally participated in locust outbreak prevention and control, with all key informants from the national and municipal levels personally having participated in locust plague control. Figure 1 shows various key identified actions and activities that are carried out in the event of a locust emergency/outbreak vs. the percentage of sampled institutions that engage in that activity. The national level institute engages in various identified actions, but it does not engage in the provision of spraying services, in early warning and preparedness activities, or in mobilizing local communities to set up and establish local surveillance systems, nor does it carry out livelihood protection and restoration activities directly (Figure 1). These functions are the remit mainly of institutions at the county level and/or the municipal level, and to some extent institutions at the provincial level. Thus, of all sampled county and municipal level institutions: 78% and 67%, respectively, provide spraying services; 89% and 100%, respectively, implement early warning and preparedness activities; and 78% and 50%, respectively, engage in mobilizing communities and in establishing local locust surveillance systems. Livelihood restoration is carried out only by institutions at the county level, with 89% of all sampled county level institutions in this study reporting that they engage in livelihood protection and restoration for populations that have been affected by a locust outbreak.

Figure 1 further shows that institutions at the county level carry out all the identified key functions related to locust management and control in China. At the same time, some activities are carried out by all institutions across all administrative levels. These are mainly service functions (i.e., monitoring swarm activity, reporting on locust spread, communication and digital data services, project management, and coordination of the national locust strategy), financing, and capacity building. Service functions escalate upwards. For example, a municipal-level institute aggregates data and/or consolidates reports from several counties on locust spread—both of which are passed on and aggregated at the provincial level, and which then feed into the management and coordination of the national locust strategy. Capacity building functions are ongoing activities that take place continuously as part of building up a cadre of institutions and personnel that are able to respond in the face of an outbreak. Capacity building activities, as well as project management and coordination functions, are varied, but include training of staff on response actions, action planning for an outbreak, and developing guidelines on the use of synthetic chemicals and/or biopesticides, among other issues.

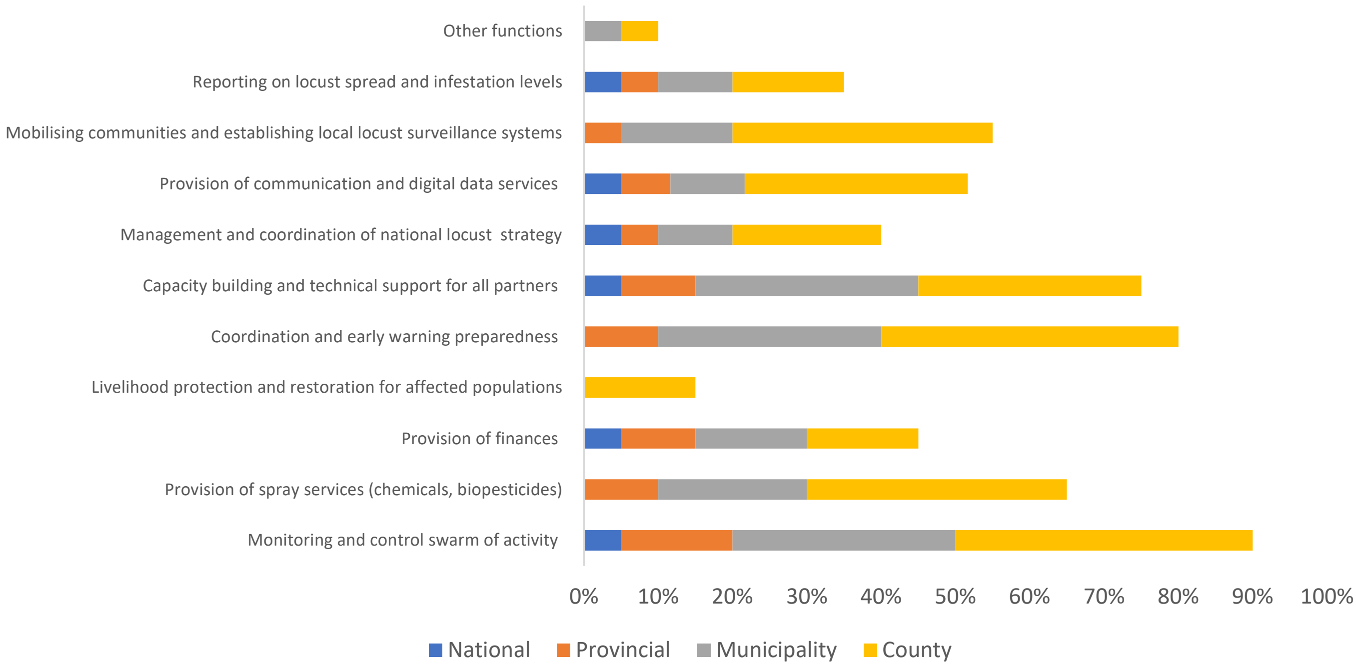

Figure 1. Roles of different administrative level institutions in response to and management of locust outbreaks.

3.2. Use of Biopesticides in Locust Response

All survey respondents were involved in the response and management of locusts where biopesticides were used. All surveyed stakeholders consider these products very effective for locust control. The government provides the approval for the chemical pesticides and/or biopesticides that are used for locust control; however, the procedure for deciding which products to use during an outbreak is different for locusts and grasshoppers. For locusts, the Agricultural Plant Protection Institution determines the type and quantity of the chemical pesticides or biopesticides needed. The central government then allocates funding according to the plan, i.e., before an outbreak occurs. For grasshoppers, however, the procurement needs are decided by the Agricultural Plant Protection Institution and the Forestry institutions. As with locusts, funds are then allocated by the central government in advance, i.e., prior to an outbreak, according to the plan.

A different process again was used for the severe *C. kiangsu* (Orthoptera: Arcypteridae—yellow-spined bamboo locust (YSBL)) invasion which affected the country in 2020. An expert group was appointed by the Office of Locust Plague Control Headquarters. This expert group, led and facilitated by the Ministry of Agriculture and Rural Affairs, was mandated to make recommendations on the types and quantity of chemical pesticides or biopesticides to use. The final choice of product was then made by the County Agriculture and/or Forest Protection Stations in accordance with the list of nonrestricted pesticides published by the Ministry of Agriculture and Rural Affairs based on the expert group recommendations.

Survey respondents stated that currently in China, there are a wide variety of biopesticides available on the market for the control of locusts. Despite this, respondents stated that there are cases in which biopesticides were not selected to manage locust outbreaks. Four main factors contribute to this—perceptions that biopesticides are costly, concerns over their level of effectiveness, perception that biopesticides are not available in markets, and belief that field application of biopesticides is difficult (Figure 2).

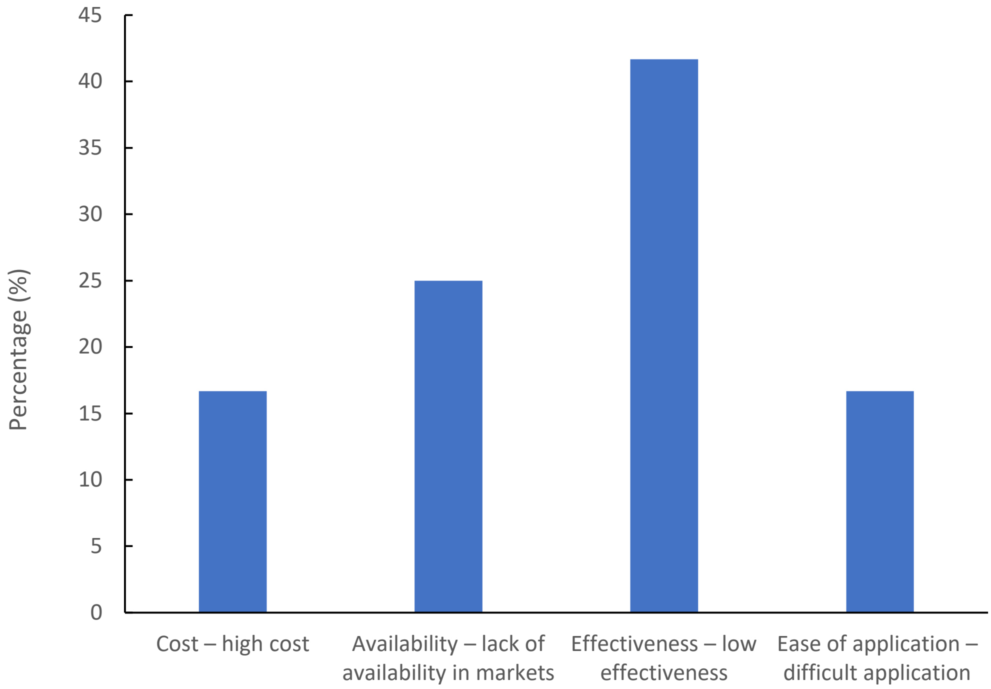

Figure 2. Factors hindering the use of biopesticides for locust response/management.

Yunnan Province YSBL Response Process

Between June and September 2020, YSBL migrated in large swarms to several border counties of Yunnan Province, China from neighbouring countries. Although not historically the most problematic locust species, in the 2020 outbreak approximately 8900 hectares of land were affected in the three worst-hit areas: Pu'er, Xishuangbanna, and Honghe. By the end of July 2020, the total control area was estimated to be around 360 km^2. Process mapping was carried out for Yunnan Province to better understand the 2020 locust management process. Table 1 presents the main outcomes of the process mapping. The province acted on two fronts—an administrative and a technical one—with administrative structures being formed to support implementation of technical actions.

Table 1. Yunnan Province 2020 yellow-spined bamboo locust control actions.

Administrative System Structures Established	Related Technical Actions Carried Out
Formation of authoritative agency: *Formed the YSBL Emergency Prevention and Control Program*	**Empower lead agency for action**: *Ministry and Province invested 14.27 million with Chinese RMB currency into emergency prevention and control of YSBL*
Establishment of multi-sectoral leadership: *Coleadership by the Provincial Forestry and Grass Bureau, Agriculture and Rural Affairs, and the Yun-nan Provincial Foreign Affairs Office*	**Decisive technical actions**: (*i) Established 25 locust monitoring sites including entomological radar and detection light trap; (ii) put in place 38 emergency control teams; (iii) sufficient locust control measures made available to cover 28,000 km^2 of farmland*
Inclusion of competent technical expertise, from all levels: *Relevant stakeholders in Forestry and Agricultural sector—national, provincial, municipal, and county levels*	**Public awareness**: *Outreach activities carried out for local farmers and extension officers in affected and neighbouring provinces focusing on prevention*

4. Discussion

4.1. Stakeholder Roles and Responsibilities

The surveyed institutions play various roles, some overlapping, some unique, with six key roles common to all surveyed institutions, regardless of administrative level: (i) monitoring and controlling swarm activity; (ii) financing; (iii) capacity building and technical support for government and other national partners; (iv) project management to guide and coordinate the national locust management strategy; (v) provision of communication and digital data services; and (vi) reporting on locust spread in invaded and locust-prone areas. From all but two of the six common roles, it is evident that all sampled institutions are engaged in the country's locust prevention management strategy. Despite different institutions having similar roles, the way that different institutions and different administrative levels within an institution carried out these roles differed. This ensures that there is no duplication of roles and that efforts are complementary. In many instances' higher levels aggregate data and information as they flow in from lower administrative levels and also provide technical support as needed. For example, monitoring involves a wide range of activities, including systematic monitoring via manual surveys in locust prone areas, remote sensing, and/or unmanned aerial vehicle (UAV) reconnaissance with ground fixed spot monitoring. In this case the county level may, for example, take the lead in the manual surveys, while longer-term ground-fixed spot monitoring may be led by experts at the provincial level. This type of institutional coordination, resourcing, and division of roles has also been found to contribute to successful locust management in Nepal [42].

The county level is multifunctional, with activities taking place at that level for all identified roles. This includes being a 'first-responder' once an invasion has been reported by conducting ground surveys to verify the extent of invasion, monitoring breeding grounds, and determining resources needed for prevention and response. In addition, county-level personnel also lead in mobilizing communities to establish local locust surveillance systems and helping end users with information on how to use biopesticides (e.g., dosage and the application methods). In essence, county institutions respond to a locust invasion in their jurisdiction, and all these services are essential and must be given consideration for strengthening, as they have the potential to improve scientific and strategic management of the pest and to facilitate an effective, rapid response. The county level administration also has the capacity to allocate finances for combating locust outbreaks, although the central government remains the main source of funds. They also report all invasions to the municipality and onwards to the province administration for further support and preparedness. Insights from South Africa [12,43], show similar patterns, with empowerment of local institutions being key for the successful control and management of locust invasions. Empowerment of local entities facilitates ground truthing, which can facilitate the availability of up-to-date information and improved knowledge about the ecology of the pest, as well as timely and consistent monitoring and evaluation, all of which have been shown to be important for the preventative management of locusts [44].

The national-level institute is fully engaged in project management activities to guide and coordinate the national locust management strategy, as well as in providing communication and digital data services, reporting on locust spread in invaded and locust-prone areas, and providing finances. These are strategic, high-level functions that ensure that all other stakeholders are efficiently coordinated, well informed, and capacitated to carry out their own core functions, and that they have sufficient resources. The national level institute in China is not involved in early warning and preparedness activities. This might be worth considering going forward, as evidence from South Africa shows that national government involvement in early warning and preparedness actions and activities has been instrumental in the prevention of brown locust plagues in South Africa [43].

4.2. Use of Biopesticides in Locust Response

Decision-makers working in institutions that are mandated to control and manage locusts are aware that the country has biopesticides available in the local market. Despite their availability, biopesticides are not always selected and used for the control and management of locust outbreaks. This is because decision makers are often concerned with ensuring that a management plan is highly effective with high mortality of the pest during an outbreak, and that there is continued high mortality after the treatment phase. Thus, chemical pesticides are almost always selected in an emergency due to their fast action. However, evidence exists that shows that combinations of different biopesticides result in high mortality of locusts [9,11,45]. Furthermore, although chemical pesticides provide high initial mortality, biopesticides tend to increase their effects slowly over time and then continue working long after the initial spraying [46]. Stakeholders cited the high cost of biopesticides, as well as difficult application processes, as further hindering biopesticide use. Although costs of biopesticides are generally higher than for chemical pesticides, increased local production has resulted in their price reductions as compared to the past. This is particularly true in China [47]. Lack of market availability of pesticides was also cited, despite there being widespread distribution of the products [47].

To increase the use of biopesticides for locust control, there is therefore the need to provide more information on the efficacy and market availability of biopesticides to decision makers in key mandated institutions. Information on efficacy should include evidence-based local exemplars and case studies, and where possible, this should include comparisons with the long-term outcomes of using biopesticides vs. chemical pesticides on locust populations. Since pest outbreaks necessitate quick and decisive actions for success, information packages should be made available to decision-makers on an ongoing basis, not just when there is an outbreak. In addition, there is the need to ensure that extension services and all other personnel, including farmers, involved in pest control and management are trained in biopesticide application techniques. This is because evidence shows that training and demonstrations can help with the selection of pesticide alternatives, including biopesticides [48,49].

4.3. Lessons from the Yunnan Province YSBL Response Process

In Yunnan Province, the success of the YSBL control centered around swift and decisive multifaceted administrative and technical actions, as well as multiagency engagement. For example, in the same month as the first wave of invasions, the national government formed and mandated the YSBL Emergency Prevention and Control Program to take immediate actions to curb the locust plague. This program was jointly led by the Provincial Forestry and Grass Bureau and Agriculture and Rural Affairs and the Yunnan Provincial Foreign Affairs Office. Membership of the YSBL Emergency and Control Program consisted of key relevant stakeholders in the forestry and agricultural sectors from the national, provincial, municipal, and county levels. These administrative structures were then financed by the national government to take decisive action. These actions included mobilizing personnel, chemicals, and equipment to set up sites for local management. These actions were complemented by raising awareness amongst extension officers and farmers in both affected and nearby provinces. These efforts centered on prevention and control in the affected sites and activities for avoiding second takeoffs in nonaffected sites. The case of Yunnan demonstrates that locust control success was the result of government commitment, which manifested in institutional actions. This concurs with the findings of locust control studies from Africa [50]. The case of Yunnan also demonstrates the importance of flexibility in strategic decision-making and actions.

The snapshot of the locust control process from Yunnan Province is one layer of an integrated national locust response protocol, which involves various institutions from all administrative levels in the country. The process is inherently highly complex but efficient, with multisectoral agencies working closely together to prevent and/or manage an outbreak. Some actions originate and are implemented at the county level, such as site verification upon receipt of farmer reports, while other actions are multilevel, multiinstitutional activities involving different sectors. For example, the development of a management scheme for a locust outbreak in one county will involve not only the Plant Protection Stations of the Agriculture Bureau at the county, municipal, and provincial levels, but will also include the engagement of the Agricultural and Rural Administrative departments. These work together with local relevant administration departments including Transportation, Public Security, Finance, Development and Reform, Emergency Management, Publicity, and Forestry and Grassland. In addition, at the national level, the National Agriculture Technology Extension Service Center (NATESC) within the Ministry of Agriculture and Rural Affairs (MARA) and National Forestry and Grassland Administration would be engaged.

5. Conclusions

In China, stakeholders at various administrative levels, including national, provincial, municipal, and county, are engaged effectively and without duplication in locust management and response processes. The multiplicity of stakeholders at various levels works well as a result of strong interagency coordination, dedicated government funding, and the articulation of clear roles and responsibilities. In addition, there is flexibility in the approach, with government and stakeholders able to vary government processes in the event of a locust outbreak. These factors, coupled with decisive administrative and technical actions in the event of an outbreak, and most of all, empowerment of the county level, has seen China succeed in controlling recent locust outbreaks.

Furthermore, government commitment towards the promotion of biopesticides for locust control is manifested in China, with central government leading in the preparedness processes that includes action planning and setting aside funding for the procurement and supply of biopesticides. Despite this and the availability of biopesticides locally, the use of chemical pesticides is prevalent. This is due to negative perceptions about the efficacy and costs of biopesticides, lack of expertise with their field applications, and inadequate information about their market availabilities. Actions are therefore needed by the relevant authorities to enhance decision-maker awareness of the market availabilities and field applications of biopesticides for locust control. This requires the deliberate promotion of biopesticides via capacity-building of staff in decision-making positions within relevant mandated institutions at various administrative levels. Most importantly, there is also need to educate decision-makers about the efficacy of biopesticides and the advantages of their use in relation to the environment, human health, and target specificity.

Future areas of research should include modelling the expected impact and cost effectiveness of chemicals vs. biopesticides, thus increasing the evidence base as a means to promote biopesticides. Research results should be disseminated widely to personnel from all relevant institutions at different public administrative levels that are engaged in locust control in the country. In addition, other research should center around metrics-based process mapping that includes analysing the time lag between strategic actions during a locust outbreak. This would facilitate a better understanding and mapping of workflows, and it would contribute to improving the efficiency of different actors across all relevant administrative structures in the event of a locust emergency.

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Informed Consent Statement: Consent to interview representatives of an institution was sought in writing (via email) from the institution. This included explaining the purpose of the study and how data would be collected, analysed and used. Once the institutional consent had been granted, informed consent from individuals representing the institutions, was sought prior to commencement of the key informant interview. The key informants were informed of the purpose of the study, how data would be collected, analysed and used. In addition, key informants were told that the interview was voluntary and they were free to stop at any time or not to respond to any question that they were uncomfortable with.

Data Availability Statement: The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation. The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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