American Journal of Agricultural and Biological Sciences

Original Research Paper

Area-Wide Control Program of Chinese Citrus Fly *Bactrocera minax* (Enderlein) in Sindhuli, Nepal

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Article history
Received: 30-09-2019
Revised: 13-01-2020
Accepted: 18-01-2020

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Abstract: Citrus plays a significant role in providing nutrition to people and generating income for the citrus farmers in Nepal. Among various biotic problems in citriculture, Chinese Citrus Fly (CCF), *Bactrocera minax* (Enderlein) (Diptera: Tephritidae) has become a major threat to the production of the tight skin citrus fruits, viz. sweet orange, lemon and lime in recent years. This invasive species originated in China and seems to have entered into north-eastern Nepal through Bhutan and Sikkim (India). The damage to sweet orange (*Citrus sinensis* (L.) Osbeck) by CCF has shown a yearly increasing pattern since 2014 in the central hilly citrus orchards in the districts of Sindhuli and Ramechhap. Sindhuli district holds the first position in terms of sweet orange acreage and its production in Nepal. Conventional pest control measures including pesticide cover spray seemed to have resulted in limited effect in controlling CCF. Thus, as a pilot program, an Area-Wide Control Program (AWCP) of this pest was conducted in 40 ha of sweet orange orchards at Golanjor Rural Municipality-4, Tinkanya in Sindhuli, Nepal to minimize the fruit damages by maggots of *B. minax*. AWCP focused on the life cycle based management strategy of this pest, targeting the female adult fly population. Formulated protein bait (Great Fruit Fly Bait) containing 25% protein hydrolysate and 0.1% Abamectin was used as spot application underside of the 0.5 to 1 m^2 leaf for 10 times at a weekly interval from May to July 2018 as per the protocol developed by Ecoman Biotech, China. The result revealed that the leaf underside spot treatment with the protein bait was highly efficient to minimize the sweet orange fruit losses from 56.7 to 10.9%. Coordination among stakeholders along with sound technical aspect and managerial function seemed essential for the successful implementation of *B. minax* AWCP.

Keywords: AWCP, *Bactrocera minax*, Citrus, Nepal, Protein Bait, Sweet Orange

Introduction

Citrus fruits are grown commercially in about 140 countries in the world (NRC, 2010). Citrus is an important fruit commodity in the mid-hill of Nepal. Mandarin (*Citrus reticulata* Blanco) holds the first position in terms of area and production followed by sweet orange (*Citrus sinensis* (L.) Osbeck) in Nepal (Amgai *et al.*, 2016). Citrus fruits are generally consumed as fresh fruit as well and extraction of juice and further processing (Adhikari and Rayamajhi, 2012). Sindhuli and Ramechhap are the two major sweet orange growing districts in Nepal. The sweet orange variety produced in Sindhuli is called JUNAR in Nepal has its own history of origin in the Ratanchura and Nakajoli villages there. Thus, the sweet orange cultivation in Sindhuli is vital for the income generation and for the name and fame of the district. The sweet orange produced in Sindhuli is popularly known all over the country as "SINDHULIKO JUNAR" means sweet orange from Sindhuli.

Nowadays, sweet orange production has several problems such as lack of irrigation facility in the orchard, unavailability of quality planting materials, poor adaptation of recommended orchard husbandry measures, incidence of insects and diseases, post-harvest losses and marketing problems, etc. Fruit flies (*Diptera*: *Tephritidae*) are devastating pests of fruit and fruit vegetables having global importance (Aluja *et al.*, 2012; Aluja and Mangan, 2008; Adhikari *et al.*, 2016). Fruit flies (*Diptera*: *Tephritidae*) are one of the most destructive and well-known pests of fruits and vegetables around the globe (USDA, 2009). Fruit loss due to the infestation of Chinese Citrus Fly (CCF), *Bactrocera minax* (Enderlein) has become a devastating issue since 2014 (Adhikari and Joshi, 2018; Adhikari *et al.*, 2018) that originated in China, seems to have entered into the north-eastern Nepal region through Bhutan and Sikkim (India) (Joshi, 2019). The reasons behind the failure of widespread success in pest control are lack of thorough understanding of pest biology, population dynamics, agroecosystem and climatic patterns (Stenseth *et al.*, 2002; Parmesan and Yohe, 2003).

The concept of Area-Wide Control Program (AWCP) involved developing and integrating biologically-based pest control technologies into a comprehensive management package that would be economically viable, environmentally sensitive and sustainable. Jessup *et al.* (2007) highlighted the achievement of AW-IPM programs that were depended on the proper monitoring of fruit flies, correct and rapid response to incursions and active participation by all growers and other stakeholders' area under the AW-IPM program. Multiagency collaboration and transfer of area-wide IPM approaches to farmers for suppression of fruit flies are also important component of the AW-IPM program (Vargas *et al*., 2007). The technologies included in the AWCP were field sanitation, protein bait sprays and/or traps, etc. Many of these technologies along with the Great fruit fly bait (Protein hydrolysate 25+0.1% Abamectin) were developed by Ecoman Biotech in China and were transferred to the citrus orchards in Sindhuli. AWCP was implemented to manage CCF in Sindhuli, Nepal with an objective of suppression of fly populations and fruit damage minimization. This paper highlights on the result obtained from the said technology backed AWCP against CCF in the Sindhuli orchards of sweet orange.

Methodology

The AWCP of *Bactrocera minax* (Enderlein) was carried out in Golanjor Rural Municipality -4, Tinkanya covering 40 ha of sweet orange orchards in 2018. This organized program was the joint efforts of Junar Superzone (Prime Minister Agriculture Modernization Project, Program Implementation Unit), Sindhuli, Karma Chemical Company Pvt. Ltd. (Kathmandu), Ecoman Biotech (China) and the sweet orange growers of Tinkanya, Sindhuli, Nepal. The technical protocol along with the protein bait (Great fruit fly bait) of AWCP was provided by Ecoman Biotech, China. The activities performed to accomplish the *B. minax* AWCP could be divided into two aspects, viz. managerial and technical (Fig. 1).

Managerial aspect included consultation with stakeholders in the district, local and national levels, clustering of selected sweet orange orchards for proper spray plan, orientation (training and education) to spray persons and orchard owners before spray program and monitoring and feedback during and after spray. An interaction program with concerned technical and managerial personnel of Junar Superzone was organized at Khaniyakharka, Sindhuli and a workshop was organized by Junar Superzone, Sindhuli at Sindhulimadi to share the managerial and technical aspects of AWCP. Moreover, a national workshop on *B. minax* AWCP was organized at Kathmandu to share and get feedback on the ongoing activities from national and international experts.

The technical aspect of this program- assessment of fruit loss due to the maggots of *B. minax* in each selected orchards, monitoring of adult emergence using nets in the ground under the sweet orange trees and using protein bait traps were accomplished accordingly. The major feature of the AWCP protocol is to attract the newly emerged adult flies in the protein bait as a lethal dinner. The protein bait solution was prepared out of Great fruit fly bait 1 part in 2 parts of water and 50 ml of this prepared solution was sprayed in an area of 0.5 to 1 m^2 underside of the leaves of one in three productive sweet orange trees. The spray was performed in all citrus orchard clusters on the same day. The spray was repeated ten times in each cluster at an interval of 7 days from May 13 to July 14, 2018, as presented in Table 1.

Table 1: Protein bait spray schedule

SN	Spray action	Spray date	Protein bait + Water = Spray solution
1	First spray	13 May 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
2	Second spray	19 May 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
3	Third spray	26 May 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
4	Fourth spray	2 June 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
5	Fifth spray	9 June 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
6	Sixth spray	16 June 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
7	Seventh spray	23 June 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
8	Eighth spray	30 June 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
9	Ninth spray	7 July 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit
10	Tenth spray	14 July 2018	Protein bait 97.34 lit + Water 194.72 lit = 194.82 lit

DOI: 10.3844/ajabssp.2020.1.7

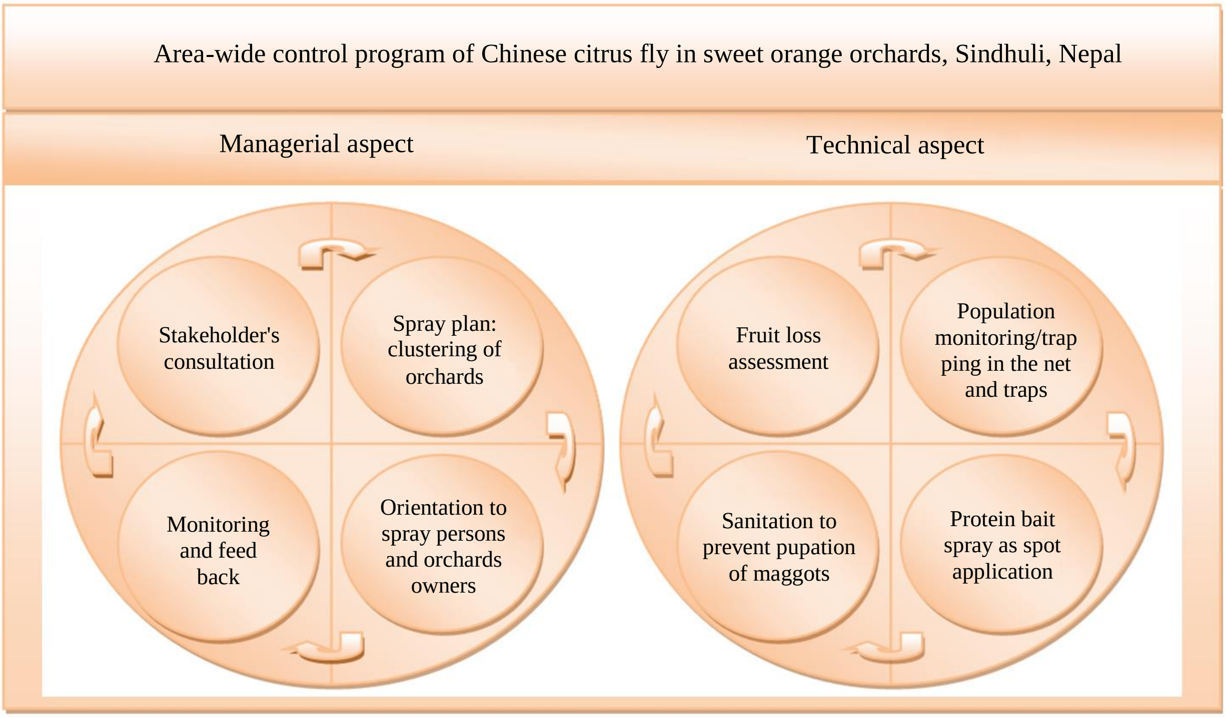

Fig. 1: Managerial and technical aspects of AWCP of CCF, *Bactrocera minax* (Enderlein) in Sindhuli, Nepal

Data on clusters of AWCP, assessment of CCF incurred fruit damages in individual orchards in 2017, AWCP-2018 and assessment of CCF incurred fruit damages in 2018 from selected orchards were collected and analyzed using MS Excel and R-Studio statistical package.

Results and Discussion

Details on Clusters of AWCP

GPS location (longitude, latitude and elevation) of each site is shown in Table 2 and Fig. 2. The total orchard owners were recorded highest, 82, in Majhkhuvinde followed by Mathlo Aalegaun (43) and Ranikhola (39). The total orchard owners involved in the AWCP were 231. The area under sweet orange cultivation, number of productive sweet orange trees is illustrated in Table 2. The largest cluster was Majhkuvinde followed by Mathlo Aalegaun and Tallo Aalegaun. Similarly, the number of spots sprayed once and the numbers of spray persons involved in the AWCP is presented in Table 2. In Australia, the pest free area of fruit fly has been achieved and maintained by clustering different areas using Area-Wide Integrated Pest Management (AW-IPM) principles. Whereas, some parts of Australia have endemic populations of pest species of fruit flies (Jessup *et al*., 2005).

Assessment of Fruit Damage Due to CCF, B. minax in 2017

The average fruit loss due to CCF, *B. minax* was reported 56.7% in the year 2017. Highest fruit damage was recorded in Ranikhola (73.25%) followed by Tamaure (71.5%), Majhkuvinde (52.6%), Mathlo Aalegaun (45.7%) and Tallo Aalegaun (40.5%), respectively.

The fruit loss due to the maggots of CCF, *B. minax* was reported increasing in trend as compared to the previous year in a tune of 17 to 30% 2014 to 2017 in the Sindhuli district (DADO Sindhuli, 2018).

AWCP and Assessment of Damaged Fruits Due to CCF, B. minax in 2018

Assessment of the effectiveness of AWCP was conducted by assessing the damage of fruits due to the *B. minax* maggots and other causes. The result revealed that the deployment of AWCP was highly efficient to minimize the *B. minax* incurred sweet orange fruit losses by 45.8% (56.7% in 2017 to 10.90% in 2018) that the difference is highly significant (Table 3 and Fig. 4). Fruit loss recovery in each cluster after AWCP in 2018 is obviously seen in the light of losses obtained in different clusters before AWCP deployment (Fig. 3).

The fruit loss is directly related to production depletion and income minimization to the growers. Moreover, other factors other than *B. minax* like water stress, nutritional disorders, bug damage, etc. also found responsible to deplete fruit yield to 6% as observed in 2018 by the growers (Fig. 5). Thus, in this context, *B. minax* solely should not be incriminated for the fruit damage in the orchards.

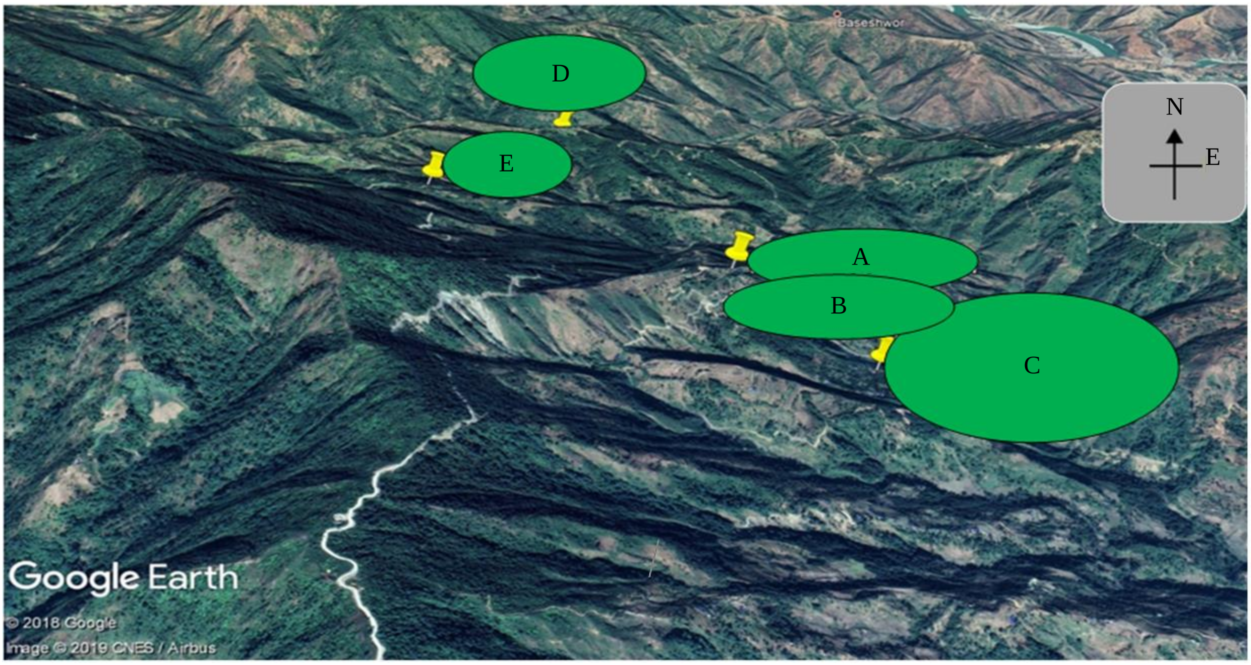

Fig. 2: Clusters of AWCP of CCF, *B. minax* at Tinkanya, Sindhuli, Nepal

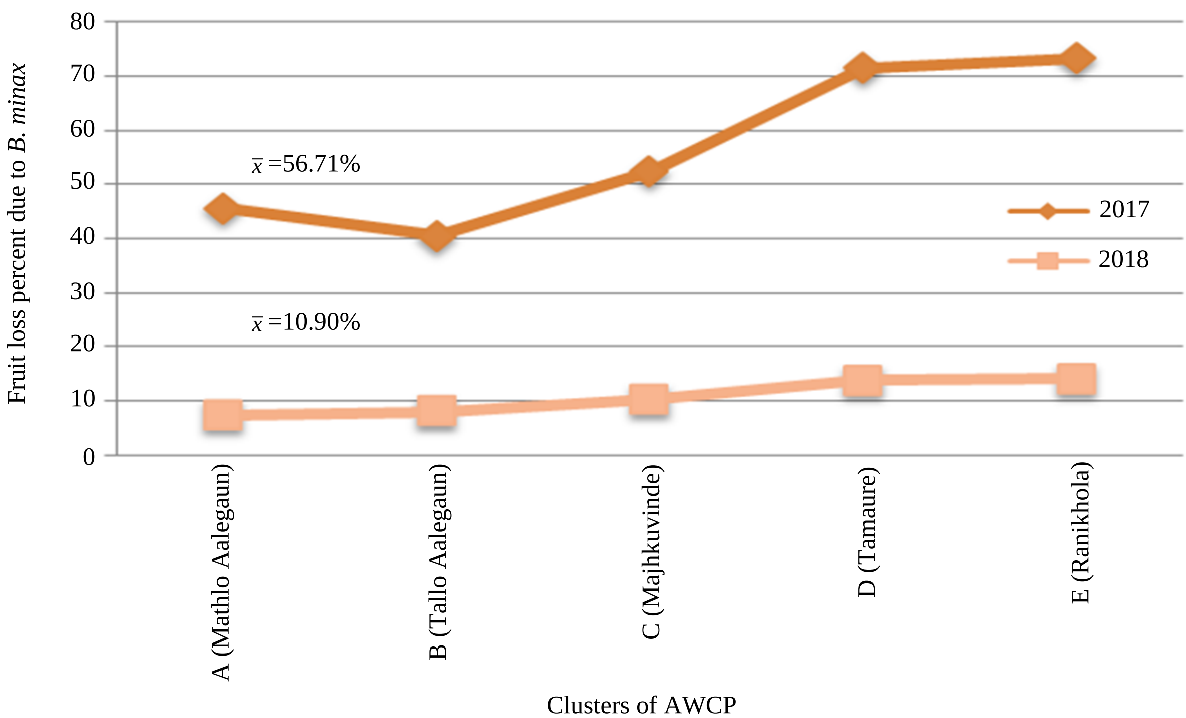

Fig. 3: Sweet orange fruit damage due to CCF, *B. minax* before and after AWCP

DOI: 10.3844/ajabssp.2020.1.7

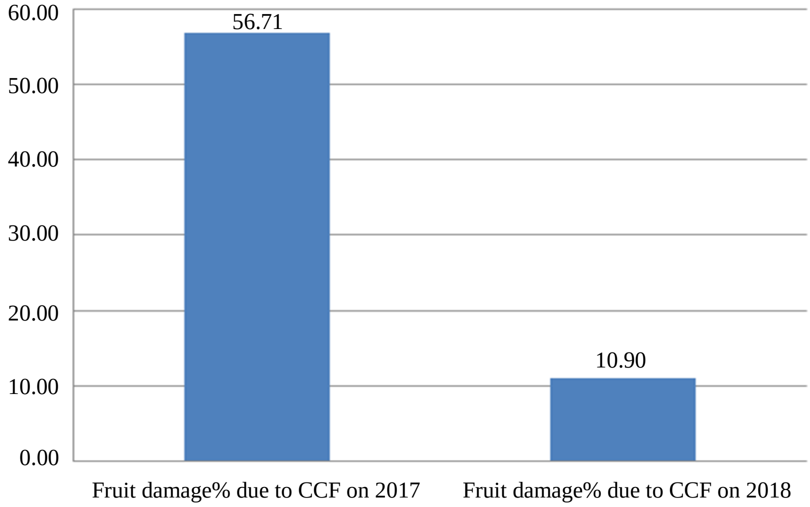

Fig. 4: Comparision of fruit damage due to *B. minax* before and after AWCP

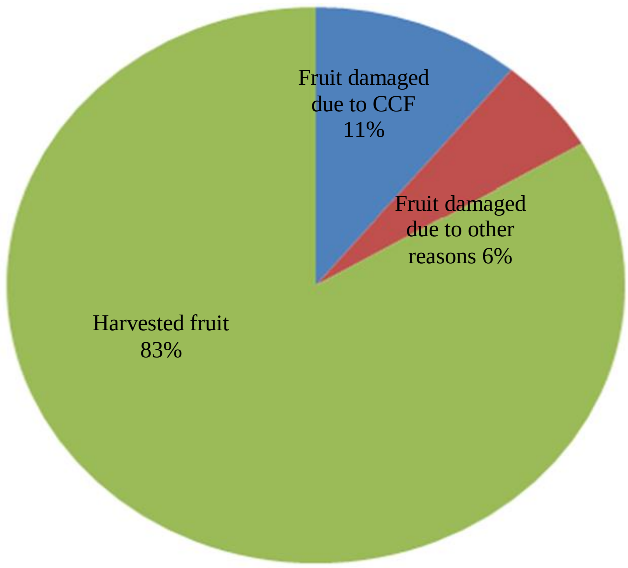

Fig. 5: Sweet orange fruit damage due to different causes in 2018

Table 2: Detail of clusters of AWCP (Longitude, latitude, elevation, total orchard owners, number of productive sweet orange trees and percentage of fruit loss due to CCF, *B. minax* in 2017, number of spots to be sprayed once and spray person involved in AWCP)

SN	Cluster	Clusters of AWCP (Villages/ Settlements)	GPS location and elevation (masl)	Total orchard owners	Number of productive trees	Fruit loss (%) due to *B. minax* in 2017	Number of spots sprayed once	Number of spray person involved
1	A	Mathlo Aalegaun	N 27013.670' E 086003.507' 1240	43	3300	45.72	1287	2
2	B	Tallo Aalegaun	N 27014.124' E 086003.592' 1092	29	3860	40.54	1100	2
3	C	Majhkuvinde, Thakurigaun, Dandatole	N 27013.412' E 086003.729' 1091	82	6833	52.55	2278	4
4	D	Tamaure, Kirate, Simle	N 27013.532' E 086003.642' 1010	38	2010	71.50	670	1
5	E	Ranikhola	N 27013.763' E 086002.448' 1435	39	1175	73.25	392	1
Total/average				231	17178	56.71	5727	10

Table 3: Assessment of fruit damage due to CCF, *B. minax* before and after AWCP

Assessment of AWCP	Mean fruit damage (%)	sd	df	t-value	p-value
Before AWCP	56.71	33.77	27	8.2012	8.312e-09
After AWCP	10.90	10.97			

Table 4: Marketable sweet orange production and total income before and after AWCP

Cluster	Marketable sweet orange production in 2017 (mt.)	Marketable sweet orange production in 2018 (mt.)	Total income in 2017 before AWCP (in thousands)	Total income in 2018 after AWCP (in thousands)
A	98.52	167.80	4433	7551
B	126.23	194.79	5681	8765
C	178.32	336.54	8025	15144
D	31.51	95.05	1418	4277
E	17.29	55.42	778	2494
Total	409.00	841.77	18405	37880

Integrated Pest Management (IPM) is one method to achieve sustainable agricultural production with less damage to the environment (Kogan and Bajwa, 1999). Area-wide management of fruit fly in orange orchards in Karo district of North Sumatra, Indonesia over a period of 2 years (2013 to 2014) was implemented by Ministry of Agriculture of Indonesia, together with GIZ and other related stakeholders that suppressed the population of fruit fly and saved fruit production by about 50% (ASEAN SAS, 2015). In China, area-wide pest management is not commonly adopted by all growers. Whereas, few large cooperative growers for export citrus production counties such as Shimen in Hunan and Pinghe in Fujian practiced AWCP to manage *B. minax* (Xia *et al.*, 2018). Protein bait application along with proper sanitation effectively reduced infestation by fruit fly in papaya orchards in Hawaii (Jaime *et al.*, 2009). A similar result was observed in the sweet orange orchards at Tinkanya village of Sindhuli district. NRs. 19,475,000 additional income was achieved from the investment of NRs. 3000,000 for the purchase of protein bait, technical and managerial support to the sweet orange (Junar) growers (Table 4).

Conclusion

Area-Wide Control Program of insect pest includes the tools in practices in the specific area at national, regional and smaller area levels. Fruit fly management measures such as lethal baiting (attracting and baiting fruit fly adults in the protein hydrolysate bait with insecticide), trapping, sanitation against pupating maggots, community awareness programs were employed in the specific location against CCF (*B. minax*). The technical aspect and managerial functions are essential for the successful implementation of the AWCP of *B. minax.* At the same time, coordination among stakeholders is crucial to deploy AWCP. The cost of adaptation of AWCP economic and environmental friendly as it is applied in particular spots rather than blanket sprays of pesticides in conventional practices.

Challenges

Size of sweet orange orchards varied from small to bigger (<500 m^2 to 11500 m^2) included mostly small landholder growers. Besides, the orchards in scattered patterns with mountain terrain added difficult accessibility to pay a visit to growers (transportation problem. Mostly, the orchards were intercropped with maize that hindered smooth spray activity. Alternate hosts of CCF, *B. minax* has still not yet discovered in the Nepal context. Similarly, besides partial life history of *B. minax*, detail biology of this pest remained matters of study.

Recommendations

Along with the technical issues that support a successful AWCP of *B. minax*, attention should be given for the functional coordination among the concerned stakeholders with the addition of addressing a large number of non-technical issues that arise during the campaign. This is a novel technique should be transferred to the necessary problematic areas. Further research on biology and management of this insect pest should be continued.

Acknowledgement

Authors are thankful to the University Grants Commission, Bhaktapur and Agriculture and Forestry University, Chitwan, Nepal for providing support to conduct research activity on Chinese citrus fly. Equally, Sweet orange growers; Junar Superzone, Sindhuli; Karma Group, Kathmandu and Ecoman Biotech, China are acknowledged for conducting AWCP of fruit fly in Sindhuli, Nepal.

Author’s Contributions

Debraj Adhikari: Coordinated in all research activities, data-analysis and write-up of the manuscript.

Resham Bahadur Thapa: Contributed in the research design, reviewed and advised for write-up.

Samudra Lal Joshi: Contributed in the research design, data analysis reviewed and advised for overall write-up.

Xing Hui Liang: Contributed for the concept of area-wide control program of pest and reviewed on the write-up.

Jason Jinping Du: Contributed for the concept of area-wide control program of pest, supported on the research activities and reviewed on write-up.

Ethics

This article contains unpublished material and it is original research. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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