AREA-WIDE CONTROL PROGRAM IN MANAGEMENT OF CHINESE CITRUS FLY, *BACTROCERA MINAX* (ENDERLEIN) (DIPTERA: TEPHRITIDAE), IN CITRUS ORCHARDS, SINDHULI, NEPAL

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ABSTRACT

Chinese citrus fly, Bactrocera minax (Enderlein) *(Diptera: Tephritidae) is one of the important citrus pests in Nepal, India and Bhutan including China where it was originated. Since 2014/15, the problem of B. minaxin sweet orange fruit is being faced by citrus growers in Sindhuli, Nepal. To mitigate the problem of B. minax,* Chinese citrus fly in the orchards, a*field practice of area wide control program (AWCP) was piloted in the selected 231 citrus orchards for the first time in Sindhuli in 2018 which has been adopted by 1153 citrus growers in 2019. The obvious recessions of mean fruit damage percentages due to B. minax in the sweet orange orchards at different locations in 2018 (range: 3.9 ± 1.1% to 29.7 ± 9.6%) and 2019 (range: 2.6 ± 0.8% to 7.5 ± 2.3%) have been achieved by virtue of B. minax management through AWCP with poisonous protein bait component and sanitation measure in the citrus orchards.*

Key words: AWCP, *Bactrocera minax,* Chinese citrus fly, protein bait, sanitation and sweet orange

INTRODUCTION

The Chinese citrus fly, *Bactrocera minax* (Enderlein) (Diptera: Tephritidae), is a major pest of citrus fruits especially in Asia (Gao *et al.*, 2013; Chen *et al.*, 2012; Drew *et al.*, 2006) with a geographical distribution, exclusively, in China, Bhutan, India (Sikkim and Western Bengal) and Nepal (CABI, 2020). It has oligophagous feeding habit concentrated only in citrus preferably to *Citrus aurantium*, *C. maxima*, *C. reticulata* and *C. sinensis* and related genera of Rutaceae as host plants (CABI, 2020). This China originated species of fruit fly is an invasive insect (Yang *et al.*, 2013), and, seemingly, it invaded Nepal first in the citrus orchards in the eastern parts of the country from India (Sikkim and West Bengal) and Bhutan (Joshi, 2019; Adhikari and Joshi, 2018; Bhandari *et al.*, 2017; Wang *et al.*, 2016; Drew *et al.*, 2013). Reportedly,*B. minax*inherited univoltine in life cycle with more than 5 months long over-wintering pupal diapause in soil under the canopy of the host tree (Zhou *et al.*, 2012; Dorji *et al.*, 2006; Dong *et al.*, 2013; Allwood *et al.*, 1999). Khan *et al.* (2005) highlighted on the weather factors as a whole imposed maximum effect on fruit fly infestation in fruit crops. Chen and Xie (1955) reported that the Chinese citrus fly (*B. minax*) was one of the *Bactrocera* species bearing

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uniquely larger body size in its all stages of life cycle. This species of fruit fly has been reported as the most cold tolerant amongst *Bactrocera* species (Xia *et al.*, 2018; Luo and Chen, 1987; Fan *et al.*, 1994).

Area-wide control program (AWCP) is an economically viable, environmentally sensitive and sustainable pest management measure that involved developing and integrating biologically-based pest control technologies into a comprehensive management package in a large crop area (Adhikari *et al.*, 2020). It included eco-friendly pest management measures instead of traditional blanket pesticide spray. AWCP was implemented for the first time in the country'spest management history from April to July 2018 in 40 ha of the citrus orchardsin Sindhuli district through the joint effort of Prime Minister Agriculture Modernization Project (PMAMP), Project Implementation Unit (PIU), Junar Superzone (Sindhuli), Karma Chemicals (Kathmandu), Beijing Ecoman-Biotech (China) and the sweet orange growers of Tinkanya, Sindhuli, Nepal to manage the Chinese citrus fly, *B. minax*. The major management measure of Chinese citrus fly employed were spot application of lethal protein bait and sanitation of the maggot infested fruits. The objective of this program was to suppress the population of the Chinese citrus flies to minimize the extent of fruit damages due to their infestations. This program was conducted in some selected sweet orange citrus orchard farmers as a pilot program in 2018.Encouraged with success in managing this pest through AWCP movement in 2018, it motivated a large group of farmers of Junar Superzone area of Sindhuli district in 2019 and 2020 to adopt AWCP in their citrus orchards against the Chinese citrus fly. This paper presents the outcomes of AWCP in the recession of fruit losses by Chinese citrus fly in the premises of citrus (sweet orange) orchards in Sindhuli district.

MATERIALS AND METHODS

Main pest management activities included in AWCP against Chinese citrus fly (CCF) in the citrus orchards of Sindhuli are i) treatment preplanning (stakeholder's consultation) of poisonous protein bait spray (spot application),ii) fruit damage/loss assessment and monitoring the adult fruit fly emergence to fix onset of protein bait spray in orchards, iii) orientation to spray-persons and orchards owners, and coordinating protein bait spray treatments in each of the farmers owned orchard clusters (n = 5 in 2018 and n = 8 in 2019) and iv) post treatment orchard-field sanitation.Scheme for seasonal phenology stages of fruit bearing citrus tree (Table 1, second row), phenophase determination of *B. minax* (Table 1, third row) together with the crop-season-based AWCP procedures are shown in Table 1 (fourth row). The AWCP working detail against CCF in Sindhuli such as clustering citrus orchards including their owners in Table 2 and number of citrus orchards, with their respective clusters and spray-persons involved in years 2018 and 2019 are presented in Table 3.

Table 1. Seasonal phenology of fruit bearing citrus trees, *B. minax* and AWCP adopted measures in Sindhuli, Nepal

Months / Particulars	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Stages of citrus tree/fruit	Flowering and fruit setting					Fruit development and maturity					Fruit ripening and harvesting	
Life stages of *B. minax*	Pupae (inside soil)					Adult emergence and egg laying in fruit rind			maggots (inside fruit)			Pupae (inside soil)
Measures of AWCP						**Protein bait spray** (spot application)			**Orchard sanitation** (collection of nfested fruits)			

Table 2. Citrus orchard owners and clustering citrus orchards in AWCP domain at Golanjor 4, Tinkanya, Sindhuli, Nepal

SN	Citrus orchard owners (representative of farmers in the respective cluster of orchards)	Cluster identity (n = number of farmers included in cluster of orchards)	SN	Citrus orchard owners (representative of farmers in the respective cluster of orchards)	Cluster identity (n = number of farmers included in cluster of orchards)
1	Posta Bahadur Thakuri	1. Golanjor-4, Tinkanya, Majh Kubhinde (n = 82)	15	Yam Bahadur Sinjali	3. Golanjor-4, Tinkanya, Tamaure (n = 38)
2	Chandra Bahadur Tamang		16	Lal Bdr. Purbachane Magar	
3	Madhu Malla Thakuri		17	Ram Bahadur Bhujel	
4	Mukti Bahadur Thakuri		18	Shiva Bahadur Pulami	
5	Man Bahadur Thakuri		19	Nara Bdr. Jargha Magar	
6	Lek Bahadur Thakuri		20	Padam Kumar Magar	
7	Bishnu Thakuri		21	Dan Bahadur Ramtel	4. Golanjor-4, Tinkanya,
8	Yadhav Bahadur Thakuri		22	Bhakta Bahadur Aale	

9	Gunda Bahadur Thakuri		23	Pokche Aale	Mathillo Aalegaun (n = 43)
10	Prem Thakuri		24	Krishna Bahadur Magar	
11	Prem Bahadur Jyu Thakuri		25	Dok Bahadur Thada	
12	Bhanubhakta Magar	2. Golanjor-4, Tinkanya, Tallo Aalegaun (n = 29)	26	Rukman Gurung	5. Golanjor-4, Tinkanya, Ranikhola (n = 39)
13	Purna Bahadur Thada Magar		27	Tirtha Bahadur Gurung	
14	Gunda Bahadur Thada Magar		28	Chandra Bdr. Purbachane	

CITRUS ORCHARD OWNER PARTICIPATION IN AWCP DOMAIN

The locations of different farmers owned sweet orange orchards were categorized in five different clusters in Golanjor Rural Municipality–4, namely 1) Majhkubhinde, 2) Tallo Aalegaun, 3) Tamaure, 4) Mathillo Aalegaun, and 5) Ranikhola, respectively, at varying altitude in masl accompanied with associated number of orchards in parentheses 1089 (82), 1225 (29), 1268 (38), 1380 (43), and 1462 (39), respectively.

The number of citrus orchard owners participated in the pilot AWCP were 231 (farmers included in 5 different clusters of orchards) from Golanjor-4, Tinkanaya, Sindhuli in 2018 With the influence of AWCP encouraged results in the management of *B. minax*, the number of participants increased to 1153 (farmers included in 8 different clusters of orchards) in AWCP in 2019 covering 8 clustered citrus orchards of four local governments of Sindhuli district namely; Sunkoshi rural municipality-7 (Majhuwa), Kamalamai municipality-3 (Jalkanya), Golanjor rural municipality 1-6 (1-Dundbhanjang, 2-Bittijor, 3-Bhuwaneswori, 4-Tinkanya, 5-Ratanchura and 6-Baseswor) and Tinpatan rural municipality-7 (Toshramkhola) i.e. the command area of Junar Superzone under PMAMP, PIU, Sindhuli.Similarly, the numbers of spray-persons involved increased from 10 (2018) to 26 in 2019 (Table 3).

Table 3. Farmers, orchards and spray-persons involvement in AWCP against *B. minax* in Sindhuli, Nepal

Year	No. of citrus orchards owned hy farmers	No. of clusters of orchards	No. of spray persons
2018	231	5	10
2019	1153	8	26

AWCP TECHNOLOGY

The Ecoman-Biotech developed AWCP technology in China was applied in the citrus orchards of Sindhuli. This technology included the Great Fruit Fly Bait (protein bait) along with its treatment method and spray scheduling.

FEMALE *B. minax* BAIT MATERIAL FOR AWCP

The Great Fruit Fly Bait a commercial product of Ecoman-Biotech, China was a readymade bait material mixed of two components, namely Protein hydrolysate (bait) 25 % and 0.1 % Abamectin (insecticide).

Fig. 1. Protein bait application on lower leaf surface (Left)
and sanitation of orchard collecting dropped infested fruits (Right)

PREPARATION OF BAIT SOLUTION AND SPOT APPLICATION

An aqueous bait solution for treatment was prepared from the Great Fruit Fly Bait (GFFB) and water at a ratio of 1 part GFFB in 2 parts of water. Thus, prepared aqueous bait solutionwas sprayed @ 50 ml solution over 0.5 to 1 m^2 area under side of the leaves (Fig. 1 Left) in one tree among three productive sweet orange trees at a location in weekly interval,which was repeated for 10-12 times (Ecoman-Biotech, 2018).

ORCHARD-FIELD SANITATION

After completing treatment schedule, orchard-field sanitation operation was practiced to prevent sheltering *B. minax* pupaein soil under the host tree canopy in the orchard. The orchard sanitation operation included the distribution of plastic bags each of dimension length and width (64 cm and 40cm) and thickness of sheet was 45 grams per square meter (GSM) to farmers to put in dropped CCF infested fruits periodically (Fig. 1 Right). Periodically collected CCF infested fruits were then buried into pit of 1 to 1.5 m depth with 30 cm thick soil coverage at the ground-level. Besides, some growers dipped maggots infested fruits in water pond, kept in bio-gas plant, burned in fire, maggots fed to poultry and fruit fed to livestock or/and processed locally to make liquor in order to prevent pupation and break life cycle of the fruit fly.

B. DAMAGE ASSESSMENT

B. minax fruit damage was assessed in each orchard by sampling three productive trees at harvesting stage in the AWCP domain of 28 citrus orchards (Table 2). In course of *B. minax* fruit damage assessment, infested fruits were ascertained by observing oviposition sting and/or matured maggots escaped holes on the rind surface in fruits through visual observation. The suspected dropped fruits were cut-opened for the presence of maggots inside. The overall damaged fruits due to *B. minax* from AWCP included 5 clusters in 2018 and 8 clusters in 2019 to compare mean damaged fruits obtained in 2017, i.e. to with no AWCP orchard management condition.

STATISTICAL ANALYSIS

Microsoft Excel 97-2003 worksheet was used to derive mean and standard error of mean for fruit damage assessment from the data generation of different citrus orchards. Student 't-test' was performed for the mean comparison among the means of *B. minax* incurred sweet orange fruit damages from each of the orchard clusters before AWCP in 2017 and after in 2018 and 2019.

RESULTS AND DISCUSSION

FRUIT DAMAGE ASSESSMENT

The highest CCF mean sweet orange fruit damage percentage in no AWCP situation in 2017 (before AWCP) revealed (86.7 ± 13.3%) in Ranikhola followed by Tallo Aalegaun (78.3 ± 4.4%), Tamaure (78.3 ± 7.0%), Mathillo Aalegaun (63.6 ± 15.8%) and Majhkubhinde (27.7 ± 7.8%). In 2018 (after AWCP), the mean fruit damage percentage receded in the localities to a tune of 29.7 ± 9.6% (Ranikhola), 19.4± 2.4% (Tamaure), 8.0 ± 3.9% (Tallo Aalegaun), 6.6 ± 2.7% (Mathillo Aalegaun) and 3.9 ± 1.1% (Majhkubhinde) respectively. Similarly, in 2019, a receded pattern of mean fruit damage percentage obtained in the clustered orchards in 2019 to a tune of 7.5 ± 2.3% (Ranikhola), 7.0 ± 0.8% (Tamaure), 4.3 ± 1.5% (Mathillo Aalegaun), 2.9 ± 0.5% (Majhkubhinde) and 2.6 ± 0.8% (Tallo Aalegaun) respectively. Hence, with AWAP in 2018 and 2019, the mean fruit damage in each location receded remarkably in comparison to without AWAP in 2017. The recessions in mean fruit damagein 2018 and 2019 are obviously an impact of AWCP with applications of the Great Fruit Fly Bait in the citrus orchard clusters (Table 4).

The obvious recessions of mean fruit damage percentages in 2018 (range: 3.9 ± 1.1% to 29.7 ± 9.6%) and 2019 (range: 2.6 ± 0.8% to 7.5 ± 2.3%) by virtue of *B. minax* management in citrus orchards through AWCP and the mean fruit damage percentages (range: 27.7 ± 7.8% to 86.7 ± 13.3%) before AWCP inception in 2017 in different orchards were statistically verified using

Student's 't-test' for an efficacy confirmation of the AWCP management against CCF in Sindhuli citrus orchards. The statistical results of Student's 't-tests' against the mean fruit damage percentages in different orchards without AWCP *B. minax* managementof three years in the same orchards with AWCP *B. minax* management in 2018 and 2019 are shown in Table 4. In Majhkubhinde, the mean fruit damage (MFD) 27.7% in 2017 reduced to 3.9% in 2018 (highly significant ($p \leq 0.0065$)); in Tallo Aalegaun, MFD 78.3 % in 2017 reduced to 8.0% in 2018 (very highly significant; $p \leq 0.0001$); in Tamaure, MFD 78.3% in 2017 reduced to 19.4% in 2018 (very highly significant: $p \leq 0.0001$); Mathillo Aalegaun, MFD 63.6% in 2017 reduced to 6.6% in 2018 (highly significant; $p \leq 0.0117$); in Ranikhola, MFD 86.7% in 2017 reduced to 29.7% in 2018 (highly significant; $p \leq 0.0126$). In contrary to 2017 orchard management situation, the MFD% for each of the clustered orchards location obtained in 2018 and 2019 (Table 4, columns 4 and 6) with AWCP management situation are not statistically different in 't-test' (Table 4, columns 4, 6 and 7) except Tamaure (MFD 19.4% in 2018 vs 7.0% in 2019 (very highly significant; $p \leq 0.002$) and Ranikhola (MFD 29.7% in 2018 vs 7.5% in 2019 (significant; $p \leq 0.0433$).

The variation in effectiveness of management of Chinese citrus fly might be due to the orchards' location, surrounding's vegetation, skills of spray-persons for spot application and other managerial aspects. Van Schoubroeck (1999) highlighted on the need of both monitoring and management measures for the development of effective IPM practice.

Table 4. Locationwise fruit damage assessment due to *B. minax* in Sindhuli, 2017-2019

S N	Location (no. of orchard owners)	Mean fruit damage % in 2017 (± SE)	Mean fruit damage % in 2018 (± SE)	T-test for mean fruit damage %in 2017 and 2018 (*P*-value)	Mean fruit damage % in 2019 (± SE)	T-test for mean fruit damage % in 2018 and 2019 (*P*-value)
1	Majhkubhinde (11)	27.7 ± 7.8	3.9 ± 1.1	0.0065**	2.9 ± 0.5	0.2309(ns)
2	Tallo Aalegaun (3)	78.3 ± 4.4	8.0 ± 3.9	0.0001***	2.6 ± 0.8	0.1198(ns)
3	Tamaure (6)	78.3 ± 7.0	19.4 ± 2.4	0.0001***	7.0 ± 0.8	0.0002***
4	Mathillo Aalegaun (5)	63.6 ± 15.8	6.6 ± 2.7	0.0117**	4.3 ± 1.5	0.2373(ns)
5	Ranikhola (3)	86.7 ± 13.3	29.7 ± 9.6	0.0126**	7.5 ± 2.3	0.0433*

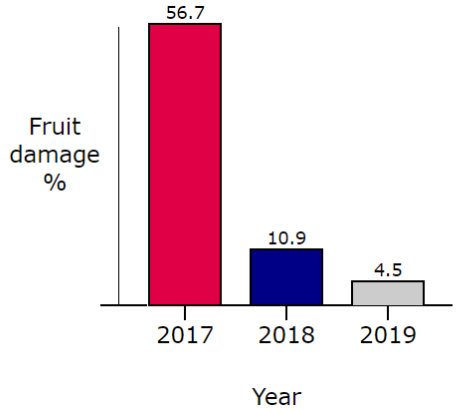

Fig. 2. Average fruit loss due to Chinese citrus fly in sweet orange orchards in Sindhuli, Nepal

Fig. 2 shows the comparison in the pattern of *B. minax* incurred the overall mean sweet orange fruit damage percentages obtained in 2017 (without AWCP management practice) with 2018 and 2019 (with AWCP management practice against the Chinese citrus fly). Sweet orange fruit losses due to Chinese citrus fly reduced drastically from 56.7 ± 6.4% in 2017 to 10.9 ± 2.1% and 4.5 ± 0.6% in 2018 and 2019, respectively. The result is statistically very highly significantly different ($p \leq 0.0001$) (Fig. 2). The statistics of sweet orange fruit losses due to Chinese citrus fly was 56.7±6.4%, which indicates that due to AWCP for CCF indicated sweet orange fruit production in Sindhuli district increased by 45.8%. Acharya and Adhikari (2019) reported less than 7 % fruit loss from the trees sprayed with Great Fruit Fly Bait in 2018.

CONCLUSION

Spot applications of lethal protein bait (the Great Fruit Fly Bait) for *B. minax* adult fly control, and orchard sanitation to prevent its pupae to pupate in soil remained major components of AWCP that helped achieve managing Chinese citrus fly in sweet orange orchards in Sindhuli, Nepal. The AWCP is eco-friendly management practice where both the technical and managerial aspects run side by side for the successful implementation of the program. AWCP saved sweet orange fruits from *B. minax* by 45.8 % in the sweet orange orchards of Sindhuli district. Thus, AWCP management of Chinese citrus fly, *B. minax*, in citrus orchards, Sindhuli, Nepal has emerged as a proven practice to sweet orange (junar) farmers in the localities, and bears a great scope of dissemination of this management practice against *B. minax* in citrus orchards in other potential citrus dominated districts in Nepal.

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