Review Article

BIOLOGY AND MANAGEMENT OF CHINESE CITRUS FLY, *Bactrocera minax* (Enderlein) (DIPTERA: TEPHRITIDAE)

D. Adhikari*[1], R. B. Thapa[1], S. L. Joshi[2], J. J. Du[3], and S. Tiwari[1]
[1]Agriculture and Forestry University, Rampur, Chitwan, Nepal
[2] Nepal Agricultural Research Council, Nepal
[3] Beijing Ecoman Biotech Co. Ltd., China

*Corresponding author: adhikari.debraj1@gmail.com
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ABSTRACT

The Chinese citrus fly, *Bactrocera minax* (Enderlein) (Diptera: Tephritidae) is an important insect pest of citrus species which causes significant fruit damage in Nepal, India, Bhutan and China. An attempt has been made to review the biological aspects and management measures of this pest compiling published literatures in the national and international journals, proceedings, reports, newsletter and books. This review highlights the findings on the nomenclature, morphology, distribution, biology of the Chinese citrus fly and provides potential prospect of pest management measures, which are useful to the researchers, policy - makers, citrus growers and extension workers.

Keywords: *Bactrocera minax*, Citrus, Chinese citrus fly, life cycle, management

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are one of the most destructive phytophagous insect pests of fruits and vegetables, causing remarkable loss on the world horticultural crops. This pest reduces production and has proven to be a trade obstacle (Luciano et al., 2019; Allwood, 1997**;** Drew & Lioyd, 1987). Tephritidae is one of the biggest dipteran families (Drew, 1989), with medium-sized, pictured-winged, and elaborately ornamented insects that are frequently described to as “peacock flies” due to their strutting and vibrating action (De Meyer et al., 2010; Satarkar et al., 2009; Agarwal & Sueyoshi, 2005; Kapoor, 1993). Because of significant damage on citrus crops, large-scale management programs have been developed to combat them in many regions of the globe (Vargas, Pinero, & Leblanc, 2015). The impact of the fruit fly pest has been focused in Nepal since the commercialization of farming. In response to a 2012 agreement between Nepal and China to export citrus fruits from Nepal to China while considering pest quarantine rules into account, protocol-based frequent fruit fly surveillance in the citrus farms of Sindhuli and Syangja districts was implemented (Nepal China Agreement, 2012; PPD, 2014). During preliminary fruit fly surveillance in Sindhuli district in 2014, *Zeugodacus cucurbitae* (Coquillett, 1899), *Bactrocera dorsalis* (Hendel, 1912), *Bactrocera zonata* (Saunders, 1842), *Zeugodacus tau* (Walker, 1849), and *Zeugodacus scutellaris* (Bezzi, 1913) were identified in male lure traps (Sharma, Adhikari, & Tiwari, 2015). *Bactrocera dorsalis* (Hendel, 1912), *Bactrocera zonata* (Saunders, 1842), *Bactrocera correcta* (Bezzi, 1916), *Zeugodacus cucurbitae* (Coquillett, 1899), *Zeugodacus tau* (Walker, 1849), *Zeugodacus scutellaris* (Bezzi, 1913), *Zeugodacus diversus* (Coquillett, 1904), *Zeugodacus caudatus* (Fabricius, 1805), *Bactrocera minax* (Enderlein, 1920), *Zeugodacus yoshimotoi* (Hardy, 1973), *Bactrocera tsuneonis* (Miyake, 1919), *Dacus longicornis* (Wiedemann, 1830), *Bactrocera nigrofemoralis* (White & Tsuruta, 2001), *Bactrocera latifrorns* (Hendel, 1915), *Zeugodacus artifacies* (Perkins, 1938), *Bactrocera tuberculata* (Bezzi, 1916), *Dacus ciliatus* Loew, 1862, *Bactrocera abbreviata* (Hardy, 1974), *Bactrocera aethriobasis* (Hardy, 1973), *Bactrocera digressa* (Radhakrishnan, 1999), *Dacus feijeni* White, 1998, *Bactrocera nigrifacia* Zhang, Ji and Chen, 2011, *Bactrocera rubigina* (Wang and Zhao, 1989), *Bactrocera syzygii* White and Tsuruta, 2001, *Zeugodacus duplicatus* (Bezzi, 1916), *Dacus maculipterus* Drew and Hancock, 1998 and *Dacus trimacula* Wang, 1990 are fruit fly species reported in various time periods by various authors in Nepal (Sharma, Adhikari, & Tiwari, 2015; Adhikari & Joshi, 2018a; Bhandari, Ansari, Joshi, Subedi, & Thakur, 2017; Leblanc, Bhandari, Aryal, & Bista, 2019; Tiwari, 2016; Kapoor, Malla, & Ghosh, 1979).

Chinese citrus fly, *Bactrocera minax* (Enderlein) belongs to the Family Tephritidae, Order Diptera and Class Insecta (CABI, 2021**;** Hancock & Drew, 2019). This is one of the most destructive insect pests of citrus in the Asian region of China, Bhutan, India and Nepal (Bhandari et al., 2017; Wang, Xiong, & Hong, 2016; Drew, Romig, & Loday, 2006). Chinese citrus fly is a univoltine and oligophagus pest (feeds single plant Family - Rutaceae) and feeds exclusively on the citrus fruits (Xia, Ma, Hou, & Ouyang, 2018; Chen et al., 2016). However, *B. minax* is a major pest of tight- skinned citrus in Nepal, which is geographically distributed from the eastern hilly area to central hilly part of the country, and extending to the western part of Nepal in the present scenario. According to a study conducted in 2006 at the National Citrus Research Program (NCRP), Paripatle, Dhankuta, *B. minax* was the species impacting the citrus fruits at NCRP, Dhankuta and the surrounding area. Fruit flies infesting citrus orchards were surveyed extensively in five districts of Nepal, including Dhankuta, Tehrathum, Gorkha, Lamjung, and Syangja, and their biology was investigated to confirm the species of fruit flies. It was *B. minax* emerged from the maggots samples retrieved from Tehrathum while none of the samples yielded adults from Gorkha, Lamjung and Syangja (NCRP, 2011). These findings confirmed that *B. minax* was a problematic fruit fly species in Nepal's eastern region indicating a need for the better monitoring and management strategy to combat the fruit fly problem in citrus groves. *B. minax* is a significant pest in China's major citrus-growing regions causing significant citrus fruit losses in plantations in 2008 (Rasid et al., 2021). In Nepal, fruit losses (occasionally up to 100%) incurred of *B. minax* in the sweet orange orchards are becoming devastating since 2014 in Sindhuli district, which is a main sweet orange pocket of Nepal (Adhikari & Joshi, 2018a).

Recently, for the management of *B. minax*, protein bait-based area-wide control program (AWCP) had been practiced in the citrus orchards in Sindhuli and in the vicinity of its adjoining districts (Adhikari, Thapa, Joshi, Liang, & Du, 2020a). It included an integration of life cycle and behavior-based management measures of *B. minax* in a large area in a mode of a community campaign. Use of protein bait in spots in citrus trees and orchard sanitation performing regular removing of dropped fruit fly infested citrus fruits were the important measures along with the reinforcement of technical and managerial aspects of AWCP. It required community efforts and coordination among stakeholders for the successful implementation of AWCP in the orchard premises. This paper based on a review of literatures highlights on the findings on the identity, distribution, and biology of *B. minax* along with its various management measures.

MATERIALS AND METHODS

Attempt have been made to review the biology and management of Chinese citrus fly, *B. minax* gleaning through the published literatures in the national and international journals, proceedings, reports, newsletter and books.

LITERATURE REVIEW

Geographical distribution

The distribution of *B. minax* is geographically limited to China (Chongqing, Guangxi, Guizhou, Hubei, Hunan, Jiangxi, Shaanxi, Sichuan, Yunnan), Bhutan, India (West Bengal and Sikkim), and Nepal (Figure. 1) (EPPO, 2021; Drew, Romig, & Dorji, 2007; Dorji et al., 2006; Drew, Dorji, Romig, & Loday, 2006).

Figure 1. Geographical distribution of *B. minax*
Source: EPPO (2021) (modified)

Nomenclature and identification

Chinese citrus fly, *B. minax* belongs to genus *Bactrocera*, subgenus *Tetradacus* and species *minax* (Hancock & Drew, 2019). *B.* (*T.*) *minax* has been identified parataxonomically in Nepal mainly based on morphological traits of the fruit flies which is equally applicable for the field identification of the targeted fruit flies in the study area (Adhikari & Joshi, 2018a). This is one of the larger fruit fly species. The face is fulvous, with narrow elongate facial markings reaching the oral margin, a red-brown scutum with no dark patterns, and a yellow scutellum with a narrow red-brown basal band. The appendages, such as the legs and wings, are mostly fulvous, with microtrichia in the outer corner of cell bc and the outer 1/2 of cell c, a broad fuscous costal band overlapping R4+5 and becoming darker towards the apex but not expanding into a spot, a narrow fuscous cubital streak but not reaching the wing margin, and supernumerary lobe weak. The abdomen is elongate, oval, and petiolate (as in many *Dacus* species), terga III-V orange-brown, with a moderately broad transverse fuscous band across the anterior margin of tergum III and a medium width medial longitudinal pale fuscous band over all three terga, anterolateral corners of tergum IV fuscous, and anterolateral corners of tergum V pale fuscous (Figure 2).

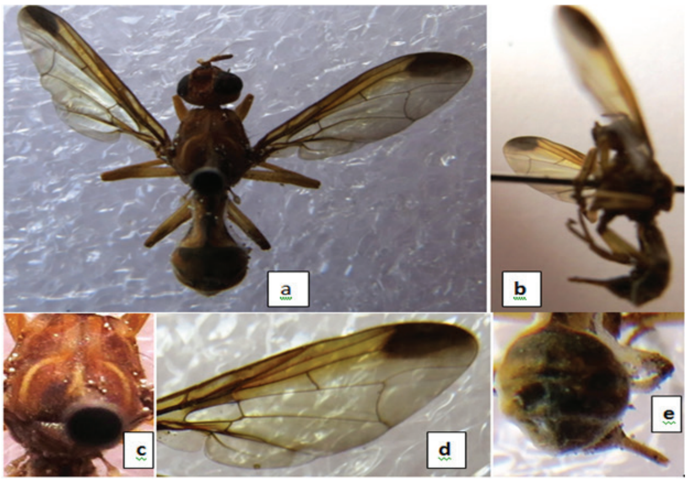

Figure 2. Field identifiable morphological structures of *B. minax*; a. Holistic view, b. Lateral view, c. Dorsal view, d. Wing, e. Dorsal abdomen

Source: Adhikari & Joshi, 2018a

Species confirmation from *B. ?tsuneosis* to *B. minax*

The Chinese citrus fly (*B. minax*) is morphologically resembling to the Japanese fruit fly (*B. tsuneonis* Miyaka) (Drew & Romig, 2013), but anterior supra-alar setae is absent (EPPO, 2021). Hence, the former *B. minax* was mistakenly considered synonymous with the later *B. tsuneonis* (EPPO/CABI, 1996). In December 1984, the Chinese citrus fly, *B. minax*, was identified for the first time on a sweet orange in Helambu, Sindhupalchok district of Nepal (Joshi & Manandhar, 2001), which was identified as *B. ?tsuneonis*. Later, while validating the insect museum fruit fly specimens of National Entomological Research Centre, NARC, Dr. Gary J. Steck, Curator of Diptera, Florida State Collection of Arthropods, Florida, USA confirmed it as *B. minax* on 26 September 2007 (Paudyal, Shrestha, & Regmi, 2016**;** Joshi, 2019). Simultaneously, he identified *B. minax* fruit fly specimens taken from sweet oranges in Dhankuta on April 27, 2007. *B. minax* has invaded sweet oranges in Nepal's eastern mid-hills, particularly in the Dhankuta and Tehrathum districts (NCRP, 2011). Unfortunately, in the course of the trade agreement of Nepal with China, Nepal submitted its citrus insect pest inventory including the then identified *B. ?tsuneosis* to China in 2012 (Nepal-China Agreement 2012). As *B. ?tsuneosis* of Nepal is now authentically identified as *B. minax*, National Plant Protection Organisation-Nepal (NPPO-Nepal) ought to request NPPO-China to change *B. ?tsuneosis* to *B. minax* in its regulated quarantine pest list (Adhikari, Joshi, Thapa, Du, Sharma, & GC, 2019). The fruit fly surveillance of citrus orchards in Sindhuli district confirmed sweet orange (*Citrus sinensis* (L.) Osbeck) being devastated by *B. minax* (Adhikari & Joshi, 2018b).

Hosts

The Chinese citrus fly (*B. minax*) is an oligophagus pest species attacking on citrus fruits (Rutaceae) (Dong et al., 2013; Wang & Luo, 1995). In China, this species infests mostly sweet oranges (Xia, Ma, Hou, & Ouyang, 2018), whereas, in Bhutan, mandarins are greatly infested (Dorji et al., 2006). In Nepal, mostly tight-skinned oranges such as lemon and sweet orange are damaged by this pest but recently mandarin fruits are reportedly infested of *B. minax* (Dhaulagiri Media, 2020). A complete host plant list of *B. minax* all belonging to Family Rutaceae as of the USDA Compendium of Fruit Fly Host Information (CoFFHI) (Chang, Liquido, Nakamichi, & Ching, 2018) is presented in Table 1. However, CABI (2021) reported 9 specific *Citrus* spp. host plants with asterisk in plants are depicted in Table 1.

Table 1. Host of Chinese citrus fly

SN	Common Name	Scientific Name
1	Lime	*Citrus aurantiifolia* (Christm.) Swingle
2	Sour orange	*Citrus aurantium* (L.)
3	Yuzu	*Citrus junos* (Siebold ex Tanaka)
4	Lemon	*Citrus limon* (L.) Osbeck
5	Pomelo	*Citrus maxima* (Merr.)
6	Citron	*Citrus medica* (Lush.)
7	Grapefruit	*Citrus paradisi* (Macfad.)
8	Mandarin orange	*Citrus reticulata* (Blanco)
9	Sweet orange	*Citrus sinensis* (L.) Osbeck
10	Tangerine	*Citrus tangerina* (Tanaka)
11	Citrus unshiu	*Citrus unshiu* (Yu.Tanaka ex Swingle)
12	Tangor	*Citrus nobilis*
13	Kumquat Meiwa	*Fortunella crassifolia*
14	Kumquat round	*Fortunella japonica*
15	Kumquat oval	*Fortunella margarita*
16	Trifoliate orange	*Poncirus trifoliate* (L.)

Chinese citrus fly (*B. minax*) invasion in Nepal

Joshi (2019) put forward the reportedly extended invasion of the Chinese citrus fly (*B. minax*) in the citrus orchards of 11 districts of Nepal, namely Dhankuta, Sankhuwasabha, Sindhuli, Ramechhap, Dolakha, Kavrepalanchok, Sindhupalchok, Lamjung, Parbat, Gulmi, and Myagdi in Nepal. But the present scenario in 2021 showed the reportedly *B. minax* invasion extended to the citrus orchards of 20 mid-hill districts, namely Taplejung, Terhathum, Sankhuwasabha, Dhankuta, Bhojpur, Khotang, Solukhumbu, Okaldhunga, Sindhuli, Ramechhap, Dolakha, Kavrepalanchok, Sindhupalanchok, Lamjung, Syangjya, Parwat, Baglung, Gulmi, Myagdi, and Arghakhachi (Figure 3). Thus, it is experienced that every time the *B. minax* invasion is extending in the country obviously from the eastern parts to the western parts of Nepal. Further, it seems that *B. minax* is invading to the loose skin citrus fruits like mandarin orange in absence of tight skin citrus fruits like sweet orange.

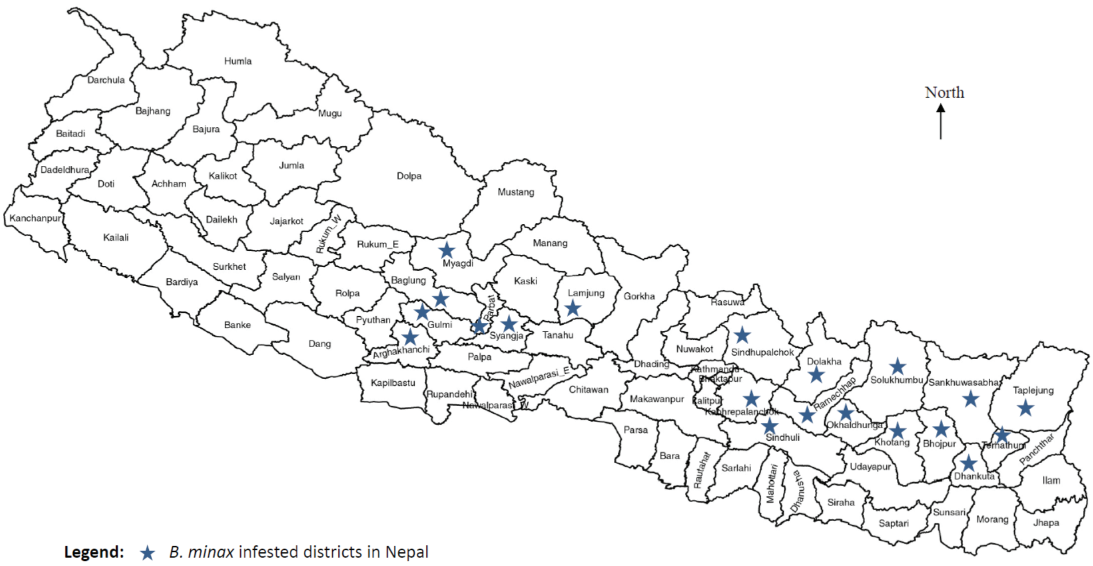

Figure 3. Country status of *B. minax* invasion in citrus orchards in Nepal

Source: Joshi (2019) and Survey (2021)

Bio-ecology of Chinese citrus fly (*B. minax*)

The life cycle and behavior of the pest is important to develop management strategies. Chinese citrus fly (*B. minax*) is a univoltine fruit fly species (Xiao, Niu, Han, & Desneux, 2012). Adhikari et al., (2020b) illustrated the life stages in the different months of the year in the sweet orange (*Citrus sinensis*) orchards of Sindhuli district in 2014 (Table 2). Similar life stages and time period were recorded in China (Xia, Ma, Hou, & Ouyang, 2018). Adults of *B. minax* emerged from soil during April to May and became active for mating about 25-30 days after feeding on proteinous food for oviposition from May to July (Wang & Luo, 1995; Dorji et al., 2006). Female adults laid eggs inside the fruit rind in clutches usually on an average of 14-17 (maximum 35) eggs per oviposition event, all together more than hundred during lifetime (Zhang, 1989). According to Sun (1961), eggs measured 1.1 to 1.5 mm in length and 0.2 to 0.4 mm in width. In July-August eggs hatched into larvae (maggots) (Xiong et al., 2016). Thus, the developing maggots proved to be the destructive stage of this insect by feeding on the pulps and juice inside fruits. Maggots developed inside the fruit into three instars from June/July to September/October to change into mature maggots, the prepupae. The matured maggots of milky white to pale yellow color measured 15-18 mm in length (Rasid et al., 2021). Maggot stage remained for 52-72 days depending on the temperature (Lu, He, Ruan, & Mou, 1997). Infested fruits, lighter in weight, contained an average of 9.5 maggots inside (Zhang, 1989). The matured maggots exited the dropped fruits making noticeable holes on the fruit rind, and even from the tree held up fruits down to ground. Pre-pupae entered into pupae stage inside soil that overwintered for around 6 months (October to April) (Zhang, 1989). Generally, an acquired pupation depth in soil is 3 to 5 cm (Zhang, 1989; Dorji et al., 2006). Pupae measured 9 to 10 mm length with diameter of 4 mm, which remained oval in shape and yellow-brown in color that changed into slightly dark brown (Wang & Luo, 1995; Zhang, 1989). The adult flies looked wasp like probably the largest (body length 10-13.2 mm, wing span ~10.8 mm) of all *Bactrocera* species, which were brownish colored with yellow markings, wings with a dark band along the external margin (Drew, Roming, & Dorji, 2007; Drew, 1979; Chen & Xie, 1955). Management strategy of this pest should link with its biology and inherent behavior. Table 2 presents the life stages of *B. minax* in different locations of China and Nepal.

Table 2. Life cycle of *B. minax* in major citrus production provinces of China and Nepal

Country	Life stage of *B. minax*	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
China (Hunan)	Adult												
	Egg												
	Maggot												
	Pupa												
China (Shaanxi)	Adult												
	Egg												
	Maggot												
	Pupa												
China (Hubei)	Adult												
	Egg												
	Maggot												
	Pupa												
Nepal (Sindhuli)	Adult												
	Egg												
	Maggot												
	Pupa												

Source: Xia et al. (2018), Adhikari et al. (2020b)

The pupae of *B. minax* overwintered in soil that remained diapaused for more or less 6 months in winter before emerging adult flies in the spring (Xia, Ma, Hou, & Ouyang, 2018; Wang & Luo, 1995; Wu, 1958). Chilling temperature and duration had an impact on the length of pupal diapause. The length of pupal development found to be reduced by higher temperatures exposures (Dong et al., 2013). The heat accumulation in degree days (DD) in pupae of Chinese citrus fly to emerge into adult fruit flies was a major physiological phenomenon to predict its adulthood in the infested orchards. The DD values of *B. minax* for Hubei and Shaanxi population in China were 447.3 ^{0}C (with respect to 11.9 °C minimum threshold temperature, MTT) and 511.3°C (with respect to 11.5 ^{0}C MTT), respectively, but no statistically difference (Ma, Suiter, Chen, & Niu, 2019). Similarly, Luo & Chen (1987); Li, Wang, & Zhao (1999) reported 567.9 ^{0}C (with respect to 10.57 ^{0}C) and 579.51 ^{0}C (with respect to 10.26 ^{0}C MTT), respectively. The heat accumulation acquired of 2137.21 ^{0}C, however, was observed to emerge adult *B. minax* fruit flies out of pupae in case of 4.51 ^{0}C lowest threshold temperature (Ke, 2013).

Nature of damage and extent of fruit losses

With the help of its elongated ovipositor, the adult female fly oviposited eggs beneath the skin of green, immature citrus fruits (20-30 mm) (Rasid et al., 2021; Liu et al., 2015; Allwood et al., 1999). Inside the mature fruits, maggots fed on the juice and pulps. As a result, the larval stage of this pest remained the most devastating (Dorji et al., 2006). The fruits around the feeding spot turned prematurely yellow and finally dropped as a result of their feeding activity. When the maggots gained maturity, they escaped the fruit through an exit hole and pupated in soil (Ecoman Biotech, 2014). According to the Fletcher (1989), adult flying and the transportation of infested fruits, were the primary modes of transportation and spread from one location to another. Fruits contained eggs and maggots that were extremely difficult to detect (CABI, 2021). Many *Bactrocera* species could fly up to 100 km.

Chinese citrus fly, *B. minax* remained the most devastating citrus pest (Xia, Ma, Hou, & Ouyang, 2018). In extreme cases, this insect could inflict damage up to 100 % in fruit production (Wang et al., 1990). In 2017, an average fruit loss of 56.7% was reported due to *B. minax* in the selected sweet orange orchards of Sindhuli district, Nepal (Adhikari, Thapa, Joshi, Liang, & Du, 2020a). In Guizhou, China, an incidence of fruit infested of *B. minax* throughout the province differed from less than 1% to 100%, where as infested fruits were found 20 to 40 % in Zunyi, China (Xia, 1998; Yang, 1989). In Bhutan, this Chinese citrus fly caused around 20-70 percent fruit losses in untreated orchards (NPPC, 2021).

Management practices

Ten different management measures such as sanitation, trapping adult using para-pheromone lures, chemical insecticides, botanicals, cultural measures, exclusion through bagging and netting, food lure/protein bait, bio-pesticides, post-harvest treatments and sterile insect technique mentioned in fruit fly management (Adhikari, Joshi, Thapa, Pandit, & Sharma, 2020c), whereas, only seven management measures were recommended by the extension advisory service providers in Nepal (Adhikari, Joshi, Thapa, Pandit, & Sharma, 2020c). According to Dhillon, Singh, Naresh, & Sharma (2005), fruit fly management options such as sanitation of infested fruits, bagging of fruits, protein bait application, use of para-pheromone traps and chemical insecticides were recommended practices for the growers. Monitoring insect pest remained important aspect of successful implementation of insect pest management. This insect of a univoltine life cycle (one generation per year) in nature inherently attacked a wide range of citrus fruits such as sweet orange, lemon and mandarin etc. (Table 1). Cue lure or methyl eugenol were observed non-attractive to *B. minax* (Xia, Ma, Hou, & Ouyang, 2018). So, main suggested actions against the pest were i) to monitor citrus orchard using protein bait traps @1 trap per ha, ii) to take an action when 4-6 adult flies (ca 1 cm long body with 1 cm wings, brownish body with three yellow markings in thorax, dark band along the margin of front wing) detected in traps, iii) to check egg laying puncture site with some sticky gum on the fruit-rind, iv) to observe maggots contained fallen fruits in orchard (special clue: infested fruit lighter in consistency with exit holes on fruit rind), and vi) to recognize the pest attack history in the orchard to apply prevention measures.

B. minax preventive thumb rule may be “Ready for applying prevention measures in the successive fruit season when maggot infested fruits in the preceding fruit season are obviously observed in the orchard” (Adhikari, 2016).

Cultural measures: Cultural measures suppressed fruit fly infestations by reducing the situations they required to survive (like shelter, food, water). Improper orchard management measures increased the occurrence of fruit fly, so it was necessary to follow recommended orchard management practices (like regular pruning, optimum manure and fertilization and irrigation etc.) (Gautam, Srivastava, Singh, Karki, Adhikari, & Acharya, 2020). Increased charging of fruit flies in the orchard was observed in case dropped fruit fly infested fruits remained unattended. Therefore, sanitation of maggots infested fruits in proper manner prevented pupation and decreased the incidence of fruit fly problem in the successive fruit season (Wang & Lou, 1995). To optimize the pest free sanitation in orchards, collection and burying of maggot infested dropped fruits at least 30 cm deep in a soil pit, or feeding them to livestock, or using them for biogas, or killing them in sealed plastic bag exposed to sun, or dipping them in water pool, or burning them in fire helped break the chain of fruit fly life cycle. Collecting fallen fruits only once a day and disposed them either one of the ways stated above would prevent puparia formation with a result of minimization of the fruit fly population in the following year (Adhikari, 2016). Effective community mobilization in order to manage this pest (maggot) included infested fruit collection and use of environmentally friendly approach like lethal protein baiting. Similarly, proper tillage of soil under the tree canopies killed maggots and/or pupae (Wang & Zhang, 2009**;** Fan, 2002**;** Wang & Luo, 1995**;** Peng, 1990**;** Chen, 1957). *B. minax* infestation rates of 50 to 100% could be reduced to less than 1% with the proper sanitation procedures (Wang & Zhang, 2009**;** Wang & Luo, 1995**;** Peng, 1990). Reported other measures of cultural methods were soil treatment/tillage, removal of host plants, crop rotation, clean cultivation, weeding, pruning, conservation of natural enemies, early harvesting, bait traps and repellent crops (Adhikari, Joshi, Thapa, Pandit, & Sharma, 2020c). In Bhutan, cultural measures including soil tillage, and also natural predation (birds eating pupae) appeared to have a role in decreasing the number of pupae in orchards (Dorji, Mahat, & Loday, 2010).

Exclusion measures: Netting whole plants or bagging/wrapping individual fruit escaped fruit fly oviposition (Adhikari, 2016). Bagging of individual fruit served producing high quality fruits with uniform golden color that enhanced cosmetic value of the fruits (Xia, Ma, Hou, & Ouyang, 2018). Wax paper or oiled newspaper fruit bagging practice when flower petals dropped after fertilization prevented fruit fly egg laying (Sarker, Rahman, & Barman, 2009; Liu & Zhou, 2016).

Biological measures: In Bhutan, just one parasitoid, *Diachasmimorpha feijeni* van Achterberg was identified against Chinese citrus fly (van Achterberg, 1999) but its biological efficiency against *B. minax* control remained still obscure. However, no specific information on the natural control of B. minax from parasitoids is currently known. Potential findings on the use of microbial pesticides such as entomopathogenic fungi and nematodes were revealed in recent times as reviewed by Dias, Zotti, Montoya, Carvalho, & Nava (2020). Adhikari (2016) mentioned soil incorporating fungal pathogen *Metarhizium* @ 2-3 kg/ha against larvae and/or pupae in soil after fruit harvest (Jan-Feb).

Botanicals: Soil should be treated with crushed neem seed cake @ 50-60 kg/ha after fruit harvest (Jan-Feb) (Adhikari, 2016). Fortnightly spraying of Azadirachtin based product (3 ml/l water) in the orchard during May-July deterred egg laying by fruit flies (Adhikari, 2016**;** Shafiullah, Amin, Miah, Rahman, & Ahmed, 2016). Jaleel et al. (2020) mentioned four botanical products such as *Seriphidium brevifolium*, *Piper nigrum*, *Azadirachta indica* and quercetin to manage *B. dorsalis* and *B. correcta.* Sultana, Aslam, Ahmed, & Howlader. (2013) reported neem (*Azadirachta indica*); leaves of basil (*Ocimum basilicum*), mahua (*Madhuca indica*), lantana (*Lantana camara*), eucalyptus (*Eucalyptus globulus*), surjokonna (*Spilanthes acmella*) and flowers of golden shower (*Cassia fistula*), rosy periwinkle (*Catharanthus roseus*) and orchid (*Mokara charkuan*) botanicals for the management of melon fruit fly.

Chemical measures: Malathion is the commonly used pesticide to make lethal protein hydrolysate bait spray against fruit flies (Roessler, 1989). Because the oviposition time from mid June to late July is well defined, a systemic insecticide (such as abamectin) cover up application in early July followed by a second treatment in late July would provide high mortality of eggs in fruit (Adhikari, 2016). Soil treatment of Malathion 5 DP @20 kg/ha after fruit harvest was also useful (Adhikari, 2016). Pesticides such as abamectin, chlorpyrifos, phoxim are often used to against *B. minax* populations. Abamectin was found to have the greatest level of toxicity. Chlorpyrifos, on the other side, had the most effect on pupae, while phoxim had more influence on adult emergence (Rasid et al., 2021).

Quarantine measures: Strict quarantine measures supported to prevent an entry and spread of the exotic pests (Wang & Lou, 1995). Sweet orange should be originated from the *B. minax* freedom area or from a place of production found without the pest on regular inspections for 3 months before fruit harvest (EPPO, 2021). Fruit irradiation of 50-90 Gy (Gray), as phytosanitary measure against *B. minax,* is a recommended deal in plant quarantine (Gao, Wang, Li, & Tang, 1999**;** Zhao et al., 1995). Imported citrus plants with roots should be free of soil or have the soil treated to prevent *B. minax* puparia (EPPO, 2021).

Protein bait: Bait sprays are based on the notion that a protein source that produces ammonia attracts both male and female tephritids. Bait sprays have an advantage over cover sprays in that they can be used as a spot treatment to attract flies to the pesticide while reducing the impact on natural enemies. Spraying a protein bait combination with a little amount of insecticide found to be an effective method for controlling fruit fly populations on a large scale (Conway & Forrester, 2011). Fruit fly population control using bait sprays was successful because freshly emerging females required protein to develop sexually (McQuate, 2009**;** Perez-Staples, Prabhu, & Taylor, 2007). Trapping adult flies was effective by using protein hydrolysate bait/lure with Malathion 50 EC to prevent egg lying on fruits. Such device should be installed @ 20 traps/ha. From early May to late July, twice-weekly protein bait spray would significantly lower the fly population and prevent oviposition in growing fruits (Adhikari, 2016).

Area-Wide Control Program (AWCP) of *B. minax*: The AWCP was designed to combat the *B. minax* pest in sweet orange plantations in Sindhuli, Nepal. The goal of this initiative was to reduce the number of Chinese citrus fly populations in order to reduce the amount of fruit damage caused by *B. minax* maggots. A joint venture of the Prime Minister Agriculture Modernization Project, Project Implementation Unit (Junar Superzone, Sindhuli), Karma Chemical Company Pvt. Ltd., Kathmandu, Ecoman Bio-tech, China, and the sweet orange (Junar) growers of Tinkanya, Sindhuli, Nepal commenced AWCP against *B. minax* from April 2018 in 40 hectares of Junar orchards at Golanjor-4, Tinkanya. Trapping adult flies in net and in protein hydrolasate bait was organized in farmers' citrus orchards. Lethal protein hydrolysate in the form of GREAT Fruit Fly Bait (protein hydrolysate 25% and 0.1% abamectin) was used in an aqueous bait spray. Fifty (50) ml of aqueous solution prepared of 1 part GREAT Fruit Fly Bait in 2 part water was applied on 0.5 to 1 m^2 area under side of the leaf in the citrus tree @7-8 spots/ropani (= 508.7 m^2)/week for ten times. Managerially, Stakeholders' consultation, clustering of orchards for the spray plan, orientation to the spray persons, monitoring of spray and observation and feedback were taken into account for the AWCP campaign. The result of AWCP of Chinese citrus fly (*B. minax*) was effective to minimize the sweet orange infestation of *B. minax* maggots. Citrus growers of Sindhuli district, Nepal and the vicinity of its immediate districts had happily adopted this *B. minax* management technology (Adhikari, Thapa, Joshi, Liang, & Du, 2020a; Adhikari, Thapa, Joshi, Du, & Acharya, 2020b**;** Adhikari, Joshi, Thapa, Pandit, & Sharma, 2020c).

CONCLUSION

Chinese citrus fly (*B. minax*) is one of the major pests of citrus, which causes immense citrus fruit damage in China, Bhutan, Nepal and India. *B. minax* morphologically resembles to *B. tsuneonis*. It has a univoltine life cycle with complete metamorphosis. Inherently, it goes for obligatory diapause for about 6 months in winter. Integration of management measures in community level is important to minimize the loss due to this pest. Protein bait based area-wide control program remarkably minimizes sweet orange fruit damages incurred of *B. minax* maggots.

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