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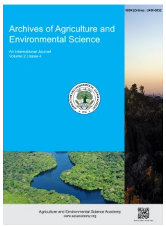

ORIGINAL RESEARCH ARTICLE

CrossMark

Life cycle and eco-friendly management of Chinese fruit fly (*Bactrocera minax*) in sweet orange (*Citrus sinesis* Osbeck) in Nepal

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ABSTRACT

Sweet orange (*Citrus sinensis* Osbeck) is a highly profitable fruit crop of Nepal. However, for the past five years, farmers experienced poor productivity partly attributed to the severe infestation of exotic Chinese fruit fly (*Bactorcera minax*), particularly in Sindhuli and Ramechhap district of Nepal. In this context, we attempted to review on identification, life cycle, and eco-friendly management of Chinese fruit fly. The review is documented based on a field visit and relevant works of literature from Journal articles, books, pamphlets, etc. The Chinese fruit fly has tremendous ability to take a long-range flight, thus, migrated from China to Bhutan and crossing the Indo-Nepal eastern border, finally reached to eastern mid-hills of Nepal. Moderate temperature and low humidity of mid-hills of Nepal are favorable for the exponential growth of the pest. Being sweet orange most preferable commodity, the host range of the fly includes almost all the citrus fruits. The fly has damaged 20-50% of the fruit every year and resulted in a loss of millions of rupees. Therefore various pest management practices can be deployed for sustainable eco-friendly management of the pest. The Chinese fruit fly can be successfully managed by hydrolase protein baits, regular pruning, augmentation of bio-control agents, and using soft systemic insecticides. Various other options for the management of Chinese fruit fly are also discussed with their biological efficacy for the sustainable and eco-friendly management of pests.

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INTRODUCTION

Sweet orange (*Citrus sinensis* Osbeck), belongs to Rutaceae, is originated from south China. Delicious, juicy, and yellow to orange-red aromatic fruit consists of 10-14 segments, enclosed within the peel. Being a mesocarp edible portion, the fruit is categorized as Hesperdium (Goudeau *et al*., 2008). It is commercially grown worldwide, particularly in tropical, semi-tropical, and warm temperate climate (Nicolosis *et al*., 2000). Sweet orange is a rich source of energy, sugars, fat, proteins, vitamins (A, B, C, and E) and minerals like calcium, potassium, iron, zinc, phosphorous and magnesium (Angew, 2007, Etebu and Nwauzoma, 2014; USDA, 2014). The fruit has anti-oxidant, anti-cancer, anti-inflammation, anti- Arteriosclerosis, and anti-obesity properties (Etebu and Nwauzoma, 2014); also, the aroma of sweet orange is used as a tranquilizer for reducing anxiety in humans (Goes *et al*., 2012). Sweet orange, commonly known as Junar, is one of the highly demanded high-value horticultural crops of Nepal. It is cultivated in 48 districts of Nepal; but, the fruits of Sindhuli and Ramechhap district are well known for its quality (Ghimire *et al*., 2006). Farmers have been cultivating Sweet orange for 40 years and they consider the sweet orange (Junar) tree as a gift from their ancestors (Adhikari and Rayamajhi, 2012). The fruit is cultivated in 6991 hectare with a productivity of 10 mt/ha (MoALD, 2017); however, in recent years the productivity of sweet orange is retarding due to the severe infestation of the exotic Chinese fruit fly.
Chinese fruit fly (*Bactrocera minex*) is one of the most economi-

cal pests of citrus in Asia. It belongs to the order Diptera and family tephritidae (Wang and Luo, 1995). Being sweet orange preferable commodity (Xia *et al.*, 2018), the multivoltine fly is oligophagous (Dong *et al.*, 2013). Due to its tremendous ability to take a long-range flight, they were migrated from China to Bhutan (Dong *et al.*, 2014), and crossing the Indo-Nepal eastern border, finally reached to eastern mid-hills of Nepal (Drew *et al.*, 2006; Adhikari and Joshi, 2019). The number of flies will increase exponentially at moderate temperature and low humidity (Xia *et al.*, 2018). Similar climatic condition prevails in mid-hills of Nepal, making favorable for burgeoning fruit fly infestation. It prefers to inert white creamy color 1.2-1.5mm size egg in young, green, soft-skinned tissue of fruits. Then, creamy white larva (12-19 mm in length) developed inside the fruits and finally falls in the soil for pupation (Adhikari and Joshi, 2019). About 20-30% of the fruits of Nepal were damaged by exotic Chinese fruit fly (Adhikari *et al.*, 2018; Adhikari and Joshi, 2019), similar damage was observed in China and Bhutan (Dori *et al.*, 2006; Dong *et al.*, 2014). Xia *et al.* (2018) reported that the pest can even damage 100% of the fruits. There is a paucity of research in the management of Chinese fruit in Nepal and the available literature is basically in the Chinese language. In recent days some farmers of Sindhuli district have done a remarkable job in managing fruit flies. So, the Knowledge on the fruit fly management approach that farmers Sindhuli district has adopted must be disseminated all across the citrus growing farmers of Nepal and even the world. Keeping these scenarios in view, an attempt has been made to review on identification, life cycle, eco-friendly management of Chinese fruit fly.

MATERIALS AND METHODS

Relevant research articles, books, posters, pamphlets, and field observations related to the management of Chinese fruit fly were collected and the major findings were summarized in the text and flow diagram. Secondary data on the production of sweet orange and damage caused by Chinese fruit fly was collected from government sites and presented in the trend graph.

Life cycle of Chinese fruit fly

Chinese fruit fly requires one year completing its life cycle (Figure 1). The pupa overwinters in the soil at the depth of 3-7 cm (Wu *et al.*, 2008), they can remain in the soil for 5 to 7 months (Van Schoubro, 1999). Because of the remarkable ability to lower their respiration rate, pupa of Chinese fruit fly can survive even in high moisture content (Li *et al.*, 2019). The adult emerges from the soil in April/May; their number reached a peak in June/July and starts to decline in august (Van Schoubro, 1999, Dori *et al.*, 2006 and Wu *et al.*, 2008). It is an extremely large species and can be easily distinguished by its morphology. They have yellow scutulum with a narrow red-brown basal band; elongate oval and petiolate abdomen with orange-brown color in third to fifth terga; a moderately broad transverse fuscous band across the anterior margin of the third tergum, and medial longitudinal pale fuscous band over all three terga. The fly has fulvous legs and wings with bc and c fuscous and red-brown scutum with dark brown pattern (Adhikari and Joshi, 2018 and CABI, 2019). The adult of *Bactrocera minax* looks similar to *Bactrocera tsuneonis*, however, tsunesosis differs from minex by the absence of anterior supra-alar setae and female aculenus (Lin *et al.*, 2007) cited by (CABI, 2019). Females mature during late May and they can remain in orchard up to September, but the duration of maturation may vary due to climatic and topographic variation. Male starts to die, during mid-May, after mating (Dori *et al.*, 2006). Oviposition period is mid-June to mid-July (Dori *et al.*, 2006 and Wu *et al.*, 2008) but in Nepal, female oviposit during March to July (Adhikari and Joshi, 2019), during oviposition size of fruit is about 10mm diameter (Dori *et al.*, 2006). It was reported in the mid-hills of Nepal that, the mature female can lay 50 to 200 eggs (Adhikari and Joshi, 2019). With the help of sharp ovipositor, it prefers to inert white creamy color 1.2-1.5mm size egg in young, green, soft-skinned tissue of fruits. After 30 days of oviposition, 12-19mm length creamy white larva developed inside the fruits. The larva feeds on the juice and other contents of mesocarp for 15 days. When they get mature, bore hole in the mature fruit and fall on the soil where they start pupation. The various study revealed that twelve—on average—larva developed inside single fruit (Adhikari and Joshi, 2019). The transmission of fruit fly takes place by the transportation of fruits and pupa brone soil. Besides, the adult can make the long-range flight (CABI, 2019). Gautam *et al.* (2019) reported that the fruit fly count was found higher in 1200 meter altitude from sea level.

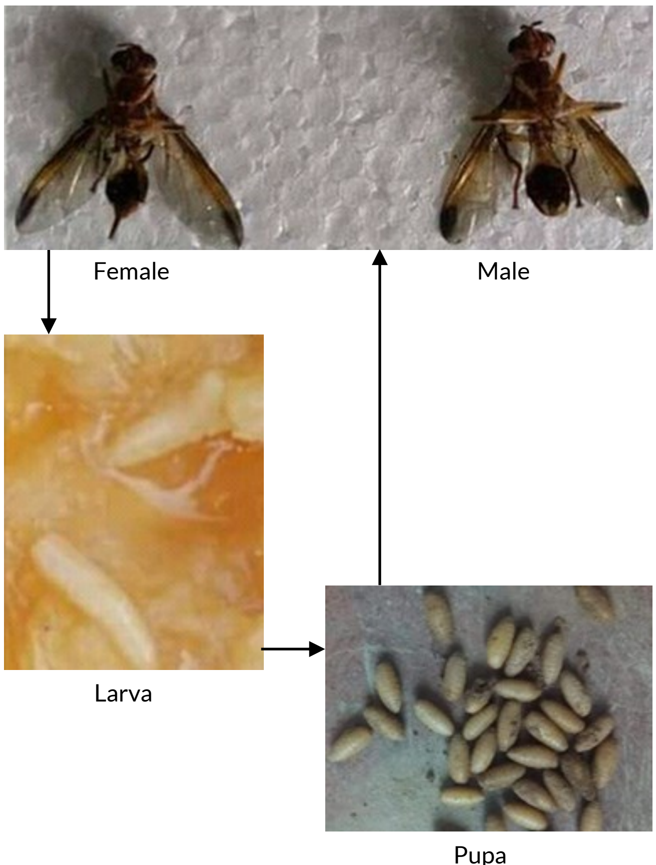

Figure 1. *Life cycle of Chinese fruit fly.*

Extent of damage in Nepal

Despite the increasing trend of the area of cultivation (MoALD, 2017), the production of Sweet orange in the Sindhuli district (the hub of sweat orange) of Nepal has followed retardation gear (Figure 2). Trend analysis depicted that the production of Sweet orange is retarding. The low production can be attributed to the fact that the severe infestation of exotic fruit flies from China. Annually about 30% of fruits get damaged by the exotic Chinese fruit fly (Adhikari *et al.*, 2018 and Adhikari and Joshi, 2019). Similar damage was noticed in china and Bhutan (Dori *et al.*, 2006 and Dong *et al.*, 2014).

Monitoring

The fly prefers to attack Sweet orange, however, the insect attack on almost all citrus fruits (Xia *et al.*, 2018). Most of the fruit fly can be monitored by using sex pheromones and para pheromone; however, *Bactrocera minax* is not known to be attracted to any male lure (Drew *et al.*, 2006 and Zhou *et al.*, 2012). Hydrolysate protein derived from enzymatic industrial processing of beer yeast can be used to monitor the pest; the protein also contains orange juice, brown sugar, and ammonium acetate (Zhou *et al.*, 2012). China made various attempts for monitoring and controlling of the Chinese fruit fly; they have used Sugar-vinegar-wine mixture, Torula yeast, and Jufeng attractant, but, hydrolase protein bait was found most effective (Zhou *et al.*, 2012). Researchers used McPhailtrap containing protein bait (using 25% protein hydrolysate and 0.1% abamectin) for monitoring fruit fly (Newell, 1936 and Gautam *et al.*, 2019). The trap should be installed at the rate of one Mcphail trap per hectare. Brownish color insect with the medial longitudinal pale fuscous band over all three terga, reveals the incidences of fruit fly in an orchard (Adhikari and Joshi, 2018). The recently infected fruit has small holes and they released fluid, such fruits must be monitored and destroyed. If the fruit contains creamy white larva, on cutting the dropped fruit, it reveals the orchard was attacked by the fly (Adhikari and Joshi, 2019). Generally, the infected fruits are light in weight. If such symptoms are seen in an orchard, effective management must be adopted for controlling the further spread.

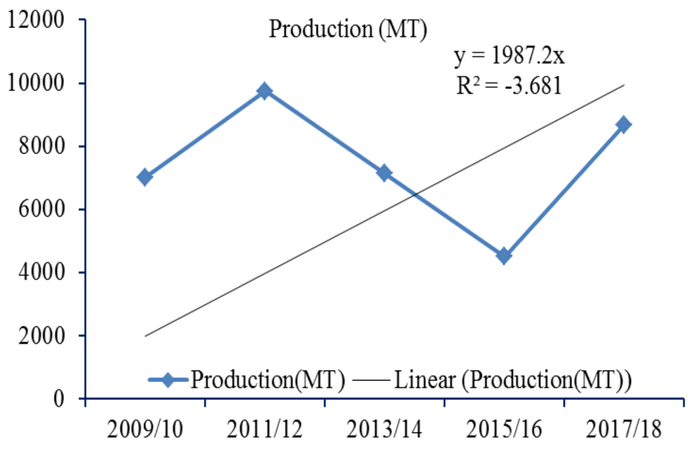

Figure 2. *Production of sweet orange in Sindhuli, Nepal.*

Prevention of spread

Gautam *et al.* (2019) reported that an inappropriate orchard management practice increases the incidence of a fruit fly; therefore, regular training/ pruning operation and a balanced dose of fertilizer are suggested. Training and pruning destroy the place for harboring the insect and a balanced dose of fertilizer helps to rejuvenate the orchard. Maintaining field sanitation reduces the incidence of the fly from 50-100% to 1% (Wang and Luo, 1995) cited by (Xia *et al.*, 2018). Bagging of fruits with wax coated or oil soaked paper, after pollination and development of small-sized fruits, helps to prevent the attack and spread of flies. Sarker *et al.* (2009) reported that the brown paper bag was found effective in controlling the fruit flies. Bagging is not common in citrus; however, it is done basically for obtaining a golden color fruit (Xia *et al.*, 2018). Proper disposal of infected fruits is another measure for the prevention of further spread. Deep burial, tight packaging in polythene plastic, immersing in water, burning, and feeding in hooper of FYM based gas plant can be done for controlling the spread of the pest. Infected fruits (fallen fruit) must be collected and should be buried deep down to the 1-1.5m pit in such a way that the infected fruit remains at least 30cm below the surface. Pupa can not emerge to adults from the soil depth more than 30cm (Darwish *et al.*, 2015). If the procedure of deep burial is followed, the infected fruits can also be used for compost making. Besides, these fruits can also be used as feed in FYM based gas plants for the generation of cooking gas. Liang *et al.* (2010) reported that the packaging of infested fruit in the plastic bag for 120 hours is sufficient to kill 100% of the larva. Similarly, the larva can be killed completely by immersing in water for 20 days (Liang *et al.*, 2010). Quarantine is another measure that can be adopted for controlling the spread of fruit flies during transportation. Quarantine check posts must be established at various locations; moreover, identification and destruction of the infected fruit must be done at every quarantine check post (Figure 3 a,b)

Tight packaging of fruit in plastic bag (a).

Deep burial of the infected fruit (b).

Figure 3 (a, b). *Method to control spread of the pest.*

Management of Chinese fruit fly

Biological management

Tillage, during the winter season, exposes the pupa over the ground surface and they can be managed; by handpicking followed by destruction, exposure to predators, and destruction of habitat (Roger-Estrade *et al.*, 2010). Neem based products can be used for the management of the insect because Neem extract has physiological and behavioral effects on insects. After processing of Neem, Neem oil and Neem cake is obtained; both of them have anti-insecticidal properties. Contact action of Neem seed cake on larva and pupa of fruit cause high larval mortality and delay in pupation (Mahmoud and Shoeib, 2008 and Silva *et al.*, 2011). Dusting Neem (50-60 kg/ha), after harvesting of fruit, in soil damage pupa. Oviposition can be reduced by spraying Neem oil (at the rate of 3 ml/liter) from April to June at a fortnight interval (Adhikari, 2019). Morgan (2009) reported that metabolites like Azadiractin and 3-tigloylazadirachtol present in Neem are responsible for the mortality of pupa. The derivatives of Neem extract cause repellence or oviposition deterrence in fruit flies (Stark *et al.*, 1992 and Silva *et al.*, 2011). The entomopathegenic fungus can also be used for controlling fruit flies. This fungus parasite on the insects and retard their growth and development (Ekesi *et al.*, 2005). Soil treatment with 2-3 kg *Metarhizium anisophilae*, after harvesting of fruits, is proved to be beneficial for managing pupa of fruit fly (Dimbi *et al.*, 2003, Ekesi *et al.*, 2005 and Adhikari, 2019).

Male-sterile technique (SIT)

Sterilization of male is done by irradiation, genetic manipulation, and chemo-sterilization. Sterile males are released in the citrus orchard for mating with the female; after mating, the female either does not lay eggs or lay sterile eggs (Dhillon *et al.*, 2005). The sterile eggs or no production of eggs is due to transmission of dominant lethal mutation that kills the progeny. This technique is best suited for organic farming (Dhillon *et al.*, 2005). Sterile insect technique (SIT) was used in various countries (Klassen, 1994, Walter *et al.*, 2000; Zhou *et al.*, 2012 and Pereira *et al.*, 2013) for management of the insect. But developing countries, like Nepal, could not bear the heavy investment in the production and release of sterile insects.

Using protein bait

Female flies require protein for ovarian development and production of the egg (Mangan, 2003 and Perez-staples *et al.*, 2007). Under natural conditions, these flies get protein from bacteria developed in feces of birds (Drew *et al.*, 1983) cited by (Zhou *et al.*, 2012). But due to the scarcity of such bacteria under natural conditions, these flies can be easily attracted by hydrolysate protein bait. These proteins are derived from enzymatic industrial processing of beer yeast (Zhou *et al.*, 2012). The various attempt has been made in china for controlling of a Chinese fruit fly; they have used sugar-vinegar-wine mixture, Torula yeast, and Jufeng attractant, but Hydrolase protein bait was found to be most effective (Wang *et al.*, 2010; Zhou *et al.*, 2012; Adhikari, 2019 and Adhikari and Joshi, 2019). For the preparation of protein bait, 5-10 ml Protein Hydrolase + 2ml 50 EC Malathion or 0.5 ml chloropyriphos 25 EC or 2-3 ml fipronil 5 SC is mixed in one-liter water (Adhikari and Joshi, 2019). Nowadays Chinese great fruit fly bait is available in the market; it is easier to use, basically for the farmers of developing countries like Nepal. The bait is sprayed when the fruit attained marble size; during this period the female flies become active. Effectiveness of protein bait can be achieved by spraying from April to June (Adhikari and Joshi, 2019). The widespread site-specific technique of spraying protein bait was found effective in the Sindhuli district of Nepal. The procedure of making bait and method of spray is mentioned in the Figure 4.

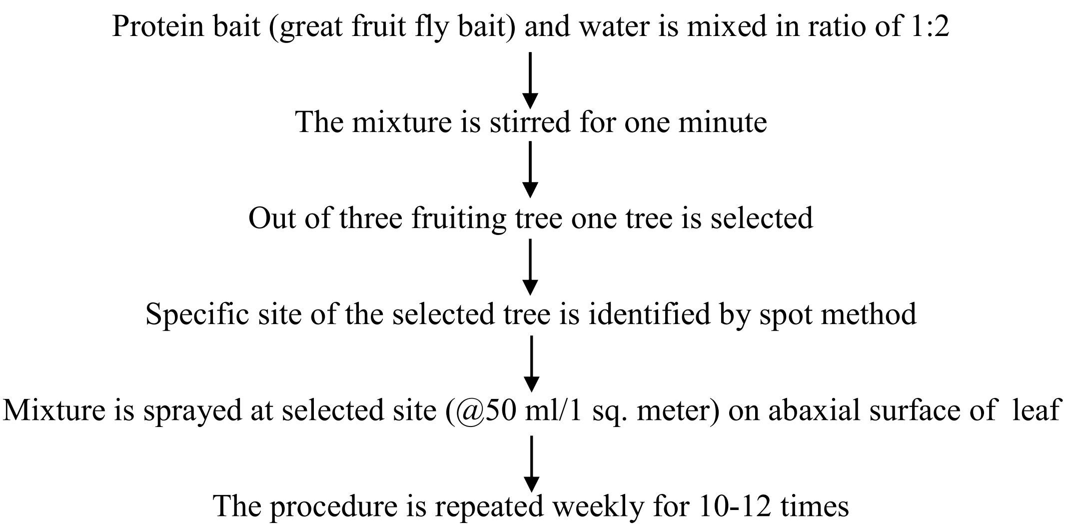

Figure 4. *Procedure for making and spraying protein bait.*

Chemical management

For controlling the emergence of flies from the pupa, dusting 5% Malathion (at the rate of 20kg /hectare) after harvest was found effective (Adhikari, 2019). Similarly, dusting Carbosulfan (75kg/ha) on the soil, spraying 48% chlorpyrifos on the ground is equally effective (Xiang and Zheng, 2008 and Adhikari, 2019). Mass trapping is a common method for the management of fruit flies (Vargas *et al.*, 2002 and Zhou *et al.*, 2012), and can be done by suspending bottles with a solution of trichlorofon + 10% sugar (Xiang and Zheng, 2008). Various chemicals like Imidachloropid and evermectin had a significant repellent effect on female flies; whereas Spinosad, Carbosulfan, Avermectin, and Hexaflumuron had a significant repellent effect on male adult (Shi *et al.*, 2019). Spraying a 1000x solution of 48% chloropyriphos + 3% brown sugar during the mating period was found to be effective for reducing the number of larva in fruits (Xiang and Zheng, 2008). For controlling Chinese fruit fly, in China, Abamectin was proven to be the most potent pesticide; but, for pupa, Chlorpvrifos was effective (Liu *et al.*, 2015). However, Chlorpvrifos being an organophosphorous compound, its use must be restricted because such pesticides have high toxicity and longer residual period (Dhillon *et al.*, 2005 and Liu *et al.*, 2015). It is not advisable to apply a high dose of chemical pesticides as it reduces the population of the beneficial non-target organism and imposes a negative impact on agroecology (Smith and Stratton, 1986, Goulson, 2013 and Chagon *et al.*, 2015).

Conclusion

The Chinese fruit fly can be successfully managed by spraying hydrolase protein baits, using soft systemic insecticides like abamectin, imidchloropid, and spinosad during fly emergence to maturation stage. Also, dusting malathion in the soil during pupation, augmentation of *Metarhizium anisophilae*, and Neem based botanical insecticides are effective for the management of the pest. They can be prevented from the spread by tight packaging of damaged fruits in transparent plastic bags followed by exposing in intense daylight, burning, and deep burying of damaged fruits. Moreover, feeding the damaged fruits to the animal, using as a substrate for production of FYM based cooking gas can also be done for controlling the further spread.

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