



Study on Area Wide Control Programme for Enhancing Mandarin Plantation Productivity in Sikkim

Tashi Choki Bhutia¹, Tabitha Donbiaksiam^{2*}, Passang Tamang³, Tshering Thendup Bhutia⁴, Sangay Bhutia⁵ and Rinkumit Lepcha⁶

¹Deputy Director, Department of Horticulture, Govt. of Sikkim, 737102, India.

²Assistant Professor, FGI, College of Agricultural Sciences, 795106, Manipur, India.

³Additional Director, Department of Horticulture, Govt. of Sikkim, 737102, India.

⁴Principal Director, Department of Agriculture, Govt. of Sikkim, 737102, India.

⁵Inspector, Department of Horticulture, Govt. of Sikkim, 737102, India.

⁶VLW, Department of Horticulture, Govt. of Sikkim, 737102, India.

(Corresponding author: Tabitha Donbiaksiam*)

(Received: 07 June 2025; Revised: 24 July 2025; Accepted: 19 August 2025; Published online: 11 September 2025)

(Published by Research Trend)

ABSTRACT: The Area-Wide Control Program (AWCP) was implemented in the Sikkim region to address the severe infestations of the Chinese citrus fly (*Bactrocera minax*) that significantly impact Mandarin (*Citrus reticulata*) plantations. The program also sought to increase farmer awareness about pest control strategies, empowering them to adopt integrated pest management practices for long-term sustainability. The long-term sustainability of the AWCP lies in its reliance on eco-friendly pest control methods and its ability to engage local farmers in the process. The pilot project, conducted in the Khamdong Block of Gangtok District, employed sustainable pest control methods, including protein baits combined with biological insecticides (Spinosad 45%) and the use of mimic traps for monitoring. Protein baits, which were combined with biological insecticides such as Spinosad 45%, were applied in the orchards. This research highlights the economic and ecological benefits of adopting integrated pest management (IPM) strategies, particularly in regions committed to organic farming. Despite challenges related to the region's terrain and weather conditions, the AWCP proved to be a cost-effective and environmentally sustainable solution. The use of chemical pesticides is not only restricted due to organic certification requirements but also due to the ecological sensitivity of the region. The program successfully reduced the Fruit Damage Rate (FDR) to approximately 20%, leading to increased yields and improved fruit quality in Mandarin. The study further explores the potential for scaling the AWCP to other regions and crops affected by similar pest infestations, emphasizing the long-term sustainability of such programs in enhancing the agricultural productivity.

Keywords: Area-Wide Control Program, *Bactrocera minax*, protein baits, spinosad, biological insecticides.

INTRODUCTION

Mandarin orange (*Citrus reticulata* Blanco), belonging to the Rutaceae family, is one of the most commonly grown citrus fruits in India. Mandarin cultivation in Sikkim has a rich history, dating back to the early 19th century, and continues to be a major economic activity for the state's agricultural sector. Despite its economic importance, mandarin plantations in Sikkim face considerable challenges due to pest infestations, particularly from fruit flies such as *Bactrocera minax* (Dorji *et al.*, 2006; Pandey *et al.*, 2023). The Chinese citrus fly is a major pest not only in India but also in other parts of Asia, including Nepal, Bhutan, and China. It has been reported to be well distributed to a wide range of temperate regions of Asia, including Nepal, Bhutan, China and India (West Bengal and Sikkim) (Fan *et al.*, 1994; Drew *et al.*, 2006).

Pheromone traps are usually used to reduce insect infestations (Sharath *et al.*, 2022) but this pest is particularly challenging because it is not attracted to para-pheromones, unlike other common fruit flies, making conventional control methods less effective (Adhikari *et al.*, 2021). The premature fruit drop results in a reduction in yield, and the damaged fruit cannot be sold, further exacerbating the economic burden on farmers (Xia *et al.*, 2018; Rai & Upadhyay 2025). Traditional pest control methods, such as chemical insecticides, have been employed to combat fruit fly infestations. However, these methods present several limitations, especially in regions like Sikkim, which has adopted organic farming practices. Chemical methods can have adverse environmental impacts, including contamination of soil and water, and can lead to the development of resistance in pest populations over time (Acharya & Shrestha 2021). The use of biological

insecticides such as Spinosad, a naturally derived compound, was crucial in maintaining the organic certification of the orchards, while still effectively managing the pest population (Etebu & Nwauzoma 2014). The present work aims at reducing *Bactrocera minax* infestations in mandarin orchards while enhancing the productivity of the mandarin plantations with an area-wide strategy as it covers large sections of infested orchards, creating a coordinated pest management effort across multiple farms and also increases farmer awareness about pest control strategies, empowering them to adopt integrated pest management practices for long-term sustainability (Devi *et al*, 2022; Pariyar & Goswami 2023). This research shows the effect of approaching infestation in mandarin plantation is a sustainable manner using biological insecticides which are ecologically and economically friendly and increases farmer's income.

MATERIALS AND METHODS

The pilot project for Area wide control program (AWCP) in the Khamdong block of Gangtok district was initiated in 27/03/2023, following reports of significant fruit drops in mandarin orchards due to fruit fly (Table 1). The trial site covers 50 acres of mandarin orchards, situated at an altitude ranging from 739 to 1400 meters above sea level (Fig. 2). The site selection process was based on several factors, including the severity of fruit fly infestations and the willingness of local farmers to participate in the AWCP (Table 2, Fig.1). A preliminary survey was conducted by field staff to assess the infestation levels across the

Khamdong Block, using questionnaires and field visits to document the extent of fruit fly damage in different orchards. A total of 106 households were surveyed, and orchards with the highest fruit fly infestations were identified. The primary method used for controlling *Bactrocera minax* was the application of protein baits combined with the biological insecticide Spinosad 45% (Abdel-Razek & Abd-Elgawad 2021). The application began when the fruit size reached 10-15 mm. The protein bait was mixed with water in a 2:1 ratio (two parts water to one part of protein bait), and the solution was sprayed in small quantities (50 ml per tree) under the leaves of every third productive tree (Fig. 3). Spraying was conducted at weekly intervals over a 10-week period, starting in May 2023 and continuing until July 2023 (Fig. 4) and adequate irrigation is maintained for better soil microbial population and its activity in the soil (Kumar *et al.*, 2024). Mimic traps were also used to monitor the fruit fly population. Red ribbons were used to mark trees that are sprayed. Assessment of efficacy of protein bait application was done by randomly selecting 10 trees at 5 points inside the trial plots/clusters(C) where fruits were randomly selected and cut off for checking symptoms (Table 3). Another way of analyzing fruit damage rate was at harvest season, where just 20 days before harvesting 70 fruits each were randomly selected from 10 trial plots and checked the early ripening fruits and the damage fruit percentage by *Bactrocera minax* (Table 4). Microsoft Excel-97-2003 was used to obtain the mean, standard deviation and standard error of mean for fruit size assessment.

Table 1: Step by Step procedure adopted in the study.

Category	Details	Explanation
Location of Trial Site	Khamdong Block, Gangtok District, Sikkim	The trial site was selected due to high infestation rates of <i>Bactrocera minax</i> . Covering 50 acres, it is located at altitudes of 739-1400 meters above sea level.
Total Area Covered	50 acres	The program targeted a large orchard area to ensure significant pest control impact across multiple farms.
Number of Orchards	177 households surveyed	The survey identified orchards with the highest pest infestation levels for inclusion in the trial.
Altitude	739 to 1400 meters above sea level	Sikkim's mountainous terrain presented logistical challenges for spraying and monitoring.
Survey Methods	Questionnaires, field visits, orchard infestation assessment	Surveys were conducted to determine the extent of <i>Bactrocera minax</i> infestation, helping to select target orchards for the AWCP program.
Protein Bait Composition	Protein bait mixed with water (2:1 ratio)	Protein baits were prepared by mixing two parts water with one part protein bait and applied under tree leaves to attract and kill fruit flies.
Spraying Schedule	50 ml per tree, weekly intervals (10 weeks)	The spraying started when fruits were 10-15 mm in size, and applications were made weekly over a 10-week period from May to July 2023.
Traps Used	Mimic traps placed throughout orchards	Traps were deployed to monitor fruit fly populations, helping to adjust the spraying schedule as necessary.
Biological Insecticide	Spinosad 45% SC	Spinosad is a naturally derived biological insecticide compatible with organic farming, used in combination with protein baits to kill fruit flies.
Spraying Method	Sprayed under leaves of every third productive tree	Trees were selected for spraying based on productivity, with red ribbons marking trees that had been sprayed for accurate tracking.
Organic Farming Compliance	Strict adherence to Sikkim's organic farming regulations	The program followed organic regulations, using only biological and environmentally friendly pest control solutions like Spinosad.
Monitoring Frequency	Weekly monitoring of traps and bait effectiveness	Traps were regularly monitored to measure fruit fly activity and to assess the need for adjusting the pest control approach.
Rainfall Consideration	Avoided spraying during rainy periods	To maximize effectiveness, spraying was avoided during rainfall to prevent the bait from washing away and reducing its impact.

Table 2: Trial site location detail.

Clusters(C)	Spots	Fruit bearing tress
C1-Khamdong	701	1885
C2-Simick Lingzey	631	1719
C3-Ralap	300	968
C4-Beng	661	2133
C5-Ramitey	442	1500
TOTAL	2735	8205

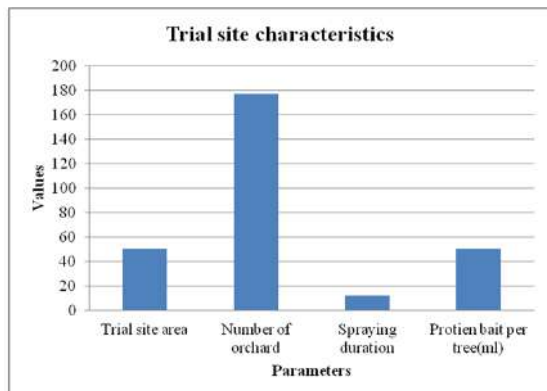


Fig. 1. Trial Site Characteristics (Bar Chart): Shows the area covered, the number of orchards surveyed, the duration of the spraying schedule, and the amount of protein bait applied per tree.



Fig. 2. Altitude Range (Line Chart): Displays the minimum and maximum altitudes of the trial site in Khamdong Block, highlighting the geographical challenge.

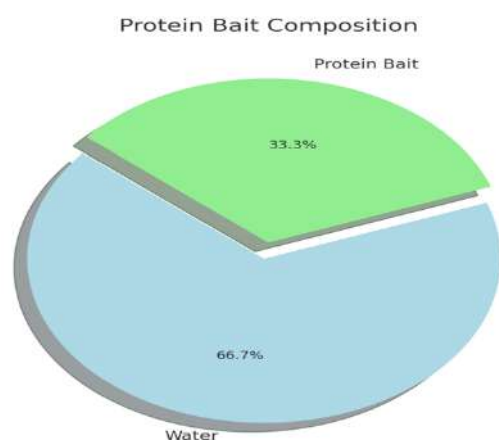


Fig. 3. Protein Bait Composition (Pie Chart): Illustrates the 2:1 ratio of water to protein bait used in the pest control mixture.

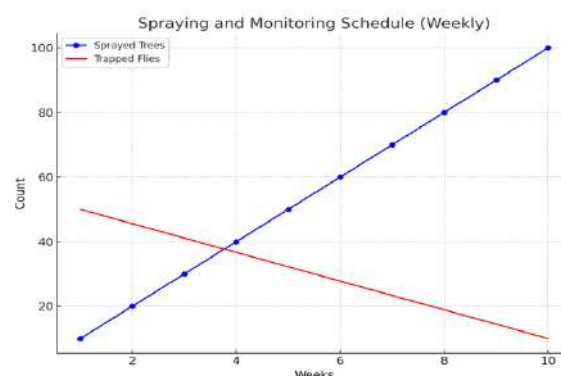


Fig. 4. Spraying and Monitoring Schedule (Line Chart): Tracks the weekly progress of sprayed trees and the reduction in trapped fruit flies over the course of the program.

A critical component of the AWCP was the formation of a specialized sprayer team. This team was composed of local farmers and horticultural staff, who underwent extensive training in pest management techniques. The training sessions included theoretical and practical components, where the participants learned about the life cycle of *Bactrocera minax*, the appropriate use of protein baits and traps, and how to ensure optimal coverage during spraying.

RESULT AND DISCUSSION

The Area-Wide Control Program (AWCP) demonstrated significant effectiveness in managing the infestation of the Chinese citrus fly (*Bactrocera minax*) in mandarin plantations (Vreysen *et al.*, 2007; Ashok *et al.*, 2020). The results from the Khamdong Block pilot project showed a notable reduction in fruit damage, with the Fruit Damage Rate (FDR) decreasing from 70-90% in heavily infested areas to approximately 20% after the intervention. This reduction in damage highlights the efficacy of protein baits and biological insecticides (Spinosad 45%) used in the AWCP. The use of mimic traps to monitor pest populations also allowed for timely adjustments in spraying schedules, further contributing to the program's success (Adhikari *et al.*, 2021). Overall, the program provided substantial relief to farmers, who reported improved yields and marketable fruit quality after the intervention. The fruit bearing trees of Sikkim mandarin are observed in an increasing trend as per the total area covered and productive area of sweet orange cultivation (Table 2). Fruit size is reported to be biggest in C1 and lowest in C3 (Table 3, Fig. 4). The difference in fruit size among the cluster is also based on the location and environmental factor of the site but mostly on the application of the protein bait. The increment in the size of the fruit is as follow C1>C4>C5>C2>C3 and the report of fruit damage rate (FDR) is C1>C2>C3>C5>C4 where C1 shows maximum damage and C4 shows minimum fruit damage. The study reported that there is 20% FDR (Table 4, Fig. 5). This reduction in damage highlights the efficacy of protein baits and biological insecticides (Spinosad 45%) used in the AWCP. Despite its success, the AWCP faced several challenges during its implementation,

particularly due to the terrain and weather conditions in Sikkim. In some areas, the uneven terrain required additional manpower and time to ensure that all trees received adequate treatment. Weather conditions, especially heavy rainfall, further complicated the spraying schedule, as rain often washed away the baits before they could effectively target the fruit flies (Adhikari *et al.*, 2021). To mitigate these challenges, the spraying teams had to adjust their schedules and increase the frequency of bait application during dry periods to maintain effectiveness. There was an initial

resistance from some farmers who were skeptical of the new methods, preferring traditional pest control techniques. However, after witnessing the success of the program in reducing pest damage and improving yields, more farmers became willing to adopt the AWCP techniques. The profit obtained from the implementation of AWCP is recorded (Table 4) and further supports its for sustainable agriculture and also for better income generation for mandarin farmers (Sharma & Sharma 2018).

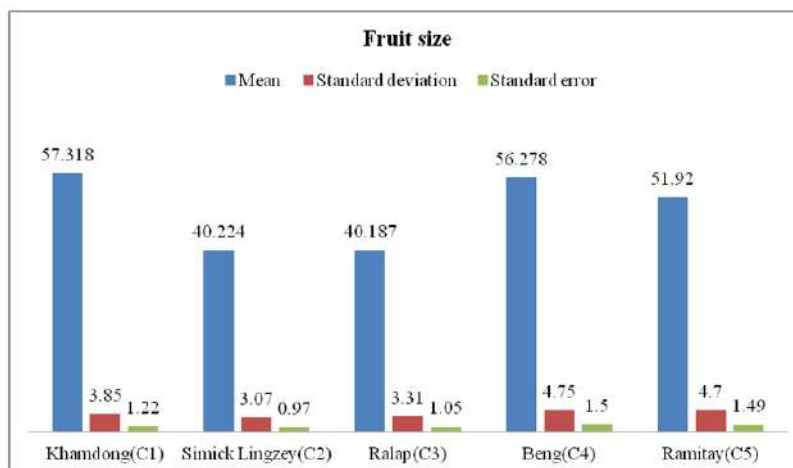


Fig. 4. Fruit size of the Mandarin.

Table 3: Fruit size data.

Fruit sizes of different clusters at maturity(in mm)					
Sr. No.	Cluster1 Khamdong	Cluster 2 Simick Lingzey	Cluster 3 Ralap	Cluster 4 Beng	Cluster 5 Ramitay
1.	60.02	42.08	40.25	50.25	49.23
2.	53.76	40.23	44.05	60.32	52.16
3.	55.56	36.99	39.12	53.14	58.45
4.	53.39	36.36	38.35	55.62	49.36
5.	51.06	42.30	38.25	61.26	55.12
6.	62.03	41.05	40.56	58.02	56.74
7.	62.15	38.97	42.35	52.44	46.23
8.	56.46	36.13	46.33	49.35	44.34
9.	58.73	45.11	35.13	62.03	56.25
10.	60.03	43.22	37.48	60.35	51.32
Mean	57.318	40.244	40.187	56.278	51.92
Standard deviation(SD)	3.85	3.07	3.31	4.75	4.70
Standard error(SE)	1.22	0.97	1.05	1.50	1.49

Table 4: Survey result of Fruit Damage Rate (FDR).

Site	No. of sample fruits	No. of damaged fruits	Fruit damage rate (in %)
C1	70	18	$18/70 = 2.57 \times 100 = 25.7\%$
C2	70	18	$18/70 = 2.57 \times 100 = 25.7\%$
C3	70	15	$15/70 = 2.14 \times 100 = 21.4\%$
C4	70	8	$8/70 = 1.14 \times 100 = 11.4\%$
C5	70	11	$11/70 = 1.57 \times 100 = 15.7\%$
TOTAL	350	70	20%

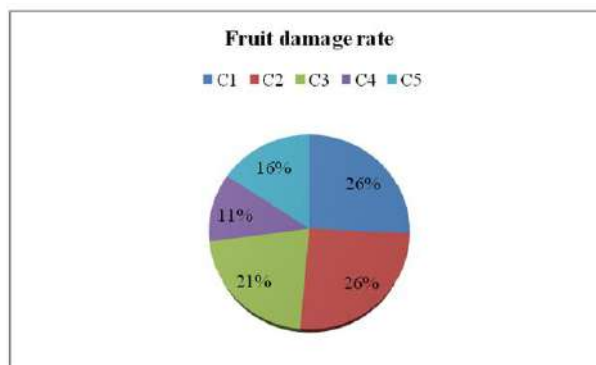


Fig. 5. Fruit damage rate.

Table 4: Survey of Orange production and income generation after the intervention of the department under Area Wide Control Program.

Sr. No.	Production Before Spraying	Production After Spraying (1 st Year)	Income Before the Spray (RS)	Income After the Spray
1.	3000 kg	5000 kg	15000/-	2,50,000/-
2.	600 kg	1900 kg	30000/-	95,000/-
3.	600 kg	1000 kg	30,000/-	50,000/-
4.	600 kg	1000 kg	30,000/-	50,000/-
5.	1800 kg	4400 kg	9000/-	2,00,000/-
6.	800 kg	1200 kg	30,000/-	60,000/-
7.	600 kg	1900 kg	40,000/-	95,000/-
8.	120 kg	300 kg	6000/-	15,000/-
9.	60 kg	300 kg	3000/-	15,000/-
10.	900 kg	1200 kg	35000/-	60,000/-

A. Economic and Ecological Benefits

The AWCP not only succeeded in controlling pest populations but also offered both economic and ecological benefits (Shepard *et al.*, 2014; Tam *et al.*, 2020). By adopting organic pest control methods, such as protein baits and biological insecticides, the program aligned with Sikkim's strict organic farming policies, which prohibit the use of synthetic chemicals. The use of eco-friendly solutions like Spinosad ensured that the pest management approach did not harm beneficial insects or pollute the environment (Cisneros *et al.*, 2002; Sarfraz *et al.*, 2005; Hertlein *et al.*, 2011; Kumar *et al.*, 2022). This method also preserved the organic certification of mandarin farms, allowing farmers to continue accessing premium organic markets and maintaining their livelihoods. Economically, the reduction in fruit damage resulted in higher yields and improved fruit quality, translating to increased income for farmers and similar results is observed worldwide in reduction in fruit damage under AWCP (Mau *et al.*, 2007; Jessup *et al.*, 2007; Lloyd *et al.*, 2010; Dyck *et al.*, 2021). Additionally, the cost-effective nature of the AWCP, which relied on low-cost protein baits and minimal pesticide use, made it a viable long-term strategy for pest management. By avoiding costly chemical treatments, farmers saved on input costs while preserving the ecological integrity of their orchards.

B. Challenges Faced During Implementation

Despite its success, the AWCP faced several challenges during its implementation, particularly due to the terrain and weather conditions in Sikkim. The mountainous landscape made it difficult to uniformly apply protein baits and set up traps across the trial sites. In some

areas, the uneven terrain required additional manpower and time to ensure that all trees received adequate treatment (Barah, 2010; Tarolli and Straffelini 2020). Weather conditions, especially heavy rainfall, further complicated the spraying schedule, as rain often washed away the baits before they could effectively target the fruit flies. To mitigate these challenges, the spraying teams had to adjust their schedules and increase the frequency of bait application during dry periods to maintain effectiveness. Additionally, there was an initial resistance from some farmers who were skeptical of the new methods, preferring traditional pest control techniques. However, after witnessing the success of the program in reducing pest damage and improving yields, more farmers became willing to adopt the AWCP techniques (Adhikari *et al.*, 2022).

C. Potential for Scaling the Program

Given the success of the AWCP in Sikkim, there is significant potential for scaling the program to other regions and crops. The principles of area-wide pest control and the use of organic solutions can be adapted to other fruit crops affected by similar pests, such as oranges, lemons, or even apples, which face threats from various species of fruit flies. Expanding the AWCP to cover a broader geographical area, both within and beyond Sikkim, could further reduce pest populations at a regional level, preventing re-infestation and ensuring sustainable pest control. The organic and sustainable nature of the AWCP also makes it highly adaptable to other states that are embracing organic agriculture. With adequate training and resources, the AWCP model could be replicated in other mountainous or difficult-to-reach areas where conventional pest

control methods are not feasible and new technologies and scientific approach is development to meet the challenges (Klessen and Vreysen 2021; Savadatti *et al.*, 2023; Vahidi *et al.*, 2023). Future efforts should focus on improving logistics for bait application in challenging terrains and enhancing farmer engagement from the outset to increase program acceptance.

CONCLUSIONS

The data of this Area Wide Control Program shows that the application of protein bait solution reduced the average fruit drop rate and helped achieve managing of Chinese citrus fly in Sikkim Mandarin in Khamdong Block. The AWCP and orchard sanitation both the technical and managerial aspects run side by side for successfully reducing the Chinese citrus fly. Protein Bait (Great Fruit Fly Bait) solution is highly effective and convenient for area-wide application, it has an economical and ecological significance in the control of Chinese Citrus fruit fly. It can effectively increase farmer income with improved production efficiency and quality produce. It will result in better reduction of the pest infestation of CCF if applied every year. AWCP includes eco-friendly pest management measures in contrary to traditional blanket pesticide spray therefore it is economically viable and environmentally friendly due to its sustainable approach.

FUTURE SCOPE

The long-term sustainability of the AWCP lies in its reliance on eco-friendly pest control methods and its ability to engage local farmers in the process. By training farmers in integrated pest management (IPM) techniques, the program has equipped them with the skills and knowledge to continue managing pests without resorting to synthetic pesticides, preserving both the environment and the organic status of their farms. This approach ensures that the benefits of the program extend beyond the initial intervention, providing a framework for ongoing pest control and productivity enhancement. The success of the AWCP in Sikkim has broader implications for the agricultural sector, particularly in regions that prioritize organic farming. The adoption of IPM strategies, as demonstrated by the AWCP, offers a viable solution for managing pest populations in a sustainable and cost-effective manner. Future recommendations for pest management in citrus orchards include expanding the program to cover larger areas, improving logistics for challenging terrains, and incorporating newer technologies like remote monitoring to enhance pest control efforts. As more regions move toward sustainable agricultural practices, the AWCP model can serve as a blueprint for integrated pest management across various crops and regions.

Acknowledgement. The authors are thankful to Department of Horticulture and Agriculture, Govt. of Sikkim for funding the research and faculty of FGI-CAS, Manipur for providing academic assistance.

Conflict of Interest. None.

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How to cite this article: Tashi Choki Bhutia, Tabitha Donbiaksiam, Passang Tamang, Tshering Thendup Bhutia, Sangay Bhutia and Rinkumit Lepcha (2025). Study on Area Wide Control Programme for Enhancing Mandarin Plantation Productivity in Sikkim. *Biological Forum*, 17(9): 50-56.