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# EFFECT OF DRONE (UAV) ASSISTED INSECTICIDES APPLICATION ON *Helicoverpa armigera* (HUB.) AND ITS PARASITOIDS IN CHICKPEA

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**ABSTRACT**

A field experiment was carried out in the *rabi* season of 2025-26 at Rameshwara village in Nyamathi taluk, Davanagere district, Karnataka, to evaluate the use of agricultural drone for the application of insecticides to achieve effective control of the chickpea pod borer, *Helicoverpa armigera* (Hub.), and also to examine the effect of this approach on the associated natural enemies. Emamectin benzoate 5% SG was used for the first spray and chlorantraniliprole 18.5% SC for the second spray at recommended dose through a knapsack sprayer and varied doses through an agricultural drone. The application of emamectin benzoate 5% SG at 200 g in 50 L of water per hectare by drone gave the lowest mean larval population of 1.25 larvae per metre row length and a 31.35 per cent reduction compared to the control during the first spray. For the second spray, chlorantraniliprole 18.5% SC at 250 ml in 50 L of water per hectare recorded the lowest mean larval population of 0.78 larvae per metre row length and a 56.56 per cent reduction as compared to the control. When the results from all the treatments were pooled, emamectin benzoate 5% SG at 200 g in 50 L of water per hectare followed by chlorantraniliprole 18.5% SC at 250 ml in 50 L of water per hectare yielded a mean larval population of 1.01 per metre row length and a 44.01 per cent reduction compared to the control. The highest seed yield of 19.70 q/ha, a net return of ¹ 72,766/ha and a benefit-cost ratio of 2.69 were obtained when emamectin benzoate 5% SG at 100 g in 50 L of water per hectare was followed by chlorantraniliprole 18.5% SC at 125 ml in 50 L of water per hectare, and this was done by means of the drone. Among the treated plots, lowest dose via drone had relatively higher populations of *Campoletis chlorideae* Uchida (0.875 per plot) and *Peribaea orbata* (Wiedemann) (0.175 per plot), while higher doses via drone and knapsack sprayer dose had lower populations, none of which were statistically different. The results showed that the amount of insecticide used had an impact on both pest suppression and on the presence of natural enemies. Drone application reduced water demand by 90 per cent and spray operation time by 75 per cent as compared to knapsack spraying. It therefore follows that the use of an appropriate quantity of insecticide via drone application can lead to effective management of *H. armigera*.

***Key words*:** agricultural drone, chickpea, *Helicoverpa armigera*, natural enemies, *Campoletis chlorideae*

## Introduction

Chickpea, which is known as *Cicer arietinum* L., is a pulse crop that is grown widely in India, yet its productivity is limited by a number of insect pests. Of these pests, the gram pod borer, *Helicoverpa armigera* (Hub.), is one of the most damaging since its larvae feed on the leaves, flowers and the developing pods. Damage to the reproductive parts can have a direct effect on seed yield, so effective management at the right time is essential (Kumawat *et al.* (2025)).

The pest is kept in check by a number of parasitoids, predators and pathogens. Chemical insecticides are often used whenever *H. armigera* populations become at economically harmful levels. But the indiscriminate use of insecticides may have an effect on the various biological control agents that occur in nature. As a result, a sound pest management programme must take into account not just the capacity of an insecticide to control the target pest but also its effect on beneficial organisms and the naturally occurring pathogens (Mahajan *et al.* (2025)).

Agricultural drones offer an alternative means of applying pesticides which can greatly decrease the need for carrier water and at the same time improve operational efficiency. Yet, the use of low spray volumes may change the concentration of the spray and affect both the deposition and exposure of target and non-target organisms. It is therefore important to assess different amounts of insecticide when applying it by drone if an effective and practical application method is to be identified.

The study was therefore carried out with a view to assessing various amounts of emamectin benzoate 5% SG and chlorantraniliprole 18.5% SC applied by means of an agricultural drone for the control of *H. armigera* in chickpea, and also to examine the occurrence of some of the main natural enemies, such as *Campoletis chlorideae* Uchida and *Peribaea orbata* (Wiedemann) under the different treatment conditions.

## Material and Methods

The experiment took place in the *rabi* season of 2025-26 in a chickpea field belonging to a farmer in Rameshwara village, Nyamathi taluk, Davanagere district, Karnataka. It was arranged using a restricted randomized complete block design with six treatments and four replications. The experimental area included 24 plots, each measuring 10 by 10 m, and there were 3 m buffer zones between the different treatments and replications. Before taking up of the spray, the parameters of the agricultural drone enclosed in the Table 1 were ensured.

The initial spraying took place when the *H. armigera* population had reached the economic threshold, that is, 1.76 larvae per metre of row length. For the first spraying, emamectin benzoate 5% SG was applied and for the second spraying, which was carried out 15 days after the first spraying, chlorantraniliprole 18.5% SC was used. The treatment details are depicted in Table 2.

The number of *H. armigera* was recorded from selected metre row lengths both before and after spraying, and observations were made at one, five, 10 and 15 days after spraying. The degree of reduction as compared to the control was calculated in order to assess the effectiveness of each treatment.

**Table 1:** Parameters of the agricultural drone used against pod borer in chickpea during *rabi*, 2025-26.

| Type | Hexacopter |
|---|---|
| No. of spray nozzles | 4 |
| Spray nozzle type | Hollow cone |
| Spray rate | 10 L spray solution per acre |
| Flying speed | 3 m/s |
| Wind velocity | < 10 km/hr |
| Flight height | 1.5 m above the crop canopy |
| Pressure | 2 to 3 kg/cm$^3$ |
| Spraying time | 6AM - 10 AM and 3 PM - 6 PM |

In each treatment, natural enemies linked to *H. armigera* were recorded. The observations covered the larval parasitoid, *Campoletis chlorideae* (pupae/plot) and the tachinid parasitoid, *Peribaea orbata* (adults/plot). For recording the observations of tachinids, three pod borer larvae were brought from each treatment to the laboratory at each spraying schedule and looked for the emergence of the parasitoid. As a result, 27 tachinids were evaluated larvae were evaluated for tachinid emergence from each treatment.

The extent of pod damage was determined at harvest by counting the number of damaged pods and the total number of pods. Seed yield was recorded and given as quintals per hectare. For each treatment, the gross return, net return and benefit-cost (B:C) ratio were calculated. Operational efficiency was assessed by referring to the formulae given by Wang *et al.*, (2020) in terms of water and time savings by agricultural drone. Phytotoxicity was evaluated by making visual observations for symptoms such as chlorosis, necrosis, wilting, scorching, hyponasty and epinasty at one, five, 10 and 15 days after spraying.

The pod damage (%) and reduction over control (%) were calculated using the following formulae:

$$\text{Pod damage (\%)} = \frac{\text{Number of infested pods}}{\text{Total number of pods}} \times 100$$

$$\text{Reduction over control (\%)} = \frac{\text{Larval count in control} - \text{Larval count in treatment}}{\text{Larval count in control}} \times 100$$

## Results and Discussion

The efficacy of insecticides applied through drone and knapsack sprayer against pod borer, *Helicoverpa armigera* in chickpea during *rabi* 2025-26 has been presented in Table 3. A clear relationship between the amount of insecticide used and the response was seen during the first spray with emamectin benzoate 5% SG. The treatment which received emamectin benzoate 5%

**Table 2:** Details of insecticidal treatments implemented in the experiment during *rabi*, 2025-26.

| Tr. No. | Treatment details | Plant protection equipment used |
|---|---|---|
| $T_1$ | First spray - Emamectin benzoate 5% SG @ 100 g in 500 L of water<br>Second spray - Chlorantraniliprole 18.5% SC@ 125 ml in 500 L of water / ha | Knapsack sprayer |
| $T_2$ | First spray - Emamectin benzoate 5% SG @ 200 g in 50 L of water<br>Second spray - Chlorantraniliprole 18.5% SC @ 250 ml in 50 L of water / ha | Agricultural drone |
| $T_3$ | First spray - Emamectin benzoate 5% SG @ 100 g in 50 L of water<br>Second spray - Chlorantraniliprole 18.5% SC @ 125 ml in 50 L of water / ha | |
| $T_4$ | First spray - Emamectin benzoate 5% SG @ 75 g in 50 L of water followed by<br>Second spray - Chlorantraniliprole 18.5% SC @ 93.75 ml in 50 L of water/ha | |
| $T_5$ | First spray - Emamectin benzoate 5% SG @ 50 g in 50 L of water<br>Second spray - Chlorantraniliprole 18.5% SC @ 62.5 ml in 50 L of water /ha | |
| $T_6$ | First spray - Emamectin benzoate 5% SG @ 25g in 50 L of water<br>Second spray - Chlorantraniliprole 18.5% SC @ 31.25 ml in 50 L of water / ha | |

SG at 200 g in 50 L water/ha applied by drone had the lowest mean larval population at 1.25 larvae per metre row length (mrl) and the greatest reduction compared to the control, amounting to 31.35 per cent. The next was the drone application of 100 g in 50 L water/ha, which gave a larval population of 1.36 larvae/mrl and a reduction over control of 25.55 per cent. The conventional knapsack application of 100 g in 500 L water/ha yielded 1.40 larvae/mrl and a 23.35 per cent reduction compared to the control. As the amount of insecticide was further reduced, efficacy decreased steadily: at 75 g the number was 1.48 larvae/mrl with a reduction of 18.79 per cent; at 50 g it was 1.58 larvae/mrl and a reduction of 13.46 per cent; and at 25 g the figure was 1.68 larvae/mrl with a reduction of 7.69 per cent. The untreated control had 1.84 larvae/mrl.

The fact that the 200 g dose performed better when applied by drone shows that a low carrier water volume does not necessarily lead to a reduction in the efficacy of the insecticide as long as an adequate amount of active ingredient is delivered. This increased level of suppression could be due to a more even distribution of the spray droplets over the crop canopy and to effective deposition on the plant surfaces. When using a UAV, the spraying is carried out above the canopy, and the airflow produced by the rotors can affect both the movement and deposition of the droplets. According to Wang *et al.*, (2020), as mentioned in the experimental interpretation, optimised UAV flight conditions resulted in better spray deposition and greater canopy penetration than those achieved with conventional application methods. Hence, the current results show that 50 L of water per hectare can be enough for drone based delivery, provided that the amount of insecticide is adequate.

The second application of chlorantraniliprole 18.5% SC gave an even more effective treatment response. When chlorantraniliprole 18.5% SC was applied at a rate of 250 ml in 50 L of water per hectare by means of a drone, it resulted in the lowest mean number of larvae, which was 0.78 larvae/mrl, representing the greatest reduction compared to the control at 56.56 per cent. The drone application using 125 ml in 50 L of water per hectare yielded 0.88 larvae/mrl and a 50.70 per cent reduction over the control, whereas the knapsack treatment with the same amount of 125 ml but in 500 L of water per hectare gave a value of 1.01 larvae/mrl and a 43.44 per cent reduction over the control. As the amount used was reduced, the efficacy decreased gradually, since 93.75 ml produced 1.24 larvae/mrl and a 30.89 per cent reduction, 62.5 ml led to 1.39 larvae/mrl and a 22.21 per cent reduction, and 31.25 ml resulted in 1.46 larvae/mrl and an 18.44 per cent reduction. The untreated control had 1.79 larvae/mrl.

The findings showed that decreasing the volume of the carrier water from 500 to 50 L/ha did not affect the performance of chlorantraniliprole as long as the amount of insecticide remained the same. On the contrary, the drone application of 125 ml in 50 L of water per hectare resulted in a smaller larval population and a greater reduction compared to the conventional method of applying the same quantity in 500 L of water per hectare. It therefore seems that spray volume and insecticide quantity should be treated as separate factors: it is possible to successfully reduce the carrier volume using drone technology, but reducing the amount of insecticide below the effective level gradually impairs pest suppression.

The combined results from the first and second applications still showed that the greater amounts of insecticide were superior in terms of biological effectiveness. The drone application, which used emamectin benzoate 5% SG at a rate of 200 g in 50 L of water per hectare, followed by chlorantraniliprole 18.5% SC at 250 ml in 50 L of water per hectare, gave the lowest pooled larval population of 1.01 larvae/mrl and

the greatest reduction compared to the control, amounting to 44.01 per cent. The drone treatment using 100 g followed by 125 ml in 50 L of water per hectare yielded 1.12 larvae/mrl and a reduction of 38.19 per cent, while the knapsack application with the same amounts produced 1.20 larvae/mrl and a reduction of 33.49 per cent. As the insecticide quantity was further reduced, control became progressively worse, the lowest dosage giving 1.57 larvae/mrl and only a 13.26 per cent reduction over the control, as opposed to 1.81 larvae/mrl in the untreated control.

Pod damage also showed the effect of spray volume, which are displayed in Fig. 1. After the second spraying, the treatment that used chlorantraniliprole 18.5% SC at 250 ml in 50 L water/ha applied by drone had the lowest mean pod damage at 7.14 per cent, this representing a 49.40 per cent reduction compared to the control. The application of 125 ml by drone resulted in 8.27 per cent pod damage and a 41.38 per cent reduction, while the corresponding knapsack application recorded 8.94 per cent pod damage and a 36.63 per cent reduction. As the quantity was reduced, the damage increased progressively, amounting to 11.29 per cent at the lowest rate. These findings show that sufficient insecticide deposition when using low volume drone spraying can offer effective protection for developing pods, something that is especially important since *H. armigera* causes its most economic damage during the reproductive phase. .

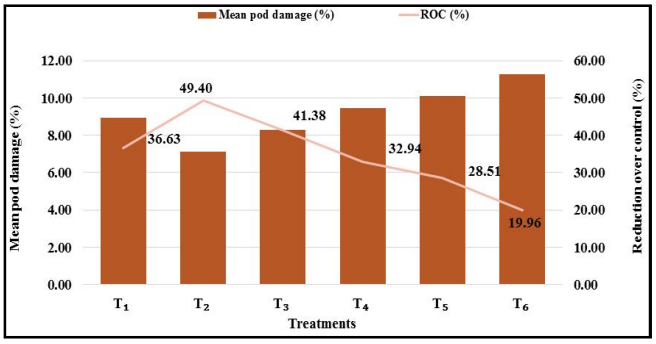



**Fig. 1:** Efficacy of chlorantraniliprole 18.5% SC applied as second spray through agricultural drone at different concentrations and knapsack sprayer on pod damage in chickpea by pod borer during *rabi*, 2025-26.

**Treatment details:** $T_1$: Chlorantraniliprole 18.5% SC@ 125 ml in 500 L of water/ ha as second spray via knapsack; $T_2$: Chlorantraniliprole 18.5% SC@ 250 ml in 50 L of water/ ha as second spray via agricultural drone; $T_3$: Chlorantraniliprole 18.5% SC@ 125 ml in 50 L of water/ ha as second spray via agricultural drone; $T_4$: Chlorantraniliprole 18.5% SC@ 93.75 ml in 50 L of water/ ha as second spray via agricultural drone; $T_5$: Chlorantraniliprole 18.5% SC@ 62.5 ml in 50 L of water/ ha as second spray via agricultural drone; $T_6$: Chlorantraniliprole 18.5% SC@ 31.25 ml in 50 L of water/ ha as second spray via agricultural drone.

Ragiman *et al.*, (2024) observed that drone applied insecticides produced superior damage reduction and benefit-cost ratio compared to manual application in rice ecosystem. These international studies validate the superior performance of drone based chlorantraniliprole application in achieving effective pest management.

Even though the greatest amounts of insecticide were more biologically effective, the economic analysis showed that achieving complete pest suppression did not mean achieving the highest profitability. The cost economics of the experiment are presented in the Table 4. The treatment using emamectin benzoate 5% SG at 100 g in 50 L of water per hectare, followed by chlorantraniliprole 18.5% SC at 125 ml in 50 L of water per hectare, yielded the highest seed output at 19.70 q/ha, which was more than that from the treatment with higher insecticide quantities at 19.21 q/ha. The conventional knapsack application with the same amount of insecticide 100 g plus 125 ml gave a yield of 17.70 q/ha, while the untreated control produced only 11.63 q/ha. The drone treatment with 100 g plus 125 ml produced a value of produce of Rs 1,15,738/ha, a net return of Rs 72,766/ha and a B:C ratio of 2.69. By contrast, the higher quantity treatment obtained a net return of Rs 68,944/ha with a B:C ratio of 2.57. Sabitha *et al.*, (2022) reported that chlorantraniliprole 18.5% SC at optimized dosages was highly effective in reducing the infestation of pests while delivering superior economic returns in rice crop. Kodandaram *et al.*, (2026) similarly reported, in an economic evaluation of pest management modules against the legume pod borer, *Maruca vitrata* (Fab.) in cowpea that a chlorantraniliprole based spray module gave the highest seed yield and the best benefit-cost and incremental benefit-cost ratios among the schedules tested. These findings from a recent, independently conducted pulse crop study reinforce the economic benefits of insecticide schedule and dose optimization observed in the present investigation.

The reason why the 100 g + 125 ml drone treatment is more economical is due to the balance it achieves between good pest suppression and lower insecticide costs. Even though greater amounts of insecticide led to better larval suppression, the extra biological advantage was not enough to offset the higher cost of the insecticide used. The findings therefore indicate that the aim of drone spraying should not be to maximize the amount of insecticide deposited, but rather to find the smallest amount of insecticide which gives sufficient pest control together with the best economic return.

The fact that the drone proved to be more operationally efficient gave it an extra benefit. Using 50 L of water per hectare rather than 500 L of water per hectare led to

**Table 3:** Efficacy of insecticides applied through drone and knapsack sprayer against pod borer, *Helicoverpa armigera* in chickpea during *rabi* 2025-26.

| Tr. No. | Mean number of larvae per one meter row length | | | | | | | | | Mean | ROC* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | First spray: Emamectin benzoate 5% SG | | | | | Second spray: Chlorantraniliprole 18.5% SC | | | | | |
| | 1 DBS* | 1 DAS* | 5 DAS | 10 DAS | 15 DAS | 1 DAS | 5 DAS | 10 DAS | 15 DAS | | |
| $T_1$ | 1.80 (1.52) | 1.55 (1.43) | 1.23 (1.31)$^{abc}$ | 1.10 (1.26)$^{abc}$ | 1.30 (1.34)$^{abc}$ | 0.95 (1.20)$^{bc}$ | 0.80 (1.14)$^{cd}$ | 0.86 (1.17)$^{cd}$ | 1.15 (1.28)$^{abc}$ | 1.20 | 33.49 |
| $T_2$ | 1.78 (1.51) | 1.60 (1.45) | 1.00 (1.22)$^{c}$ | 0.87 (1.17)$^{c}$ | 1.00 (1.22)$^{c}$ | 0.73 (1.11)$^{c}$ | 0.61 (1.05)$^{d}$ | 0.68 (1.08)$^{d}$ | 0.88 (1.17)$^{c}$ | 1.01 | 44.01 |
| $T_3$ | 1.80 (1.50) | 1.63 (1.46) | 1.13 (1.27)$^{bc}$ | 1.05 (1.24)$^{bc}$ | 1.18 (1.29)$^{bc}$ | 0.85 (1.16)$^{c}$ | 0.68 (1.08)$^{cd}$ | 0.71 (1.10)$^{d}$ | 1.00 (1.22)$^{bc}$ | 1.12 | 38.19 |
| $T_4$ | 1.80 (1.52) | 1.59 (1.44) | 1.30 (1.34)$^{abc}$ | 1.20 (1.30)$^{abc}$ | 1.50 (1.41)$^{ab}$ | 1.15 (1.28)$^{abc}$ | 1.02 (1.23)$^{bc}$ | 1.14 (1.27)$^{bc}$ | 1.38 (1.36)$^{ab}$ | 1.36 | 25.00 |
| $T_5$ | 1.73 (1.49) | 1.68 (1.46) | 1.53 (1.42)$^{ab}$ | 1.38 (1.36)$^{ab}$ | 1.58 (1.44)$^{ab}$ | 1.35 (1.35)$^{ab}$ | 1.24 (1.31)$^{ab}$ | 1.38 (1.37)$^{ab}$ | 1.43 (1.39)$^{ab}$ | 1.48 | 18.02 |
| $T_6$ | 1.83 (1.52) | 1.76 (1.50) | 1.61 (1.45)$^{a}$ | 1.53 (1.42)$^{a}$ | 1.68 (1.47)$^{a}$ | 1.05 (1.42)$^{a}$ | 1.48 (1.40)$^{a}$ | 1.55 (1.43)$^{a}$ | 1.55 (1.42)$^{a}$ | 1.57 | 13.26 |
| SEm± | - | - | 0.20 | 0.20 | 0.21 | 0.27 | 0.30 | 0.32 | 0.22 | - | - |
| CD (P=0.05) | NS | NS | 0.59 | 0.59 | 0.64 | 0.81 | 0.92 | 0.97 | 0.66 | - | - |
| CV (%) | - | - | 7.14 | 7.62 | 7.91 | 8.75 | 8.90 | 8.13 | 8.57 | - | - |

*DBS: Day Before Spraying; *DAS: Days After Spray; figures in parentheses are square root transformed values; Means in the columns followed by the same alphabet do not differ significantly by DMRT; *ROC: Reduction over control was calculated by considering observations from an untreated plot

**Treatment details:** $T_1$: Emamectin benzoate 5% SG @ 100 g in 500 L as first spray followed by chlorantraniliprole 18.5% SC@ 125 ml in 500 L of water/ ha as second spray via knapsack; $T_2$: Emamectin benzoate 5% SG @ 200 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC@ 250 ml in 50 L of water/ ha as second spray via agricultural drone; $T_3$: Emamectin benzoate 5% SG @ 100 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC@ 125 ml in 50 L of water/ ha as second spray via agricultural drone; $T_4$: Emamectin benzoate 5% SG @ 75 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC@ 93.75 ml in 50 L of water/ ha as second spray via agricultural drone; $T_5$: Emamectin benzoate 5% SG @ 50 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC@ 62.5 ml in 50 L of water/ ha as second spray via agricultural drone; $T_6$: Emamectin benzoate 5% SG @ 100 g in 25 L as first spray followed by chlorantraniliprole 18.5% SC@ 31.25 ml in 50 L of water/ha as second spray via agricultural drone

a water saving of 90 per cent. The time required for spraying was reduced by 75 per cent as well, and the theoretical field capacity rose from 0.7 ha/h using a knapsack sprayer to 2.7 ha/h using the agricultural drone. This amounts to approximately a three fold increase in field capacity. These kinds of savings are especially important in chickpea production systems since water availability, the availability of labour and the ability to carry out timely pest control can all hinder conventional spraying operations.

The fact that the carrier volume has been reduced should not be taken as a reason for proportionally decreasing the amount of insecticide. It is clear from the results that even though the carrier volume could be reduced from 500 to 50 L/ha, lowering the insecticide below the effective level led to a gradual decrease in pest suppression. For example, in the first spraying, reducing the amount of emamectin benzoate from 200 to 25 g caused the degree of reduction compared to the control to fall from 31.35 to 7.69 per cent. In a similar way, in the second spraying, when the amount of chlorantraniliprole was reduced from 250 to 31.25 ml, the reduction compared to control dropped from 56.56 to 18.44 per cent. It follows that when using low volume spraying, the carrier water should be reduced rather than the insecticide quantity being reduced arbitrarily.

The average occurrence of the two major parasitoids, *Campoletis chlorideae* and *Peribaea orbata*, varied considerably with the insecticide quantity and spray system used in chickpea, which are depicted in Table 5. The conventional method, which involved applying emamectin benzoate 5% SG at a rate of 100 g in 500 L of water per hectare followed by chlorantraniliprole 18.5% SC at 125 ml in 500 L of water per hectare using a knapsack sprayer, yielded 0.175 *C. chlorideae* pupae per plot and 0.05 *P. orbata* adults per plot. Of the drone-based treatments, the one with the highest insecticide rate comprising emamectin benzoate 5% SG at 200 g in

**Table 4:** Cost economics of insecticides applied using agricultural drone and knapsack sprayer in chickpea against pod borer during *rabi*, 2025-26.

| Tr. No. | Yield (q/ha) | Basic Cost of Cultivation (Rs/ha) | Insecticide Cost (Rs/ha) | Application Cost (Rs/ha) | Total Plant Protection Cost(Rs/ha) | Total Cost of Cultivation (Rs/ha) | Gross returns (Rs/ha) | Net Return (Rs/ha) | B:C* Ratio |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | 17.70$^{abc}$ | 40,000 | 1,472 | 1,800 | 3,272 | 43,272 | 1,03,988 | 60,716 | 2.40 |
| $T_2$ | 19.21$^{ab}$ | 40,000 | 2,400 | 1,500 | 3,900 | 43,900 | 1,12,844 | 68,944 | 2.57 |
| $T_3$ | 19.70$^{a}$ | 40,000 | 1,472 | 1,500 | 2,972 | 42,972 | 1,15,738 | 72,766 | 2.69 |
| $T_4$ | 18.30$^{ab}$ | 40,000 | 1,472 | 1,500 | 2,972 | 42,972 | 1,07,513 | 64,541 | 2.50 |
| $T_5$ | 16.85$^{bc}$ | 40,000 | 911 | 1,500 | 2,411 | 42,411 | 98,964 | 56,553 | 2.33 |
| $T_6$ | 15.30$^{c}$ | 40,000 | 911 | 1,500 | 2,411 | 42,411 | 89,888 | 47,477 | 2.12 |

*B:C ratio- Benefit Cost ratio; Means in the yield column followed by the same alphabet do not differ significantly by DMRT

**Treatment details:** $T_1$: Emamectin benzoate 5% SG @ 100 g in 500 L as first spray followed by chlorantraniliprole 18.5% SC @ 125 ml in 500 L of water/ ha as second spray via knapsack; $T_2$: Emamectin benzoate 5% SG @ 200 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC @ 250 ml in 50 L of water/ ha as second spray via agricultural drone; $T_3$: Emamectin benzoate 5% SG @ 100 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC @ 125 ml in 50 L of water/ ha as second spray via agricultural drone; $T_4$: Emamectin benzoate 5% SG @ 75 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC@ 93.75 ml in 50 L of water/ ha as second spray via agricultural drone; $T_5$: Emamectin benzoate 5% SG @ 50 g in 50 L as first spray followed by chlorantraniliprole 18.5% SC @ 62.5 ml in 50 L of water/ ha as second spray via agricultural drone; $T_6$: Emamectin benzoate 5% SG @ 100 g in 25 L as first spray followed by chlorantraniliprole 18.5% SC @ 31.25 ml in 50 L of water/ha as second spray via agricultural drone

50 L of water per hectare followed by chlorantraniliprole 18.5% SC at 250 ml in 50 L of water per hectare had the lowest levels of both parasitoids, with only 0.05 C. chlorideae pupae per plot and no *P. orbata* adults. On the other hand, gradually reducing the amount of insecticide led to an increase in the number of natural enemies. The treatment that used 100 g of emamectin benzoate followed by 125 ml of chlorantraniliprole in 50 L of water per hectare gave a result of 0.20 *C. chlorideae* pupae per plot and 0.05 *P. orbata* adults per plot, while the corresponding lower amounts of 75 g plus 93.75 ml also produced 0.20 and 0.05 individuals per plot, respectively. When the amount was further reduced to 50 g plus 62.5 ml, the number of parasitoids increased to 0.50 *C. chlorideae* pupae per plot and 0.125 *P. orbata* adults per plot. The highest levels were found when the lowest amount of 25 g of emamectin benzoate was used together with 31.25 ml of chlorantraniliprole in 50 L of water per hectare, giving 0.875 *C. chlorideae* pupae per plot and 0.175 *P. orbata* adults per plot. Therefore, the results clearly show a negative relationship between the amount of insecticide and the occurrence of the parasitoids, with smaller amounts of insecticide promoting greater survival and activity of both *C. chlorideae* and *P. orbata*. Moreover, the drone application using 50 L of water per hectare achieved either similar or higher levels of parasitoid occurrence than the conventional application using 500 L of water per hectare when the insecticide amount was the same, showing that the reduction in the volume of carrier water by itself does not always lead to greater suppression of these natural enemies.

The phytotoxicity tests showed that all the spray concentrations tested were safe for chickpea under the experimental conditions in question. When emamectin benzoate was applied at rates between 0.5 and 4.0 g/L and chlorantraniliprole at rates between 0.625 and 5.0 ml/L, there were no visible signs of chlorosis, necrosis, wilting, scorching, hyponasty or epinasty during the observations made at 1, 5, 10 and 15 days after spraying. This therefore proves that the low volume drone applications tested did not result in any observable phytotoxic effects on the crop during the course of the experiment. Das and Borah (2018) reported similar safety profiles for nereis toxin analogues in pulse crops, observing no phytotoxic symptoms when cartap hydrochloride was applied to paddy crop. Tigga *et al.*, (2018) reported similar safety outcomes with imidacloprid based applications in rice, supporting the general safety profile of modern insecticides belonging to different chemical classes. The consistent absence of phytotoxicity across spray volume variations in the present study, corroborated by international research findings, provides confidence in optimizing application rates without compromising crop health. These findings validate the principle of selective toxicity in modern insecticide development and confirm that chlorantraniliprole and emamectin benzoate are safe for chickpea crops, even at doses significantly exceeding the recommended field rate.

The overall findings are in agreement with the idea that UAV based spraying can increase the efficiency of pesticide application provided that the flight conditions, droplet deposition, amount of insecticide and the volume

**Table 5:** Average number of natural enemies of pod borer encountered during the study in chickpea during *rabi*, 2025-26.

| Tr. No. | Treatment details | PPE | CC | PO |
|---|---|---|---|---|
| $T_1$ | First spray of emamectin benzoate 5% SG @ 100 g in 500 L of water followed by chlorantraniliprole 18.5% SC@ 125 ml in 500 L of water/ ha as second spray | Knapsack sprayer | 0.175 | 0.05 |
| $T_2$ | First spray of emamectin benzoate 5% SG @ 200 g in 50 L of water followed by chlorantraniliprole 18.5% SC @ 250 ml in 50 L of water/ ha as second spray | Agricultural drone | 0.05 | 0 |
| $T_3$ | First spray of emamectin benzoate 5% SG @ 100 g in 50 L of water followed by chlorantraniliprole 18.5% SC @ 125 ml in 50 L of water/ ha as second spray | | 0.2 | 0.05 |
| $T_4$ | First spray of emamectin benzoate 5% SG @ 75 g in 50 L of water followed by chlorantraniliprole 18.5% SC @ 93.75 ml in 50 L of water/ha as second spray | | 0.2 | 0.05 |
| $T_5$ | First spray of emamectin benzoate 5% SG @ 50 g in 50 L of water followed by chlorantraniliprole 18.5% SC @ 62.5 ml in 50 L of water/ha as second spray | | 0.5 | 0.125 |
| $T_6$ | First spray of emamectin benzoate 5% SG @ 25g in 50 L of water followed by chlorantraniliprole 18.5% SC @ 31.25 ml in 50 L of water/ha as second spray | | 0.875 | 0.175 |
| PPE: Plant protection equipment used; CC: *Campoletis chlorideae* (pupae/plot); PO: *Peribaea orbata* (adults/plot) | | | | |

of the carrier solution are properly optimised. This study has shown that the use of drones with 50 L of water per hectare is capable of achieving effective suppression of *H. armigera* while at the same time greatly reducing water use and the time required for application. Yallappa *et al*., (2025) have also reported similar advantages of using UAVs for pesticide application, having demonstrated effective application of chlorantraniliprole by UAV at about 47 L/ha in groundnuts. Nevertheless, the current results stress that the success of low volume application relies on keeping an adequate amount of active ingredient and making sure that the canopy is uniformly covered.

When evaluating the biological effectiveness, pod protection, seed yield, economic returns, operational efficiency and the presence of parasitoids, the use of emamectin benzoate 5% SG at a rate of 100 g in 50 L of water per hectare, followed by the application of chlorantraniliprole 18.5% SC at 125 ml in 50 L of water per hectare, by means of an agricultural drone, proved to be the most appropriate treatment under the conditions of the present study. Even though the higher amounts of 200 g followed by 250 ml led to greater suppression of *H. armigera*, they did not result in the highest seed yield or the best economic return and were linked to a lower occurrence of *C. chlorideae* and *P. orbata*. It was therefore the 100 g plus 125 ml combination that offered a more favourable balance between pest control and crop productivity, while achieving a 90 per cent saving of water, a 75 per cent reduction in spray operation time, a field capacity of 2.7 ha/h, a seed yield of 19.70 q/ha, a net return of Rs 72,766/ha and a B:C ratio of 2.69.

It is therefore practical to use a spray volume of 50 litres of water per hectare in the application of agricultural drones in chickpea, on the condition that the amount of insecticide is optimised. The results make it clear that reducing the volume of the carrier water can considerably enhance operational efficiency without necessarily leading to a decrease in pest control performance, although a excessive reduction in the quantity of insecticide results in a loss of efficacy. The findings thus support the use of optimised, low volume spraying by drone as a resource efficient method for the management of *H. armigera* in chickpea.

## Conclusion

This study showed that the use of agricultural drones could effectively control *H. armigera* in chickpeas when using just 50 litres of water per hectare, leading to significant reductions in both water usage and the time required for spraying. Application of emamectin benzoate 5% SG at a rate of 200 g in 50 litres of water per hectare, followed by chlorantraniliprole 18.5% SC at 250 ml in 50 litres of water per hectare, via drone, gave the highest biological effectiveness, the pooled larval population being 1.01 larvae per mrl and representing a 44.01 per cent decrease compared to the control.

The inclusion of observations on natural enemies gave a more comprehensive evaluation of how the treatments performed. The untreated control had the highest number of *C. chlorideae* and *P. orbata*, whereas $T_2$ which achieved the best pest control had only 0.50 *C. chlorideae* per plot and no *P. orbata*. On the other hand, $T_6$ had 8.75 *C. chlorideae* per plot and 5.00 *P. orbata* per plot, showing a relatively higher presence of parasitoids at the smaller insecticide doses.

The combination of applying emamectin benzoate 5% SG at a rate of 100 g in 50 L of water per hectare, followed by the use of chlorantraniliprole 18.5% SC at 125 ml in 50 L of water per hectare by means of a drone, gave the most favourable overall balance between pest control and crop performance. This treatment yielded

1.12 larvae per mrl, a seed yield of 19.70 q/ha, a net return of Rs 72,766 per hectare and a B:C ratio of 2.69.

The findings from the natural enemy experiment show that the amount of insecticide used should be optimised rather than being decided on the basis of achieving the highest possible mortality of the pest. A treatment which achieves adequate suppression of *H. armigera* while still allowing some biological control to take place might be more appropriate for inclusion in an integrated pest management programme. For the conditions of the present study, the combination of 100 g emamectin benzoate plus 125 ml chlorantraniliprole applied via drone using 50 L of water per hectare provides a promising balance between efficacy, yield, economic considerations and the occurrence of natural enemies.

Overall, drone assisted insecticide application represents a promising resource efficient technology for chickpea pest management, with 90 per cent water savings and a 75 per cent decrease in the time needed for spraying. It is nevertheless necessary to go along with the appropriate choice of the amount of insecticide and to take into account the naturally occurring parasitoids in order to achieve a more sustainable management of *H. armigera*.

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## References

Das, P. and Borah B. (2018). Bio-efficacy and phytotoxicity of cartap hydrochloride 50% + buprofezin 10% WP against yellow stem borer of rice. *J. Entomol. Zool. Stud.*, **6(6)**, 410-413.

Kodandaram, M.H., Wangi N., Sabale P.R., Manu B. and Revanappa B. (2026). Development of pest management modules and their economic evaluation for legume pod borer, *Maruca vitrata* (Pyralidae: Lepidoptera) in cowpea (*Vigna unguiculata*). *Indian J. Agric. Sci.*, **96(1)**, 101-105.

Kumawat, S., Sharma S.L., Kumari H., Naga B.L., Meena R.K. and Meena S.K. (2025). Population Dynamics of *Helicoverpa armigera* (Hubner) in Chickpea. *Indian J. Entomol.*, **87(2)**, 470-473.

Mahajan, G., Dwivedi S.A., Shaniware Y., Bachhav S. and Kale D. (2025). Integrated management and seasonal dynamics of *Helicoverpa armigera* in chickpea: a review. *J. Sci. Res. Rep.*, **31(6)**, 96-102.

Ragiman, S., Talluri K.B., Varma N.R.G. and Sagar V.B. (2024). Unmanned aerial vehicle (UAV)-assisted pesticide application for pest and disease prevention and control in rice. *Int. J. Agric. Biol. Eng.*, **17(5)**, 88-95.

Sabitha, C., Dhurua S., Sreesandhya N. and Suresh M. (2022). Bio-efficacy of insecticide and fungicide mixtures against leaf folder, stem borer, BPH and sheath blight of rice. *J. Entomol. Zool. Stud.*, **10(2)**, 139-143.

Tigga, V., Kumar A., Sahu P.S., Khan H.H. and Naz H. (2018). Assessment of the efficacy of certain chemical insecticides against rice gundhi bug, *Leptocorisa acuta* (Thun.) in Naini, Allahabad region. *Int. J. Chem. Stud.*, **6(1)**, 959-961.

Wang, G., Li X., Andaloro J., Chen P., Song C., Shan C., Chen S. and Lan Y. (2020). Deposition and biological efficacy of UAV-based low-volume application in rice fields. *Int. J. Precis. Agric. Aviat.*, **3(2)**, 65-72.

Yallappa, D., Veerangouda M., Maski D., Palled V., Bheemanna M., Sushilendra, Ravi Y., Badgujar C.M. and Ashoka N. (2025). Experimental investigation of drone-based insecticide application for effective pest management in groundnut field crop. *J. Agr. Eng.*, **62(1)**, 1-15.