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Feasibility study on hexacopter UAV based sprayer for application of environment-friendly biopesticide in guava orchard

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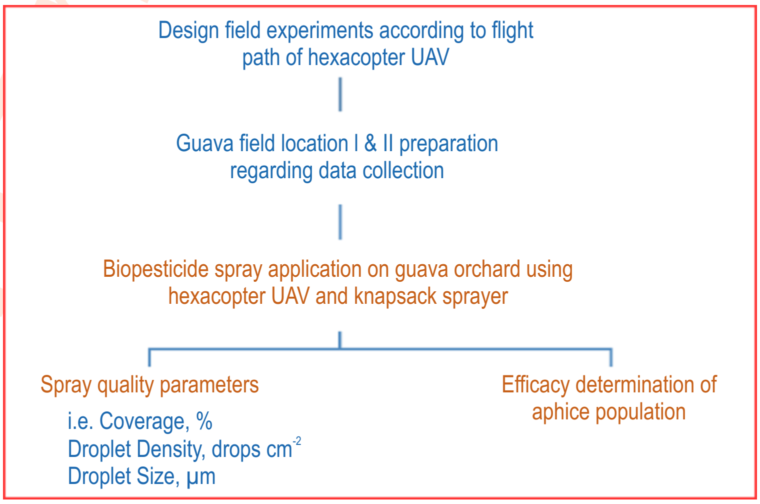
Abstract

Aim: To study the feasibility of hexacopter UAV based sprayer for application of environment-friendly biopesticide in guava orchard.

Methodology: Field experiments were conducted in Punjab (India) during 2020. UAV was evaluated for spraying environment-friendly bio-pesticidein guava orchard. UAV was operated at 2.0 m height above the tree top.The water and oil sensitive papers were fixed on the outer side as well as inside of selected guava trees at four different canopies. Organic neem seed kernel based azadirachtin 0.15% EC biopesticide was used at recommended dose. After spraying, all water and oil sensitive papers were collected for further laboratory analysis. All spray quality parameters, *i.e.,* coverage (%), droplet density (droplets cm^{-2}), droplet size (µm) and uniformity coefficient were determined. For the efficacy of drone sprayer insects were counted before and 1, 2, 7 days after spray (DAS) and reduction in number of insects was calculated.



Results: The on-flight field capacity of spraying with UAV was 3.0-3.3 ha h^{-1} whereas actual field capacity was found to be 2.0-2.3 ha h^{-1}. The total mean coverage area was found in the range of 2.67-10.67%. The maximum coverage was at the top canopy (inner and outer) of tree which was significantly higher than all other observation points on the canopy. The mean droplet density was found in the range of 14.67-28.33 droplets cm^{-2}. The highest droplet density (28.33 droplets cm^{-2}) was found at the top outer side of the tree canopy. The volume median diameter was found in the range of 208.0-418.3 µm whereas, number median diameter was in the range of 138 to 269 µm. The percent reduction in aphid population 1, 2 and 7 days after spray (DAS) was 38.06, 68.28 and 62.69%, respectively whereas it was 47.95, 78.69 and 70.90% with knapsack sprayer.

Interpretation: Hexacopter UAV sprayer is effective in terms of quality of spray and effective control of aphid population.

Key words: Aphid, Bio-efficacy, Droplet density, Drone spraying, Hexacopter UAV

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Introduction

Pests and diseases significantly affect agricultural production and account for about 30% of crop loss globally (Godfray *et al.,* 2010). Therefore, the prime objective of researchers is to adopt an efficient crop protection technology that can effectively control plant pests and diseases for sustainable agricultural productivity. For many years manned aircraft have been utilized in agriculture to collect aerial imagery or carry spraying systems over large areas in short period of time (Huang *et al.,* 2013). Manned aircraft require large open areas for safe operation, leaving smaller fields to be sprayed with conventional ground equipment, which now can be managed using smaller unmanned aerial vehicles. Use of unmanned aerial vehicle (UAV), commonly known as drone, is an emerging practice in many developed countries and in developing country like India (Li *et al.,* 2019). UAV is a remotely controlled aircraft, operated semi-autonomously or autonomously, with no human pilot on-board (Eisenbeiss, 2004; Parmar, 2021). There are wide varieties of UAV and they continue to be used extensively in martial and civilian applications. On a broader scale, they are classified as rotary-wing and fixed-wing aircraft.

Aerial pesticide applications from manned aircraft are considered extremely dangerous due to their high frequency of accidents (Mannarino *et al.,* 2017). The hazards along with the requirement of expensive equipment and personnel to conduct manned aerial applications makes them an expensive option. Aerial applications with UAVs are considered a safer alternative to manned aircraft due to lack of an on-board pilot (Faical *et al.,* 2017; He, 2018) and hence restriction to human touch with fertilizers, pesticides, and other dangerous substances (Shilin *et al.,* 2017). Geographical tracking, field mapping, crop monitoring and precision farming are a few sectors where UAVs play a massive role. UAVs are extensively being developed to support the practice of precision agriculture as overuse of agricultural chemicals is being avoided via reducing and optimizing the inputs (Huang *et al.,* 2013). UAVs apply a lower spray volume of pesticide than conventional aerial or ground-based applications, and at an application height lower than aerial but higher than ground-based applications (He, 2018). In orchards, the application of crop protection chemicals is being done using various types of agricultural machines like knapsack sprayers, foot pump operated sprayers, tractor operated hydraulic sprayers, self-propelled power sprayers etc.

The use of hydraulic sprayer creates widespread concern regarding the negative environmental consequences of agrochemicals in liquid form (Panneton *et al.,* 2005) and the use of a conventional type of sprayer create problems like chemical wastage viz-a-viz environment contamination, health hazard and not upholding the end-use quality in orchards (Martinez-Guanter *et al.,* 2020). During spraying operation, even a low level of exposure to pesticides may lead to adverse health effects. However, the use of UAVs/drones for spraying pesticides can reduce farmer's contact with the chemicals (Giles and Billing, 2015). It can also improve the spraying operation by avoiding the application of pesticides outside the desired area. Drones can lift considerable payload at one time and can cover a larger area in a single go. It could be more convenient for farmers to program the drones in a predefined pattern according to their farm boundary and let the drone fly over the selected area for pesticide application. Drone spraying has its own advantages like greater efficiency, mobility and larger area coverage in lesser time (Guo *et al.,* 2019).

Researchers have conducted experiments on chemical spraying with UAV based sprayers in different crops. Qin *et al.* (2018) conducted study in wheat crop to control powdery mildew. Lou *et al.* (2018) conducted experiment on cotton crop to find the effect of flying height on droplet distribution, drift and control of cotton aphids and spider mites. Chen *et al.* (2016) studied the effect of spray parameters of small unmanned helicopter on distribution regularity and droplet deposition in hybrid rice canopy. Chen *et al.* (2017) and Zang *et al.* (2015) conducted field experiments on UAV based spraying technology in citrus orchards. Martinez-Guanter *et al.* (2020) reported no difference in chemical application cost of the aerial platform and conventional equipment in citrus orchards. Tang *et al.* (2018) reported benefits of UAV based spraying in orchards in terms of spraying quality, timeliness, effectiveness, reduction in labour cost and protection of operator from harmful chemicals. In most of the cases hazardous chemicals were used to control insect-pests. Keeping that in view, a projecton UAV mounted sprayer for spraying environment-friendly biopesticide in guava orchards, was initiated. The UAV used was a hexa-copter and we worked out the technical details of the complete system. The main objective of this study was to check the feasibility of Hexacopter UAV based pesticide spraying system to control the aphid population and assess spray quality in guava orchard.

Materials and Methods

Description of UAV and spraying system: The vertical take-off and landing (VTOL) type hexa-copter drone was used for sparing in orchards. The drone was powered with two Lithium Polymer (LiPo) batteries. Its maximum payload capacity was about 24 kg. The UAV was capable of stable flights with the wireless radio control system. The hexa-copter UAV comprised of several components like, frame having foldable size of 800 x 700 mm, fuselage, landing gear, armsand propellers.It was powered by two lithium polymer batteries having 16000 mAh capacity and having nominal voltage 44.4 V. Its maximum flight duration, with payload, was about 12-15 min and was having communication range within 1 km area. The spraying system of UAV comprised of pesticide tank having 10 l capacity, a 12V DC diaphragm pump and four ultra-low volume (ULV) nozzles fitted on carbon fibre boom with nozzle discharge rate of 0.85 l min^{-1}. It covered 3.5 m swath width area at 2.0 m flying height above the canopy. The stationary view of the system is shown in Fig. 1.

Performance evaluation of Hexa-copter UAV based spraying system: To study the performance of UAV for spraying in orchards, initial field trials were conducted at farmer's field at village Sheikhpura (Location I), District Bathinda, Punjab. Elaborative study to analyse spray quality parameters and bio-efficacy in guava orchard was conducted at Research Farm of School of Organic Farming (Location II), Punjab Agricultural University, Ludhiana, Punjab. At location I, insecticide (Confidor 17.8 SL) was sprayed using hexacopter UAV based sprayer in guava orchard having trees of age 8 years.

The average height of the trees was 4.20 m and UAV was operated at 2.0 m height above the tree top. At location II, the hexacopter UAV was evaluated for spray of environment-friendly biopesticide (*i.e.,* neem leaf extract) in guava orchard having trees of age 3 years with a mean tree height of 2.6 m. As a control, biopesticide was also sprayed using conventional manually operated knapsack sprayer for comparison purpose. The tree height was measured using standard measuring tape from 10 different trees at each location and its mean was taken. The hexacopter UAV was operated at 2.0 m height above the treetop.The theoretical and actual field capacity of the hexacopter UAV was calculated as per the standard formulas and method prescribed by Padmanathan and Kathirvel (2007). The average tree to tree spacing was 5 m whereas the average row to row spacing was 6 m. The experiments were conducted during days with low to no wind at a low elevation in an area surrounded by reasonable tree wind-breakers to protect the experimental area from unwanted wind. Field parameters of two guava orchards is given in Table 1.

Before the flight, UAV spraying system pre-flight check was done. The GPS coordinates of the field were noted down with the help of hand-held GPS. Water and oil sensitive papers were fixed on the outer side as wellas inside of selected guava tree sat four different canopies (*i.e.,* top, middle, bottom and centre) using binder clips. Total of seven water and oil sensitives strips were clamped on each tree. Organic neem seed kernel based (Azadirachtin 0.15% EC) was used as an insecticide and recommended dose was prepared for location II. After spraying with drone based spraying system, all water and oil sensitive papers were collected for further laboratory analysis. The rubber gloves were indispensable during the process of collecting water and oil sensitive papers. A 600-dpi digital image of each water and oil sensitive paper was acquired with a handheld scanner in the laboratory. All spray quality parameters *i.e.,* coverage (%), droplet density (droplets cm^{-2}), droplet size (µm) and uniformity coefficient were determined using Drop Scan software (Zhu *et al.,* 2011). The deposit structure plays a major role in the toxin efficacy (Ebert *et al.,* 1999). For the efficacy of drone sprayer, insects were counted before and 1, 2, 7days after spray (DAS) and reduction in number of insects was calculated as per method described by Qin *et al.* (2016). Split plot design was used to analyze the data from field trials and interactions between the factors were determined. The data were transformed to square root transformation before statistical analysis and then comparison between treatments was done using analysis of variance (ANOVA). All the experiments were replicated thrice for each treatment. IBM SPSS Statistics V22.0 software was used for analysis of variance and for comparison of mean values at 5% level of significance.

Results and Discussion

To enhance the spray deposition and to minimize the drift losses, researchers have suggested operating parameters for UAV spraying system as 2.0 to 3.0 ms^{-1} flying speed and 2.0 to 3.0 m flying height above crop canopy (Parmar, 2019), Yallappa *et al.,* 2017; Chen *et al.*, 2020) Lou *et al.* (2018) also suggested UAV flight height of 2.0 m above plant canopy for higher droplet uniformity, coverage, and lesser drifting loss. Keeping in view, the hexacopter UAV based sprayer was operated at 3.0 m s^{-1} flying speed and at a flying altitude of 2.0 m above the target area, *i.e.,* guava tree as per the experimental design. The trials for field evaluation of hexacopter UAV for spraying in guava orchards were conducted as per the method prescribed by Shilin *et al.* (2017). The results of the field experiments are given in Table 2. The on-flight field capacity of spray with hexacopter UAV was 3.0-3.3 ha h^{-1} whereas actual field capacity (without considering battery charging time) was 2.0-2.3 ha h^{-1}. The actual field capacity of hexacopter UAV was analogous to that stated by Meivel *et al.* (2016) who developed spraying system for quadcopter type UAV and reported the actual field capacity of 2.1-3.0 ha hr^{-1}.

Table 1: Crop and field parameters

Parameters	Specification: Location I	Specification: Location II
Fruit tree (variety)	Guava (Allahabad Safeda)	Guava (Variety - Shweta)
Average age, years	8	3
Avg. height of crop, cm	420	260
Row to row spacing, cm	600	600
Tree to tree spacing, cm	500	500
Tree canopy width, cm	400	300
Type of spray	Insecticide [Confidor 17.8 SL (Imidacloprid)]	Biopesticide (Neem Kavach, 0.15%)

Table 2: Field performance of hexacopter UAV for spraying in guava orchard

Parameter	Results
Drone speed, (ms^{-1})	3
Area covered, (ha)	1
Insecticide sprayed (2 flights), l	9 + 8 = 17
Theoretical (on-flight) field capacity, ($ha\ h^{-1}$)	3.0-3.3
Actual field capacity*, ($ha\ h^{-1}$)	2.0-2.3
Drone height above plant top, (m)	2.0
Spray rate, ($l\ min^{-1}$)	1.96-2.36
Swath width, (m)	2.5-3.0

***Note:** This includes take-off and landing time, time delay during turning at waypoints, tank filling/re-filling time, UAV pre-checking time and setting of ground control station (software); This does not include battery charging time and UAV assembly/dis-assembly time

Table 3: Spray quality parameters in guava tree canopy

Canopy	Coverage (%)	Droplet Density (droplets cm^{-2})	NMD (µm)	VMD (µm)	Uniformity Coefficient
Top outer	10.67^{a}	28.33^{a}	269.0^{ab}	418.3^{ab}	1.63^{a}
Top inner	10.67^{a}	14.67^{b}	187.7^{b}	260.7^{b}	1.38^{a}
Middle outer	7.67^{ab}	19.67^{ab}	211.0^{a}	450.3^{a}	2.13^{a}
Middle inner	6.67^{b}	14.67^{b}	167.7^{b}	289.7^{b}	1.71^{a}
Bottom outer	4.67^{bc}	20.67^{ab}	169.3^{b}	327.7^{ab}	1.92^{a}
Bottom inner	4.00^{bc}	18.33^{b}	153.3^{b}	243.7	1.59^{a}
Centre	2.67^{c}	17.00^{b}	138.0^{b}	208.0^{b}	1.53^{a}

Data followed by different small letters in the same column are significantly different among treatments at P<0.05 by Tukey's test

Table 4: Efficacy of drone sprayer for control of insects

	Aphid Population/5cm apical twig			
Treatments	**Before spray NS**	**1 DAS S**	**2 DAS S**	**7 DAS S**
T1= Hexacopter UAV sprayer	26.80(2.36a)	16.60(3.92a) [38.06]	8.50(2.90a) [68.28]	10.00(3.15a) [62.69]
T2= Knapsack sprayer	24.40(2.66a)	12.70(3.51a) [47.95]	5.20(1.98b) [78.69]	7.10(2.50a) [70.90]
T3= Untreated Control	25.60(2.78a)	27.20(5.14b)	29.30(5.40c)	37.40(6.09b)
S. Em. ±	0.36	0.41	0.32	0.28
CD (0.05)	0.80	1.13	1.62	1.70

DAS: Days after spray; Those in () are square root transformed values and [] are per cent reduction over control; Mean values in the same column showing similar alphabets are at par; NS = non-significant; S= significant

The spray quality parameters, determined as per the method prescribed by Parmar (2019), is tabulated in Table 3. The spray quality was found to be dependent on the external parameters such as wind effect, leaf area index, structure of canopy and operator's skill. Many other researchers have also listed these parameters (wind effect, leaf area index (LAI), structure of canopy and operator's skill)as important external constraints that effect spray quality (Zhang *et al*., 2016; Xu *et al*., 2006; Rawn *et al*., 2007). The total mean coverage area was in the range of 2.67-10.67% at 17 $l\ ha^{-1}$. The recorded coverage was lower than 13-22% at 22 $l\ ha^{-1}$ as reported by Hunter *et al.* (2019), who also operated the drone at analogous flying speed of 3.0 ms^{-1}. Sarghini *et al.* (2019) also conducted field experiments with UAV sprayer and reported deposit coverage traces between 13.39-15.97%, because of wind variability and nozzle selection being two influential parameters for the coverage. The maximum coverage was in the top canopy (inner and outer) of the tree which was significantly higher than all other observation points on the canopy, except in the middle outer location, where it was at par. The spray coverage at the

Fig. 1: A view of the UAV used for spraying in orchards.

Fig. 2: Field view of spraying with drone in guava orchard (a) village Sheikhpura and (b) at research farm of School of Organic Farming, PAU Ludhiana.

middle (inner and outer) and bottom (inner and outer) locations was statistically identical due to the downward air flow or thrust created by propellers of UAV. The lowest spray coverage was achieved at central location (2.67%) of the tree. The droplet density has a significant role in effective control of insects and pests (Xu *et al.,* 2012). The mean droplet density with UAV based spraying system was found in the range of 14.67-28.33 droplets cm^{-2} in guava orchard.

The highest droplet density, *i.e.,* 28.33 droplets cm^{-2} was found at the top outer side of tree canopy which was statistically similar to that recorded at middle outer and bottom outer location. At all other locations, *i.e.,* top inner, middle inner, bottom inner and at centre, droplet density was found to be non-significantly different due downward air thrust produced by propellers of UAV that helped in increased penetration and deposition of spraying liquid throughout the tree canopy. The results are in line with those reported by Hou *et al.* (2019) who conducted experiments on citrus trees using UAV spraying system and found maximum droplet density of 27.15 droplets cm^{-2}. The droplet size may influence the biological efficacy of applied pesticide as well as environmental hazards (Taylor *et al.,* 2004).

The optimum droplet size should be 50-500 µm for orchard spray application because droplets below 50 µm size get easily drifted away from the target whereas for droplets above

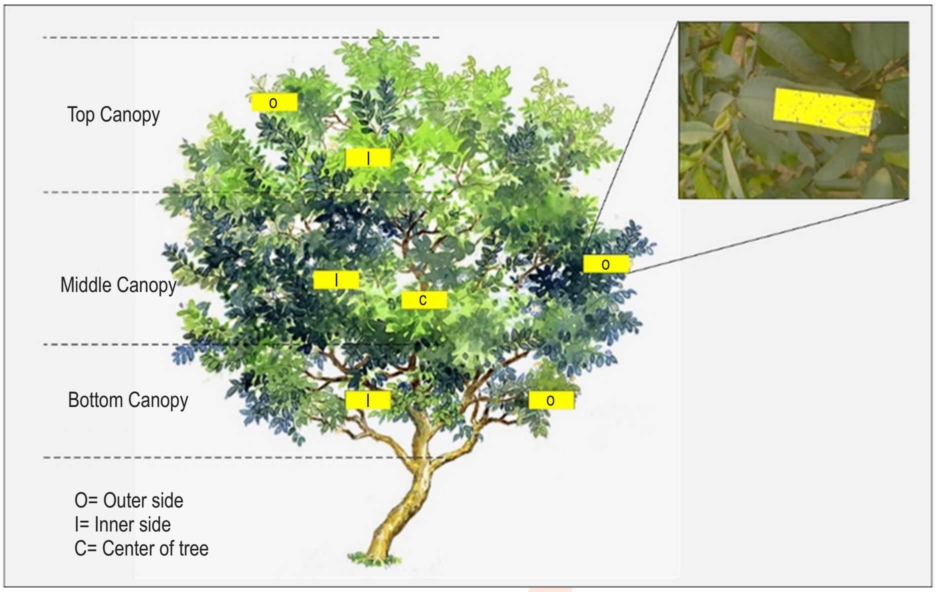

Fig. 3: Positioning of water sensitive paper and data collection after spraying with UAV.

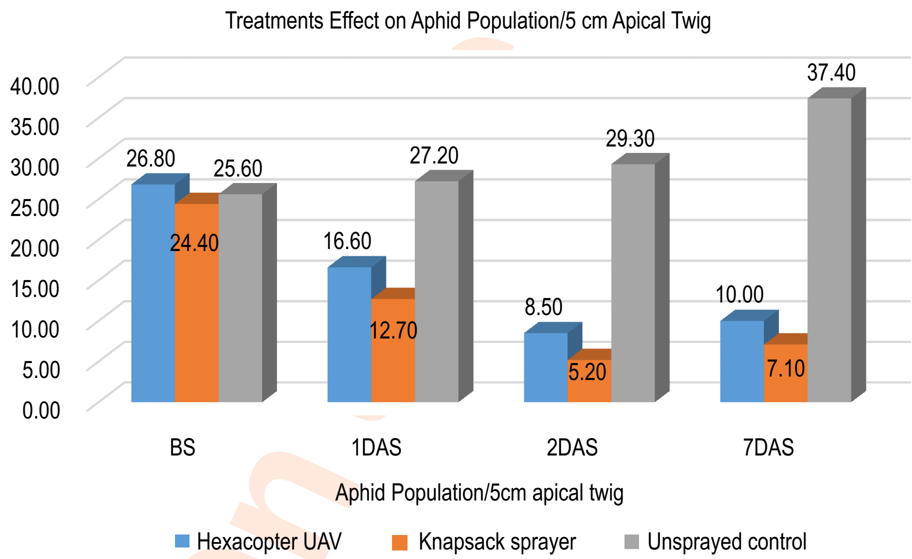

Fig. 4: Treatment effect on aphid population per 5 cm apical twig.

500 µm size, the drift loss was significantly lesser but they created problems like low spray volume, lesser coverage, and reduced biological efficacy in the spray. The smaller droplets are more sensitive to meteorological conditions and therefore, are more vulnerable to wind effect. Therefore, emphasis on optimum droplet size is needed (Ferguson *et al.,* 2015). The droplet size in terms of volume median diameter was found in the range of 208.0-418.3 µm whereas, the number median diameter range between 138.0 to 269.0 µm. Similar trend was observed by Taylor *et al.* (2004) in their experiments on drone-based spraying. At the bottom and center canopy of guava tree, the droplet size was smaller due to wide canopy of guava tree. Further, the smaller droplets remained in the suspended state and later got deposited inside the tree canopy. The uniformity coefficient of spray with hexacopter UAV based sprayer ranged between 1.38 to 2.13 and was statistically non-significan different (P>0.05) in all canopies

of guava trees. This shows that the spray done by hexacopter UAV on guava tree was uniform throughout the tree canopy.

Field experiments were conducted for feasibility check of UAV based sprayer for control of aphid population in guava orchard in contrast to knapsack sprayer and untreated control. Organic neem seed kernel based (Azadirachtin 0.15% EC) was used as an insecticide at the recommended dose. Data pertaining to efficacy of drone sprayer for controlling insects is presented in Table 4 and the results are presented in Fig. 4. Before spraying, the average aphid population per 5 cm apical twig was 26.80, 24.40 and 25.60 for Treatment T1, T2 and T3, respectively which was non-significantly different. After one day of spraying (1 DAS), hexacopter UAV sprayer (T1) and knapsack sprayer (T2) were found significantly effective in tumbling the aphid population to 16.60 and 12.70 aphid per 5 cm apical twig. After two days of spray application (2 DAS), there was highly significant drop in aphid population in T1 (8.50 aphid per 5 cm apical twig) and T2 (5.20 aphid per 5 cm apical twig), respectively.

After seven day of spraying (7 DAS), there was increase in aphid population in UAV and knapsack treatments, which was non-significantly different from each other but it was still significantly lower than control. The percent reduction in aphid population 1, 2 and 7 days after spray (DAS) was 38.06, 68.28 and 62.69%, respectively, whereas it was 47.95, 78.69 and 70.90% after spraying with knapsack sprayer. The results are in line with those observed by Lou *et al.* (2018) for controling aphids (63.7%) and spider mites (61.3%) in cotton crop using drone based spraying technology. Some limitations were also observed in use of hexacopter UAV for spraying in orchards. The battery endurance time for drones was found very low (12-15 min). It is important to find a balance between payload and flight time of the drone. As a safety measure, it was not possible to spray area near the electricity cables and poles. The UAV/drone can be operated in manual as well as auto-pilot mode. The statement in the paper is providing readers an insight about the challenge/difficulty during operation of UAV in orchards under manual mode. The present work yielded a successful development of a hexacopter based UAV spraying system for application of environment-friendly biopesticide in guava orchards.

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Add-on Information

Authors' contribution: A. Verma: Conceptualization of experiment, field experiment, data collection&analysis and manuscript writing; **M. Singh:** Conceptualization of experiment and data analysis. **R.P. Parmar:** Field experiment, data collection & analysis and manuscript writing. **K.S. Bhullar:** Field experiment and data collection.

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