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Development of a plant protection UAV and evaluating its efficacy in managing rice leaf folder (*Cnaphalocrocis medinalis* Guenee.)

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Abstract
Drones (Unmanned Aerial Vehicles, UAV) have revolutionized agriculture by optimizing the use of several farm operations and through reducing input costs. The present study aimed at designing a plant protection UAV and evaluating its efficacy against rice leaf folder. A hexacopter drone was designed by Acharya N G Ranga Agricultural University and designated as "ANGRAU Pushpak-01" with certain specifications and Payload Data suitable for plant protection spraying in rice. Field studies were taken up during kharif seasons (rainy seasons) of 2020 and 2021 in farmers fields of Guntur district of Andhra Pradesh, India on transplanted rice. The test insecticide used in the present study was flubendiamide 480 SC (39.35% W/w). The UAV hexacopter was optimized for its forward flight speed, height of aerial spraying for delivering spray width and for obtaining maximum spray width using standard protocols. Field studies involved five treatments (four replications), a) 100% RDP (recommended dose of pesticide) with UAV, b) 75% RDP with UAV, c) 50% RDP with UAV, d) 100% manual spray with human back pack motorized spray, and e) water spray using UAV in a RCBD fashion. Nursery was raised during both seasons of study and 30-days-old seedlings were transplanted into main fields and treatments were imposed with flubendiamide spray at 60 days after transplanting (DAT). Leaf folder damage was assessed at prior to flubendiamide spray treatment-wise, then periodically and finally at 10 DAS (Days after spray). Grain yields were harvested replication-wise, pooled and assessed treatment wise for both the field studies in successive years. Our results on optimization of spray technology indicated that aerial spray with UAV at a height of 0.6 m above canopy was ideal in delivering maximum spray width. Further, at this height, there was good amount and uniform distribution of flubendiamide as evaluated by HPLC. The flubendiamide at 75% UAV spray could yield uniform deposition on rice canopy (top, medium, and bottom), and is equally effective compared to 100% UAV spray of flubendiamide. Further, UAV sprays at both these concentrations are more effective in terms of droplet distribution compared to 100% UAV spray with human back pack motorized spray. Field studies indicated that leaf folder damage was effectively reduced with flubendiamide sprays at 100% and 75% RDPs with UAV with no significant differences. However, these treatments were significantly superior to 100% RDP of spray using human back pack sprayer. Similarly, grain yields were significantly superior in 100% RDP and 75% RDP-UAV sprayed plots with no significant differences between them. Further, both these treatments were significantly superior to 100% RDP spray using human back pack sprayer in grain yield enhancement. Overall, our results suggested the efficacy of "ANGRAU-Pushpak-01" UAV hexacopter in reducing leaf folder in rice and enhancing grain yields when sprayed with flubendiamide at 75% RDP, thus offering scope for reduced pesticide costs compared to spraying with 100% RDP of flubendiamide using human back pack motorized sprayer under the conditions evaluated.

Keywords: Drones, UAV, ANGRAU-pushpak-01, rice, leaf folder, flubendiamide, grain yields

Introduction
Unmanned Aerial Vehicles (UAVs) or Unmanned Aerial Systems (UAS) or Drones and their applications have revolutionized agriculture. Multifarious uses through UAVs/Drones have been established in various agricultural operations worldwide. Especially, the role of drone technology in pest and disease management has been demonstrated in various crops. Pests and diseases in crop plants have been reported to be assuming devastating forms if their timely detection and management is relegated. As such, timely interventions in pest management will not only bring effective results, but can also be viable and cost effective.

Under Indian scenario, wherein the country is largely dependent on agrarian economy, timely management of pests and diseases assumes paramount significance. Drone applications in agriculture have the potential to enhance efficiencies right from crop growth, plant protection and thereby yields. However, drone technology and its application in Indian Agriculture need to gain momentum. Drone technology for plant protection spraying brings multifarious advantages over manual application like less labour intensive, high spraying uniformity, good droplet deposition both horizontally and vertically, reduction in pesticide dose & Spray fluid volume, time saving, energy saving and elimination of drudgery to the farmer. However, prior to application of drones in a particular crop for pest/disease management, it is mandatory to standardize and optimize the spray technology that dictates the vertical deposition of spray fluid on crop canopy, standardization of aerial spray height by UAV, which is ambient for flight and for obtaining maximum spray width. Besides, it is also important to monitor the environmental conditions such as wind speed and direction during field operations with UAV to avoid spray drift. Several researchers have investigated the UAV associated spray drift with regard to determination of drift deposition (Tsai *et al*., 2005) [17]. Also the effect of UAV height on crop canopy and its speed on spray deposition was investigated by various researchers (Qiu *et al*., 2013) [11]. According to Wei-Cai Qin *et al* (2016) [18], spray technology determines the initial deposition of a spray insecticide with UAVs. Further, for homogenous distribution of droplets and for maximum penetrability, flight height and flight speed are the governing factors besides the prevailing natural wind (Wei-Cai Qin *et al*, 2016) [18].

Rice is a staple food for majority of world's human population. Biotic stresses are one of the major bottlenecks for achieving higher production and productivity levels (Singh *et al*., 2020) [15]. Losses to a tune of 52% are reported by biotic stresses of which, insect pests amount to 21% (Brookes and Barfoot, 2003) [2]. Among insect pests of rice, leaf folder is a major pest, causing significant losses worldwide. Under Indian conditions, grain yield losses ranged from 11.9% (Cultivar: HPR 2143) to 37.9% (Cultivar: Kasturi Basmati). The leaf infestation levels in Kasturi Basmati also were higher up to 77.2% (Chhavi *et al*., 2017) [5]. Average attainable grain yield losses as reported by other researchers range from 20% to 30% (Savary *et al*., 2000) [13]. Conducive factors for leaf folder's abundance are high humidity and optimum temperatures (Gangwar, 2015) [7]. Factors such as expanded rice areas with new irrigation systems, multiple rice cropping, reduced genetic variability of modern semi dwarf rice varieties, application of high levels of nitrogenous fertilizers, and insect resurgence are the reasons for increased leaf folder damage (Gangwar, 2015) [7]. Leaf folder damage severity is directly correlated with the adverse effect on ripened grain rate and 1000-grain weight. Further, qualitative losses on grains were also reported with decreased amylase content that subsequently deteriorates grain palatability (Won *et al*., 2008) [19].

Presently, leaf folder in rice is managed through application of chemical insecticides such as flubendiamide and thiodicarb that are documented to be effective in reducing the associated leaf damage as well as enhancing the grain yields. Besides, the beneficial insects with these chemicals are also proved be safer with application of these insecticides (Zala and Sipai, 2021) [20]. However, leaf folder management often demands application of insecticides more than once on a standing crop. Besides, the harmful effects of chemicals on human and animal health, environmental pollution due to pesticide exposure by drift due to manual spraying are also a concern. It is precisely at this juncture, the applications of drones offer cost-effective, rapid and time-saving spray technologies to agricultural crops. Besides, the scope of reducing the recommended dose of chemicals is also enhanced with aerial spraying by drones.

Several researchers have documented the efficacy of drones in rice against insect pests (Chen *et al*., 2020) [4]. However, standardizing the spray technology for vertical and horizontal distribution of a spray fluid with aerial spraying by UAV is a pre-requisite on a particular crop that is targeted to be sprayed with. Moreover, optimizing of pay load parameters of UAV such as tank volumetric capacity, number of nozzles and their discharge capacity, nozzle type etc is a pre-requisite for drone operational parameters such as drone forward speed, height of the UAV above the crop canopy, width of spray coverage, and time required for coverage of unit field area, besides battery consumption. All these factors will result in cost-effectiveness of UAV spraying over conventional spraying of pesticides. Several researchers have evaluated the effect of UAV-based spraying on vertical distribution of droplet distribution in rice (Cao *et al*., 2021) [3].

An ideal UAV that is designed for agricultural purposes such as plant protection should be able to deliver maximum spray width (horizontal distribution) from a particular height of crop canopy. Besides, the spray technology that is designed for a particular UAV should be able to deliver droplets uniformly on to the crop canopy. This is especially true on a crop such as rice, wherein uniform distribution on top, medium and lower leaves is essential for effective management of pests and diseases. Moreover, the applied dosages of a pesticide ought to be safer to plants without any phytotoxic effects.

Against this backdrop, Acharya N G Ranga Agricultural University has designed an UAV for plant protection spraying in rice with specified spray technology, payload data and other configurations for delivering insecticide on rice canopy for pest management. Specifically, our present study focused on designing, development, optimization of a hexacopter UAV for aerial spraying in rice against leaf folder management, enhancing the grain yields and establishing the effectiveness of UAV spraying over conventional spraying. The long term goal is to come up with pest/disease specific recommendations in rice for major pests and diseases through Standard Operating Procedures for major agricultural crops in general and for rice in particular as in the present study.

Material and Methods

Design of Plant Protection UAV by Acharya NG Ranga Agricultural University: A hexacopter UAV was designed specifically for plant protection spraying in agriculture crops by Acharya N G Ranga Agricultural University. The UAV built by Acharya N G Ranga Agricultural University (ANGRAU) with the specifications as discussed below was designated as "ANGRAU-Pushpak-01", a model RPAS (Remotely Piloted Aircraft System). The registration approval pertaining to the "ANGRAU-Pushpak-01" was obtained based on guidelines issued by DGCA (Directorate General of Civil Aviations" for its usage in agricultural operations for research purpose (The Gazette of India, 2021) [10].

The specifications pertaining to technical parameters and payload data are detailed below (Table 1).

Table 1: Technical parameters of Remotely Piloted Aircraft System (RPAS) (UAV) designed by Acharya NG Ranga Agricultural University as "ANGRAU-Pushpak-01" for Plant Protection research

S. No	Classification		Parameters
1	Official Designation	:	Model RPAS (Remotely Piloted Aircraft System) (approved by DGCA)
2	Size (mm)	:	1495 mm*1308mm*500mm (Arms unfolded with motor and without propellers)
3	Category of drone	:	'Small' category with all up weight of 24.8 kg
4	Motors Type & Specification	:	BLDC (Brushless Direct Current) with 120 KV rating; Input Current: 80A; IPX7
5	Maximum Thrust of each Motor	:	12kg/Axis (48V, Sea Level)
6	Battery Specification	:	16,000 mAH capacity with charging C rating 5C and discharging C rating: 15 C and Burst Discharge rating: 30C; 6S1P; 22.2 V and 355.2 Wh
7	Spray width	:	2.8 m
8	Pay Load capacity	:	12 kg
9	Maximum working efficiency	:	5.31 minutes per acre
10	Spray system	:	Rotary atomization
11	Operation method	:	Remote operated
12	Positioning mode	:	Dual GPS (Global Positioning Systems)
13	Forward speed of the UAV	:	5.5 meters per second
14	Tank capacity	:	12 L
15	Nozzle type	:	Flat fan
16	Number of nozzles	:	4 (110015 VP)
17	Nozzle flow rate	:	0.42 to 0.45 L per minute
18	Spraying angle	:	Vertically down
19	Spray angle	:	110 degrees
20	Spray fluid volume	:	25 L ha^{-1} (Low volume and high concentration)
21	Spraying	:	
22	Radio communication frequency	:	2.40 to 2.4 giga Hz

The Payload Data of "ANGRAU-Pushpak-01" plant protection UAV is given in Table 2.

Table 2: Payload Data of "ANGRAU-Pushpak-01" plant protection UAV

S. No	Parts		Weight (g)
1	Maximum Spray fluid Volume capacity of the tank	:	12 L
2	Actual (filled) Spray fluid Volume in tank	:	10 L
3	Active chemical ingredient recommended (by CIB&RC) to control Leaf folder in rice	:	Flubendiamide 39.35% W/w 480 SC
4	Type of spray fluid	:	Soluble concentrate (SC) mixed in water

Optimization of Spray Technology by UAV for pesticide application

a) Standardization of spraying height and regularity of distribution of droplet deposition (vertical distribution) and spray width (horizontal distribution) with ANGRAU-Pushpak-01-UAV

Vertical Spray Distribution

Commercially available yellow colored water sensitive spray cards were used for obtaining information on droplet distribution and their coverage on rice canopy when sprayed by ANGRAU-Pushpak-01. The water sensitive spray cards are with size of 25 mm X 75 mm. These cards were tied to top, middle and bottom portions of rice leaves in rice fields at randomly spaced locations and then aerially sprayed with UAV. Once the water droplets had come into contact with the cards on top, medium and lower leaves, the card surfaces quickly turned blue and the color change was distinctly visible.

The spray cards after color change were properly dried, then placed in plastic bags individually, and subjected to data analysis. Cards were scanned and the data were analyzed using image processing software iDAS for obtaining the information on droplet coverage density and the amount of deposition (Cao *et al*., 2021) [3].

Horizontal Spray Distribution

The ideal (maximum) spray widths (horizontal distribution) were evaluated at different heights of spraying UAV was determined as follows. White colored water sensitive spray cards with size 140 mm X 710 mm were used under laboratory conditions. These cards were spread on uniform floor and aerial spraying with water was carried out with UAV at different heights. Once the water droplets had come into contact with the cards, the card surfaces quickly turned blue and the color change was distinctly visible. The water sensitive spray cards were dried, placed in plastic bags and correlations were drawn between different heights of UAV aerial spraying and the spray widths obtained accordingly for final arrival of ideal spray height for obtaining maximum spray width.

b) Analysis of droplet deposition effect and pesticide efficacy through UAV application on top, mid and lower leaves by pesticide residue analysis using High Performance Liquid Chromatography (HPLC)

The droplet deposition effect (quantum of pesticide) on rice leaves and pesticide efficacy when sprayed with ANGRAU-Pushpak-01-UAV was determined on top, medium, and lower leaves of rice under field conditions was determined indirectly through pesticide residue analysis. The pesticide use in our studies is flubendiamide (BAYER-FAME®) 480 SC (39.35%W/w). The methodology for insecticide deposition and its effect and efficacy on rice leaves was by High

Pressure Liquid Chromatography (HPLC) with UV detection as per the standard procedures laid out by Gopal and Mishra (2008) with slight modifications wherever applicable and the results were expressed in mg kg^{-1} of pesticide.

Field studies on rice leaf folder management using ANGRAU-UAV

Details of Rice Cultivar & Insecticide: The popular rice Cultivar used in our field studies is BPT 5204 (Samba Mashuri). The seed is procured from Rice Research Station, Bapatla of Acharya N G Ranga Agricultural University, Andhra Pradesh, India. It is an early maturity (130-135 days) bold variety, Important characteristics of the Cultivar are a) compact and drooping nature, b) Plant height of 110-120 cm, c) Fine grain with good cooking quality, d) High yielding, e) Suitable for *kharif*, and f). Average yield of 5.5 to 6.0 t ha^{-1}.
The BPT-5204 Cultivar is susceptible to Brown Plant Hopper (BPH), gall midge, Sheath blight, Bacterial Leaf Blight (BLB), Blast and Stemborer. The Cultivar is susceptible to leaf folder (Appala Raju *et al*., 2018) [1].
The insecticide used in the present experiments is flubendiamide (BAYER-FAME®) 480 SC (39.35%W/w), procured from Bayer Crop Science Ltd. The normal dosage in rice is 50 ml in 200 L of water with human back pack motorized sprayer (knap-sack type fog sprayer) for one hectare. The spray fluid applied with human back pack motorized sprayer is 200 L $acre^{-1}$, whereas with UAV, a total of 10 L spray fluid was applied per acre.

Location of field trials, season, soil characteristics and field outlay details

The field studies were carried out in farmers' fields of Davuluru village of Kollipara mandal of Guntur district, Andhra Pradesh, India during kharif 2020 and 2021. The soils are of clayey in nature, and the field coordinates are 16°15'39.3"N 80°43'03.9"E, 16°15'39.1"N 80°43'08.9"E, 16°15'33.1"N 80°43'04.0"E & 16°15'34.3"N 80°43'09.1"E. The village Davuluru falls under Krishna Agroclimatic zone of Andhra Pradesh, India. The field trials were carried out in a contiguous area of five acres. There are five treatments with four replications in a RCBD (Randomized Complete Block Design) fashion. The treatments include a) 100% Recommended Dose of Pesticide (RDP) with UAV; b) 75% RDP with UAV; c) 50% RDP with UAV; d) 100% RDP with human back pack motorized sprayer; and e) Untreated control (Water spray).
Each replication (plot) size is about 1012 m^2, amounting to 4048 m^2 (one acre) for four replications, making the treatment size of 1 acre. The whole experimental area is five acres excluding buffer zones (5m each), that separates individual replications/treatments. The following is the outlay of experimental plot with five treatments and four replications laid out in RCBD fashion (Table 3).

Table 3: Field design and division of experimental areas for drone (UAV) spraying of insecticide (flubendiamide) for rice leaf folder management (*kharif* 2020 & 2021) at Davuluru village of Guntur district of Andhra Pradesh, India.

Blocks	Arrangement of Replications/Treatments				
1	T5R1	T4R1	T1R1	T2R1	T3R1
2	T3R2	T5R2	T4R2	T2R2	T1R2
3	T1R3	T3R3	T5R3	T4R3	T2R3
4	T2R4	T1R4	T4R4	T5R4	T3R4

Environmental Monitoring & Drone Spray Details

The wind condition at the time of spraying by UAV is about 10.5 kmph. The temperature at the time of aerial spray was 31C and a relative humidity (RH) of 62%. The wind direction at the time of UAV spray was "East-West" and so the UAV (drone) travel direction was also "East-West" to avoid spray drift.
The forward speed of the drone is 5.5m s^{-1} and the width of aerial spray was 2.8 m. The aerial spray by drone was at a height of 0.6 m above crop canopy.

Crop Growth & Management

A nursery area of 1600 m^2 (for transplanting into 5 acres of main field) was used for producing rice seedlings with the Cultivar, BPT-5204. The rice seeds were soaked in water for 24h, and then incubated for about 24h before sowing. Standard agronomic practices for nursery beds were followed according to the guidelines advocated by ANGRAU for rice cultivation in Krishna Agroclimatic zone of Andhra Pradesh. Need based application for managing pests and diseases in nursery were carried out using insecticides or fungicides as the case may be. The seed rate for nursery was 50 kg ha^{-1}.
One month age old seedlings were transplanted in main fields and a nursery area of 40 m^2 was used for one acre. The spacing adopted for transplanting of rice was 20 X 15 cm.

Imposition of Treatments

In our field studies, leaf folder incidence and damage was monitored at regular intervals. First spray of insecticide using drone or human back pack motorized sprayer as the case may be according to the treatment specifications was imposed at 60 days after transplanting (DAT).

Assessment of Leaf folder Damage

The leaf folder intensity was calculated based on the number of damaged leaves out of total leaves from 10 randomly selected hills in each randomized plot. The per cent leaf damage by leaf folder was arrived by using the formula as per the standard procedures (Sulagitti *et al*., 2017) [16].

$$\text{\% Leaf folder incidence} = \frac{\text{Number of damaged rice leaves}}{\text{Total number of leaves}} \times 100$$

Grain yield assessment

The crop was harvested replication-wise, dried and then recorded separately, and then pooled treatment-wise and the whole data were subjected to data analysis for testing the significance of mean yield variation among different treatments. The per cent yield increase over control (untreated, water spray) was calculated by using the following formula (Sulagitti *et al*., 2017) [16].

$$\begin{array}{c}\text{\% Increase in rice grain yield} \\ \text{in treatments over control}\end{array} = \frac{\text{Yield in Treatment-Yield in Control}}{\text{Yield in Control}} \times 100$$

Phytotoxicity studies

Visual observations were adopted to assess the phytotoxicity of flubendiamide when applied aerially with UAV using standard protocols (Shankar *et al*., 2019). Ten plants each in a) 100% Recommended Dose of Pesticide (RDP) with UAV; b) 75% RDP with UAV; and c) 50% RDP with UAV; d) 100% RDP with human back pack motorized sprayer; and e) Untreated control (Water spray), replication-wise were observed for chlorosis, leaf tip burning, necrosis, epinasty, hyponasty, vein clearing, scorching, and wilting at zero, 1, 3, 5, 7, and 10 days after spraying. These symptom manifestations were graded on 0-10 point phytotoxicity scale where 0=00; 1=1-10%; 2=11-20%; 3=21-30%; 4=31-40%; 5=41-50%; 6=51-60%; 7=61-70%; 8=71-80%; 9=81-90%; and 10=91-100%.

Statistical Analysis

The significance of difference among various treatments under study for both leaf folder damage as well as grain yields was determined based on CD at 5% level of significance. The data for leaf folder damage were square root transformed.

Results and Discussion

Standardization of Spray height & width with UAV

Our preliminary experiments (not given in methodology) on determining UAV time based on fixed & effective spray widths of 2.8 m and 3.2 m indicated that the time taken for spraying pesticide volume of 25 L ha^{-1} was 12 minutes and 12.8 minutes (Fig 1).

Our experiments for determining the effective spray width based on height of UAV above rice canopy indicated that at 0.6 m above canopy, the effective spray width achieved was 2.8 m and at a height of 1.0 m, the effective spray width obtained was 3.2 m. Beyond these specified spray heights, the effective spray widths were found reducing with concomitant increase in spray heights using UAV (Fig 2).

Quantity of pesticide (flubendiamide) deposition on rice canopy in field studies

The flubendiamide deposition was highest on top canopy, followed by middle canopy, and lower canopy for all the treatments with UAV spray and manual spray (Fig 3).

At Top Canopy: The flubendiamide deposition was highest with UAV 100% RDP (3.2 mg kg^{-1}), followed by 75% RDP with UAV (3.0 mg kg^{-1}), and 50% RDP with UAV (1.4 mg kg^{-1}), and with manual spray (0.9 mg kg^{-1}).

At Middle Canopy: The flubendiamide deposition was highest with 75% RDP (1.7 mg kg^{-1}), followed by 100% RDP (1.6 mg kg^{-1}), 100% RDP with manual spray with human back pack motorized spray (0.7 mg kg^{-1}), and 50% RDP with UAV (0.4 mg kg^{-1}).

At Lower Canopy: The flubendiamide deposition was highest with 100% RDP with UAV (1.4 mg kg^{-1}), followed by 75%RDP (1 mg kg^{-1}), manual spray with UAV with 100% RDP (0.4 mg kg^{-1}), and 50% RDP (0.2 mg kg^{-1}) (Fig 3).

g) Field experiments in managing rice leaf folder using UAV spray application of flubendiamide

Leaf folder damage

Field studies indicated that the mean decrease in leaf folder damage was highest in plots with flubendiamide sprays with UAV at 100% RDP (66.80%) and 75% RDP (66.21%) with no significant differences between them based on the pooled data for *kharif* 2020 and *kharif* 2021. Further, these two treatments were significantly superior to mean leaf folder damage (for pooled data of both years of study) in 100% RDP of flubendiamide spray with human back pack motorized spray (52.51%). The flubendiamide spray at 50% RDP with UAV recorded a mean per cent decrease of 10.69 over control based on pooled data of field studies in *kharif* 2020 and *kharif* 2021 and was significantly inferior over other treatments under study (Table 4).

Similar trend of significant differences in decrease of leaf folder damage was noticed during both years of field studies. During *kharif* 2020, the treatment of flubendiamide spray at 100% RDP with UAV was about 68.01% decrease of leaf folder damage over control and was significantly superior over 100% RDP with flubendiamide spray with human back pack motorized spray (50.18% decrease in leaf folder damage over control, water spray). However, as observed in pooled data analysis, there was no significant difference between 100% RDP of flubendiamide spray with UAV and 75% RDP spray of flubendiamide (67.53%) in *kharif* 2020 with respect to decrease in leaf folder damage over control. The treatment, 50% RDP spray of flubendiamide with UAV however was significantly inferior (9.2%) over 100% RDP with flubendiamide spray with human back pack motorized spray (50.18%) in terms of decrease in leaf folder damage over control, the water spray. The water spray with UAV during *kharif* 2020 recorded a leaf folder of 78.2%, whereas 100% RDP with flubendiamide spray by UAV and 75% RDP with flubendiamide spray by UAV recorded leaf damage of 15.10% and 13.80% respectively with no significant differences between them. However, both these treatments were significantly better than 100% RDP of flubendiamide with human back pack spray (28.10% leaf damage) based on the leaf damage assessed at 10 DAS (days after spray).

During *kharif* 2021, based on the assessment at 10 DAS, the mean decrease in leaf folder damage was highest in 100% RDP with flubendiamide spray with UAV (65.72%), followed by 75% RDP with flubendiamide spray with UAV (65.17%) with no significant differences between them. However, both these treatments were significantly superior over 100% RDP with flubendiamide spray by human back pack spray (55.17% decrease in leaf folder damage).This treatment however is significantly superior when compared to 50% RDP with flubendiamide spray by UAV (12.03%) with respect to leaf folder damage reduction over water spray by UAV.

The water spray with UAV during *kharif* 2021 recorded a leaf folder of 78.90%, whereas 100% RDP with flubendiamide spray by UAV and 75% RDP with flubendiamide spray by UAV recorded leaf damage of 18.10% and 18.60% respectively with no significant differences between them. However, both these treatments were significantly at par with 100% RDP of flubendiamide with human back pack spray (22.10% leaf damage) based on the leaf damage assessed at 10 DAS (days after spray). The leaf folder damage in water sprayed plots with UAV was significantly highest over others under study during *kharif* 2021 (Table 4).

Grain yields

The results on effect of various treatments in enhancing rice grain yields with UAV application of flubendiamide against leaf folder incidence were significant. Among different treatments, no significant differences were found involving flubendamide application either through UAV (at 100%, and 75% RDP levels) or with human back pack motorized sprayer (100% RDP). However, all these flubendiamide treated plots were significantly superior over untreated control plots (water spray). All these findings were true with respect to individual years of experimentation during *kharif* 2020 and 2021, as well as under pooled analysis.

The pooled data revealed highest grain yield in 75% RDP (flubendiamide) with UAV application (5.76 t/ha). This was followed by grain yields in 100% RDP of flubendiamide application with UAV (5.55 t/ha) and these differences were not signficant. Flubendiamide, when applied with human back pack motorized sprayer recorded grain yields of 5.49 t/ha and this is significantly superior over 50% RDP of flubendiamide with UAV. Control plots received a grain yield of 1.59 t/ha and these yields were significantly inferior over all other treatments under study (Table 5).

The per cent increase in grain yields over untreated controls (water spray) was arrived for pooled data of *kharif* 2020 and *kharif* 2021 field studies. The UAV spray with 75% flubendiamide recorded 262% more grain yields over control plots (water spray). The grain yields were 190% more over control plots when sprayed with 50% of RDP of flubendiamide by UAV. The plots that were sprayed with 100% RDP of flubendiamide have recorded 245% more grain yields over control (Fig 4).

Phytotoxicity tests

The insecticide, flubendiamide did not show any phytotoxicity symptoms (chlorosis, leaf tip burning, necrosis, epinasty, hyponasty, vein clearing, scorching & wilting) right from zero, 1, 3, 5, 7, & 10 days after spraying with UAV at 100% RDP; 75% RDP; and 50% RDP. Further, the insecticide had no phytotoxic symptoms even at 100% RDP with conventional spraying manually (Table 6).

Overall, our results on development of a plant protection UAV for managing leaf folder in rice can be inferred as follows. An hexacopter UAV designated as “ANGRAU-Pusphak-01” was designed with specified parameters as indicated previously and with specified Payload Data (indicated previously). The designated UAV height above canopy that was selected was 0.6 m above canopy in our present studies since the crop stage was prior to inflorescence stage. The flubendiamide spray with UAV at 75% dose was equally effective with its 100% spray dose with UAV in managing leaf folder and enhancing grain yields. Further, the flubendiamide spray at 75% and 100% dosages of RDP (flubendiamide) were superior to 100% spray with manual spray with human back pack sprayer in grain yield enhancement, spray fluid deposition on top, medium, and lower crop canopy.

Based on our results, it can be inferred that UAV spraying of flubendiamide was effective and at 75% RDP at a height of 0.6 m in reducing leaf folder damage and enhancing grain yields. At this dose, further, there was no phytotoxicity exhibited along with other treatments too on crop canopy.

Farmers generally adopt pesticide application twice at a fortnight interval for sucking pests based on the intensity of pest damage on a standing rice crop especially for sucking pests. Further, researchers established that rice leaf folder is managed with Phenyl Pyrazole and Neonicotinoids by spraying twice at 15 days interval (Sulagitti *et al*., 2017) [16]. In our present study, the 75% flubendiamide spray with UAV reduced the rice leaf folder damage significantly over water controls (untreated spray) during both years of experimentation (*kharif* 2020 & *kharif* 2021), thus offering ample scope for reduction on plant protection for managing rice leaf hopper.

Several researchers have standardized the spraying parameters for UAV on droplet distribution in several crops (Chojnacki and Pachuta, 2021; Mogili and Deepak, 2018) [6, 9]. It was also established that the distribution of spray liquid in certain tree crops are dependent of weight of drone (Chojjnacki and Pachuta, 2021) [6]. Droplet distribution effectively at top, medium, and lower crop canopies as in our present findings also indicated less drift with our developed UAV and high adhesive effects of the flubendiamide on rice leaves at different canopies based on our HPLC results. Earlier, researchers have established that canopy structure as an important factor that influences droplet deposition and distribution (Rawn *et al*., 2007) [12]. Our research is at initial stages in establishing spray technology for different crops for managing different pests and diseases.

Table 4: Effect of flubendiamide (Bayer-Fame®) spray with UAV on rice leaf folder (*Cnaphalocrocis medinalis*) at 60 days after transplanting of rice (BPT 5204) during *kharif* 2020 & 2021 at Davuluru village of Kollipara mandal in Guntur district of Andhra Pradesh, India.

Treatment	Mean % damage by leaffolder per 10 hills after flubendiamide spray at 60 DAT*						
	Kharif 2020			*Kharif* 2021			Pooled for both years (2020 & 2021)
	One day before spray	10 DAS**	% Decrease over control	One day before spray	10 DAS	% Decrease over control	Overall % Mean Decrease over Control
T1: 100% Recommended Dose of Pesticide (RDP) with UAV	47.20 (43.39)	15.10 (22.87)	68.01 (55.56)	52.80 (46.61)	18.10 (25.18)	65.72 (54.16)	66.80 (54.20)
T2: 75% RDP with UAV	42.50 (40.69)	13.80 (21.81)	67.53 (55.26)	53.40 (46.95)	18.60 (25.55)	65.17 (53.83)	66.21 (54.46)
T3: 50% RDP with UAV	53.10 (46.78)	48.20 (43.97)	9.23 (17.68)	58.20 (49.72)	51.20 (45.69)	12.03 (20.29)	10.69 (19.09)
T4: 100% RDP with human back pack motorized sprayer	56.40 (48.68)	28.10 (32.01)	50.18 (45.10)	49.30 (44.60)	22.10 (28.04)	55.17 (47.97)	52.51 (46.44)
T5: Untreated control (Water spray)	53.70 (47.12)	78.20 (62.17)	-45.62 (-42.49)	61.70 (51.77)	78.90 (62.65)	-27.88 (-31.87)	-36.14 (-36.95)
CD	4.73	4.72	1.88	5.82	4.56	5.90	2.72
SE (m)	1.54	1.53	0.61	1.89	1.48	1.91	0.88
CV (%)	6.78	8.39	2.82	7.87	8.07	9.21	4.16

DAT*: Days after Transplanting; DAS**: Days after Spray

Table 5: Field studies on rice (Cultivar BPT 5204) in managing leaf folder by spraying with hexacpoter UAV using flubendiamide during *kharif* (rainy season) 2020 & 2021 at Davuluru village of Kollipara mandal in Guntur district of Andhra Pradesh, India.

Treatment	Volume of spray fluid (L/ha)	Dose (ml/ha)	Grain Yields (tonnes/ha)		
			kharif 2020	*kharif* 2021	Pooled data (Mean for years 2020 & 2021)
T1: 100% Recommended Dose of Pesticide (RDP**) with UAV	25	50	5.80	5.30	5.55
T2: 75% RDP with UAV	25	37.5	5.91	5.61	5.76
T3: 50% RDP with UAV	25	25	4.64	4.58	4.61
T4: 100% RDP*** with human back pack motorized sprayer	500	50	5.65	5.34	5.49
T5: Untreated control (Water spray)	25	0	1.72	1.46	1.59
CD	--	--	0.60	0.68	0.45
SE (m)	--	--	0.19	0.22	0.15
CV (%)	--	--	8.22	9.85	6.38

Table 6: Phytotoxicity testing of flubendiamide (Bayer-Fame®) after spraying in rice (BPT 5204) with UAV for managing leaf folder (*kharif* 2020 & 2021) at Davuluru village of Kollipara mandal in Guntur district of Andhra Pradesh, India.

Treatment	*Phytotoxicity symptoms (0-10 scale) as recorded at 0, 1, 3, 5, 7, & 10 days after spraying						
	Final data at 10 days after spraying						
	Chlorosis	Leaf tip burning	Necrosis	Epinasty	Hyponasty	Vein clearing	Scorching & Wilting
T1: 100% Recommended Dose of Pesticide (RDP**) with UAV	0	0	0	0	0	0	0
T2: 75% RDP with UAV	0	0	0	0	0	0	0
T3: 50% RDP with UAV	0	0	0	0	0	0	0
T4: 100% RDP*** with human back pack motorized sprayer	0	0	0	0	0	0	0
T5: Untreated control (Water spray)	0	0	0	0	0	0	0

*Phytotoxicity symptoms on rice leaves & plants were recorded on a 0-10 scale, wherein 0=00; 1=1-10%; 2=11-20%; 3=21-30%; 4=31-40%; 5=41-50%; 6=51-60%; 7=61-70%;
8=71-80%; 9=81-90%; and 10=91-100% symptom manifestation.
**The 100% Recommended dosage of flubendiamide (RDP) 480 SC (39.35%W/w) in rice is 20 ml in 200 L of water with human back pack motorized sprayer (knap-sack type fog sprayer) for one acre & Ten litres of spray fluid was applied per acre with UAV
***All the Treatments were imposed at 60 Days after Transplanting

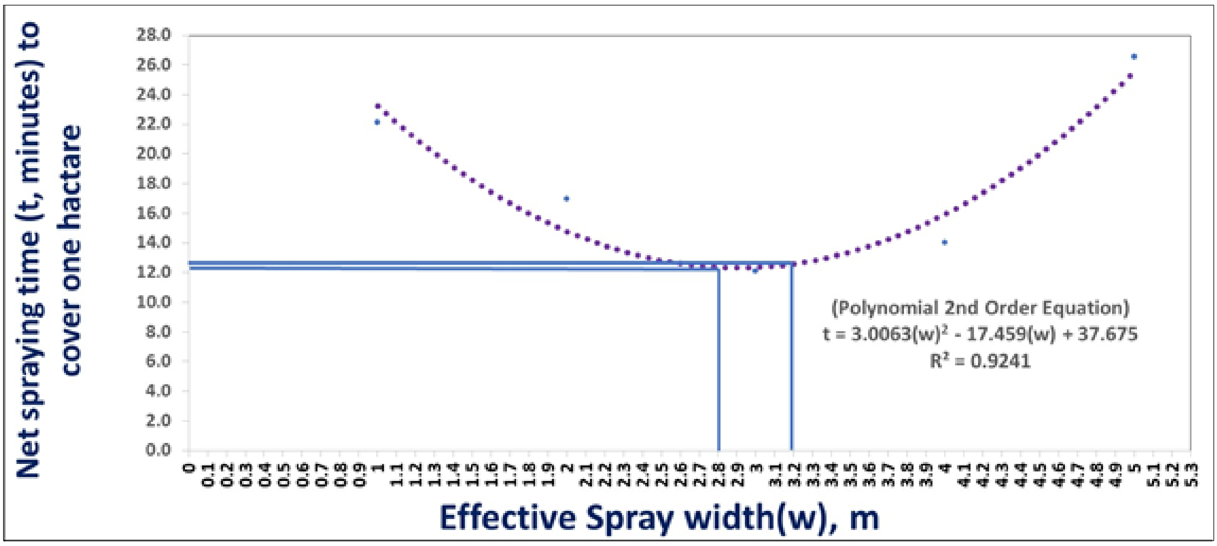


Fig 1: Determining the net spraying time of UAV for applying one hectare based on effective spray width in rice against pests

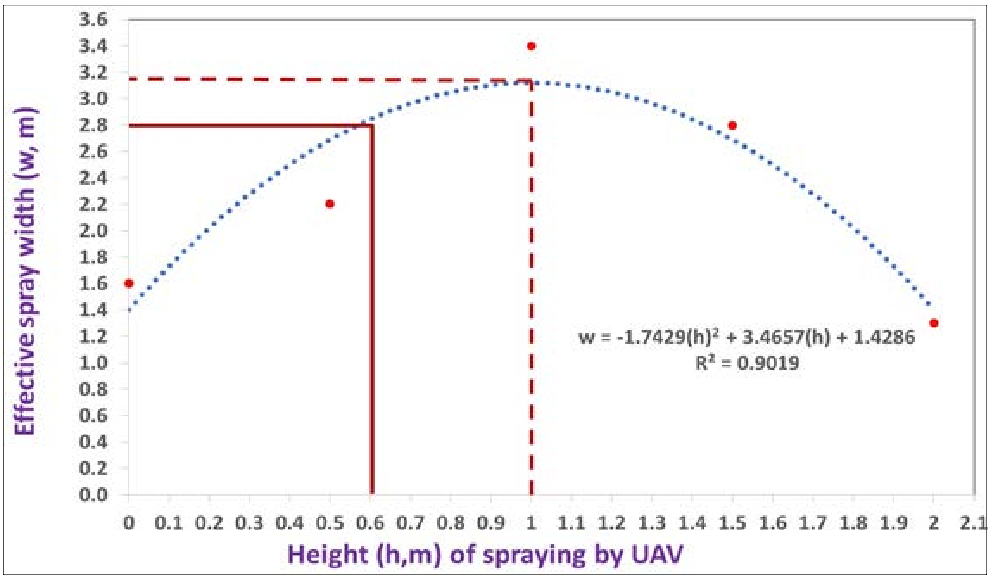


Fig 2: Determination of effective spray width based on height of UAV spray for pesticide application in rice for plant protection

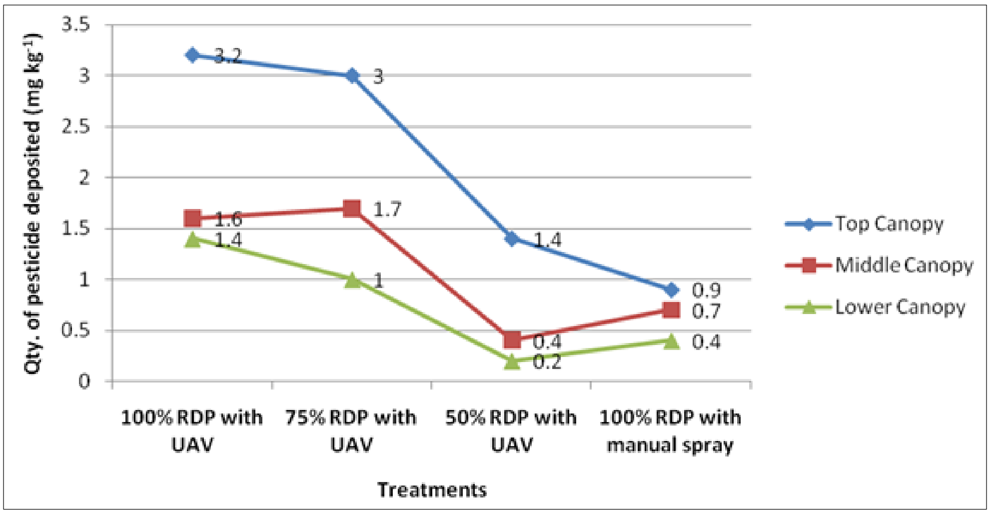


Fig 3: Flubendiamide deposition on rice canopy for spraying with UAV against rice leaf folder (*Cnaphalocrocis medinalis*).

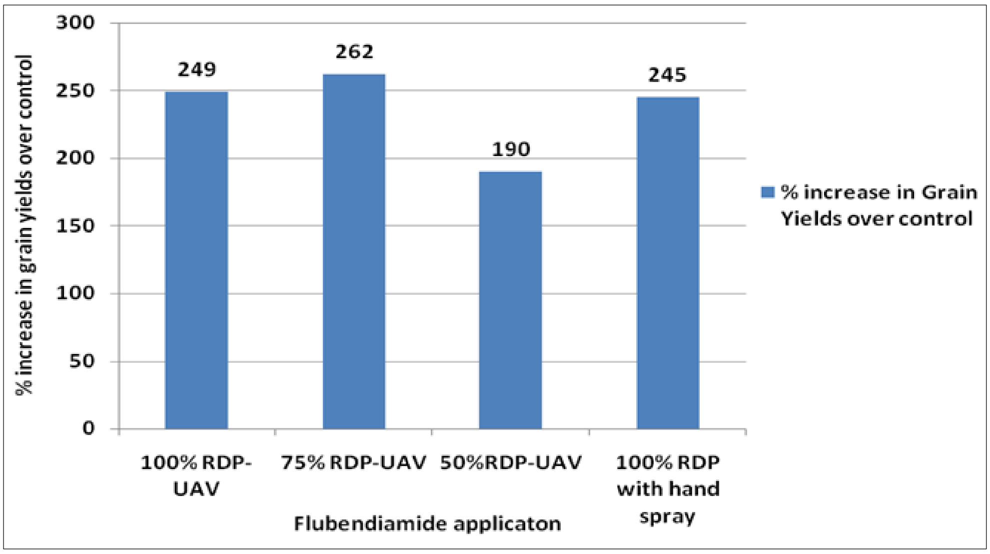
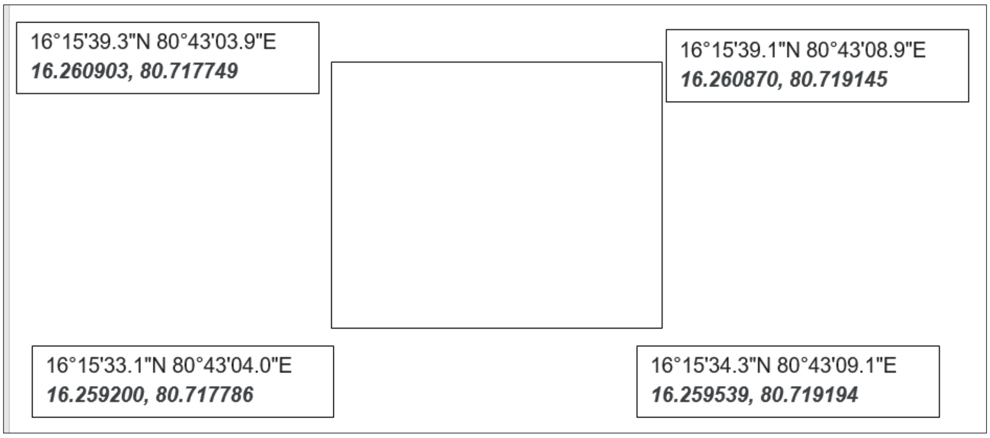


Fig 4: Per cent increase in grain yields in field experiments conducted on rice (Cv: BPT 5204) using UAV during *kharif* 2020 and 2021 in managing leaf folder (*Cnaphalocrocis medinalis*).



Conclusion

Overall, our results offer potential scope for the UAV designed by ANGRAU in reducing leaf folder damage, enhancing grain yields in rice during our experimentation in farmers' fields in *kharif* 2020 and 2021. Our long term goal is to come up with crop wise UAV recommendations in terms of its applications in different crop production and protection practices, besides suggesting UAV applications in agriculture as an economically viable, technically feasible and ecologically safe method.

References

1. Appala Raju K, Krishnayya PV, Sai Ram Kumar DV, Krishnaveni B, Manoj Kumar V. Screening of the recent rice varieties against leaf folder, *Cnaphalocrocis medinalis Guenee* (Pyralidae: Lepidoptera). Journal of Entomology and Zoology Studies. 2018;6(3):817-820.
2. Brookes G, Barfoot P. GM Rice: Will this lead the way for global acceptance of GM Crop Technology. Clc. ISAAA Briefs. No. 2003;28:45.
3. Cao YL, Yu FH, Xu TY, Du W, Guo ZH, Zhang HY. Effects of plant protection UAV-based spraying on the vertical distribution of droplet deposition on Japonica rice plants in Northeast China. Int J Agric & Biol Eng. 2021;14(5):27-34.
4. Chen P, Lan Y, Huang X, Qi H, Wang G, Wang J, *et al*. Droplet deposition and control of planthoppers of different nozzles in two-stage rice with a Quadrotor Unmanned Aerial Vehicle. Agronomy. 2020;10(303):3-14.
5. Chhavi, Ajay Srivastava, Sharma PK. Assessment of yield losses of rice caused by paddyleaf folder, *Cnaphalocrocis medinalis* Guenee. Agricultural Science Digest. 2017;37:72-74.
6. Chojjnacki J, Pachuta A. Impact of the parameters of spraying with a small unmanned aerial vehicle on the distribution of liquid on young cherry trees. MDPI Agriculture. 2021;11:1-13.
7. Gangwar RK. Life cycle and abundance of rice leaf folder, *Cnaphalocrocis medinalis* (Guenee): A Review. Journal of Natural Sciences Research. 2015;5(15):103-105.
8. Gopal M, Mishra E. Analytical method for estimation of a new insecticide flubendiamide and its safety evaluation for usage in rice crop. Bull Environ Contam Toxicol. 2008;81(4):360-364.
9. Mogili UM, Rao, Deepak BBVL. Review on application of drone systems in precision agriculture. Procedia Computer Science. 2018;133:502-509.
10. The Gazette of India. The Drone Rules, 2021. No. 477, Directorate General of Civil Aviation, New Delhi; c2021.
11. Qiu BJ, Wang LW, Cai DL, Wu JH, Ding GR, Guan XP. Effects of flight altitude and speed of unmanned helicopter on spray deposition uniform. Transactions of the CSAE. (in Chinese). 2013;29(24):25-32.
12. Rawn DFK, Quade SC, Shields JB, Conca G, Sun W, Lacroix GMA, *et al*. Variability in captan residues in apples from a Canadian Orchard. Food Addit. Contam. Part A. 2007;24:149-155.
13. Savary S, Willocquet L, Elazegui FA, Castilla N, Teng PS. Rice pest constraints in tropical Asia: Quantification of yield losses due to rice pests in a range of production situations. Plant Dis. 2000;84:357-369.
14. Shankar M, Shivaprasad G, Sumalini K, Balazzii Naaiik RVT, Cheeranjeevi K. Bio-efficacy and phytotoxicity of novel insecticides against brown plant hopper (Stal.), *Nilaparvata lugens* (Hemiptera: delhacidae) on rice. Journal of Entomology and Zoology Studies. 2019;7(5):860-865.
15. Singh P, Verma RL, Singh RS, Singh RP, Singh HB, Arsode P, *et al*. Biotic stress management in rice (*Oryza sativa* L.) through conventional and molecular approaches. In: New Frontiers in Stress Management for Durable Agriculture, Edited by, A. Rakshit *et al* (Eds); c2020. p. 609-644.
16. Sulagitti A, Raghuramanand M, Sai Reddy MS. Management of rice leaf folder (Cnaphalocrocis medinalis (Guenee) (Pyralidae: Lepidoptera) with phenyl pyrazole and neonicotinoids. Trends in Biosciences. 2017;10(23):4900-4904
17. Tsai MY, Elgethun K, Ramaprasad J, Yost M. The Washington aerial spray drift study: modeling pesticide spray drift deposition from an aerial application. Atmospheric Environment. 2005;39:6194-6203.
18. Wei-Cai Qin, Bai-Jing Qiu, Xin-Yu Xue, Chen Chen, Zhu-Feng Xu. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. Crop Protection. 2016;85:79-88.
19. Won JG, Ahn DJ, Kim SJ, Choi CD. Response of rice yield and grain quality as affected by rice leaf folder. Korean Journal of Crop Science. 2008;53:72-77.
20. Zala M, Sipai SA. Efficacy of insecticides against rice leaf folder, *Cnaphalocrocis medinalis* (Guenee). The Pharma Innovation Journal. 2021;10(12):874-879.