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Article

Optimum Flight Height for the Control of Desert Locusts Using Unmanned Aerial Vehicles (UAV)

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Abstract: Desert locust is one of the most destructive migratory pest in the world. Current methods of control rely on conventional chemical insecticides during invasion. Some environmentally friendly biopesticides based on *Metarhizium acridum* and insect growth regulators have also been deployed in preventive control operations. They have been tested in sprayers mounted on commonly used platforms such as vehicles, aircraft, and human. However, despite being used successfully, these tools present many challenges, hence the need to supplement them with suitable alternatives. The successful use of drones to control pests such as fall armyworm, planthoppers, aphids, among others, makes it an attractive technology that has the potential to improve locust management, especially in inaccessible areas. However, key parameters for the safe and optimal use of drones in desert locust control are not documented. This study established the key parameters for spraying desert locusts with a drone. To test the optimum height for spraying *Metarhizium acridum* on the locusts, the drone was flown at five different heights: 2.5, 5, 7.5, 10, and 12.5 m. At each height, the drone sprayed the ink mixture on spray cards pinned to the ground to approximate the droplet density and compare it to the standard droplet density recommended for desert locust control. To assess the efficacy of *M. acridum* and the effectiveness of drones in its application, 50 g of spores were mixed in 1 L of diesel and sprayed on caged live locusts of different stages (3rd and 4th instars, as well as the adults); they were monitored for twenty-one days in a controlled room, and their mortality was determined. Variation in droplet density between the tested heights was significant. A height of 10 m agrees with the recommended standard droplet density within the 45 droplets/cm^2 range. Mortality varied among the locusts' developmental stages within and between heights. Survival probability varied between heights for 3rd instar, 4th instar, and adults. All the developmental stages of the desert locust were susceptible to Novacrid and the recommended target stage is the 3rd instar. Management of desert locusts by the use of drone technology appears promising when the pesticides are applied at an optimum height and standard operating procedures are followed. Further research could explore the gap in the effects of environmental parameters on flight application efficiency.

Keywords: drones; *Metarhizium*; pesticides application; optimum height; droplets density; mortality rate

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1. Introduction

Desert locust, *Schistocerca gregaria* Forskål (Orthoptera: Acrididae), is one of the most destructive migratory pest in the world [1] and exhibits solitary and gregarious phases that vary in biology and behavior [2–5]. Upsurge of desert locusts have prompted the use of chemical pesticides such as organochlorines, carbamates, organophosphates, and pyrethroids as the main control measures [6,7]. However, although these chemical pesticides may provide an effective means of control, there are risks to the environment and human health and safety [8]. Moreover, invasion sometimes occurs in sensitive areas, such as near human settlements, and to some extent in protected areas with numerous beneficial organisms, which limits their use [9,10].

Consequently, safe and environment-friendly biopesticides based on *Metarhizium acridum* (Novacrid® and Green Muscle®) were developed [11–13] as oil formulations suitable for ultra-low volume (ULV) application. They have been tested in a range of commonly used spinning-disk sprayers, including the hand-held Micron Ulva-Plus and vehicle-mounted Ulva-Mast [14]. These sprayers were used successfully on various pesticide application platforms during the 2019–2022 desert locust invasions but presented some challenges, such as the accessibility of hard-to-reach areas and economic cost, both of which required improvements for the effective management of locusts [15,16].

Modern approaches and technologies, such as the use of UAVs, have the potential to complement the existing methods of desert locust management [1]. An UAV is an aircraft that flies without a human pilot onboard [1,17–22], whose development has become more practically feasible and affordable in precision agriculture [18,23,24]. The application of pest control products using UAV has been increasing over the years [25]. Importance is ascribed to the correctness of the process and application, taking into account the effects of sprayed liquid on the environment [26]. The fundamental issue in these processes is quality and efficiency, since they determine the efficacy and deposition of the pesticide [27]. One of the critical parameters to be optimized and considered for the effectiveness of UAV-enabled spraying is droplet deposition, measured by droplet density [18].

The efficiency of UAVs in spraying aphids and spider mites in cotton [28], brown plant hoppers [26], cowpea thrips [29], rice plant hoppers [30], fall armyworm in sugarcane [31], and wheat aphids [32] has been demonstrated. There have also been suggestions that UAVs can be used to apply pesticides on desert locusts [16,33], even though much remains to be completed in terms of research and implementation, or operationalization. Nonetheless, the parameters optimized in the studies on other insect pest species may not apply to desert locusts because of the differences in biology and behavior of the latter. There is a need to explore the potential of UAV technologies to improve locust management before populations build up and swarms invade extensive farming areas. One of the important factors to be considered for the effectiveness of UAV-enabled spraying is the droplet deposition. The parameters used for measuring the effectiveness of droplet deposition include droplets density. This measure is used to understand how the field is covered with pesticide and how well the pesticide is dispersed. The droplet density deposition is the number of droplets deposited per unit area and is often measured using water-sensitive papers. Effective control of pests requires the optimum dose of the pesticide applied so that droplets on the target surface can have the best coverage, spread, attachment, and absorption [18]. Droplets deposited on water-sensitive papers are counted through an automated solution, such as a swath kit, Dropscan, Agroscan, Dropleaf, and Image J software, among others. Flight altitude affects the effectiveness of a drone significantly [27,28,34] and it is logical that as the flight altitude increases, the droplet density reduces and droplet uniformity increases [34]; therefore, the goal is to achieve the highest possible flight altitude to increase effectiveness. At present, there is little information available on the optimum flight height when drones are used for desert locust control. Therefore, scientific-based field testing is required. This study established the optimum height for the application of pesticides for the control of desert locusts.

2. Materials and Methods

2.1. Field Site for the Experiment

The trials were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) Station, located at the Muguga Research Centre (1°13′ S, 36°38′ E), which lies 30 km from Nairobi, off the Nairobi–Nakuru highway. This study was conducted during the second week of October (2021) on a day when the weather was sunny and cloudless with a low relative humidity of 65%, with temperatures varying between 26 and 29 °C and wind speeds varying between 3.0 and 3.6 m s^{-1}. Temperature and wind conditions, as well as site characteristics, were similar to conditions required during some actual locust survey and control operations [13,35].

2.2. Parameters for Spraying Pesticides Using a Drone

A DJI Agras T20 drone fitted with an ultra-low volume (ULV) atomizer was used to assess the effect of spray application heights on droplet density on the ground. The drone was fitted with a Micronair 12 ULV spraying boom with three atomizers and a 20 L spray tank. White A4 papers measuring 210 × 297 mm were used as spray cards to estimate the deposition of droplets at different spray heights. The spray tank was filled to its maximum volume with a mixture of water-soluble black ink and water in a ratio of 1:3 (v/v) to produce the payload of 20 L at the start of the trial and was reloaded when the tank was empty. The spray cards were placed and pinned on the ground at intervals of 1 m in three equal and parallel rows that were 50 m apart. The drone's flight path bisected the three rows in the middle at right angles. A total of 61 spray cards were pinned on each row, 30 on the left and 30 on the right, with one card at the mid-line that marked the drone flight path (Figure 1). The spray cards were appropriately labelled according to the spray height tested and distance from the drone flight path. The flight trajectory was programmed using the drone's software to spray the ink mixture at five different heights: 2.5 m, 5.0 m, 7.5 m, 10.0 m, and 12.5 m. At each height, the drone sprayed the ink mixture at a constant flow rate of 1 L/min at a constant speed of 14 km/h. After every flight, the pinned spray cards were collected sequentially for analysis. This procedure was repeated three times for each flight height. The sprayed papers were scanned using a scanner (LaserJet Pro MFP MI30NW, Hewlett Packard) at 600 dpi and stored in Joint Photographic Group (JPG) format. The images (Figure 2) were imported to the Dropleaf app, which processed and analyzed droplet density through five steps: color space conversion to grayscale, binarization by threshold for noise removal, dilation and erosion, production of contours, and droplet identification [36]. The spread factor was assumed to be such that the values calculated by the app were the ones used for analysis.

A primary progeny of 140 desert locust hoppers in different developmental stages was obtained from the University of Nairobi, Department of Biology, and reared at the KALRO Muguga Center for six months, during which they were able to breed and generate a total of 1280 individuals in various developmental stages. A total of 324 individuals were selected for this experiment, comprising 108 individuals at the 3rd and 4th instars and adults. The temperature and relative humidity maintained in the insectary were 33 °C and 60%, respectively.

To test the efficacy of the Novacrid® biopesticide sprayed by a drone on live desert locusts, a total of 324 desert locusts were placed in 54 cages, each measuring 30 × 30 × 30 cm, with six locusts per cage. Each developmental stage had a total of 18 designated cages, of which 15 were for treatment (one treatment per drone flight height, repeated twice) and three were untreated controls.

A total of 500 g of Novacrid® biopescide was mixed with 20 L of diesel to form a homogenous solution and loaded into the drone's container. At each of the five different flight heights, one cage for each developmental stage was randomly placed in a 1 ha area, parallel to the flight route (Figure 3). The drone was launched to spray at the selected height, and this process was replicated three times. After spraying, the labelled cages were transferred to a quarantine room at the insectary, while the untreated locusts (the control) were left at the main insectary for observation, with a daily mortality recorded for a period of 21 days. The dead locusts were removed on a daily basis from the experimental cages and incubated in the laboratory at a temperature of 28 °C and 80% relative humidity to encourage external growth and sporulation of the fungus.

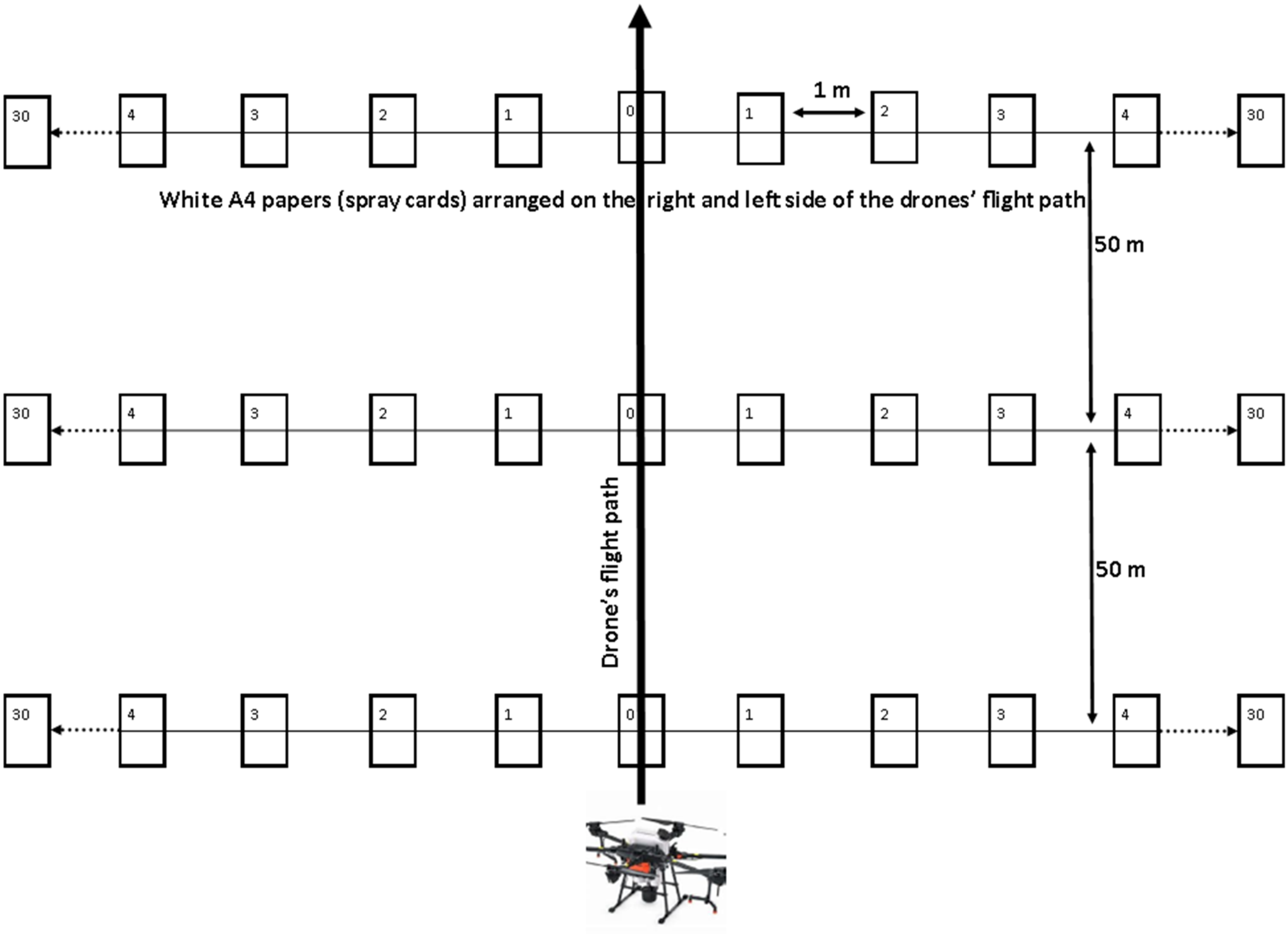


Figure 1. Illustration of the experimental layout of spray cards for establishing optimum droplet density by spraying at different heights using an Agras T20 drone fitted with a Micronair 12 ultra-low volume (ULV) spraying boom.

Figure 2. Samples of papers with droplets.

Figure 3. Wire mesh cages (objects arranged within the yellow circle) with live locusts arranged parallel to the drone flight path (object within the red circle).

2.3. Data Management and Analysis of Optimum Droplet Density at Different Flight Heights

The recorded density of the droplets was subjected to the Hampel filter in the R statistical software to identify outliers as part of data management. The Hampel filter considers outliers as values outside the interval (I) formed by the median, plus or minus 3 median absolute deviations (MAD);

$$I = [median - 3.MAD;\ median + 3.MAD], \tag{1}$$

where MAD is defined as the median of the absolute deviations from the data's median $\tilde{x} = median(x)$:

$$MAD = median(|x_i - \tilde{x}|). \tag{2}$$

To compute the optimum density of droplets, one litre sprayed in one hectare was converted to cubic micrometres (1.0×10^{15}). This was because it was known that during desert locust control, about 0.5–1.0 L of ULV insecticide was optimally sprayed in 1 hectare using rotary atomizers (spinning discs or rotating cages) to produce droplets in a small size range (50–100 µm) in diameter [13,34]. For optimization, a compromised diameter of 75 µm was used to estimate the volume of each droplet:

$$\text{Volume of each droplet} = \frac{4}{3}\pi r^3 = \frac{4}{3} \times \left(\frac{22}{7}\right) \times \left(\frac{75}{2}\right)^3 = 220,982\ \mu m^3. \tag{3}$$

Estimated droplet volume was used to estimate the number of droplets in 1 L,

$$\text{No. droplets} = \frac{1 \text{ litre } (\mu\text{m}^3)}{\text{Droplet size } (\mu\text{m}^3)} = \frac{1.0 \times 10^{15}}{220,982} = 4,525,252,525. \quad (4)$$

It was assumed that droplets were homogenously distributed in 1 ha (=100,000,000 cm^2), and then from this assumption, the optimum density of standard droplets Ø75 µm in one hectare was estimated from the following calculation, resulting in 45 droplets/cm^2:

$$\text{No. droplets } /\text{cm}^2 = \frac{4,525,252,525}{100,000,000} = 45 \text{ droplets}/\text{cm}^2. \quad (5)$$

The data on droplet density obtained from the dropleaf app was subjected to statistical analysis using R statistical software(Version 4.1.1). Anova was used to test the effect of flight height on droplet deposition. Tukey's honest significant difference (HSD) test was used where significant effects of flight heights on droplet density were observed ($p < 0.05$). One sample t-test was used to compare the standard calculated density against densities at different spray heights.

2.4. Efficacy of Metarhizium on Desert Locusts

Mortality in respective cages was transformed into percentages and corrected using Abbotts's correction formula to eliminate natural mortality as follows [37]:

$$Corrected\ mortality(\%) = \left(\frac{Trt - Co}{100 - Co}\right), \quad (6)$$

where Trt and Co are the daily treatment and control mortality, respectively.

Data were subjected to the Shapiro–Wilk test to test for normality. Mortalities in the 3rd instar, 4th instar, and adult stages in all the cages were subjected ANOVA to test the effect of spraying height on mortality. The Cox proportional hazard model was used to assess the statistical difference in survival probability of different developmental stages between flight heights. Survival distribution curves were generated using the Kaplan–Meier estimator.

3. Results

3.1. Variation in Droplet Density among Different Drone Flight Heights

Droplet density varied significantly among the tested heights ($F_{4,40}$ = 7.2; $p < 0.001$) (Table 1). The highest and lowest mean droplet densities (152.2 ± 4.8 and 24.8 ± 6.51) were recorded at the lowest (2.5 m) and highest tested flight height (12.5 m), respectively. Droplet density observed at 5.0 m, 7.5 m, 10.0 m, and 12.5 m did not vary significantly, but at 2.5 m it was significantly different from other tested flight heights except for 7.5 m (Table 1).

Table 1. Mean (±SE) spray droplet density at different drone flight heights.

Flight Height (m)	Mean (±SE) Droplet Density
2.5	152.2 ± 24.8 [b]
5.0	75.3 ± 11.1 [a]
7.5	96.0 ± 29.4 [ab]
10.0	40.2 ± 10.1 [a]
12.5	24.8 ± 6.51 [a]
$F_{4,40}$	7.2
p-Value	0.0002

Same letters indicate no significant difference.

3.2. Optimum ULV Spraying Heights Using a Drone

One sample comparison between standard droplet density and observed mean droplet density varied among different heights (Table 2). Mean droplet densities were significantly higher than the standard density (45 droplets/cm^2) at 2.5 m (t_{227} = 6.02; p < 0.05) and 5 m (t_{289} = 3.63; p < 0.05). The mean droplet density at 10 m was not different from the standard droplet density (t_{308} = 1.031; p > 0.05). Mean droplet density at a flight height of 10 m was concordant with the volume application rate (VAR) recommended by the manufacturer because the mean droplet density observed was within the standard range of 45 droplets/cm^2. However, the droplet density was lower than the standard at 12.5 m (t_{343} = 6.39; p < 0.05).

Table 2. One sample *t*-test comparison of the standard droplet density (45 droplets/cm^2) against droplet densities observed at different spray heights using a drone.

Spray Heights	**Mean Droplet Density**	**One Sample *t*-Test (Mu = 45 Droplets/cm^2)**		
(m)	**($\bar{x} \pm$ SE)**	***t*-Value**	***Df***	***p*-Value**
2.5	152.2 ± 24.8	6.02	227	7.07 × 10^{-9} ***
5.0	75.3 ± 11.1	3.63	289	0.0003 ***
7.5	96.0 ± 29.4	2.07	369	0.039 *
10.0	40.2 ± 10.1	1.03	308	0.304
12.5	24.8 ± 6.51	6.39	343	5.61 × 10^{-10} ***

*** shows strong significant difference of mean droplet density from the standard droplet density. * show least significant difference.

3.3. Effects of Drone Spraying Height on Mortality of Desert Locusts

Mortality varied among the locusts' developmental stages at different heights ($F_{2,30}$ = 25.71; p < 0.0001) (Table 3). Variation in mortality between different developmental stages was evident at 10.0 m ($F_{2,6}$ = 16.73; p = 0.0035) and 12.5 m ($F_{2,6}$ = 27.97; p < 0.0009). At 10.0 m, the mortality of the 3rd and 4th instars was similar and high compared to the adults, while at 12.5 m, the mortality of the third instar was high, followed by the fourth and lowest in adults. Mortality of all the locusts' stages was similar at 2.5 m ($F_{2,6}$ = 1.22; p = 1.00), 5.0 m ($F_{2,6}$ = 2.04; p = 0.21), and 7.5 m ($F_{2,6}$ = 1.53; p = 0.29).

Table 3. Mortality of different life cycle stages of desert locusts sprayed with Novacrid® biopesticide at different spray heights using an Agras T20 drone fitted with an ULV atomizer.

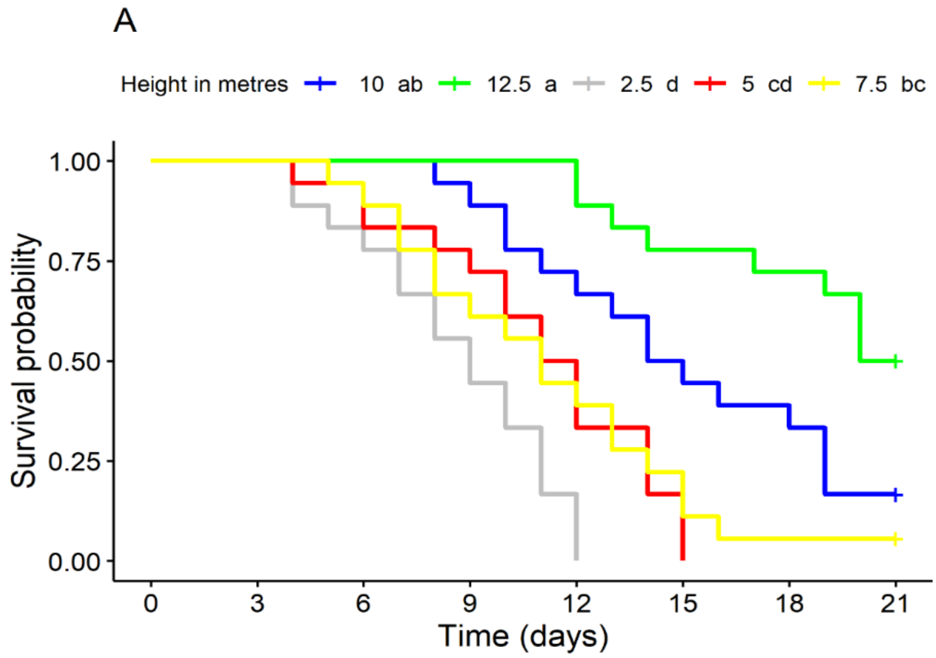
Stages of Desert Locusts	**Drone Spraying Height (Metres above Ground Level)**						
	2.5	**5.0**	**7.5**	**10.0**	**12.5**	$F_{4,10}$	***p*-Value**
Third	100.00 ± 0.00 ^{cA}	100.00 ± 0.00 ^{cA}	86.66 ± 6.67 ^{bA}	80.00 ± 0.00 ^{bB}	40.00 ± 0.00 ^{aC}	68.50	<0.0001
Fourth	100.00 ± 0.00 ^{cA}	86.66 ± 6.67 ^{bcA}	86.66 ± 6.67 ^{bcA}	73.33 ± 6.66 ^{bB}	26.66 ± 6.67 ^{aB}	22.74	<0.0001
Adults	100.00 ± 0.00 ^{dA}	83.33 ± 8.33 ^{cA}	75.00 ± 0.00 ^{cA}	50.01 ± 0.00 ^{bA}	0.00 ± 0.00 ^{aA}	109.00	<0.0001
$F_{2,6}$	1.22	2.04	1.53	16.73	27.97		
p-value	1.00	0.21	0.29	0.0035	0.0009		

The same superscripted lowercase letters in the same row indicate no significant difference in the mortality among different spray heights, while the same superscripted uppercase letters in the column indicate no significant difference in the mortality across life cycle stages; Turkey test (HSD), p = 0.05.

Mortality of all the locusts' stages varied between heights ($F_{4,30}$ = 143.39; p < 0.0001) (Table 3). Variation of mortality between heights was evident in the third instar ($F_{4,10}$ = 68.50; p < 0.0001), with the highest and similar mortality at 2.5 m and 5.0 m (100 ± 0.00), followed by 7.5 m (86.66 ± 6.67), 10.0 m (80.00 ± 0.00), and lowest at 12.5 m (40.00 ± 0.00). Similar variation was observed at the fourth instar ($F_{4,10}$ = 22.74; p < 0.0001) and adults ($F_{4,10}$ = 109.00; p < 0.0001). Both the fourth instar and adults exhibited the same trend of reduced mortality with an increase in spray height, except at 5.0 m and 7.5 m, where mortality was the same. Interaction between spray heights and different stages of locusts also had a significant effect on mortality ($F_{8,30}$ = 3.6745; p = 0.004271).

3.4. Effects of Drone Spraying Height on Survival Rates of Desert Locusts

The survival rate of different locusts' developmental stages (3rd, 4th, and adults) varied between different heights (Figure 4). Survival probability varied between heights for the 3rd instar (χ^2_4 = 56.84; $p < 0.0001$), the 4th instar (χ^2_4 = 54.17; $p < 0.0001$), and adults (χ^2_4 = 47.57; $p < 0.0001$). In the 3rd and 4th instars, locusts sprayed at 2.5 m and 5.0 m did not survive and all died by the 12th and 15th days, respectively. High survival probability was observed at 12.5 m, followed by 10.0 m, and least at 7.5 m, where some treated locusts remained alive after 21 days of monitoring. On the other hand, all the adults sprayed at 2.5 m died, while a high survival rate was observed at 12.5 m, followed by 10.0 m, 7.5 m, and 5.0 m, respectively.



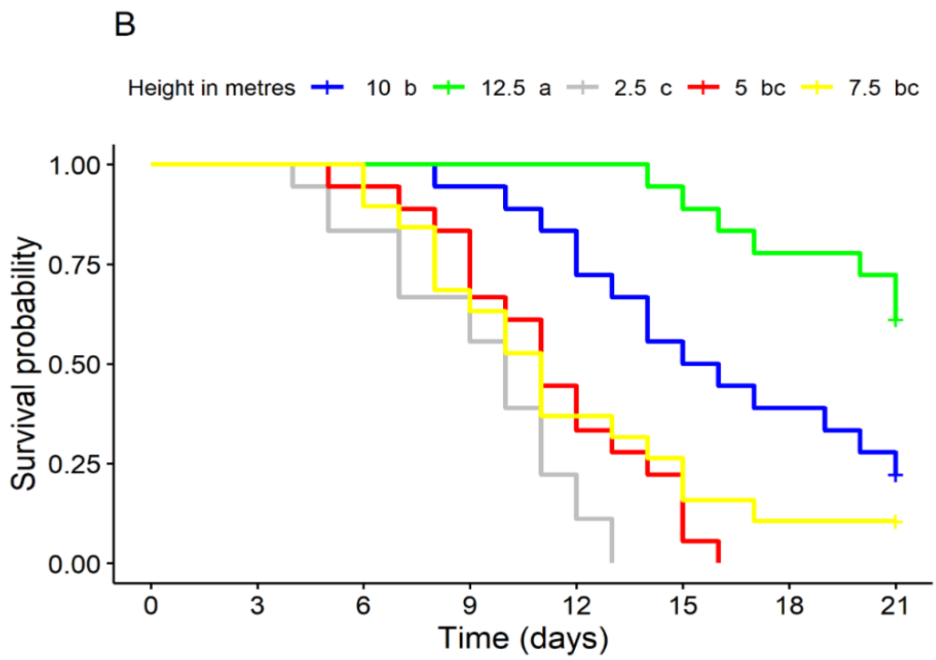


Figure 4. *Cont.*

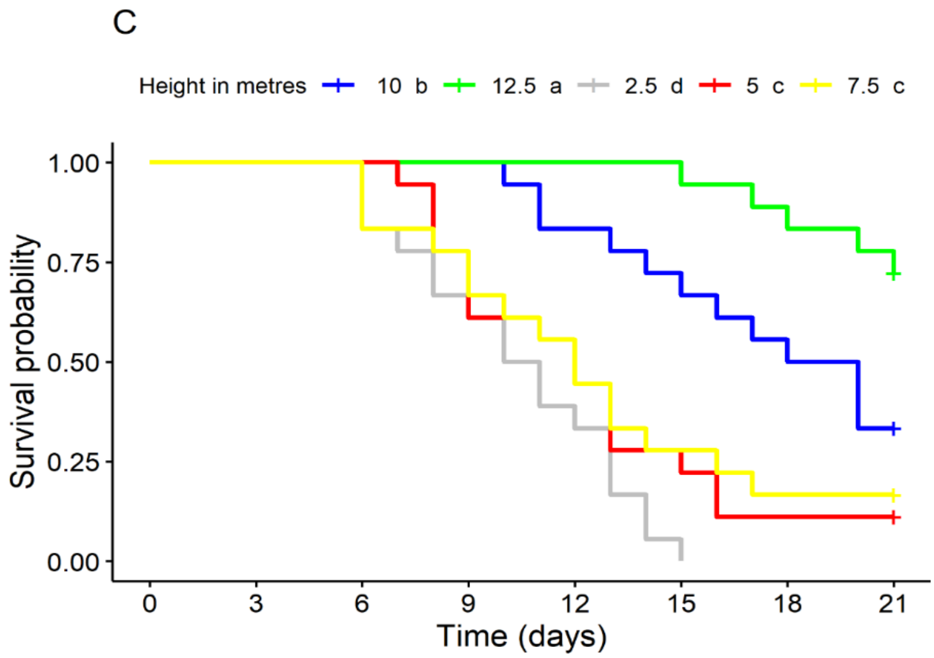


Figure 4. Kaplan—Meier survival curves for different stages of desert locusts sprayed with Novacrid® at different drone flight heights. The same small letters adjacent to the legend indicate no significant difference in the survival distribution curve at $p > 0.05$. (**A**) Survival curve of the 3rd instar, (**B**) survival curve of the 4th instar, and (**C**) survival curve of adults. "+" indicates right censorship.

4. Discussion

According to the formula derived from the information provided by Dobson [35], the recommended optimum droplet density for use in the management of desert locust is 45 droplets/cm^2. In this study, the droplet densities at the selected heights of 2.5 m, 5.0 m, 7.5 m, 10.0 m, and 12.5 m were 152.2 ± 4.8, 96.0 ± 29.4, 75.3 ± 11.1, 40.2 ± 10.1, and 24.8 ± 6.51, respectively. In reference to the optimum droplet density as provided by Dobson [35], the droplets were deposited more uniformly and sufficiently at the flight height of 10.0 m (40.2 ± 10.1). When the flight height was lower or higher than 10.0 m, the droplet densities indicated either over- or under-spraying, respectively. At lower heights (2.5 m, 5.0 m, and 7.5 m), the droplet density was higher near the nozzle area, resulting in an uneven distribution of droplets. Additionally, the swirling airflow caused by the flight effect of the drone flying perpendicular to the ground resulted in increased downward pressure on the droplets when the flight height was too low.

The variation of droplet densities with spray heights reported in this study matches the findings of earlier experiments in which a higher density of droplets was reported at lower heights than at higher heights [34,38–40]. High volumes and droplet densities at lower heights can also be the result of a strong downward swirling airflow that makes the air below sway substantially and affects the distribution and density of the droplets [26,40,41]. Lower droplet density at 12.5 m can be attributed to the downwash wind field above the ground, which is weakened when this flight height is maintained. Additionally, the weakened wind field in a vertical orientation causes an increase in the horizontal wind field that aggravates droplet transfer and drift to non-target areas, resulting in a sharp reduction in the density of droplets deposited on the target. These results are similar to a recent observation that an increase in height changes the downwash wind field, leading to a gradual reduction in droplet deposition within the effective target area [39,40]. The increased distance and time required for the spray to reach the targeted area also cause it to be dragged by the ambient air at higher heights compared to lower heights [41].

Drones have been identified as a potential platform for the application of pesticides in pest and weed management [24]. Their use in the management of desert locusts has been challenged by a lack of data on optimum spraying height and the efficacy of biopesticides on different development stages of locusts in a field setting. This study demonstrated that although the application of Novacrid® at all the spraying heights tested caused mortality in the three different developmental stages of the desert locust, there were variances in the mortality rate and survival probability. In this experiment, lower spray heights produced a high rate of mortality and a lower survival probability in all the tested locust's lifecycle stages compared to higher spray heights (12.5 m), which was comparable to other similar studies conducted to assess effects of spraying heights on mortality of other pests upon application of synthetic pesticides using a drone [26,39,42,43]. For example, a significantly higher mortality of wheat hoppers was reported when sprayed with chlorpyrifos pesticides at lower flight heights [26]. The high concentration of conidia at a lower height can be attributed to reduced drift that maximized pesticide deposition in the target. Depending on the pesticide used, accuracy in deposition and distribution is dependent on application height [40], which could affect the penetration of the active ingredients of the pesticides [43]. Furthermore, as the height increases, droplet dispersion increases and deposition decreases, causing pesticides to be carried to non-target areas [39].

Our findings on the mortality and survival of the desert locust can also be explained by the mode of action of *Metarhizium acridum*, which is through direct contact and germinates, invading the hemocoel within 24 h after application of conidia to the insect's cuticle. The rate of mortality achieved is dependent on the dosage of conidia that is in contact with the locusts [11].

In this study, it was observed that at all heights, the 3rd instar was more susceptible to Novacrid®, followed by the 4th instar, and finally adults. The comparatively lower dose received at 12.5 m lengthened the infection period and lowered the mortality rate, leading to a high survival probability after 21 days of application. This finding was similar to those of other studies that treated desert locusts of different stages with *Metarhizium acridum* [44–46]. For example, experimental studies in a laboratory setting have previously reported the highest mortality (50%) in the 3rd instar, followed by the 5th instar (43%), and adults (33%) [44]. In this study, at the selected height of 10.0 m that deposited the standard droplet density, mortality was highest in the 3rd instar (80%), followed by the 4th instar (73%) and adults (50%). The high percentage of mortality observed at the 3rd nymphal stage could be due to a weakened immune system coupled with a soft exoskeleton that enabled the biopesticide to penetrate faster compared to the 4th instar and adults. At the hopper stage, their behavior includes banding and marching, and the band densities tend to reduce with the increase in size (30,000 hoppers per m^2 for the first instar and 50 to 100 hoppers per m^3 for the late instars) [4]. Therefore, targeting the most susceptible early stages is also cost-effective in terms of the density of bands that will be controlled at once unlike the female adult desert locusts which can lay at least one egg pod before dying after an estimated 21 days of Novacrid® application. Therefore, drones can be used to improve the control of desert locusts.

5. Conclusions

This study has demonstrated that spraying desert locusts using a drone at any height below 10.0 m may lead to over-deposition of the pesticide, while heights above 10.0 m may lead to under-application, which may limit exposure of the locusts to *Metarhizium* spores or pesticide molecules. This study demonstrated that spraying a control agent from a specific height is more effective than other heights tested.

Despite all the developmental stages of the desert locust being susceptible to Novacrid®, the recommended target stage for management using this biopesticide is the 3rd instar stage because of the higher mortality rate and lower survival probability at this stage.

Further studies could explore the gap in the effects of environmental parameters on application efficacy and the effectiveness of using more than one drone (drone swarms), which allow greater area coverage at the same time.

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