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Research Article

Using drone for chemical control of cabbage aphid, *Brevicoryne brassicae* L. (Hemiptera: Aphididae) in canola fields

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Abstract. Canola, *Brassica napus* L. is a significant oilseed crop, containing 35 to 45% oil in its seeds, and can be cultivated in various climatic regions. Cabbage aphid, *Brevicoryne brassicae* L. is the most important pest of the canola fields in Iran. Chemical insecticide application using ground sprayers is the primary method for controlling *B. brassicae* in canola fields. However, the dense and tall growth of canola plants poses challenges for maneuvering ground sprayers, which can potentially cause damage to the plants. Therefore, in this study, we evaluated the feasibility and efficacy of aerial spraying of canola fields against cabbage aphid using drone, and compared it with ground spraying. During two growing seasons, this study was conducted in canola fields of Miandoab and Ilakhchi in northwest Iran. Aphid populations were sampled 24 hours before sprayings and 48 hours, 72 hours, and two weeks after sprayings. A six-rotor drone equipped with micronair rotary atomizers was employed for aerial spraying, while a tractor-mounted sprayer was used for ground applications. Results demonstrated that aerial spraying with drone was significantly more efficient, achieving two to six times higher efficacy against cabbage aphids than ground spraying, as measured by the reduction in aphid populations. Image analysis of water-sensitive cards indicated that drones produced finer droplets with smaller volume median diameters. Economic analysis revealed that aerial spraying was more cost-effective despite higher initial costs due to lower operational expenses and reduced water usage. These findings underscore the potential of using drones for precision pesticide application in canola farming.

Keywords: Aerial spraying, Pest management, Precision agriculture, Pesticide efficiency

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Introduction

Vegetable oils, derived from oil seeds, are the most widely used oils in the food industry. Approximately 90% of the edible vegetable oil required in Iran is sourced through imports (Shirani Rad & Deshiri, 2002). Canola (*Brassica napus* L.) is a significant oilseed crop, containing 35 to 45% oil in its seeds, and can be cultivated in various climatic regions of Iran. Consequently, the cultivation area for canola has increased in recent years, leading to a rise in the diversity and impact of pests and diseases (Anzabi *et al.*, 2009; Elahii *et al.*, 2018). One of the most important pests affecting canola in Iran is the cabbage aphid (*Brevicoryne brassicae* L.). This aphid feeds on the aerial parts of the plants, causing substantial damage to canola and other species within the cruciferous family. The pest is prevalent across the country, particularly in arid regions, where severe population outbreaks are common. During late winter and early spring, large aphid populations can develop in canola fields, damaging the plants by feeding on the growing shoot tips. This feeding causes wilting, flower abortion, and reduced pod set, significantly impacting crop yield (Seyyedi-Sahebari *et al.*, 2021).

In recent years, technological advancements have paved the way for innovative approaches to pest management. Specifically, small unmanned aircraft systems (sUAS), commonly known as drones, have emerged as a promising tool for precision agriculture and pest control. Drones offer several advantages over traditional tractor-mounted or ground-based sprayers, including reduced pesticide exposure for operators, the ability to cover large areas swiftly, access to hard-to-reach locations, suitability for diverse terrain conditions, and the prevention of soil compaction caused by heavy machinery (Filho I *et al.*, 2019; Rebelo & Nascimento, 2021).

Recently, drones have been used for applying pesticides on various crops around the world (Yallappa *et al.*, 2017; Hafeez *et al.*, 2023; Paul *et al.*, 2023; Vitória *et al.*, 2023). Yallappa *et al.* (2017) developed a drone-mounted sprayer and tested it on different crops. The cost of operation for groundnut and paddy crops using the drone-mounted sprayer was 345 and 367 Rs ha-1, respectively. The spray uniformity was increased with increase in height of spray and operating pressure. Assessing the weed control efficiency of pre-emergence, early post-emergence and post-emergence application of herbicides using drone and knapsack sprayer indicated that drone application of pretilachlor fb bispyribac-Na is an effective strategy to manage weeds in direct-seeded rice and more advantageous in terms of energy-use and profitability (Paul *et al.*, 2023). Fungicide application using a drone showed sufficient efficiency in the control of fungal diseases in coffee crops (Vitória *et al.*, 2023). Drone sprayer was also more efficient than tractor sprayer against date cicala pest (Safari & Sheikhi Garjan, 2020) and extensive research has been conducted on the impact of drone parameters, such as flight height and speed, on the dispersion of chemical pesticide droplets, drift, and their effectiveness against various pests (Huang & Thomson, 2011; Qin *et al.*, 2016; Shengde *et al.*, 2017; Subramanian *et al.*, 2021).

Drones operate at high speeds, but their performance can be influenced by environmental factors, and aerial spraying may lead to droplet drift (Hilz & Vermeer, 2013). Drift occurs when sprayed droplets are carried away from the target area by airflow during pesticide application (Matthews *et al.*, 2014). The deposition (positioning on the surface of foliage) and drift of droplets are crucial aspects in evaluating the efficiency of sprayers. Minimizing drift is essential to prevent unintended exposure to non-target organisms and to reduce environmental contamination (Huang & Thomson, 2011). Droplet size is crucial in pesticide spraying, as it directly impacts target coverage, drift, pesticide efficacy, and environmental effects. Smaller droplets can penetrate foliage and reach target pests more effectively, especially in dense canopies or complex plant structures. However, they can remain airborne longer and are more prone to being carried away by wind, potentially contaminating nearby water bodies, crops, or residential areas. Conversely, larger droplets are less susceptible to drift, thereby reducing environmental impact and off-target deposition. Additionally, coarse sprays are more likely to deliver pesticides to the soil surface (Matthews *et al.*, 2014; de Lima *et al.*, 2018).

Optimal droplet size ensures maximum contact with the pests, enhancing the effectiveness of the pesticide in controlling the target population. Producing uniform pesticide droplets is essential for high-quality spraying (Matthews *et al.*, 2014). Pesticide applicators can adjust equipment settings such as nozzle type, pressure, and spray volume to achieve the desired droplet size. It is essential to consider factors such as weather conditions, target species, and application technique to optimize droplet size for effective and environmentally responsible pesticide spraying (Azizpanah *et al*,. 2015; Xue *et al.*, 2021). Another factor influencing the quality of pesticide application is crop characteristics, including the shape, number, and size of leaves, the height of the first reproductive branch, and the diameter of the stem. These traits can impact the uniformity of spraying, wind entrainment, evaporation, and the delivery of droplets to the target (da Cunha *et al.*, 2018; de Lima *et al.*, 2018). The depth of droplet penetration into the plant canopy is also dependent on the method of pesticide application (ground or aerial), the volume of pesticide used, and the model and angles of the sprayer nozzles (França *et al.*, 2018).

There are different methods to evaluate the pesticide sprayers and the extent of pesticide droplet penetration into the canopy. Evaluating spray distribution typically involves using a quantitative method to determine droplet deposition and drift. The selection of a specific method generally depends on several factors, including the availability of human resources, the biological and physical characteristics of the target product, and the required accuracy (Jokar, 2021). Water-sensitive paper cards are useful tools for efficiently and quickly evaluating and monitoring sprayer performance. They can be used to determine droplet densities, penetration, widths, and distribution, assess the effectiveness of spray nozzles, and ensure the application of an adequate amount of spray liquid. The top side of the water-sensitive card is yellow and coated with a water-sensitive dye such as bromophenol blue. It becomes tinted with dark blue dots following exposure to spray droplets while the opposite side repels water (Matthews *et al.*, 2014).

For approximately 30 years, these cards have been used by different users (farmers and researchers) to evaluate the spray distribution and droplet deposition rate in both ground and aerial spraying (Salyani *et al.*, 2013). Due to their affordability and ease of use, water-sensitive cards have replaced other quantitative methods such as colorimetry, fluorimetry, and spectrometry which are more accurate, but expensive and time-consuming (Derksen and Gray, 1995; Pergher & Gubiani, 1995; Hoffmann & Salyani, 1996). Before spraying, the cards are clipped to various parts of the crop, and after spraying, the number and size of pesticide droplets are examined (Thériault *et al.*, 2001). Water-sensitive cards have been used in the field on several crops such as wheat, soybean, apple, citrus, and even greenhouse plants to evaluate the spray quality and other operational variables of different sprayers (Zhu *et al.*, 2008; Derksen *et al.*, 2010; Ozkan *et al.*, 2011).

In Iran, the prevalent method for controlling *B. brassicae* involves the repeated use of chemical insecticides applied via various types of ground sprayers. This approach is often labor-intensive, time-consuming, and usually inefficient due to poor targeting. The dense and tall nature of canola plants complicates maneuvering ground sprayers, leading to potential plant damage (Shirani Rad & Deshiri, 2002; Seyyedi-Sahebari *et al.*, 2021). Consequently, using drones for spraying canola fields could offer a more efficient and straightforward alternative to traditional ground-based methods. This study aimed to assess the feasibility and efficiency of using drones to spray canola fields to combat *B. brassicae.* Therefore, the efficiency, droplet size and deposition, and costs of aerial spraying were assessed and compared with ground spraying.

Materials and methods

Study site

This study was conducted in two canola-growing regions in northwest Iran (Ilkhchi 38S, 585249E 4200783N, and Miandoab 38S, 601219E, 4083309N) during *B. brassicae* outbreaks in 2020 and 2022. The low population of aphid in northwest Iran did not allow us to repeat the experiment in 2021. The experiments were conducted to evaluate and compare the efficiency of aerial insecticide application with ground spraying. In the first year, we selected a canola field with an area of 1 ha in Ilkhchi and divided it into three plots, 0.7 ha for aerial spraying (by drone), 0.15 ha for ground application, and 0.15 ha for control. Two 1.2 and 1.4 ha fields, a few hundred meters apart, were selected in Miandoab in the second year. Each field was divided into two plots, 1 ha for aerial spraying and 0.2 ha as its control and 1 ha for ground spraying and 0.4 ha as its control. At least a 10 m buffer between plots was considered to avoid the drift effect. Both aerial and ground treatments were applied simultaneously with pesticide application by local farmers. *B. brassicae* infestations occur most frequently in canola from early flowering to late pod development, and chemical pesticides are usually applied when the first aphid populations are observed in the field.

Aerial application

A six-rotor drone (JT10L-606, Joyance tech, Shandong, China) with a tank volume of 10 L, a spraying width of 3.5 to 5.5 m, and two micronair rotary atomizers was used for aerial spraying. Micronair nozzles produce particles with a diameter of 50–200 µm. The drone was flown 2 m above the canopy with autopilot function and a speed of 5 ms-1.

Ground spraying

A tractor-mounted sprayer equipped with a 1000 L tank, a 20 m hose and lance, a cone nozzle, and a piston pump capable of producing high pressures of up to 40 bar, was used for ground spraying.

Insecticide

Imidacloprid (35% SC, Ariashimi Company, Tehran, Iran) was applied at a 0.5 L ha-1 rate for aerial and ground sprayings. This volume of insecticide was mixed with 9.5 L of water in the drone tank and 500 L of water in the ground sprayer tank. Sprayings were conducted from 10 a.m. to noon and at stable weather conditions.

Samplings

The aphid population was sampled four times in all plots. The first sampling occurred 24 hours before spraying, followed by three more samplings at 48 hours, 72 hours, and two weeks after spraying. One plant was selected every 10 steps across plot diameters, and 15 cm of the terminal stem, where *B. brassicae* typically form dense colonies, was cut (Fig. 1). The stems were placed in plastic bags individually, transferred to the laboratory, and the total number of aphids was counted under a 20× hand lens. The number of samples was 50 to 200, depending on the plot size. The efficiency of aerial and ground sprayings was calculated and compared using the Henderson-Tilton formula (Henderson & Tilton, 1955):

$$\text{Efficiency\%} = 1 - \left(\frac{n\ in\ C\ before\ treatment \times n\ in\ T\ after\ treatment}{n\ in\ C\ after\ treatmant \times n\ in\ T\ before\ treatmaent}\right) \times 100$$

where n is insect number, C is control and T is treatment.

We also conducted a 1-way ANOVA to test the effect of aerial and ground sprayings on the number of surviving *B. brassicae* using lm() function in R (version 4. 3. 3, R Core Team, https://www.R-project.org). We used LSD to compare treatment means. Additionally, the aphid population before spraying was compared between treatment and control plots, to ensure that the differences were due to the treatments.

Droplet size and deposition in aerial and ground spraying

Water-sensitive cards (25×75 mm) were used to measure droplet size and deposition in both aerial and ground sprayings (Fig. 2). The upper side of the card becomes tinted with dark blue dots upon contact with sprayed droplets, making them useful for determining the spray quality of different sprayers. Ten water-sensitive papers were clipped to the terminal part of ten randomly selected canola plants (15 cm below the tip of the stem) in each plot before spraying and collected immediately after spraying. DepositScan software (USDA Agricultural Research Service) was used to measure the droplet size and evaluate spray coverage. The papers were scanned with HP LaserJet M1132 scanner and the images were loaded into the software. Image analysis was conducted and volume median diameter (VMD) and coverage percentage values were obtained. VMD, expressed in micrometers (µm), is the droplet diameter at which the spray volume is divided into two equal parts: half of the volume consists of droplets smaller than the VMD, and the other half consists of larger droplets (Matthews *et al.*, 2014). Two-sample t-test was used to compare the VMD and coverage percent between aerial and ground spraying treatments (R version 4. 3. 3).

Economic comparison of aerial and ground spraying

To determine the economic efficiency of aerial and ground spraying, we compared the costs of both methods, including time, machinery, labor, insecticide, water, and fuel.

Fig .1. (A) Dense colony of *B. brassicae* on the terminal stem of a canola plant. (B) Terminal stem being sampled by cutting 15 cm

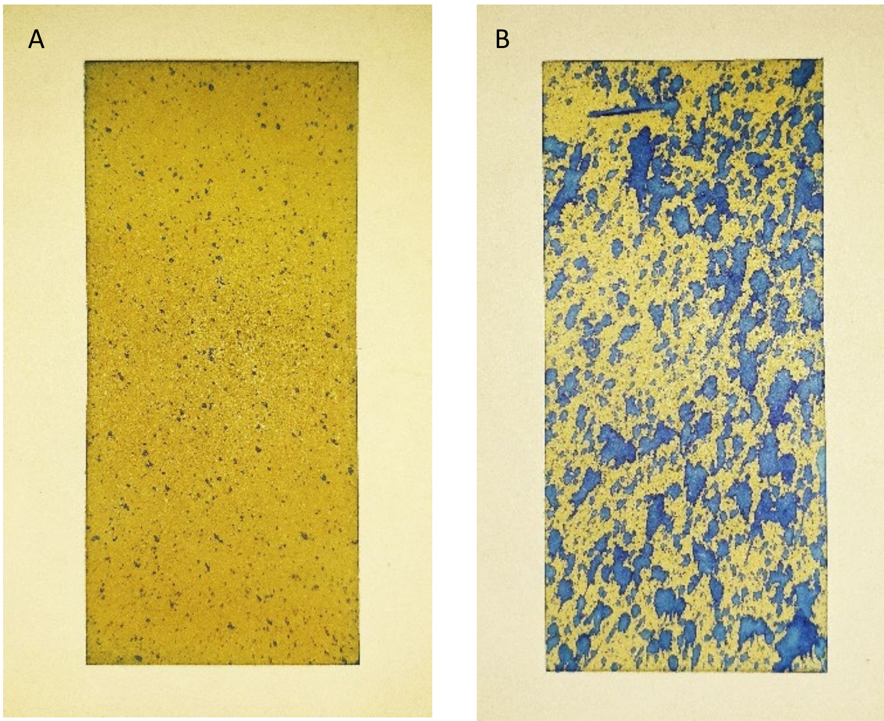

Fig. 2. Water-sensitive papers used to assess droplet size and deposition in aerial (A) and ground (B) spraying applications

Results

The efficiency percentages of aerial and ground spraying calculated by Henderson-Tilton formula are shown in Table 1. Aerial spraying was 2 to 6 times more efficient than ground spraying in both years and all sampling dates. We found that there was a difference in *B. brassicae* population in the plots before spraying, indicating a difference in population density between the plots in 2020 (Table 2). Consequently, mean comparisons of the number of surviving *B. brassicae* after spraying were not performed, as the observed differences could not be attributed to the treatments or the initial population variations. In 2022, the mean number of *B. brassicae* in the experimental plots was not significantly different before spraying, indicating that differences observed after spraying could be attributed to the treatment. Therefore, the number of surviving *B. brassicae* after spraying was compared between treated and control plots (Table2). The mean number of insects 48 hours after treatment was significantly lower (8.5 ± 1.5) in the aerial spraying treatment compared to the ground spraying treatment (38.5 ± 2.8) and control (58.5 ± 2.2). Three days after treatment, the mean number of insects in the aerial spraying treatment remained significantly lower than in the control but was not significantly different from the ground spraying treatment.

Droplet size and deposition

The mean VMD (mean of 10 cards) of droplets from the drone nozzles was significantly smaller than those from ground sprayer nozzle (Student t-test, $t = 6.49$, $df = 18$, $P < 0.001$) (Fig. 3). The coverage percentage of the drone was also lower (Student t-test, $t = 11.63$, $df = 18$, $P < 0.001$).

Table 1. Efficiency (%) comparison of aerial spraying by a drone and ground spraying by a tractor-mounted sprayer against *Brevicoryne brassicae* in canola fields, evaluated at 48 hours, 72 hours, and 14 days after treatment.

Year	Treatment	48 h	72 h	14 DAT*	Mean
2020	Aerial spraying	65.96	56.31	43.61	47.65
	Ground spraying	20.00	20.64	26	22.21
2022	Aerial spraying	77.00	58.85	57.85	64.56
	Ground spraying	12.00	18.20	16	15.4

*: Days after treatment

Table 2. Mean comparison of *Brevicoryne brassicae* numbers per sample in treatment and control plots before and after sprayings in 2022

	Before spraying	48 h after spraying	72 h after spraying	14 d after spraying
Aerial spraying	51.5a*	8.5a	15.6a	21.6a
Ground spraying	42.4a	38.5b	26.1ab	20.0a
Control	44.7a	58.5b	48.6b	55.6b

* Different letters in each column mean significant difference at 0.05 probability level

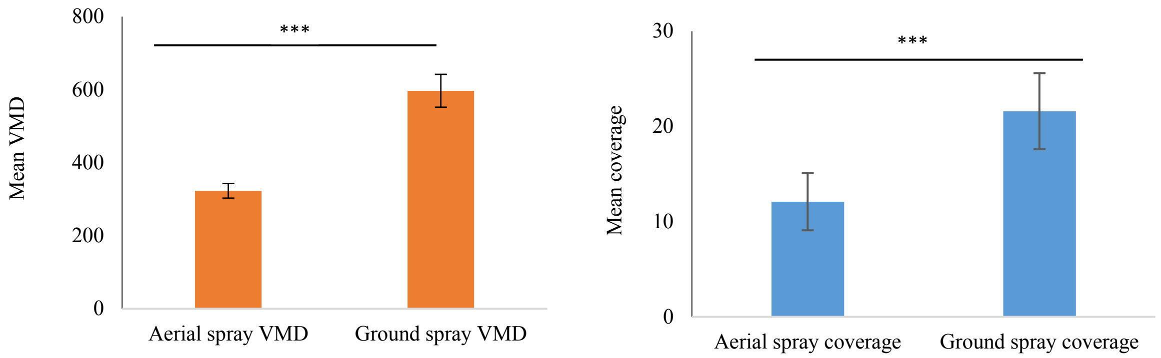

Fig. 3. Mean volume median diameter (VMD) and mean coverage obtained from image analysis of water-sensitive cards for aerial and ground sprayings. Significant differences between the two methods were observed ($P < 0.001$).

This result was expected because the ground sprayer uses a higher volume of spray liquid, producing larger droplets that cover more surface area on the paper. However, these larger droplets are more likely to reach the soil surface compared to the smaller droplets produced by the drone.

Economic comparison of aerial and ground spraying

Costs of aerial spraying included drone rental, insecticide, and water; and ground spraying costs included tractor and sprayer rental, labor, insecticide, water, and crop damage caused by tractor or worker. Costs were simplified using "m" for one million Iranian rials (IRR). Insecticide cost was 5.5 mIRR for both spraying methods at 0.5 l. ha-1 spraying rate. Ground spraying used 50 times more water than aerial, but its cost was negligible and ignored in economic calculations. Drone rental was 4 mIRR/ha, including the pilot, while tractor rental was 3 mIRR/ha including the driver. The ground spraying and carrying of the lance and hose involved one worker paid 3 mIRR ha-1. Based on the information obtained from crop protection experts at each region, crop damage caused by the tractor or worker during spraying was estimated at least 5%, costing 0.011 mIRR. Total costs were 8.5 mIRR for aerial spraying and 11.72 mIRR for ground spraying (Table 3) Spraying one hectare took 10 minutes with a drone and 60 minutes with a ground sprayer.

Table 3. Costs of aerial and ground spraying against *Brevicoryne brassicae* in canola fields per hectare

	Aerial spraying	Ground spraying
Insecticide (mIRR*)	5.5	5.5
Rental cost (mIRR)	4	3
Worker (mIRR)	0	3
Crop damage (mIRR)	0	0.011
Total (mIRR)	9.5	11.72

* Million Iranian Rials

Discussion

In this study, the efficiency of aerial and ground spraying of canola fields against *B. brassicae* was compared. Results indicated that aerial application was two to six times more efficient than ground spraying in both years and all sampling dates. Better efficiency may be achieved due to the production of finer droplets by the micronair nozzles of the drone. In these nozzles, the toxic liquid turns into droplets with a diameter of less than 400 microns (Matthews *et al*., 2014). The propellers of the drone also generate a downwind flow which helps deposition of the droplets on the plants. The finer droplets create a more uniform toxic coating, increasing the probability of insects' contact with the insecticide, thus enhancing spraying efficiency. Shengde *et al.* (2017) confirmed that the wind field created by the UAV rotor is a key factor in droplet distribution and deposition. Since *B. brassicae* populations tend to settle in the terminal part of the canola stem, spraying from above the canopy ensures adequate coverage without needing to penetrate deeply into the canopy.

Our findings align with other research. Safari and Sheikhi Garjan (2020) found that aerial spraying of date palms against date cicala pest, *Ommatissus lybicus* (Hemiptera: Tropiduchidae) had a quality coefficient 1.35 times higher than ground spraying. They also noted that the lance sprayer had a 42.6% insecticide loss compared to 11% with drones, due to the propeller-induced airflow directing droplets downward. Qin *et al.* (2016) found that the landing and distribution of droplets in rice fields are closely related to the height and speed of the spraying drone and the optimal droplet coverage was achieved with a drone spraying at a speed of 5 m/s and a height of 1.5 m, resulting in a 92% efficiency rate. The low height and speed of the drone flight in our study may justify the high efficiency of aerial spraying compared to ground spraying.

According to our results, although the mean number of surviving aphids was significantly lower in aerial spraying compared to ground spraying and control 48 hours after treatment, no significant difference was observed between aerial and ground spraying 14 days after treatment, indicating population regrowth. The number of surviving aphids after treatment is important as aphids are classic r-strategists and have high reproductive capacity and the ability to invade new habitats (Nalam *et al*., 2019). Parthenogenetic reproduction and winged adults allow aphids to rebuild the population even with low survivors. Therefore, even when an efficient control method is applied, a small number of individuals that survive after treatment may reproduce quickly and form large colonies, necessitating the need to repeat the treatment. The results of image analysis of water-sensitive cards with Depositscan software indicated that the mean VMD of the droplets produced by the ground sprayer is twice larger than the droplets produced by the drone nozzles. Droplet size is a crucial factor in pesticide spraying as it directly influences the efficacy and safety of the application. Large droplets, exceeding 200 micrometers, settle quickly due to sedimentation, mitigating spray drift concerns. In a coarse spray, large droplets tend to follow a vertical trajectory and primarily collect on horizontal surfaces. If not captured by foliage, these droplets will reach the soil surface (Matthews *et al*., 2014). In contrast, smaller droplets provide superior foliage coverage as they are more susceptible to air currents, altering their trajectory from the nozzle. These droplets, moving along a more horizontal plane, can impact the vertical parts of crops such as stems, petioles, and the more upright leaves of monocotyledon crops. While small droplets released above flat fields may travel considerable distances, most are filtered out by crop foliage. Consequently, few droplets reach the undersides of the leaves unless the nozzle is adjusted to spray upwards, or there are leaf-movement-induced air turbulences or upward airflows (Matthews *et al*., 2014; Xue *et al*., 2021).

Water used for ground spraying was 50 times more than aerial spraying. Given Iran's prolonged drought crisis, reducing water consumption in agriculture is vital. A 50-fold reduction in water usage by drones is significant, especially on a large scale. The total costs of aerial and ground spraying were 8.5 mIRR and 11.72 mIRR, respectively. The time required for spraying one hectare was 10 min for the drone and 60 min for the ground sprayer. Therefore, automated drone spraying can be faster and more cost-effective compared to manual spraying methods, especially for large or hard-to-access areas. Drones provide flexibility in pesticide application across dense and high crops such as canola which is challenging for traditional spraying equipment or manual labor. Additionally, using drones reduces operator exposure to hazardous chemicals. While our study emphasizes the potential of using drones for pesticide application in canola fields, there are some limitations in aerial spraying of large or uneven fields. Most drones have limited carrying capacity for pesticides, which may necessitate frequent refills and limit the area covered in a single flight. Pesticide drift, especially at higher flight altitudes, and the possibility of contamination of non-target areas and the limitation of the UAV's battery power and the need to charge it in short intervals during spraying are other limitations of aerial spraying. Weather conditions and regulations governing drone operations are other limitations which can affect drone applications. Despite these challenges, ongoing advancements in drone technology and regulatory frameworks are likely to enhance the viability and adoption of drones for pesticide application in agriculture.

Author's Contributions

The author confirms sole responsibility for the following: **Roghaiyeh Karimzadeh**: conceptualization, final review and edit, supervision, project administration, and funding acquisition. **Elsa Tabatabaie**: methodology, formal analysis, and investigation. **Mir Jalil Hejazi**: conceptualization, final review, and edit. **Saeid Behmaram**: draft preparation, edit, and visualization.

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Data Availability Statement

All data supporting the findings of this study are available within the paper.

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Ethics Approval

Only insects were used in this study. All applicable international, national, and institutional guidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by any of the authors.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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استفاده از پهپاد برای کنترل شیمیایی شته مومی کلم *Brevicoryne brassicae* L. (Hemiptera: Aphididae) در مزارع کلزا

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چکیده: کلزا، *Brassica napus* L. با ۳۵ تا ۴۵٪ روغن در دانه‌های خود یکی از مهم‌ترین گیاهان روغنی در دنیاست و می‌تواند در مناطق اقلیمی مختلف کشت شود. شته مومی کلم، *Brevicoryne brassicae* L. مهم‌ترین آفت مزارع کلزا در ایران است و در حال حاضر کاربرد حشره‌کش‌های شیمیایی با استفاده از سمپاش‌های زمینی رایج‌ترین روش کنترل این آفت می‌باشد. اما تراکم و ارتفاع زیاد گیاهان کلزا در مزرعه، حرکت سمپاش‌های زمینی را مشکل کرده و موجب آسیب به گیاهان می‌شود. بنابراین، در این مطالعه، کارآیی سمپاشی هوایی مزارع کلزا علیه شته مومی کلم با استفاده از پهپاد بررسی و با سمپاشی زمینی مقایسه شد. این مطالعه طی دو فصل زراعی، در مزارع کلزای میاندوآب و ایلخچی واقع در شمال غرب ایران انجام شد. نمونه‌برداری از جمعیت شته ۲۴ ساعت قبل از سمپاشی و ۴۸ و ۷۲ ساعت و دو هفته بعد سمپاشی انجام شد. برای سمپاشی هوایی از یک پهپاد شش روتور مجهز به اتمایزرهای چرخشی میکرونیر و برای سمپاشی زمینی از یک سمپاش پشت تراکتوری استفاده شد. نتایج نشان دادند که سمپاشی هوایی با پهپاد به صورت معنی‌داری مؤثرتر از سمپاشی زمینی بوده و دو تا شش برابر کارآیی بیشتری در کاهش جمعیت شته داشت. تجزیه تصویر کارت های حساس به رطوبت نشان داد که هواپیماهای بدون سرنشین قطرات ریزتری با قطر متوسط حجمی کوچکتر تولید می کنند. تجزیه و تحلیل اقتصادی هم نشان داد که سمپاشی هوایی علیرغم هزینه های اولیه بالاتر به دلیل هزینه های عملیاتی کمتر و کاهش مصرف آب مقرون به صرفه تر می‌باشد. این یافته‌ها بر پتانسیل استفاده از پهپادها برای کاربرد دقیق آفت‌کش‌ها در مزارع کلزا تأکید می‌کنند.

کلمات کلیدی: سمپاشی هوایی، مدیریت آفات، کشاورزی دقیق، کارآیی آفتکش

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