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DRONE SPRAYING OF FUNGICIDES TO CONTROL ASIAN SOYBEAN RUST

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Abstract: This study aimed to determine the viability, assess technical parameters, and test the efficiency of agricultural drones as a vehicle for spraying fungicides to chemical control of Asian soybean rust, compared to application technologies using backpack sprayers and tractor-mounted sprayers. The trials were conducted over two soybean seasons, during the 2020/2021 and 2021/2022. In the first season, treatments consisted of three types of spraying: drone at 10 L/ha application rate, tractor-mounted sprayer at 150 L/ha, and backpack sprayer pressurized by CO_2 at 150 L/ha. In the second season, a treatment using the drone at 5 L/ha application rate was included. Evaluations were made by estimating rust severity at different times, calculating the area under the disease progress curve, the percentage of control compared to the untreated control, leaf defoliation percentage, thousand-grain weight, and yield. The results indicate that fungicide spraying by drone can control Asian soybean rust as effectively as CO_2-pressurized backpack sprayers and tractor-mounted sprayers.
Keywords: *Glycine max*, *Phakopsora pachyrhizi*, remotely piloted aircraft.

INTRODUCTION

In the agricultural sector, the global market for drones, also referred to as unmanned aerial vehicles (UAVs) or remotely piloted aircraft (RPAs), is estimated to have an annual growth rate of 7.8% between 2022 and 2030, reaching around US$ 26.6 billion in 2021, with projections to reach US$ 55.8 billion in 2030, of which US$ 2.3 billion is estimated for South America (Droneii, 2022). Specifically focusing on the drone spraying market, there has been significant growth in Brazil, particularly from 2021, following the regulations by the Ministry of Agriculture, Livestock, and Supply, establishing rules for the operation of remotely piloted aircraft intended for the application of pesticides, adjuvants, fertilizers, inoculants, correctives, and seeds. Such technology allowed efforts to reduce water usage, enhance efficacy, precision, and speed in application, increase adaptability to various environments, and mitigate environmental and human contamination risks.

One characteristic of drone applications is the use of reduced application rates, which allows for increased equipment autonomy and operational capacity. However, this also requires greater care in applications, particularly concerning plant coverage to reach the target (Silva, 2022). Despite increasing studies and information available on various crops and different targets, there is still a lack of research to evaluate the efficiency of this technology, especially in critical and challenging pathosystems, such as that presented by Asian soybean rust.

The Asian soybean rust is caused by the fungus *Phakopsora pachyrhizi*. It can occur at any stage of plant development, causing lesions on leaves that lead to yellowing and premature leaf drop, thereby harming pod formation, grain weight, and quality. It spreads through the wind via spores and is favored by well-distributed rainfall and extended periods of leaf wetness (Godoy et al., 2016a). Managing Asian soybean rust involves integrating cultural measures, using cultivars with genetic resistance, and spraying fungicides. Fungicides are a relevant tool in controlling the disease and their use in soybeans intensified with the entry of the fungus *P. pachyrhizi* into Brazil (Godoy et al., 2016b).

In this context, this study aimed to determine the viability, verify technical parameters, and test the efficiency of agricultural drones as a vehicle for spraying fungicides for the chemical control of Asian soybean rust, compared to application technologies using backpack sprayers and tractor-mounted sprayers.

MATERIALS AND METHODS

The trials, over two crop seasons, 2020/2021 and 2021/2022, were conducted at an experimental field in the municipality of Londrina, PR, located at latitude 23°11' S, longitude 51°11' W, and 630 meters above sea level. Precipitation - the primary climatic factor influencing plant development and disease occurrence - was monitored using a weather station.

In the first season, sowing was done on December 15, 2020, with cultivar BRS 543RR. Treatments consisted of three different types of spraying: drone at 10 L/ha application rate, tractor-mounted sprayer at 150 L/ha, and CO_2-pressurized backpack sprayer at 150 L/ha. The drone used XR 110.01 nozzles, the tractor-mounted sprayer used AXI 120.03 nozzles, and the backpack sprayer used XR 110.02 nozzles. Two sprayings were conducted based on climate monitoring, disease occurrence in the region, and crop development stages on February 5, 2021 (R2), and February 26, 2021 (R5.1). Climatic conditions during spraying and application parameters are described in Table 1. The fungicide was a commercial mixture of active ingredients bixafen + prothioconazole + trifloxystrobin (62.5 + 87.5 + 75 g a.i. ha^{-1}) at a dose of 0.5 L a.i. ha^{-1}, mixed with adjuvant (emulsifiable vegetable oil) at a dose of 0.25% v/v. The experimental design was a randomized complete block, with four replications. Experimental plots were 20 meters long, and 6 meters wide, with a spacing of 0.5 meters between rows. The length of 20 meters was adopted to provide at least 5 meters of border on each end for the drone's acceleration and deceleration. Evaluations were conducted within the central 5 meters of the two rows in each plot.

In the second season, sowing was done on November 24, 2021, with cultivar BRS 1003IPRO. Treatments consisted of four types of spraying with different application rates: drone at 5 L/ha, drone at 10 L/ha, tractor-mounted sprayer at 150 L/ha, and CO_2-pressurized backpack sprayer at 150 L/ha. The nozzle types were the same as used in the first season. Two sprayings were conducted based on climate monitoring, disease occurrence in the region, and crop development stages on January 25, 2022 (R3), and February 17, 2022 (R5.2). Climatic conditions during spraying and application parameters are described in Table 2. The fungicide used was a commercial mixture of active ingredients picoxystrobin + benzovindiflupyr (60 + 30 g a.i. ha^{-1}) at a dose of 0.6 L a.i. ha^{-1}. The experimental design was a randomized complete block, with four replications. Experimental plots were 15 meters long, and 8 meters wide, with a spacing of 0.5 meters between rows.

Evaluations in both experiments were conducted by estimating the severity (percentage of infected leaf area) of Asian soybean rust using a stereoscopic microscope and a diagrammatic scale of scores (Godoy et al., 2006), collecting 20 leaflets per plot at the mid-third height of the plants at five different times. The area under the disease progress curve (AUDPC) (Campbell & Madden, 1990), and the percentage of control compared to the untreated control were calculated. Additionally, assessments were made for treatment phytotoxicity, plant defoliation percentage when the untreated control reached approximately 90% of defoliation, thousand-grain weight in grams, and yield in kilograms per hectare, adjusted for grain moisture at 13%. The results underwent analysis of variance, and when significant, Tukey's test was used for mean separation at a 5% probability level.

Application date	Equipment/ nozzle	Rate (L/ha)	Application swath (m)	Flight height (m)	Application speed (km/h)	T[1] (°C)	RH[2] (%)	WS[3] (km/h)
February 5, 2021 (R2)	Drone DJI Agras MG-1P/ XR110.01	10	4	2	18	28	54	5 to 7
	CO_2 backpack/ XR110.02	150	2	-	3,6	27	56	4 to 6
	Tractor-mounted Jacto Adv. 2000/ AXI 110.03	150	5	-	9	30	46	6 to 8
February 26, 2021 (R5.1)	Drone DJI Agras T16/ XR110.01	10	4	2	18	26	58	3 to 6
	CO_2 backpack/ XR110.02	150	2	-	3,6	27	57	4 to 7
	Tractor-mounted Jacto Adv. 2000/ AXI 110.03	150	5	-	9	28	56	4 to 7

Table 1. Dates, equipment, application parameters and weather conditions during sprayings, in the 2020/2021 cropping season.

[1]T = temperature; [2]RH = relative humidity; [3]WS = wind speed.

Application date	Equipment/ nozzle	Rate (L/ha)	Application swath (m)	Flight height (m)	Application speed (km/h)	T[1] (°C)	RH[2] (%)	WS[3] (km/h)
January 25, 2022 (R3)	Drone DJI Agras T16/ XR110.01	5 and 10	4	3	18	33	54	5
	CO_2 backpack/ XR110.02	150	2	-	3,6	30	57	5
	Tractor-mounted Jacto Adv. 2000/ AXI 110.03	150	5	-	9	32	55	8
February 17, 2022 (R5.2)	Drone DJI Agras T16/ XR110.01	5 and 10	4	3	18	31	53	2 to 7
	CO_2 backpack/ XR110.02	150	2	-	3,6	31	53	3 to 7
	Tractor-mounted Jacto Adv. 2000/ AXI 110.03	150	5	-	9	32	52	3 to 7

Table 2. Dates, equipment, application parameters and weather conditions during sprayings, in the 2021/2022 cropping season.

[1]T = temperature; [2]RH = relative humidity; [3]WS = wind speed.

RESULTS AND DISCUSSION

In the 2020/2021 season, disease monitoring in the untreated control showed its incidence in the crop beginning around February 19, 2021, between development stages R3 and R4 (Fehr et al., 1971). September 2020 had a rainfall deficit delaying regional sowing by about 20 days, with below-average rainfall in October, November, and December (Sibaldelli et al., 2021), adversely affecting plant development and contributing to the lower incidence and slow progression of Asian soybean rust until the end of December. January had above-average rainfall (226.6 mm; historical average = 207 mm), but February was below average (73.2 mm; historical average = 169.6 mm), and March was slightly above average (131 mm; historical average = 123 mm) (Sibaldelli et al., 2022). As a result, the disease progressed but did not reach high severity compared to seasons that historically had more severe epidemics.

The severity results and AUDPC in the 2020/2021 season showed no difference among the sprayed treatments for controlling Asian soybean rust, and all were superior to the untreated control (Table 3). The percentage of control for sprayed treatments was above 95% compared to the control, considering AUDPC. Regarding defoliation, the treatments did not show significant differences among them. Some treated plots showed mild fungicide phytotoxicity after the first application, with CO2-pressurized backpack sprayer and drone treatments, typical of the prothioconazole active ingredient, characterized by yellowing and burning of leaf tissue between the veins. This apparent phytotoxicity did not seem to harm plant development. It is presumed that for the CO2-pressurized backpack sprayer treatment, phytotoxicity may have occurred due to uneven product deposition caused by changes in the applicator's walking speed within the 20-meter plot. For the drone treatment, the 15 times higher concentration of the fungicide in the solution might have favored phytotoxicity. There was no significant difference among treatments in thousand-grain weight, and there was no difference among sprayed treatments for yield, with only the tractor-mounted sprayer treatment being superior to the control.

In the 2021/2022 season, disease monitoring in the untreated control showed its incidence in the crop beginning around January 26, 2022, at development stage R3. In November and December 2021, rainfall was below the historical average for the region (Sibaldelli et al., 2022), adversely affecting plant development and contributing to the lower incidence and slow progression of Asian soybean rust. January had below-average rainfall (158 mm; historical average = 208 mm), as did February (58 mm; historical average = 167 mm), but March had significantly above-average rainfall (345 mm; historical average = 123 mm) (Sibaldelli et al., 2023). As a result, the disease did not reach high severity in January and February compared to seasons that historically had more severe epidemics. However, there was rapid disease progression in March compared to the previous two months due to favorable moisture conditions for the disease.

The severity results and AUDPC in the 2021/2022 season showed no difference among sprayed treatments for controlling Asian soybean rust, and all were superior to the untreated control (Table 4). The percentage of control for sprayed treatments ranged between 42% and 44% compared to the control, considering AUDPC. Regarding defoliation, the treatments did not show significant differences among them. The treatments showed no phytotoxicity. For thousand-grain weight and yield, there was no significant difference among treatments.

Comparing the two seasons, the treatments in the 2021/2022 season showed lower control of soybean rust compared to 2020/2021. That could be due to the difference in control presented by the fungicides used, as efficacy trials have shown that the fungicide used in 2020/2021 (bixafen + prothioconazole + trifloxystrobin) is more effective than the one used in 2021/2022 (picoxystrobin + benzovindiflupyr) (Godoy et al., 2022). Additionally, the climatic conditions in the 2021/2022 season, from March onwards, were more favorable for the disease compared to the same period in the previous season. That led to higher severity from stage R5.4 in the 2021/2022 season, increasing disease pressure and reducing the residual effect of the fungicide.

Although all sprayed treatments in both seasons showed rust control superior to the untreated control, this did not reflect significant differences among treatments in defoliation, thousand-grain weight, and yield assessments (except for yield in the tractor-mounted sprayer treatment, which was superior to the control in the 2020/2021 season). That could be explained by the late occurrence of the disease, with the highest severities observed only at the end of grain filling (R5.4 and R5.5), not allowing enough time for the disease to damage the untreated control significantly. Additionally, late planting (done in this trial to achieve greater disease severity) and below-average precipitation during both seasons tend to reduce the plants' productive

Treatment	Average severity (%)[1]					AUDPC[1]	Control (%)	Defoliation (%)	TGW (g)	Yield (kg/ ha)[1]
	R2 02/ 05/ 21	R5.1 02/ 26/ 21	R5.2 03/ 05/ 21	R5.3 03/ 12/ 21	R5.5 03/ 19/ 21					
Control	0.0	1.8 a	4.5 a	19.2 a	25.6 a	280.8 a	0	89[ns]	132[ns]	2948 b
Drone	0.0	0.2 a	0.0 b	0.4 b	1.2 b	9.9 b	96	65	140	3252 ab
CO_2 backpack	0.0	0.0 a	0.0 b	0.1 b	1.1 b	5.3 b	98	76	145	3412 ab
Tractor-mounted	0.0	0.2 a	0.1 b	0.5 b	2.5 b	14.9 b	95	65	147	3928 a
CV (%)		148	136	76	29	71		20	6	9

Table 3. Asian soybean rust severity, area under disease progress curve (AUDPC), control percentage, defoliation, thousand-grain weight (TGW), and yield in the 2020/2021 cropping season.

[1]Means followed by the same letters in the column do not differ according to the Tukey test at a 5% probability; ns = non-significant.

Treatment	Average severity (%)[1]					AUDPC[1]	Control (%)	Defoliation (%)	TGW (g)	Yield (kg/ha)
	R3 01/ 25/22	R4 02/ 01/22	R5.1 02/ 08/22	R5.4 03/ 03/22	R5.5 10/ 03/22					
Control	0.0	0.0	0.1[ns]	26.0 a	34.3 a	510.4 a	0	91[ns]	111[ns]	2320[ns]
Drone 5 L	0.0	0.0	0.0	15.5 b	16.4 b	290.0 b	43	84	115	2538
Drone 10 L	0.0	0.0	0.2	15.7 b	16.8 b	297.6 b	42	85	113	2578
Tractor-mounted	0.0	0.0	0.1	15.5 b	15.6 b	288.3 b	44	83	118	2613
CO_2 backpack	0.0	0.0	0.3	15.3 b	16.0 b	289.3 b	43	84	119	2598
CV (%)			166	5	7	5		4	6	6

Table 4. Asian soybean rust severity, area under disease progress curve (AUDPC), control percentage, defoliation, thousand-grain weight (TGW), and yield in the 2021/2022 cropping season.

[1]Means followed by the same letters in the column do not differ according to the Tukey test at a 5% probability; ns = non-significant.

potential (Rodrigues et al., 2008), and reduce the likelihood of differences between treatments in production factors.

The treatment involving the tractor-mounted sprayer was the only one with higher productivity when compared to the untreated control in the 2020/2021 crop season. That could be due to the lesser variation in the deposit of the spray provided by this spraying model compared to the others tested. The CO_2-pressurized backpack sprayer tends not to maintain uniform pressure for long, potentially causing variation in application rate and droplet size, which could be exacerbated by variations in the applicator's walking speed (Gabriel & Baio, 2013). In drone spraying, there might be less spray deposition in the upper and middle thirds, exhibiting more variability in such deposition when compared to ground-based spraying (Martini et al., 2023). Reductions in application rate in drone sprays, especially in situations where effective coverage of droplets is essential, such as in the case of Asian soybean rust, may demand strict criteria for application parameters and weather conditions, constituting a highly technical application (Soares et al., 2023). In this study, the weather conditions during spraying (Tables 1 and 2) were close to the recommended limits, which suggest relative humidity above 50%, temperature below 30°C, and wind speed between 3 and 10 km/h.

The comparison between the application rates of the drone at 5 L/ha and 10 L/ha did not show any difference in the test conditions (2021/2022 crop season). However, other results indicate that the 5 L/ha rate resulted in greater soybean defoliation than the 10 L/ha rate, suggesting that factors such as adverse temperature and humidity during spraying and the higher severity of Asian soybean rust could have influenced this difference (Soares et al., 2023). In sprays targeting wheat aphids and powdery mildew control, the use of drones with rates of 17 L/ha and 28 L/ha had deposition and control efficiency comparable to those obtained with a backpack sprayer (225 L/ha), while the drone at a rate of 9 L/ha had inferior deposition and control efficiency compared to the backpack sprayer (Wang et al., 2019). Hence, it is suggested that when intending to use application rates lower than 10 L/ha, a careful analysis of factors such as the biological target, characteristics of the product to be applied, crop development stage, and weather conditions, among others, should be conducted. If one or more of these factors pose a risk to application quality, rates equal to or greater than 10 L/ha should be used.

The deposition of sprayed phytosanitary products on plants is usually irregular within crop layers, posing a challenge to achieving biological targets with adequate control, such as *P. pachyrhizi*, where the best results come with good penetration of spray droplets inside the canopy. This objective is easily achieved with fine and very fine droplets, although these droplets are at a higher risk of drift and evaporation, negatively impacting application quality (Antuniassi & Boller, 2019). Drone applications using coarse droplets are less affected by meteorological conditions than when using medium and fine droplet classes (Silva, 2023). Therefore, regardless of the application technology used, especially in low and ultra-low-volume applications with drones, it is important to employ various adjustments and available technologies to ensure adequate spray quality. These include analyzing droplet spectra and swath overlap, selecting the spray nozzle, adding adjuvant oils, adding products in the proper order for solution preparation, appropriate application rates, and timing applications according to weather conditions, among others (Hoffmann et al., 2019; Silva, 2023; Silva et al., 2023).

CONCLUSIONS

In conclusion, the main findings of this work are that agricultural drone can be used for fungicide spraying to control Asian soybean rust, being as efficient as CO_2-pressurized backpack sprayers and tractor-mounted sprayers. Compared to tractor-mounted sprayers, drone spraying requires greater adherence to technical criteria affecting application.

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