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CROP PROTECTION

Efficacy of air-assist technology and auxiliary boom for fungicide application in soybean fields

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ABSTRACT. This study assessed the effectiveness of air-assist technology and auxiliary booms compared to conventional ground boom sprayers in disease control and yield enhancement in soybean (*Glycine max*) crops. Conducted in Campos Gerais, Paraná State, Brazil over two cropping seasons, the experiment used a randomized block design with four treatments and eight replicates: i) control (no fungicide application on soybean plants), ii) conventional ground boom sprayer, iii) air-assist technology booms, and iv) auxiliary booms sprayers. Analyses focused on disease incidence and severity, plant physiological traits, and yield components. Results indicated that plots without chemical control exhibited higher disease incidence and severity, while fungicide application methods showed no significant differences. Additionally, diseases did not markedly influence the physiological characteristics of the plants. The lack of disease control notably diminished yield potential, but neither auxiliary nor air-assist technologies significantly outperformed the conventional sprayer in enhancing crop yield parameters.

Keywords: diseases, *Glycine max*; pesticide application technology; and yield components.

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Introduction

Soybean, a plant native to Asia and member of the Fabaceae family, is distinguished by its high protein content. Used in various industries, and as a staple in human and animal diets, it ranks as a major global commodity. Brazil stands as a leading producer and exporter, achieving an average yield of 3,389 kg ha^{-1} in 2024 (Companhia Nacional de Abastecimento [CONAB], 2024).

A variety of agronomic practices aim to optimize fertilizer use and maximize yields. These include adapting cultivars to specific sites, determining optimal planting densities, ensuring precision in machinery operations, and implementing integrated management of diseases, weeds, and pests. Effective disease management strategies often incorporate chemical controls through fungicide applications (Garcia et al., 2017; Jasper et al., 2011; Justino et al., 2006).

The success of these chemical interventions hinges on selecting the right products and applying them using advanced technologies. Application technology encompasses the strategic use of scientific knowledge to place active ingredients precisely and economically, minimizing environmental impacts. Among the preferred methods is the use of ground boom sprayers equipped with booms (Matthews, 2022).

In no-tillage systems, most soybean diseases originate in the lower third of the plant. Fungicides are applied primarily for plant protection, targeting the pathogens responsible for these diseases. However, the effectiveness of these products is often limited by the basipetal translocation, which restricts their movement within the plant. Efforts are made to overcome the barriers posed by the upper leaves, known as the "umbrella effect," which can impede the distribution of the applied fungicide droplets (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2020; Zhu et al., 2019).

The integration of air-assist technology (Vortex™) with ground boom sprayers can enhance pesticide application by moving aside plants and minimizing the impact of weather conditions (Garcia et al., 2004). In studies comparing air-assist technology with conventional boom spraying for controlling Asian rust

(*Phakopsora pachyrhizi*), Christovam et al. (2010) reported significantly higher yields of 2,252 kg ha^{-1} with air-assist methods, compared to 1,727 kg ha^{-1} with conventional spraying and 1,617 kg ha^{-1} without any fungicide application. Similarly, Aguiar Júnior et al. (2011) observed that air-assist technology improved disease control and increased soybean yields. Furthermore, Prado et al. (2010) found that air-assist technology not only reduced disease severity but also enhanced yields compared to conventional spraying methods.

An additional advancement in sprayer technology is the auxiliary boom, commercially known as "Kit Alvo™." This system involves attaching a hydraulic boom with application nozzles to a conventional boom. As the auxiliary boom moves through the crop, it is designed to enhance droplet penetration and coverage within the canopy by physically manipulating the plants, spraying the product near the target, besides reducing weather influence (Bueno et al., 2014).

Alves and Cunha (2011) evaluated the efficacy of disease control in soybeans by comparing fungicide applications with and without an auxiliary boom on a ground boom sprayer. Utilizing a flat fan nozzle, they sprayed fungicides in fine droplets at a volume of 150 L ha^{-1}. Their findings indicated that while the auxiliary boom enhanced the mass of one thousand grains, it did not significantly impact the coverage of lower leaves, droplet density, or overall yield.

When spraying fungicides on soybean, Weirich Neto et al. (2013) used the spray volume of 100 L ha^{-1}. The conventional treatment involved the ULD 110 02 (Hypro™) nozzle, which produces coarse droplets. When using the auxiliary boom with Kit Alvo™, the DEFLETOR MPD 0.5 (Magno Jet™) nozzle created fine droplets. A combination of coarse (ULD 110 02 - Hypro™) and medium-sized droplets (DEFLETOR MPD 0.5 - Magno Jet™) was used in simultaneous treatments with the conventional setup and Kit Alvo™. The study found that the auxiliary boom did not significantly alter yield components when compared to conventional spraying techniques.

In their study on fungicide application in soybeans, Garcia et al. (2018) examined different spraying technologies including conventional ground boom sprayers, auxiliary booms, and a combination of both. They utilized a flow rate of 150 L ha^{-1}. The primary boom was equipped with the ADI 11002 (Jacto™) nozzle, producing medium-sized droplets, while fine droplets were emitted from the MDP 0.5 nozzle (Magno Jet™) on the drag bar. Their findings indicated significant improvements compared to the control, but no notable differences were observed among the various spraying technologies.

This study aimed to determine if air-assist technology and auxiliary boom use provide enhanced disease control in soybeans compared to conventional ground boom spraying over two cropping seasons. We evaluated disease incidence and severity, plant physiological traits, and yield components to assess the effectiveness of these technologies.

Material and methods

The study employed a randomized block design with four treatments and eight replications. The treatments included: i) control (no fungicide application on soybean plants), ii) conventional ground boom sprayer, iii) air-assist technology boom sprayer (Vortex™, manufactured by Jacto™), and iv) auxiliary boom sprayer (Kit Alvo™, manufactured by Alvo Pulverização™) (Figure 1). Evaluation plots were defined within a 50 m² area centered under the spray boom (5 x 10 m).

Figure 1. Boom with air-assist technology sprayer (A - Vortex™) and auxiliary boom (B - Kit Alvo™) designed for spraying pesticides in order to improve the penetration of drops in the leaf canopy.

The experiment took place at Farm Mutuca in Arapoti, Paraná State, Brazil, spanning two soybean growing seasons. The location is at 24°21'11" S latitude and 50°06'12" W longitude. The area features a Cfb climate type according to the Köppen classification, at an altitude of 970 meters, and uses a no-till system on a dystrophic Red-Yellow Latosol. The rotational cropping history over the past three years included wheat and soybeans.

Seeds from the cultivar BMX Apollo RR (Brasmax™) was sown in November, with row spacing of 0.5 m. The initial plant population, assessed 15 days post-emergence, was approximately 320,000 plants per hectare. Four fungicide applications were scheduled to control diseases such as mildew (*Microsphaera diffusa*) and Asian rust. Opera Ultra at 0.5 L ha^{-1} (8.0 g L^{-1} Metconazole + 13.0 g L^{-1} Piraclostrobin from Basf™) was used for all applications, with the final application also including 0.3 L ha^{-1} of Orkestra (333 g L^{-1} Piraclostrobin + 167 g L^{-1} Fluxapiroxad from Basf™). The applications targeted the phenological stages V3, V5, R2, and R5 (Ritchie et al., 1982).

The sprayer, a self-propelled Uniport 3000 from Jacto™ with a 24-meter boom and 0.5 m nozzle spacing, utilized JA2 spray nozzles from Jacto™. The application speed was set at 3.3 m s^{-1} with a pressure of 1,737 kPa and a spray volume of 125 L ha^{-1}. In treatments involving both the conventional and auxiliary booms, the JA2 nozzle functioned simultaneously on both, splitting the spray volume to maintain equivalence with other treatments and setting the pressure at 441 kPa. The selected nozzle produced a hollow cone with fine droplet size, as recommended by the manufacturer for fungicide applications (Jacto, 2022).

The weather conditions throughout the study remained consistent with historical averages, supporting the crops' productive potential. All cultural and phytosanitary practices were implemented according to the recommendations of the Agronomist overseeing the area. The spray volume adhered to the standard practices for fungicide applications at the experimental sites.

The air-assist technology on the boom delivered an average airspeed of 11.7 m s^{-1}, measured using a 3000 Kestrel™ anemo-thermohygrometer positioned 0.5 m from the air outlet at the spray bar. Spray applications were conducted under optimal conditions: relative humidity above 50%, temperature below 30°C, and wind speed ranging from 0.8 to 2.7 m s^{-1}. The 3000 Kestrel™ anemo-thermo-hygrometer also continuously monitored the weather conditions during these applications. The study focused on analyzing variables such as disease incidence and severity, plant physiological traits, and yield components.

Disease incidence was quantified as the percentage of infected plants, while severity assessments employed diagrammatic scales recommended by Godoy et al. (2006) and Mattiazzi (2003). The evaluations took place at the phenological stages V4, V6, R3, and R6.

Physiological traits analyzed included plant height, total internodes, and viable internodes (with pods). Plant height was measured using a 5.0 m Power Lock (Stanley™) steel measuring tape at the R6 stage, and internodes were identified manually based on visual assessment.

Manual procedures were utilized for harvesting, threshing, grain count per pod, one thousand grain mass, and yield calculations. Harvests were conducted in March, with the mass of one thousand grains and yield determined after adjusting for 1.0% impurities and moisture content corrected to 14.0% on a wet basis. Moisture content was assessed using a G800 Gehaka™ moisture meter. The mass of one thousand grains was weighed on a 0.1 to 500 g Diamond™ digital scale, and yield was measured in grams using a 50 kg Ramud™ digital scale.

Data analysis included Hartley's test for homoscedasticity of variances and the Shapiro-Wilk test for normality. The measured variables underwent analysis of variance (ANOVA) using the Fisher-Snedecor test, with mean comparisons conducted via the Duncan test at a significance level of $p < 0.05$.

Results and discussion

Hartley's test confirmed homoscedasticity of variances, and the Shapiro-Wilk test affirmed data normality across all studied parameters, negating the need for value transformation before variance analysis. The first crop showed significant block differences in plant height, total internodes, final population, pods per plant, and yield. In the second harvest, significant differences for blocks included mildew severity, pods per plant, and yield. This underscores the importance of distributing plots into blocks.

For soybean mildew incidence analysis, the first evaluation of the second cropping season revealed no significant differences between the control treatment and others (Table 1). Across all evaluations, treatments with phytosanitary control showed no significant differences. Similarly, in the first evaluation of the first cropping season, plots untreated with fungicides did not differ significantly from treated plots in powdery mildew severity (Table 2). Moreover, different spraying technologies, including conventional ground boom sprayers with and without air-assist and auxiliary boom technologies, showed no significant efficacy differences under experimental conditions.

Asian rust was absent in vegetative stages but notably higher in severity and incidence in reproductive stages of untreated plants (Tables 3 and 4). With over 95% confidence, it is evident that air-assist and auxiliary boom technologies performed comparably to conventional methods.

Contrary to findings by Aguiar Júnior et al. (2011) and Prado et al. (2010), who reported improved disease control with air-assist technology, our results did not replicate these effects. Additionally, chemical control and application technologies did not influence soybean physiological characteristics across two cropping seasons, with average measurements of 0.94 m plant height, 17 total internodes, and 15 viable internodes (Table 5). The auxiliary boom had no significant adverse impact on the plants.

Yield components analysis (Table 6) in the First cropping season indicated that diseases did not affect the final population (average 296,850 plants ha^{-1}), pods per plant (average 37), or grains per pod (average 2.6). However, thousand-grain mass and yield varied significantly between plots with and without fungicide treatment, though differences among application technologies were not significant (Table 6).

Table 1. Incidence (%) of powdery mildew (*Microsphaera diffusa*) on soybeans (*Glycine max*), cultivar BMX Apollo RR™, under different pesticide application technologies (PATs) during two cropping seasons, Farm Mutuca (Arapoti, Paraná State, Brazil).

Treatment	First cropping season			
	V4[1]	V6	R3	R6
Control[2]	6.0 a[3]	9.3 a	14.6 a	21.1 a
Conventional ground boom sprayer	4.3 b	6.0 b	7.5 b	7.9 b
Air-assisted boom sprayer (Vortex™)	4.3 b	5.8 b	7.3 b	7.5 b
Boom sprayer + auxiliary boom (Kit Alvo™)	4.6 b	6.1 b	7.3 b	8.1 b
Block	ns[4]	ns	ns	ns
Coefficient of variation (%)	24.6	19.8	25.5	20.1
Treatment	Second cropping season			
	V4	V6	R3	R6
Control	4.8 a	9.3 a	10.3 a	12.4 a
Conventional ground boom sprayer	3.8 a	5.8 b	7.4 b	7.6 b
Air-assisted boom sprayer (Vortex™)	4.1 a	5.6 b	7.3 b	7.3 b
Boom sprayer + auxiliary boom (Kit Alvo™)	3.8 a	5.8 b	7.0 b	7.5 b
Block	ns	ns	ns	ns
Coefficient of variation (%)	21.1	20.8	30.1	24.0

(1)Phenological stages (Ritchie et al., 1982). (2)Without fungicide spraying. (3)Means followed by the same letter within columns did not significantly differ from each other by the Duncan's test ($p > 0.05$). (4)All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test ($p > 0.05$).

Table 2. Severity (%) of powdery mildew (*Microsphaera diffusa*) on soybeans (*Glycine max*), cultivar BMX Apollo RR™, under different pesticide application technologies (PATs) during two cropping seasons, Farm Mutuca (Arapoti, Paraná State, Brazil).

Treatment	First cropping season			
	V4[1]	V6	R3	R6
Control[2]	2.5 a[3]	5.0 a	10.5 a	17.0 a
Conventional ground boom sprayer	1.7 a	2.2 b	3.8 b	4.5 b
Air-assisted boom sprayer (Vortex™)	1.5 a	1.9 b	3.9 b	4.6 b
Boom sprayer + auxiliary boom (Kit Alvo™)	1.6 a	2.1 b	4.1 b	4.6 b
Block	ns[4]	ns	ns	ns
Coefficient of variation (%)	42.9	19.8	37.1	30.0
Treatment	Second cropping season			
	V4	V6	R3	R6
Control	1.2 a	2.3 a	8.5 a	12.7 a
Conventional ground boom sprayer	0.8 b	1.4 b	4.8 b	6.6 b
Air-assisted boom sprayer (Vortex™)	0.7 b	1.2 b	4.6 b	6.8 b
Boom sprayer + auxiliary boom (Kit Alvo™)	0.9 b	1.4 b	4.9 b	7.0 b
Blocks	*[5]	*	ns	ns
Coefficient of variation (%)	30.5	45.1	37.5	21.9

(1)Phenological stages (Ritchie et al., 1982). (2)Without fungicide spraying. (3)Means followed by the same letter within columns did not significantly differ from each other by the Duncan's test ($p > 0.05$). (4)All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test ($p > 0.05$). (5) In all analyzed variables, there were significant differences for blocks by the Fisher-Snedecor test ($p < 0.05$).

Table 3. Incidence (%) of Asian rust (*Phakopsora pachyrhizi*) on soybeans (*Glycine max*), cultivar BMX Apollo RR™, under different pesticide application technologies (PATs) during two cropping seasons, Mutuca Farm (Arapoti, Paraná State, Brazil).

Treatment	First cropping season			
	V4[1]	V6	R3	R6
Control[2]	No disease diagnosed		6.9 a[3]	12.4 a
Conventional ground boom sprayer			4.9 b	6.6 b
Air-assisted boom sprayer (Vortex™)			4.6 b	6.8 b
Boom sprayer + auxiliary boom (Kit Alvo™)			4.8 b	6.9 b
Block			ns[4]	ns
Coefficient of variation (%)			28.3	28.2
Treatment	Second cropping season			
	V4	V6	R3	R6
Control	No disease diagnosed		5.8 a	12.9 a
Conventional ground boom sprayer			3.3 b	7.1 b
Air-assisted boom sprayer (Vortex™)			3.6 b	6.9 b
Boom sprayer + auxiliary boom (Kit Alvo™)			3.2 b	7.5 b
Blocks			ns	ns
Coefficient of variation (%)			40.2	24.0

(1)Phenological stages (Ritchie et al., 1982). (2)Without fungicide spraying. (3)Means followed by the same letter in the column did not differ significantly by Duncan's test (p > 0.05). (4)All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test (p > 0.05).

Table 4. Severity percentage (%) of Asian rust (*Phakopsora pachyrhizi*) on soybeans (*Glycine max*) cultivar BMX Apollo RR™, under different pesticide application technologies (PATs) during two cropping seasons, Mutuca Farm (Arapoti, Paraná State, Brazil).

Treatment	First cropping season			
	V4[1]	V6	R3	R6
Control[2]	No disease diagnosed		6.0 a[3]	18.5 a
Conventional ground boom sprayer			1.8 b	7.1 b
Air-assisted boom sprayer (Vortex™)			1.7 b	7.3 b
Boom sprayer + auxiliary boom (Kit Alvo™)			1.9 b	6.9 b
Block			ns[4]	ns
Coefficient of variation (%)			29.0	29.5
Treatments	Second cropping season			
	V4	V6	R3	R6
Control	No disease diagnosed		3.3 a	12.9 a
Conventional ground boom sprayer			1.3 b	7.0 b
Air-assisted boom sprayer (Vortex™)			0.9 b	7.0 b
Boom sprayer + auxiliary boom (Kit Alvo™)			1.0 b	6.8 b
Block			ns	ns
Coefficient of variation (%)			35.2	40.5

(1)Phenological stages (Ritchie et al., 1982). (2)Without fungicide spraying. (3)Means followed by the same letter in the column did not differ significantly by Duncan's test (p > 0.05). (4)All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test (p > 0.05).

Table 5. Physiological traits of soybeans (*Glycine max*), cultivar BMX Apollo RR™, under different pesticide application technologies (PATs) during two cropping seasons, Farm Mutuca (Arapoti, Paraná State, Brazil).

Treatment	First cropping season		
	Plant Height (m)	Total number of internodes	Number of viable internodes
Control[1]	0.95 a[2]	16 a	13 a
Conventional ground boom sprayer	0.91 a	16 a	13 a
Air-assisted boom sprayer (Vortex™)	0.95 a	17 a	14 a
Boom sprayer + auxiliary boom (Kit Alvo™)	0.92 a	17 a	14 a
Block	*[3]	*	ns[4]
Coefficient of variation (%)	3.7	7.9	14.5
Treatment	Second cropping season		
	Plant Height (m)	Total number of internodes	Number of viable internodes
Control[2]	0.96 a	17 a	14 a
Conventional ground boom sprayer	0.93 a	17 a	16 b
Air-assisted boom sprayer (Vortex™)	0.94 a	18 a	17 b
Boom sprayer + auxiliary boom (Kit Alvo™)	0.96 a	18 a	16 b
Block	ns	ns	ns
Coefficient of variation (%)	2.8	8.8	10.1

(1)Without fungicide spraying. (2)Means followed by the same letter within columns did not significantly differ from each other by the Duncan's test (p > 0.05). (3)In all analyzed variables, there were significant differences for blocks by the Fisher-Snedecor test (p < 0.05). (4)All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test (p > 0.05).

Table 6. Yield components of soybeans (*Glycine max*), cultivar BMX Apollo RR™, under pesticide application technologies (PATs) during two cropping seasons, Farm Mutuca (Arapoti, Paraná State, Brazil).

Treatment	First cropping season				
	Final population (ha)	Pods per plant	Grains per pod	Thousand-grain mass (g)	Crop yield (kg ha^{-1})
Control[1]	285,833 a[2]	36 a	2.5 a	160 b	4,046 b
Conventional ground boom sprayer	309,167 a	37 a	2.6 a	173 a	5,018 a
Boom with air-assist sprayer (Vortex™)	294,167 a	37 a	2.7 a	172 a	5,037 a
Boom sprayer + auxiliary boom (Kit Alvo™)	298,233 a	38 a	2.5 a	173 a	5,059 a
Block	*[3]	*	ns[4]	ns	*
CV (%)	5.4	10.0	7.9	2.0	16.3
Treatment	Second cropping season				
	Final population (ha)	Pods per plant	Grains per pod	Thousand-grain mass (g)	Crop yield (kg ha^{-1})
Control[2]	280,832 a	29 b	2.2 b	172 b	3,057 b
Conventional ground boom sprayer	277,917 a	38 a	2.5 a	196 a	5,202 a
Boom with air-assist sprayer (Vortex™)	298,750 a	34 a	2.5 a	200 a	4,967 a
Boom sprayer + auxiliary boom (Kit Alvo™)	285,833 a	36 a	2.6 a	196 a	5,387 a
Block	ns	*	ns	ns	*
CV (%)	10.2	8.6	4.3	2.1	15.6

[(1)]Without fungicide spraying. [(2)]Means followed by the same letter within columns did not significantly differ from each other by the Duncan's test ($p > 0.05$). [(3)]In all analyzed variables, there were significant differences for blocks by the Fisher-Snedecor test ($p < 0.05$). [(4)]All analyzed parameters showed no significant differences for blocks by the Fisher-Snedecor test ($p > 0.05$).

In the second cropping season, only the final population (average of 296,850 plants ha^{-1}) remained unaffected by diseases. Other variables exhibited lower values in plots without chemical disease control. Both air-assist technology and auxiliary boom showed no significant difference compared to conventional booms, indicating that adopting technologies beyond conventional ones was unnecessary under our experimental conditions.

Our results do not corroborate Christovam et al. (2010), who reported increased soybean yield using air-assist technology over conventional chemical control for Asian rust; notably, the highest yields in his study were lower than those in our untreated plots, reflecting a discrepancy in investment levels. Similarly, the yield improvements reported by Aguiar Júnior et al. (2011) and Prado et al. (2010) with air-assist technology were not replicated in our findings.

The increase in one-thousand-grain mass attributed to fungicide application via auxiliary boom in the study by Alves and Cunha (2011) was not evident in our results. Moreover, the auxiliary boom did not influence yield, contrasting with their 2011 findings. Notably, Alves and Cunha used flat fan nozzles, whereas we used hollow cone nozzles. Despite variations in nozzles, spray volume, application pressure, droplet size, crop seasons, cultivars, and locations, our study aligns with Weirich Neto et al. (2013) and Garcia et al. (2018), who found that auxiliary boom spraying did not significantly impact soybean yield components compared to conventional technology.

The benefits of air-assisted booms, such as enhanced spray volume delivery, plant movement facilitation, and weather influence reduction (Garcia et al., 2004), did not prove significant in our conditions. Similarly, while Bueno et al. (2014) highlighted the advantages of nozzle repositioning in auxiliary booms for better droplet penetration and crop canopy coverage, other studies (EMBRAPA, 2020; Zhu et al., 2019) suggest such strategies did not enhance fungicide efficacy beyond conventional ground boom sprayer technology. Efficacy in spraying is highly dependent on local weather conditions during application, explaining the varied results across studies.

The high standard of investment in soybeans, which surpassed the national average yield by 38% (CONAB, 2024), underscores the extensive investments in this field. Despite employing four fungicide applications and spray volumes exceeding 100 L ha^{-1}, combined with various agronomic and application techniques (Garcia et al., 2017; Jasper et al., 2011; Justino et al., 2006; Matthews, 2022), there was no discernible advantage of different application methods.

Conclusion

Incidence and severity of disease increased in plots without chemical control, but different fungicide spraying techniques did not yield significant differences. Diseases minimally affected the physiological characteristics of soybean plants. Lack of disease control reduced productive potential. Neither the auxiliary boom nor air-assist technology significantly improved crop yield parameters compared to conventional ground boom sprayers.

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