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Types of Spray Nozzles for Fungicide Application in Wheat Crop

Luiz Cláudio Garcia[1]*
https://orcid.org/0000-0001-6378-2829

Yago Calebe Schinigoski[1]
https://orcid.org/0009-0002-0969-3838

Conrado Augusto Castro Oliveira[1]
https://orcid.org/0009-0007-5683-0045

Pedro Henrique Weirich Neto[1]
https://orcid.org/0000-0002-9039-102X

Sandro Felema[1]
https://orcid.org/0000-0002-7142-0032

Daniel Ruiz Potma Gonçalves[1]
https://orcid.org/0000-0003-2015-048X

[1]Universidade Estadual de Ponta Grossa, Campus Uvaranas, Ponta Grossa, PR, Brasil.

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*Correspondence: lcgarcia@uepg.br; Tel.: +55-42-32203090 (L.C.G.).

HIGHLIGHTS

- The aim was to evaluate spray nozzles influence on the chemical control of wheat diseases.
- Treatments: control (without application of fungicides) and five different spray nozzles.
- We analyzed the incidence and severity of leaf and ear diseases and yield components.
- There was no difference among spray nozzles in all the variables analyzed.

Abstract: The aim of this study was to assess the influence of spray nozzles types on the chemical control of wheat (*Triticum aestivum*) leaf and ear diseases. The experimental design employed a randomized block design, comprising six treatments and four replications, conducted at Fazenda Escola Capão da Onça, State University of Ponta Grossa, Paraná, Brazil, during three crop seasons. The treatments included a control group (without the application of fungicides) and the application of fungicides using spray nozzles: hollow cone, double flat fan, extended-range flat fan, wide-angle flat fan, and air-induction flat fan. The sprayer utilized was a backpack pressurized by carbon dioxide (CO_2). The evaluated variables encompassed the incidence and severity of leaf and ear diseases, spray quality (covered area, density, and relative amplitude), and yield components. The findings indicated the necessity of chemical control for fungal diseases in wheat plants. Differences among nozzles were limited to spray quality parameters (coverage and droplet density), without effects on disease incidence or yield.

Keywords: plant diseases; crop yield; spraying quality; spraying technology; *Triticum aestivum*.

INTRODUCTION

Wheat (*Triticum aestivum*) ranks as the second most produced cereal globally, characterized by an annual cycle, spring habit, and substantial crop yield potential. In Brazil, Paraná state distinguishes itself with an average yield of 2,784 kg ha^{-1} [1]. Among the factors limiting wheat yield, diseases play a significant role.

Occurrence and severity are influenced by various factors, including cultivar, crop rotation, climatic conditions, and the source of pathogen inoculum. Integrated disease management often involves chemical control strategies [2; 3; 4].

Given its necessity, the efficacy of this process hinges on the accurate placement of the biologically active product on the target, in the correct quantity, economically viable, and with minimal environmental impact [5; 6; 7]. Chemical disease control predominantly employs sprayers, wherein the solution is pressurized through a hydraulic circuit to a restrictor, namely the spray nozzle. The spray nozzle regulates various parameters such as pressure range, spray volume, drop size, coverage over the target, spout angle, drop life, and drift risk. Spraying quality is assessed by parameters such as area covered, density, and relative amplitude. The relative amplitude (span) gauges the homogeneity of droplet size, with a more uniform droplet spectrum having a span value approaching zero [8; 9; 10].

In a study on the efficiency of fungicides in controlling wheat leaf diseases using different spray nozzles types, Fiallos and coauthors [11] found no significant differences in disease severity and productivity variables. Based on their interaction analysis, the authors recommended the use of wide-angle flat fan spray nozzles that generate fine drops.

Sari and coauthors [12] examined spray equipment with low application volume, concluding that the use of hollow cone hydraulic nozzles and extended-range flat fan nozzles provided better control of yellow spot (*Drechslera tritici-repentis*) and leaf rust (*Puccinia triticina*).

Investigating the influence of the spray droplet spectrum on disease control, Gulart and coauthors [13] explored several variables in two wheat cultivars. They reported that the spectrum of droplets generated by spray nozzles types with a wide-range flat jet performed best concerning disease control and crop yield.

Aiming to identify the optimal spray nozzle for fungicide application on wheat, Olivet and coauthors [14] evaluated nozzles generating a wide-range flat fan, wide-angle flat fan, and air-induction flat fan. Throughout the study, diseases' severity and crop yield in untreated plots were significantly higher compared to plots with fungicides, with no discernible differences among nozzles for the analyzed variables.

Checking the effect of nozzle configuration and ground sprayer speed on fusarium head blight management in wheat, White and coauthors [15] worked with three different dual flat fan nozzles manufactured by TeeJet Technologies were tested: air induction dual pattern flat spray tip nozzles (AI3070™), air induction turbo twinjet flat spray tip nozzles (AITTJ60™), and turbo twinjet flat spray tip nozzles (TTJ60™). Based on the results from this research, only minor differences in simulated wheat head coverage were observed across nozzle configurations.

This study aims to assess the impact of spray nozzles types, including hollow cone, double flat fan, extended-range flat fan, wide-angle flat fan, and air-induction flat fan, on the control of wheat leaf and ear diseases. We analyzed diseases' occurrence, severity, and yield, as well as spraying quality and yield components over three crop years.

MATERIAL AND METHODS

We conducted a randomized blocks experiment with six treatments and four replications during the three crop seasons. The treatments included a control group without fungicide application and the application of fungicides with spray nozzles types with a hollow cone (TXA 8002™), double flat fan (TJ60 11002™), extended-range flat fan (XR 11002™), wide-angle flat fan (TT 11002™), and air-induction flat fan (AI 11002™). The selection of nozzles was based on the diversity of jets formed and the size of the droplets generated. The plot area was 27.5 m^2 (2.5 x 11.0 m), with an evaluation area of 20.0 m^2 (2.0 x 10.0 m).

The experiments took place at the Capão da Onça School Farm, Ponta Grossa (Paraná, Brazil), under a no-till system. The farm is located at latitude 25 ° 05 '54 ”S, longitude 50 ° 03 '01 ”O, and an altitude of 1,017 m, with a climate classified as temperate. The wheat growing period in the experiment region is winter and spring. All phytotechnical practices were carried out following crop recommendations for the region [16].

In first crop season, we sowed the cultivar TBIO Itaipu™ on July 16, with a spacing of 0.17 m among lines, and the population evaluated 15 days after emergence (DAE) was 3.0 million plants ha^{-1}. Diseases such as powdery mildew (Blumeria graminis f. sp. tritici), yellow spot, and leaf rust occurred during the cultivation. Chemical control involved applying 100 g L^{-1} of trifloxystrobin + 200 g L^{-1} of Tebuconazole (Nativo™ at a dose of 0.6 L ha^{-1}) in three applications at intervals of 25 days. The first spraying occurred 50 DAE, at the phenological stage of crop tillering [17], the second in flowering, and the third during milky grain.

In second crop season, we sowed TBIO Toruk™ on June 25, with a spacing of 0.17 m among lines, and the population evaluated 15 DAE was 3.9 million plants ha^{-1}. Diseases observed included helminthosporiosis (Bipolaris sorokiniana), yellow spot, and blast disease (*Pyricularia grisea*). Precipitation was above the historical average, favoring disease occurrence. We carried out five sprays at intervals of 15 days, starting on August 14, during crop tillering. The subsequent sprays occurred during stem lengthening, earing, flowering, and milky grain.

For the first spray, we used 150 g L^{-1} of Trifloxystrobin + 175 g L^{-1} of Protioconazole (Fox™ at a dose of 0.5 L ha^{-1}) plus 150 g L^{-1} of Propiconazole (Juno™ at 0.5 L ha^{-1}). For the second and fifth sprays, we used Fox™ with 150 g kg^{-1} of Mancozebe (Manzte 800™ at 2.5 kg ha^{-1}), and during the third and fourth sprays, we used Fox™ and 500 g L^{-1} of Iprodione (Rovral™ at 0.8 kg ha^{-1}).

In third crop season, we sowed TBIO Sossego™ on June 27, with a spacing of 0.17 m among lines and a sowing density of 150 kg ha^{-1}. The plant population, 20 days after emergence, was 2.6 million plants ha^{-1}. Precipitation stayed below the historical average for the municipality of Ponta Grossa (PR), resulting in fewer diseases and reduced crop yield components. Diseases observed included powdery mildew, rust, and fusarium head blight (Gibberella zeae). We made three sprays, starting at the tillering stage on August 2nd, with intervals of 15 days. The second spray occurred in flowering, and the third during milky grain. The applied fungicides were: 750 g L^{-1} of Fenpropimorph (Versatilis™, 0.8 L ha^{-1}), 260 g L^{-1} of Pyraclostrobin + 160 g L^{-1} of Epoxiconazole (Abacus™, 350 mL ha^{-1}), and 130 g L^{-1} of Pyraclostrobin + 80 g L^{-1} of Metconazole (Opera Ultra™, 0.75 L ha^{-1}).

Spraying was always carried out with relative humidity above 55%, temperature below 30 ºC, and wind speed between 3.0 and 10.0 km h^{-1}. Environmental conditions were monitored with a Kestrel 3000™ anemo-thermo-hygrometer. The sprayer used was the backpack pressurized by carbon dioxide (CO_2). The spray volume in all sprayings was 130 L ha^{-1}, defined by the Agronomist in charge of the area. The spacing among nozzles was 0.5 m, with the height of the bar always above 0.5 m from the target. For all nozzles, the working pressure used was 200 kPa, and the application speed was 1.67 m s^{-1}. With such a spray configuration, the droplet sizes were very fine for nozzles with a hollow cone, very fine to fine for double flat fan, fine for wide extended-range flat spray, medium to coarse with a wide-angle flat fan, and very coarse in the air-induction flat fan [18].

We evaluated disease incidence and severity, spray quality (covered area, density, and relative amplitude), and grain yield components. To measure disease incidence and severity, we followed the guidelines of EMBRAPA [16], evaluating at the phenological stages of tillering, flowering, and milky grain.

For spray quality, we collected droplets sprayed on water-sensitive papers at the flowering stage. The cards were placed in a helical support in the upper, middle, and lower thirds of the culture (Figure 1), with five replications per plot. The following spray quality parameters were evaluated: covered area (%), density (droplets cm^{-2}), and relative amplitude (span - difference in diameter for $DV_{0.9}$ and $DV_{0.1}$ of the sprayed volume divided by the $DV_{0.5}$). These parameters were determined with e-Sprinkle™ software, immediately after data collection for the relative air humidity do not interfere in the results.

We harvested wheat on December 8th, first crop season, November 7th, second crop season, and November 4th, third crop season, and determined the grain yield components manually. To calculate the mass of a thousand grains and crop yield, we considered 1.0% of impurities (stone, earth, wood, etc.) and corrected the final value to 13% humidity. We verified humidity with a G800 Gehaka™ equipment and determined the mass of a thousand grains using a digital balance 0.1 to 500 g Diamond™. We measured crop yield with a digital Ramud™ balance, with a 50 kg capacity.

We checked variances homoscedasticity with the Hartley test and data normality with the Shapiro-Wilk test. Afterward, we performed Fisher-Snedecor and Tukey tests, with 95% confidence. The analyses on hydrosensitive papers were carried out in a completely randomized design.

RESULTS

The Hartley test confirmed homoscedasticity of variances, and the Shapiro-Wilk test verified normality of the data. Therefore, we did not transform the data for variance analysis. Regarding disease incidence, there were no significant differences for blocks in the first and third crops. In second crop season, differences were found only for helminthporous disease during flowering and milky grain. The results indicate homogeneity in pathogen proliferation under the experimental conditions (Table 1).

Distinct diseases were observed across the three crops, emphasizing differences in cultivars and years. Leaf diseases were more pronounced in second crop season, despite five chemical interventions. In second and third crop seasons, significant diseases affected the ears, with blast diseases being rare in the studied region. Statistical analysis showed significant differences between plots that did not receive chemical treatment and those that did, but no significant differences among spraying nozzles when analyzing disease incidence percentage.

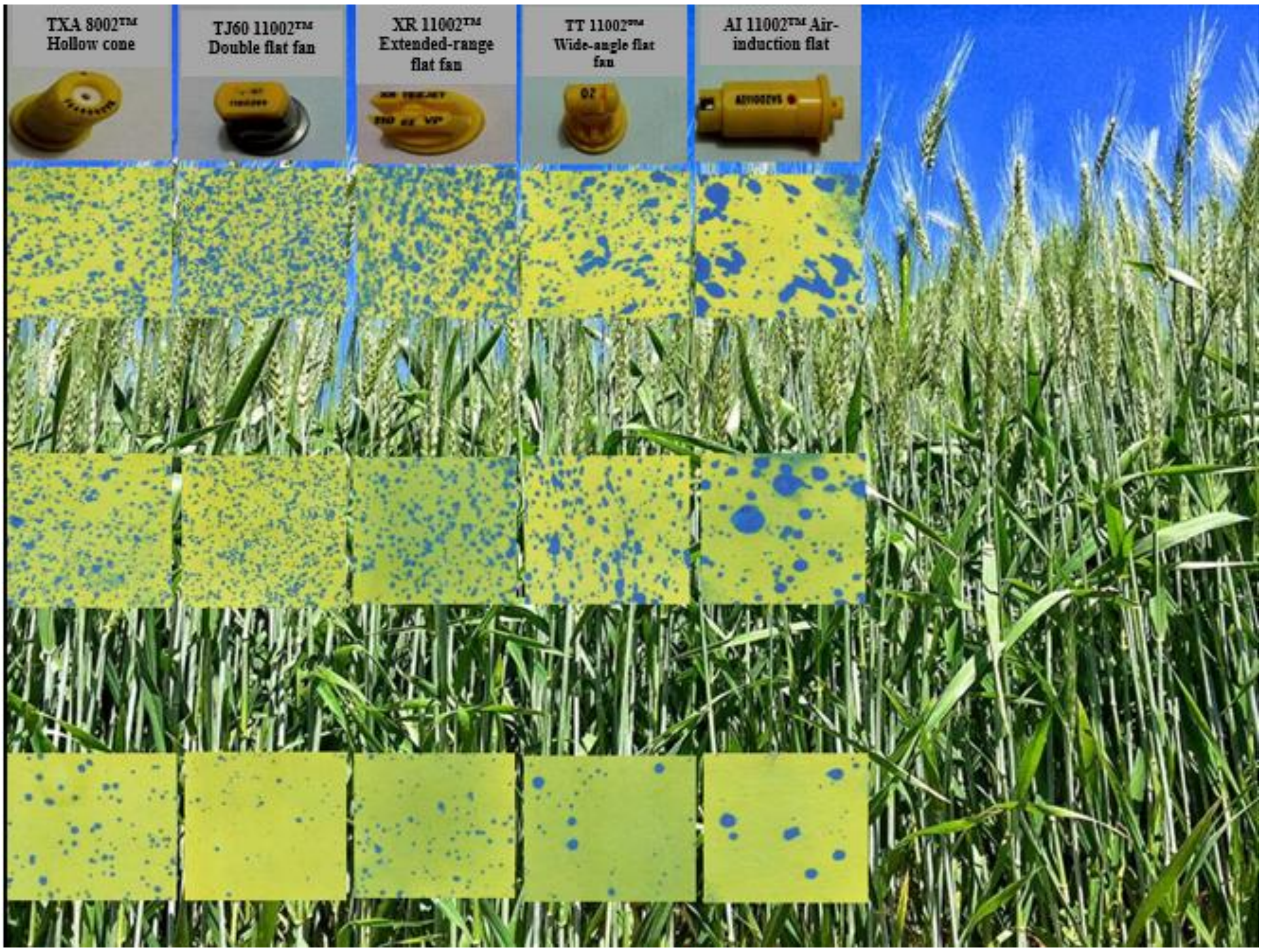

Figure 1. Water sensitive papers in the fungicides spray with different nozzles in flowering of wheat (*Triticum aestivum)* - upper, middle and lower thirds - with spray volume of 130 L ha^{-1}, spacing among nozzles of 0.5 m, working pressure of 200 kPa, application speed of 1.67 m s^{-1}, College Farm Capão da Onça, State University of Ponta Grossa (Paraná, Brazil).

The severity of illnesses in the first crop season harvest was only significant for blocks in the phenological stage of tapering to leaf rust (Table 2). In second crop season, severity percentage was significant for blocks for helminthsporiosis (phenological stages of tapering and milky grain) and blast (milky grain). In third crop season, only leaf rust in blocks was significant. The control treatment, without the application of fungicides to wheat plants, exhibited the highest severity percentages for all diseases, but the spray nozzles types were not a significant factor.

Analysis of the covered area showed higher values for nozzles designed to generate droplets with a larger diameter in the upper, middle, and lower thirds (Table 3). Regarding droplet density, nozzles designed to produce smaller drops presented higher values in the upper and middle third, but not in the lower third. A possible explanation is the lower wind interference in larger droplets when increasing the distance from the spray nozzle. The relative amplitude (span) was not affected by the nozzles, or the allocation point of water-sensitive papers, with greater dispersion of droplet diameters being reached when more droplets hit the water-sensitive papers.

Yield components did not significantly differ for blocks (Table 4). Chemical control significantly affected the mass of a thousand grains and crop yield in three crop seasons. A possible explanation is the reduction of translocation of photoassimilates to grain due to the loss of photosynthetic area in non-sprayed treatments caused by the action of diseases. In second crop season, the blast significantly affected the number of grains per ear; however, fusarium, a disease that also affects wheat ears, did not significantly reduce it.

Yields were similar in the first and second crop seasons, where rainfall stayed below the crop's needs. In second crop season, with higher rainfall, there was a greater pressure of disease occurrence, requiring a high number of fungicide sprays; however, the increased water supply and soil fertility contributed to high crop yields. The most limiting yield component was the mass of a thousand grains. The type of nozzle did not affect yield components.

Table 1. Incidence percentage of powdery mildew (*Blumeria graminis* f. sp. *tritici*), yellow spot (*Drechslera tritici-repentis*), leaf rust (*Puccinia triticina*) helminthosporiosis (*Bipolaris sorokiniana*), blast (*Pyricularia grisea*) and Fusarium head blight (*Gibberella zeae*), in wheat (*Triticum aestivum*), in the phenological stages of tillering (A), flowering (F) and milky grain (GL), controlled by the application of fungicides with different spray nozzles, at College Farm Capão da Onça, Ponta Grossa State University (Paraná, Brazil).

Cultivar Tbio Itaipu™, first crop season.

Jet types	Powdery mildew			Yellow spot			Leaf rust		
	A	F	GL	A	F	GL	A	F	GL
Control[1]	56 a[2]	69 a	92 a	48 a	65 a	78 a	39 a	55 a	84 a
Hollow cone	35 b	44 b	54 b	36 b	43 b	58 b	26 b	35 b	56 b
Double flat fan	35 b	42 b	52 b	37 b	45 b	61 b	24 b	38 b	59 b
Extended-range flat fan	34 b	43 b	54 b	34 b	43 b	59 b	25 b	37 b	58 b
Wide-angle flat fan	37 b	44 b	54 b	34 b	43 b	60 b	25 b	38 b	60 b
Air-induction flat fan	35 b	44 b	54 b	37 b	46 b	59 b	27 b	38 b	61 b
Blocks	ns[3]	ns	ns	ns	ns	ns	ns	ns	ns
Coefficient of Variation (%)	11.0	9.4	5.8	9.9	7.6	4.2	11.1	8.0	4.2

Cultivar Toruk™, second crop season.

Jet types	Helminthosporiosis			Yellow spot			Wheat blast		
	A	F	GL	A	F	GL	A	F	GL
Control	39 a	84 a	99 a	63 a	92 a	97 a	Not observed	Not observed	12 a
Hollow cone	27 b	49 b	75 b	34 c	78 b	81 b			06 b
Double flat fan	31 b	51 b	73 b	45 b	74 b	82 b			06 b
Extended-range flat fan	26 b	49 b	74 b	37 c	73 b	83 b			06 b
Wide-angle flat fan	28 b	52 b	74 b	34 c	73 b	83 b			06 b
Air-induction flat fan	27 b	51 b	74 b	37 c	73 b	82 b			07 b
Blocks	ns	*[4]	*	ns	ns	ns			ns
Coefficient of Variation (%)	10.9	4.4	2.7	9.3	5.3	2.3			11.0

Cultivar TBIO Sossego™, third crop season.

Jet types	Powdery mildew			Leaf rust			Fusarium head blight		
	A	F	GL	A	F	GL	A	F	GL
Control	19 a	48 a	61 a	2.5 a	23 a	32 a	Not observed	Not observed	28 a
Hollow cone	10 b	21 b	33 b	0.4 b	13 b	18 b			11 b
Double flat fan	09 b	21 b	36 b	0.6 b	12 b	16 b			12 b
Extended-range flat fan	12 b	22 b	34 b	0.6 b	14 b	17 b			10 b
Wide-angle flat fan	10 b	20 b	32 b	0.6 b	12 b	18 b			13 b
Air-induction flat fan	11 b	21 b	32 b	0.4 b	12 b	17 b			11 b
Blocks	ns	ns	ns	ns	ns	ns			ns
Coefficient of Variation (%)	27.4	20.0	10.9	56.9	21.0	12.1			21.3

[1] Without fungicide application on wheat plants.
[2] Averages with the same letter in the column do not differ by Tukey (P > 0.05).
[3] Not significant for blocks (P > 0.05).
[4] Significant for blocks (P < 0.05).

Table 2. Severity percentage of powdery mildew (*Blumeria graminis* f. sp. *tritici*), yellow spot (*Drechslera tritici-repentis*), leaf rust (*Puccinia triticina*) helminthosporiosis (*Bipolaris sorokiniana*), blast (*Pyricularia grisea*) and fusarium head blight (*Gibberella zeae*), in wheat (*Triticum aestivum*), in the phenological stages of tillering (A), flowering (F) and milky grain (GL), controlled by the application of fungicides with different spray nozzles, at College Farm Capão da Onça, Ponta Grossa State University (Paraná, Brazil).

Cultivar Tbio Itaipu™, first crop season.

Jet types	Powdery mildew			Yellow spot			Leaf rust		
	A	F	GL	A	F	GL	A	F	GL
Control[1]	08 a[2]	16 a	23 a	06 a	17 a	26 a	04 a	09 a	41 a
Hollow cone	03 b	05 b	07 b	03 b	07 b	15 b	02 b	03 b	16 b
Double flat fan	03 b	05 b	07 b	02 b	07 b	15 b	02 b	04 b	15 b
Extended-range flat fan	03 b	05 b	08 b	03 b	06 b	16 b	02 b	04 b	18 b
Wide-angle flat fan	03 b	06 b	07 b	02 b	06 b	16 b	02 b	04 b	16 b
Air-induction flat fan	02 b	05 b	08 b	03 b	07 b	15 b	02 b	05 b	17 b
Blocks	ns[3]	ns	ns	ns	ns	ns	*[4]	ns	ns
Coefficient of Variation (%)	34.0	25.5	18.0	37.8	18.3	20.9	28.6	31.1	10.6

Cultivar Toruk™, second crop season.

Jet types	Helminthosporiosis			Yellow spot			Wheat blast		
	A	F	GL	A	F	GL	A	F	GL
Control	04 a	08 a	10 a	09 a	25 a	32 a	Not observed	Not observed	40 a
Hollow cone	02 b	05 b	06 b	05 b	12 b	17 b			30 b
Double flat fan	02 b	05 b	05 b	05 b	12 b	17 b			32 b
Extended-range flat fan	02 b	05 b	06 b	05 b	12 b	17 b			33 b
Wide-angle flat fan	02 b	05 b	06 b	05 b	11 b	16 b			33 b
Air-induction flat fan	02 b	05 b	06 b	05 b	12 b	16 b			31 b
Blocks	*	ns	*	ns	ns	ns			*
Coefficient of Variation (%)	13.7	5.6	8.5	8.1	7.2	6.2			8.5

Cultivar TBIO Sossego™, third crop season.

Jet types	Powdery mildew			Leaf rust			Fusarium head blight		
	A	F	GL	A	F	GL	A	F	GL
Control	03 a	12 a	24 a	02 a	08 a	42 a	Not observed	Not observed	13 a
Hollow cone	01 b	02 b	10 b	01 b	02 b	21 b			07 b
Double flat fan	01 b	03 b	12 b	01 b	02 b	20 b			07 b
Extended-range flat fan	01 b	03 b	11 b	01 b	02 b	19 b			08 b
Wide-angle flat fan	01 b	03 b	10 b	01 b	02 b	18 b			06 b
Air-induction flat fan	01 b	02 b	10 b	01 b	02 b	20 b			07 b
Blocks	ns	ns	ns	ns	*	*			ns
Coefficient of Variation (%)	56.4	28.0	15.9	57.8	23.5	12.7			18.1

[1] Without fungicide application on wheat plants.
[2] Averages with the same letter in the column do not differ by Tukey (P > 0.05).
[3] Not significant for blocks (P > 0.05).
[4] Significant for blocks (P < 0.05).

Table 3. Spraying quality analyzing water-sensitive papers (Sprinkle™ software) during fungicides spray with different nozzles in flowering of wheat (*Triticum aestivum*) – average of three crop seasons – College Farm Capão da Onça, State University of Ponta Grossa (Paraná, Brazil)[1].

Jet types	Cover (%)	Density (droplets cm^{-2})	$Dv_{0.1}$[2]	$Dv_{0.5}$[3]	$Dv_{0.9}$[4]	Relative amplitude (SPAN)
Upper third						
Hollow cone	08 b[5]	350 ab	85 c	160 d	284 d	1.2 a
Double flat fan	08 b	404 a	96 c	165 d	290 d	1.2 a
Extended-range flat fan	10 ab	319 b	111 c	320 c	457 c	1.1 a
Wide-angle flat fan	13 a	243 c	200 b	459 b	609 b	0.9 a
Air-induction flat fan	11 ab	166 d	313 a	653 a	817 a	0.8 a
Coefficient of Variation (%)	18.5	29.0	16.2	12.1	15.2	16.2
Middle third						
Hollow cone	06 b	194 c	70 d	126 d	215 d	1.2 a
Double flat fan	06 b	288 a	75 d	134 e	216 d	1.1 a
Extended-range flat fan	07 b	222 b	104 c	270 c	390 c	1.1 a
Wide-angle flat fan	09 a	181 c	138 b	440 b	551 b	0.9 a
Air-induction flat fan	10 a	150 d	231 a	580 a	763 a	0.9 a
Coefficient of Variation (%)	21.6	22.1	15.7	10.3	10.6	23.7
Lower third						
Hollow cone	01 c	83 c	70 d	112 e	170 d	0.9 a
Double flat fan	02 c	74 c	72 d	129 e	189 d	0.9 a
Extended-range flat fan	02 c	128 a	91 c	223 c	333 c	1.1 a
Wide-angle flat fan	05 b	134 a	109 b	317 b	500 b	1.2 a
Air-induction flat fan	06 a	116 b	183 a	497 a	670 a	1.0 a
Coefficient of Variation (%)	26.2	22.4	22.6	16.1	12.4	18.3

[1] Not significant for blocks (P >0.05) in all analyzed variables.
[2] $DV_{0.1}$: a value where 10% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value.
[3] $DV_{0.5}$: Volume Median Diameter (also known as VMD or MVD). The VMD is a value where 50% of the total volume (or mass) of liquid sprayed is made up of drops with diameters larger than the median value and 50% smaller than the median value.
[4] $DV_{0.9}$: a value where 90% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value.
[5] Means with the same letter in the column do not differ by Tukey (P > 0.05).

Table 4. Wheat (*Triticum aestivum*) yield components with diseases controlled by the application of fungicides with different spray nozzles at Fazenda Escola Capão da Onça, Ponta Grossa State University (Paraná, Brazil).

Jet types	Spikes (ha)	Grains by Spike	Mass of a thousand grains (g)	Crop yield (kg ha^{-1})
Cultivar Tbio Itaipu™, first crop season.				
Control[2]	5,447,059 a[3]	23 a	14 b	1,778 b
Hollow cone	5,776,471 a	25 a	23 a	3,293 a
Double flat fan	5,794,118 a	24 a	24 a	3,230 a
Extended-range flat fan	5,632,353 a	24 a	24 a	3,256 a
Wide-angle flat fan	5,660,294 a	25 a	25 a	3,364 a
Air-induction flat fan	5,761,765 a	25 a	24 a	3,363 a
Coefficient of variation (%)	4.6	12.2	12.9	10.1
Cultivar Toruk™, second crop season.				
Control	5,876,471 a	17 b	33 b	3,264 b
Hollow cone	6,300,080 a	24 a	41 a	6,236 a
Double flat fan	6,255,882 a	25 a	39 a	6,037 a
Extended-range flat fan	6,251,471 a	25 a	40 a	6,313 a
Wide-angle flat fan	6,180,395 a	25 a	39 a	6,038 a
Air-induction flat fan	6,145,588 a	26 a	39 a	6,364 a
Coefficient of variation (%)	4.0	7.9	3.6	10.9
Cultivar TBIO Sossego™, third crop season.				
Control	3,530,178 a	24 a	28 b	2,294 b
Hollow cone	3,867,502 a	27 a	31 a	3,148 a
Double flat fan	3,835,471 a	27 a	31 a	3,170 a
Extended-range flat fan	3,882,217 a	26 a	31 a	3,085 a
Wide-angle flat fan	4,035,314 a	25 a	31 a	3,138 a
Air-induction flat fan	3,995,008 a	26 a	31 a	3,144 a
Coefficient of variation (%)	11.3	9.0	3.1	7.4

[1] Not significant for blocks (P > 0.05) for all analyzed variables.
[2] Without fungicide application on wheat plants.
[3] Averages with the same letter in the column do not differ by Tukey test (P > 0.05).

DISCUSSION

The incidence and severity of diseases changed each crop year, according to weather conditions and cultivar characteristics. Thus, we confirm the need to spray fungicides, as highlighted by Simón and coauthors [2], Wegulo and coauthors [3], and Souza and coauthors [4]. Similarly, Olivet and coauthors [14], studying spray nozzles for leaf disease control in wheat, asserted that the severity and crop yield in untreated plots were significantly higher than in plots where fungicides were applied. Spray nozzles types showed no effect on the efficacy of the fungicide in three susceptible wheat cultivars.

Regarding spray nozzles, our results confirm Fiallos and coauthors [11], who studied the efficiency of fungicides in the control of leaf diseases on wheat crops comparing spray nozzles types. They did not observe significant differences for disease severity and crop yield variables. However, there was no agreement on recommending the use of flat jet nozzles with a wide range, which generates fine drops, for spraying fungicides on plants.

On the other hand, Sari and coauthors [12], working with leaf disease control in wheat, recommended the use of extended-range flat fan nozzle and hollow cone hydraulic nozzles, as they observed better control of yellow stain and leaf rust. Similarly, Gulart and coauthors [13] studied the influence of the spray droplet spectrum on disease control in two wheat cultivars. These results indicate that the increase in droplet density can increase the coverage rate. However, there was a tendency for the increase in droplet density to decrease the coverage rate in the upper and middle layers of investigation.

They asserted that the spectrum of droplets generated by the spray nozzle with a wide-range flat jet promoted the best disease control and higher crop yield in both cultivars. However, this experiment was similar to the results obtained in Uruguayan lands. Olivet and coauthors [14] assert that in both years of study, severity and productivity in untreated plots were significantly higher than in plots applied with fungicide. The particularities of the different spray nozzles had no effect on the effectiveness of the fungicide on three susceptible wheat cultivars.

The average crop yield of the three harvests was 48% higher than the Paraná state average, standing out for national wheat production in Brazil [1]. Even with different cultivars, unique climatic conditions each year, the number of sprays, and different fungicides used, the results were similar regardless of the spray nozzles.

As in the experiment carried out by White and coauthors [15], several spray nozzles were tested for wheat disease control. In both studies, nozzles manufactured by TeeJet Technologies. Based on the results from this research, only minor or none differences were observed across nozzle configurations in disease control.

The importance of different spray nozzles types in defining the working pressure range, spray volume, drop size, coverage over the target, spout angle, drop life, and drift risk - highlighted by Stefanelo and coauthors [8], Madureira and coauthors [9], and Farias and coauthors [10] - was not evidenced in our study for the crop yield components. A possible explanation for our findings is that the sprays followed the recommendations made by Matthews [5], Song and coauthors [6], and Garcia and coauthors [7]. Also, the characteristics of wheat facilitated droplet penetration on the canopy, minimizing specific effects of spray nozzles.

CONCLUSION

The findings indicated the necessity of chemical control for fungal diseases in wheat plants. Differences among nozzles were limited to spray quality parameters (coverage and droplet density), without effects on disease incidence or yield.

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