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Adjuvants used in fungicide spraying on soybean plants

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Abstract

Aim of study: An adjuvant is a material that is added to a spray carrier to improve the application technology's efficiency but lacks phytosanitary qualities. Our objective was to determine the best option of combining fungicides and adjuvants to control soybean (*Glycine max*) leaf diseases in three cropping seasons.

Area of study: The experiment was developed in the Campos Gerais region (PR - Brazil).

Material and methods: The five treatments consisted of 1) control (without applying fungicides on soybean plants); 2) fungicide application on soybean plants without adjuvant; 3) fungicide with adjuvant based on mineral oil; 4) fungicide with adjuvant based on lecithin and 5) propionic acid and fungicide with 50% of the dose of adjuvant based on mineral oil + 50% of the dose of surfactant adjuvant based on lecithin and propionic acid. The analyzed variables were the physicochemical characteristics of the spray carrier, the incidence and severity of diseases, and the yield components. A completely randomized design was used to study the physicochemical characteristics of the carrier and in randomized blocks for the field experiment. We used five replicates per treatment.

Main results: No foaming and mixing incompatibility of the spray carrier was observed in any treatment. The adjuvant based on lecithin and propionic acid further acidified the spray carrier and presented the same surface tension as mineral oil. The soybean plants that did not receive chemical treatment had a higher occurrence of diseases, which reduced the productive potential.

Research highlights: Adding adjuvants to the spray carrier did not increase the performance of fungicides in controlling diseases and did not affect the yield components.

Additional key words: diseases; yield components; *Glycine max*; application technologies.

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Introduction

Brazil stands out among the world's largest producers and exporters of soybean, *Glycine max* (L.) Merr. In the 2012-15 cropping season, the crop was grown yearly in an area of approximately 30 million Brazilian hectares with an average national productivity of 2,930 kg ha^{-1} (CONAB, 2015). The productivity of soybeans is a consequence of agronomic techniques that include fertilization, positioning of cultivars, adequacy in the population, efficiency in the use of machinery, and the integrated management of unwanted organisms. Among the strategies for integrated disease management, we highlight chemical control by spraying fungicides on plants (Justino et al., 2006; Jasper et al., 2011; Garcia et al., 2018).

The efficiency of chemical control is directly related to using the appropriate product and the technology developed for its application. Application technology is the use of all scientific knowledge to give the active ingredient in the target at the right location, in the right amount, economically, and with the least amount of environmental contamination possible (Matthews, 2018).

In application technology, the efficiency of the process can be enhanced by using adjuvants. The adjuvant is an additive or supplement used to improve performance or assist in the stability of active ingredient formulations. Adjuvants are formulated combinations of penetrants, activators, spreaders, adhesives, solvents, wetting agents, pH modifiers, antifoam agents, drift reducers, emulsifiers, surfactants, etc., depending on the proposed utility. Generally, adjuvants are much cheaper than formulated active ingredients. They can reduce the dose of the required active ingredient, and the carrier volume used (Souza et al., 2014; Mullin et al., 2016).

There is a variety of studies in the literature evaluating the efficiency of spraying adjuvants with contrasting results. Aguiar Junior et al. (2011) used a wetting agent and a surfactant/emulsifier to study the impact of adding adjuvants to the fungicide solution for the control of Asian rust (*Phakopsora pachyrhizi*) in soybeans. Combining fungicide with surfactant/emulsifier did not significantly affect disease control and yield components. Nascimento et al. (2012) investigated the relationship between fungicides and seven adjuvants in soybean culture, and noted that the inclusion of adjuvants in the fungicide spray carrier altered the incidence of Asian rust while maintaining equivalent productivity, with the exception of plots containing plants that were not sprayed with fungicides.

Oliveira et al. (2016) conducted a literature review and meta-analysis on the use of pesticides in conjunction with adjuvants, finding that the adjuvant increased control levels by an average of 6.5%.

By spraying fungicides with adjuvants in soybean, Garcia et al. (2016) evaluated the physicochemical characteristics of the spray carrier, incidence and severity of diseases, and yield components. They concluded that the adjuvants changed the surface tension of the spray carrier. Adding the adjuvant to the spray carrier with fungicide reduced the incidence of diseases. Still, it did not affect yield components.

Using mineral oil (Nimbus™) alone and in conjunction with the silicone adjuvant (Break Thru™), Roehrig et al. (2018) tested different volumes of fungicide application in soybean. The greatest dependence on spreading / adhesive adjuvants occurred with spray volumes below 100 L ha^{-1}, emphasizing the mixture of mineral oil + silicon. The authors indicated that applications with higher spray volumes without adjuvants did not compromise disease control and yield components.

Thus, the objective of this study was to determine the effects of combining fungicides and adjuvants in controlling soybean leaf diseases. Adjuvants based on mineral oil and lecithin, and propionic acid were used. The study covered three cropping seasons, from 2012 to 2015.

Material and methods

Experimental design

The treatments consisted of 1) control (without treating soybean plants with fungicides); 2) fungicide application (Aproach Prima™ 80 g L^{-1} cyproconazole + 200 g L^{-1} of picoxystrobin (0.3%) on soybean plants without the use of an adjuvant; 3) fungicide with mineral oil-based adjuvant (Nimbus™); 4) fungicide with adjuvant based on lecithin and propionic acid (LI 700™); and 5) fungicides with 50% of the adjuvant dose based on mineral oil + 50% of the adjuvant dose based on lecithin and propionic acid. The rate employed for the LI 700™ was 0.15%, while the Nimbus™ was 0.50% of the spray carrier.

The variables analyzed were: the physicochemical characteristics of the spraying solution, incidence and severity of diseases, and yield components of the soybean crop. A completely randomized experimental design was adopted for the studies of the physicochemical characteristics of the spraying solution and in randomized blocks for the field experiments. We used five replicates per treatment.

Laboratory analysis

The physicochemical characteristics of the spraying solution were concentrated on foam height, stability, pH, and surface tension. The replicates were characterized by the preparation of the spraying solution in 1-L containers, with the fungicide indicated above. The tests were carried out in August 2012 at the Laboratory of the State University of Ponta Grossa (PR, Brazil) 15 minutes after mixing the fungicide and adjuvants.

The foam was measured on the spray carrier using a millimeter-gradient Digimess Kingtools™ steel ruler. Visual acuity assessed stability in forming granules for 45 minutes after mixing. The pH of the spray carrier with Phtek™ manual pH meter, model 100-B. The surface tension was determined based on NBR 13,241 (ABNT, 1994).

Field analysis

The experiments in soybean crops were carried out at Fazenda Paiquerê, located in the municipality of Piraí do Sul - PR (Brazil), in three soybean cropping seasons from 2012 to 2015, coordinates 24°20›53" S 50°07'54" W, Cfb climate, 910 m altitude, on dystrophic Red-Yellow Latosol soil, sowing system under straw. The crop rotation on the property was based on the sequence: soybean (*Glycine max*), black oats (*Avena strigosa*), corn (*Zea mays*), wheat (*Triticum aestivum*), and return to soybean.

The sowing of the conventional soybean cultivar BRS 284™ was carried out on November 10, 2012, November 15, 2013, and November 14, 2014. The spacing between rows was 0.5 m. The initial population evaluated 15 days after emergence as 293,000 plants ha^{-1} in 2012, 266,000 plants ha^{-1} in 2013 and 226,000 plants ha^{-1} in 2014. The different densities were given by the recommendations of the agronomist responsible for the area, based on the productive potential of the plot where the experiment was located each year on the property due to the rotation of crops under no-tillage system. All cultural practices and phytosanitary treatments were carried out following the cultivation recommendations for the region (EMBRAPA, 2011).

The climate records indicated values within historical averages (Fig. 1). The disease that was observed in the 2012-13 growing season was Asian rust (*Phakopsora pachyrhizi*). In 2013-14, powdery mildew (*Erysiphe diffusa*) and downy mildew (*Peronospora manshurica*) were observed. In 2014-15, all three diseases were present. The diseases were controlled by two sprays with the fungicide indicated above at a dose of 0.3 L ha^{-1}, applied at the phenological stages R1 (Ritchie et al., 1982) and R5.

The sprayer used was a self-propelled John Deere 4,630™, with a spray bar with 24 meters, nozzles spaced at 0.5 m, and JA-03™ tips. The spraying occurred at a speed of 13 km h^{-1} with a pressure of 645 kPa. The onboard computer automatically corrected the speed variations to maintain the spray volume at 100 L ha^{-1}. The sprays were carried out with relative humidity above 60%, temperature below 27^0C, and wind speed between 3.0 and 8.0 km h^{-1}. The Kestrel 3,000™ anemo-thermo-hygrometer monitored climatic conditions. The plots were delimited in the center of the bar.

Replicates were formed by plots with an assessment area of 20 m^2 (5 × 4 m) in the center of the sprayed area, where all disease and yield components evaluations were carried out. One half of the spray bar was used to spray the plots, with 20 m of displacement of the sprayer. Disease incidence and severity were determined 10 days after each fungicide application. The incidence values were obtained as the percentage of diseased plants. Severity assessments were based on diagrammatic scales developed for the soybean leaf diseases: Godoy et al. (2006) for Asian rust, Mattiazi (2003) for powdery mildew, and Kowata et al. (2008) for downy mildew.

On April 6, 2013, April 18, 2014, and April 12, 2015, harvest was done by hand. To examine the mass of a thousand grains and productivity, impurities (1.0%) and humidity were adjusted to 14.0% (CODAPAR, 2015). Moisture was obtained with the use of the Gehaka™ 6,600 device. The mass of a thousand grains was defined using a digital scale Gehaka™ BK 6,000. The productivity measurement was done with a digital scale Ramud™, with a capacity of 50 kg.

Statistical analysis

Hartley's test was applied to assess the homoscedasticity of the variances. Shapiro-Wilk measured normality. The treatment means were subjected to analysis of variance by the Fisher-Snedecor test and compared by the Tukey test, with a degree of confidence greater than 95% probability. Statistical analyzes were performed with the aid of the SASM AGRI™ software.

Results

Physicochemical characteristics of the spray carrier

The Hartley test pointed to the homoscedasticity of the variances, and Shapiro-Wilk confirmed the normality of the data for all physicochemical variables studied. Therefore, it was not necessary to transform the values to apply the analysis of variance.

The physicochemical characteristics of the spray carrier showed no foam formation and mixing incompatibility in any treatment. Thus, it was not possible to apply inferential statistics due to the absence of foam formation variance and qualitative assessment of the stability of the mixture (Table 1).

The addition of adjuvant LI 700™ acidified the spray carrier. The pH increased by combining fungicide and adjuvant based on mineral oil and it was close to neutral only with water. The addition of the two adjuvants to the fungicide solution maintained the adjuvant's acidifying effect based on lecithin and propionic acid.

The fungicide did not have any effect to modify the spray carrier's surface tension, similar to the treatment that used water as a solvent. The adjuvants studied, alone or in combination, reduced the surface tension in the same proportion, close to half the value of the spray solution only with fungicide. When spraying, adjuvants should then provide twice the number of drops per area compared to the spray without such surfactants.

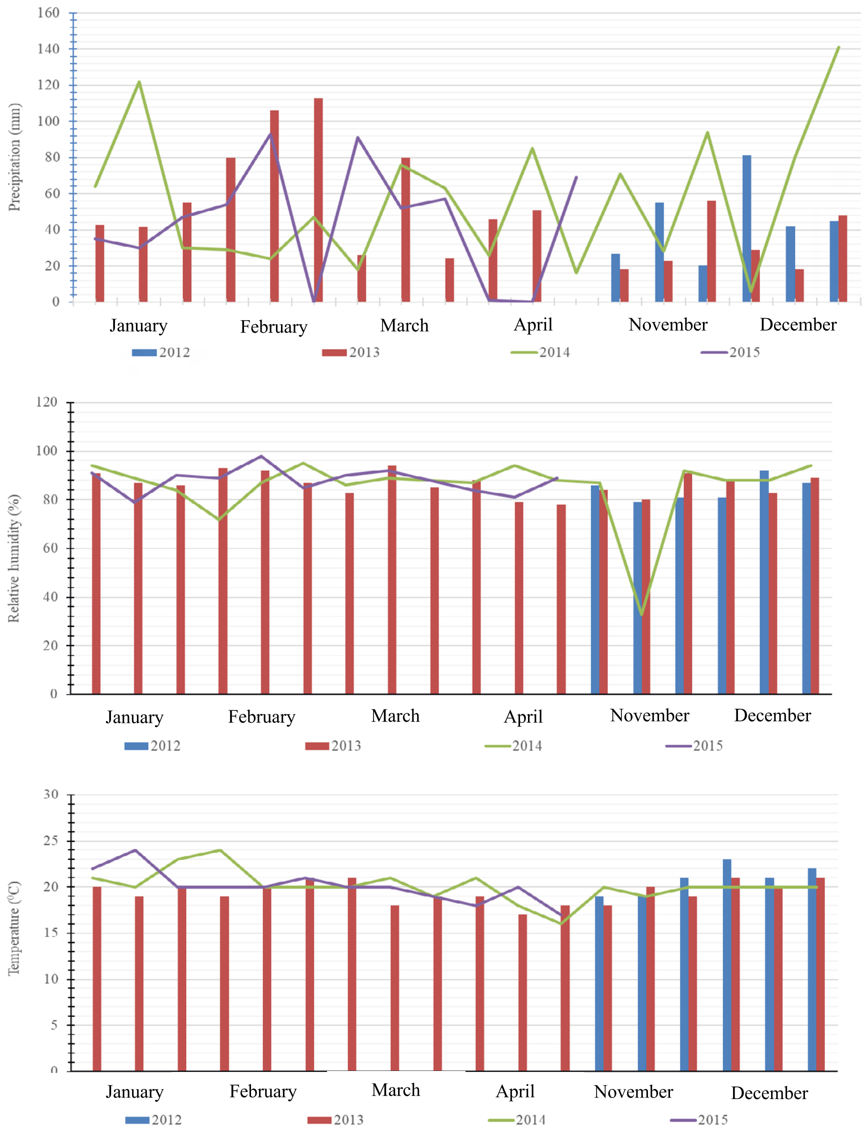

Figure 1. Weather conditions during the experiment with soybean (*Glycine max*), at Fazenda Paiquerê, Piraí do Sul (Paraná, Brazil). Source: Foundation ABC (2015).

Table 1. Physicochemical characteristics of the spray carrier with the Aproach Prima™ fungicide (0.30% of the spray carrier) and the adjuvants Nimbus™ (0.50% of the spray carrier) and LI 700™ (0.15% spray carrier), 15 minutes after mixing, analyzed in 2012 at the Laboratory of the State University of Ponta Grossa (PR, Brazil).

Treatments	Foam height (cm)	Stability	pH	Surface tension ($mN\ m^{-1}$)
Control	0.0	Yes	6.4 a [3]	72 a
Fungicide without adjuvants	0.0	Yes	5.6 b	68 a
Fungicide + Nimbus™ adjuvant	0.0	Yes	5.7 b	36 b
Fungicide + LI 700™ adjuvant	0.0	Yes	4.2 c	34 b
Fungicide + Nimbus™ + LI 700™ [1]	0.0	Yes	4.0 c	35 b
CV (%) [2]	//	//	18.7	8.8

[1] In the mixture of adjuvants half of the recommended rate was used. [2] CV: coefficient of variation. [3] Means followed by the same letter in the column did not differ significantly by Tukey‘s test (p>0.05).

Diseases incidence and severity

Statistical analysis of the incidence and severity of Asian rust highlighted significant differences (p<0.05) for blocks for incidence and severity in the second evaluation of the 2012-13 cropping season. There were also significant differences (p<0.05) in Asian rust severity of the last 2014-15 assessment, highlighting the importance of the randomized block design of the experiment (Table 2). Asian rust incidence and severity were high in harvests in which the disease appeared. Chemical control substantially reduced the incidence and severity of Asian rust up. In all evaluations, the results of the control without fungicide application differed from the other treatments, regardless of the addition of adjuvants to the spray carrier.

Regarding powdery mildew, control plots not sprayed with fungicides showed significantly higher disease incidence and severity than the other treatments in all evaluations (Table 3), so the effectiveness of the chemical treatments was verified. Regarding adjuvants, they did not improve disease control compared to the fungicide alone. The block effect of the experiment was only significant (p<0.05) in the first assessment of the severity of the last cropping season, showing the homogeneity of the experimental conditions.

For downy mildew, the differences between blocks were significant (p<0.05) for the lowest values, increasing the coefficient of variation (Table 4). Disease incidence was not affected by the treatments in the first evaluation of the 2013-14 cropping season. In other evaluations, the incidence and severity were several times higher in the control treatment, with no difference between with or without adjuvants. The 2014-15 data showed the highest values of incidence (96%) and severity (09%) for plots that did not receive chemical control. In this same growing season, fungicide treatments with or without adjuvants also presented the highest disease incidence (83%) and severity (06%).

Yield components

Regarding yield components (Table 5), there was only a significant difference (p<0.05) for blocks in the variable pods per plant in the 2012-13 cropping season. This fact illustrates how the experiment was conducted under similar

Table 2. Incidence and severity of Asian rust (*Phakopsora pachyrhizi*) in soybean (*Glycine max*), cultivar BRS 284™, 10 days after spraying with the combination of fungicides and adjuvants in the spray carrier (phenological stages R2 and R6 [1]), at Fazenda Paiquerê (Piraí do Sul - PR, Brazil).

Treatments	Incidence (%)		Severity (%)	
	R2	R6	R2	R6
2012-2013				
Control [2]	60 a [5]	71 a	25 a	80 a
Fungicide without adjuvants	43 b	61 b	12 b	32 b
Fungicide + Nimbus™ adjuvant	43 b	55 b	10 b	31 b
Fungicide + LI 700™ adjuvant	46 b	57 b	11 b	30 b
Fungicide + Nimbus™ + LI 700™ [3]	42 b	63 b	13 b	28 b
Blocks	ns [6]	* [7]	ns	*
CV (%) [4]	19	13	25	11
2014-2015				
Control	81 a	98 a	12 a	76 a
Fungicide without adjuvants	52 b	61 b	08 b	49 b
Fungicide + Nimbus™ adjuvant	50 b	55 b	07 b	45 b
Fungicide + LI 700™ adjuvant	48 b	57 b	06 b	47 b
Fungicide + Nimbus™ + LI 700™	47 b	63 b	07 b	50 b
Blocks	ns	ns	ns	*
CV (%)	10	13	28	17

[1] Phenological stages proposed by Ritchie et al. (1982). [2] No fungicide spray. [3] In the mixture of adjuvants half of the recommended rate was used. [4] CV: coefficient of variation. [5] Means followed by the same letter in the column did not differ significantly by Tukey's test (p>0.05). [6] In all analyzed variables there were no significant differences for blocks by the Fisher-Snedecor test (p>0.05). [7] In all analyzed variables there were significant differences for blocks by the Fisher-Snedecor test (p<0.05).

Table 3. Incidence and severity of powdery mildew (*Erysiphe diffusa*) in soybean (*Glycine max*), cultivate BRS 284™, 10 days after spraying with the combination of fungicides and adjuvants in the spray carrier (phenological stages R2 and R6 [1]), at Fazenda Paiquerê (Piraí do Sul - PR, Brazil).

Treatments	Incidence (%)		Severity (%)	
	R2	R6	R2	R6
2013-2014				
Control [2]	07 a [5]	10 a	05 a	18 a
Fungicide without adjuvants	02 b	05 b	01 b	08 b
Fungicide + Nimbus™ adjuvant	02 b	04 b	01 b	08 b
Fungicide + LI 700™ adjuvant	02 b	03 b	01 b	07 b
Fungicide + Nimbus™ + LI 700™ [3]	01 b	04 b	01 b	06 b
Blocks	ns [6]	ns	ns	ns
CV (%) [4]	24	28	37	23
2014-2015				
Control	44 a	87 a	08 a	17 a
Fungicide without adjuvants	36 b	53 b	02 b	06 b
Fungicide + Nimbus™ adjuvant	34 b	48 b	01 b	05 b
Fungicide + LI 700™ adjuvant	33 b	45 b	02 b	05 b
Fungicide + Nimbus™ + LI 700™	30 b	46 b	02 b	04 b
Blocks	ns	ns	* [7]	ns
CV (%) [1]	16	10	30	27

[1] Phenological stages proposed by Ritchie et al. (1982). [2] No fungicide spray. [3] In the mixture of adjuvants half of the recommended rate was used. [4] CV: coefficient of variation. [5] Means followed by the same letter in the column did not differ significantly by Tukey's test ($p>0.05$). [6] In all analyzed variables there were no significant differences for blocks by the Fisher-Snedecor test ($p>0.05$). [7] In all analyzed variables there were significant differences for blocks by the Fisher-Snedecor test ($p<0.05$).

circumstances with various crops. The treatments did not significantly ($p>0.05$) affect the density of plants, pods per plant, and grains per pod. Thus, disease control levels did not reach the point of altering the characteristics inherent to the genetics of the soybean cultivar.

The action of pathogens reduced the weight of 1,000 grains and yield in 2012-13 (18% and 52%) and 2014-15 (7% and 14%) cropping seasons. The addition of adjuvants to the fungicide solution did not enhance the efficiency of the active ingredients in the spray.

Discussion

Souza et al. (2014) and Mullin et al. (2016) previously reported on the increase in efficiency achieved by the addition of adjuvants to the application technology process (Matthews, 2018). This was achieved by modifying the pH of the spray carrier and the surface tension of the drops, as evidenced by our work.

Weather data (Fig. 1) indicated the ocurrence of high rainfall at the beginning and end of the 2012-13 cropping season, favoring the proliferation of Asian rust but reducing the occurrence of powdery mildew and downy mildew. In the 2013-14 cropping season, precipitation and temperature were high during pod filling, favoring the development of powdery and downy mildew, making the Asian rust disease more difficult to control. In 2014-15, the rains were heavy in December (during vegetative development and flowering), February (pod filling), and March (ripening), being the year that the high humidity and temperature favored the action of the pathogens.

The results confirm chemical control as an important strategy in the integrated management of diseases (Justino et al., 2006; Jasper et al., 2011; Garcia et al., 2018). The average increase of 6.5% in the control levels with adding the adjuvant to the spray solution, mentioned by Oliveira et al. (2016), was below the 9.1% tabulated with all disease assessments in this study.

The high standard of conducting the crop is evident owing to the average productivity of the three cropping seasons, being 60% higher than the national average (CONAB, 2015). When comparing the yield components from the 2013–2014 cropping season, when Asian rust did not exist, it was clear how the disease affected the soybean plants. No significant changes were found between treatment groups for any of the variables examined. Consequently, even after mildew and mildew action, it would not be necessary to spray the plants because the yield of the fungicide-free plots was the same as that of the fungicide-treated plots.

Table 4. Incidence and severity of downy mildew (*Peronospora manshurica*) in soybean (*Glycine max*), cultivar BRS 284™, 10 days after spraying with a combination of fungicides and adjuvants in the spray carrier (phenological stages R2 and R6[1]), at Fazenda Paiquerê (Piraí do Sul - PR, Brazil).

Treatments	Incidence (%)		Severity (%)	
	R2	R6	R2	R6
2013-2014				
Control [2]	02 a [5]	10 a	07 a	16 a
Fungicide without adjuvants	02 a	03 b	03 b	07 b
Fungicide + Nimbus™ adjuvant	02 a	03 b	02 b	07 b
Fungicide + LI 700™ adjuvant	02 a	03 b	02 b	06 b
Fungicide + Nimbus™ + LI 700™ [3]	01 a	02 b	02 b	06 b
Blocks	ns [6]	* [7]	*	*
CV (%) [4]	28	18	31	19
2014-2015				
Control	91 a	96 a	06 a	09 a
Fungicide without adjuvants	76 b	83 b	03 b	06 b
Fungicide + Nimbus™ adjuvant	74 b	83 b	04 b	06 b
Fungicide + LI 700™ adjuvant	74 b	82 b	04 b	06 b
Fungicide + Nimbus™ + LI 700™	75 b	82 b	04 b	05 b
Blocks	ns	ns	*	*
CV (%) [1]	04	03	34	17

[1] Phenological stages proposed by Ritchie et al. (1982). [2] No fungicide spray. [3] In the mixture of adjuvants half of the recommended rate was used. [4] CV: coefficient of variation. [5] Means followed by the same letter in the column did not differ significantly by Tukey's test ($p>0.05$). [6] In all analyzed variables there were no significant differences for blocks by the Fisher-Snedecor test ($p>0.05$). [7] In all analyzed variables there were significant differences for blocks by the Fisher-Snedecor test ($p<0.05$).

Asian rust was the only illness observed in 2012-2013. There were significant differences between treatments with and without fungicides, with a degree of confidence greater than 95% probability.

The outcomes validate the findings of Aguiar Júnior et al. (2011), who concluded that the incidence, severity, and yield components of Asian rust were not significantly affected by the combination of fungicide and surfactant/emulsifier adjuvant. On the other hand, neither the weight shift of 1,000 grains nor the control of the disease are supported by the findings of Nascimento et al. (2012). However, it is confirmed by the comparable yield values that were achieved when adjuvants were applied in the spray carrier. The findings of Garcia et al. (2016) on the yield components and the spray carrier's surface tension changed, yet the incidence of the diseases they examined did not go down. The lack of need for adjuvants above 100 L ha^{-1} for disease control, mentioned by Roehrig et al. (2018), was proven in this essay.

In conclusion, there was no foaming and mixing incompatibility in any of the treatments evaluated. The adjuvant based on lecithin and propionic acid acidified the spray carrier and presented the same surface tension as mineral oil. The soybean plants that did not receive any fungicide treatment had a higher occurrence of diseases, which reduced the weight of 1,000 grains and yield. Adding adjuvants to the spray carrier did not increase the efficiency of fungicides in controlling diseases and did not affect any of the yield components.

Data availability: Not applicable.

Competing interests: The authors have declared that no competing interests exist.

Authors' contributions: Luiz C. Garcia: Conceptualization, Methodology, and Project administration. **Guilherme H. Carraro:** Data curation and formal analysis. **Sandro Felema:** Data curation and formal analysis. **Allison J. Fornari:** Supervision and Validation. **Leandro J. V. Sformi:** Investigation and Supervision. **Thiago M. Inagaki:** Writing – review & editing.

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Table 5. Yield components of soybean crop (*Glycine max*), cultivar BRS 284™, by spraying with the combination of fungicides and adjuvants in the spray carrier, Fazenda Paiquerê (Piraí do Sul - PR, Brazil).

Treatments	Plant density (plants ha^{-1})	Pods per plant	Grains per pod	Weight of 1,000 grains (kg)	Yield (kg ha^{-1})
2012-2013					
Control [1]	272,500 a [4]	38 a	2.7 a	121 b	3,343 b
Fungicide without adjuvants	284,936 a	43 a	2.8 a	143 a	4,937 a
Fungicide + Nimbus™ adjuvant	288,003 a	45 a	2.7 a	143 a	4,991 a
Fungicide + LI 700™ adjuvant	289,989 a	46 a	2.8 a	142 a	5,171 a
Fungicide + Nimbus™ + LI 700™ [2]	283,000 a	47 a	2.7 a	144 a	5,193 a
Blocks	ns [5]	* [6]	ns	ns	ns
CV (%) [3]	08	08	06	03	13
2013-2014					
Control	262,500 a	47 a	2.7 a	156 a	5,074 a
Fungicide without adjuvants	262,125 a	47 a	2.6 a	157 a	5,073 a
Fungicide + Nimbus™ adjuvant	260,500 a	47 a	2.6 a	159 a	5,125 a
Fungicide + LI 700™ adjuvant	261,500 a	47 a	2.7 a	157 a	5,167 a
Fungicide + Nimbus™ + LI 700™	260,500 a	47 a	2.7 a	161 a	5,227 a
Blocks	ns	ns	ns	ns	ns
CV (%)	01	08	06	02	12
2014-2015					
Control	222,238 a	61 a	2.6 a	102 b	3,540 b
Fungicide without adjuvants	211,028 a	62 a	2.7 a	108 a	3,754 a
Fungicide + Nimbus™ adjuvant	219,827 a	63 a	2.7 a	111 a	4,142 a
Fungicide + LI 700™ adjuvant	217,543 a	64 a	2.8 a	109 a	4,104 a
Fungicide + Nimbus™ + LI 700™	222,845 a	64 a	2.7 a	108 a	4,145 a
Blocks	ns	ns	ns	ns	ns
CV (%)	05	03	03	02	07

[1] No fungicide spray. [2] In the mixture of adjuvants half of the recommended rate was used. [3] CV: coefficient of variation. [4] Means followed by the same letter in the column did not differ significantly by Tukey's test ($p>0.05$). [5] In all analyzed variables there were no significant differences for blocks by the Fisher-Snedecor test ($p>0.05$). [6] In all analyzed variables there were significant differences for blocks by the Fisher-Snedecor test ($p<0.05$).

References

ABNT, 1994. Agrotóxico - Determinação da tensão superficial - Método de Ensaio. Associação Brasileira de Normas Técnicas, Rio de Janeiro. 2 pp.

Aguiar Júnior HO, Raetano CG, Prado EP, Pogetto MHAD, Christovam RS, Gimenes MJ, 2011. Adjuvants and air assistance in sleeve boom sprayer on spray deposition and control of *Phakopsora pachyrhizi* (Sydow & Sydow). Summa Phytopathologica 37(3): 103-109. https://doi.org/10.1590/S0100-54052011000300004

CODAPAR, 2015. Principais produtos vegetais padronizados, classificados pela Codapar. Companhia de Desenvolvimento Agropecuário do Paraná, http://www.codapar.pr.gov.br/modules/conteudo/conteudo.php?conteudo=78. [May 8, 2015].

CONAB, 2015. Acompanhamento de safra brasileira: Grãos, 12º levantamento, setembro 2015. Companhia Nacional de Abastecimento, Brasília, DF. 139 pp. ISSN 2318-6852

EMBRAPA, 2011. Tecnologias de produção de soja - Região Central do Brasil 2012 e 2013. Empresa Brasileira de Pesquisa Agropecuária, Londrina, PR (Brazil). 263 pp. ISSN 2176-2902.

Foundation ABC, 2015. Agrometeorological monitoring system. http://sma.fundacaoabc.org/monitoramento/grafico/decendial. [May 28, 2015].

Garcia LC, Machado Júnior CR, Bochnia GP, Weirich Neto PH, Raetano CG, 2016. Adjuvants in fungicide spraying in wheat and soybean crops. Engenharia Agrícola 36(6):

1110-1117. https://doi.org/10.1590/1809-4430-eng.agric.v36n6p1110-1117/2016

Garcia LC, Taques R, Manfron F, Taques A, Inagaki T, Weirich Neto PH, et al., 2018. Trailing boom on fungicides application on wheat, bean and soybean. Int J Adv Eng Res Sci 5(9): 244-252. https://doi.org/10.22161/ijaers.5.9.27

Godoy CV, Koga LJ, Canteri MG, 2006. Diagrammatic scale for assessment of soybean rust severity. Fitopat Bras 31(1): 63-68. https://doi.org/10.1590/S0100-41582006000100011

Jasper R, Jasper M, Assumpção PSM, Rocil J, Garcia LC, 2011. Speed of sowing on soybean crop. Engenharia Agrícola 31(1): 102-110. https://doi.org/10.1590/S0100-69162011000100010

Justino A, Menon L, Bora L, Garcia LC, Raetano CG, 2006. Track of spraying in soybean and bean crops using a bar sprayer. Engenharia Agrícola 26(3): 755-758. https://doi.org/10.1590/S0100-69162006000300012

Kowata LS, May-de-Mio LL, Dalla Pria M, Santos HAA, 2008. Diagrammatic scale for assessment of soybean downy mildew severity. Scientia Agraria (Curitiba) 9(1): 105-110. https://doi.org/10.5380/rsa.v9i1.10145

Matthews GA, 2018. A history of pesticides. Wallingford, UK: CABI International. 287 pp. ISBN: 9781786394873. https://doi.org/10.1079/9781786394873.0000

Mattiazzi P, 2003. Efeito do oídio (*Microsphaera diffusa* Cooke & Peck) na produção e duração da área foliar sadia da soja, 1st ed. Piracicaba: ESALQ - Escola Superior de Agricultura "Luiz de Queiroz", 49 pp.

Mullin CA, Fine JD, Reynolds RD, Frazier MT, 2016. Toxicological risks of agrochemical spray adjuvants: organosilicone surfactants may not be safe. Front Public Health 4(92): 1-8. https://doi.org/10.3389/fpubh.2016.00092

Nascimento JM, Gavassoni WL, Bacchi LMA, Zuntini B, Mendes MP, Leonel RK, et al., 2012. Association of adjuvants with picoxystrobin+cyproconazole for Asian soybean rust control. Summa Phytopathologica 38(3): 204-210. https://doi.org/10.1590/S0100-54052012000300004

Oliveira GM, Canteri MG, Saab Abi OJG, 2016. Meta-analysis of scientific studies related to pesticide application techniques - Air assistance and adjuvant addition. Ciência Rural 46(12): 2122-2128. https://doi.org/10.1590/0103-8478cr20151067

Ritchie S, Hanway JJ, Thompson HE, 1982. How a soybean plant develops. Iowa State University of Science and Technology, Cooperative Extension, Ames, IA (USA), 20 pp. (Special Report, n. 53).

Roehrig R, Boller W, Forcelini CA, Chechi A, 2018. Use of surfactant with different volumes of fungicide application in soybean culture. Engenharia Agrícola 38(4): 577-589. https://doi.org/10.1590/1809-4430-eng.agric.v38n4p577-589/2018

Souza BJR, Perez PH, Bauer FC, Raetano CG, Weirich Neto PH, Garcia LC, 2014. Adjuvants for spraying of fungicides in wheat. Ciência Rural 44(8): 1398-1403. https://doi.org/10.1590/0103-8478cr20131099