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Application technology of imidacloprid in wheat: Effects on *Schizaphis graminum* management and natural enemies

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Wheat production is dependent on costly insecticides that generate social and environmental issues. The growing demand for a rate reduction of spray applications and increased spray efficiency make essential the research for more adequate crop management. Therefore, this study aimed to evaluate technologies of imidacloprid application on wheat aphid, *Schizaphis graminum* and its natural enemies, *Chrysoperla externa* and *Orius insidiosus*. A set of experiments were performed to evaluate the effectiveness of *S. graminum* control and the toxicity to natural enemies using imidacloprid plus adjuvants sprayed with different nozzles and application rates. Improved *S. graminum* control was observed in the association between the adjuvant lauryl ether sodium sulfate and the hollow cone nozzle for both application rates (75 and 150 L ha^{-1}), and the adjuvant copolymer of polyester + silicone + d-limonene with the asymmetric twin flat-fan nozzle at a low rate (75 L ha^{-1}), since these treatments eliminate the wheat aphid after the fifth day of treatment application. The reduction of spray volume to wheat aphid control is possible with no loss of insecticide effectiveness. Imidacloprid associated with any one of the adjuvants tested is harmful to *C. externa* and *O. insidiosus*, even at the fifth day after application the insecticide continues being harmful to the natural enemies, regardless of the technology used.

Key words: *Triticum aestivum*, *Schizaphis graminum*, ecological disturbance, insecticide impacts, natural control, neonicotinoid.

INTRODUCTION

The productivity of wheat, *Triticum aestivum* L. is strongly influenced by the attack of insect pests. Among them, the aphids (Hemiptera: Aphididae) are an important pest problem to the cultivation of winter cereals (Salvadori and

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†In memoriam

Salles, 2002). The ability of these insects to cause damage is high due to the elevated biotic potential and toxicity of the substances injected into the plant tissue during the feeding process. In intense aphid attacks during the emergency of the wheat tillering, in general, causes plant death (Gassen, 1984; Salvadori and Tonet, 2001).

The chemical control is predominantly used in the management of aphids as the green aphid of cereals, or wheat aphid (*Schizaphis graminum* Rondani, 1852), which can cause up to 50% of direct (sap suction) and indirect (fungal growth on honeydew) yield losses (Kindler et al., 2002; Van-Emden and Harrington, 2007; Royer et al., 2015). This aphid is widely distributed in the wheat production regions of the world (Blackman and Eastop, 2000). Thus, wheat production is very dependent on the use of insecticides, which increases production costs and generates several social and environmental problems (Salvadori, 1999). Chemical control of this insect pest is recommended when 10% of plants are infested during the vegetative phase or when it exceeds ten aphids per spike, until the mass phase of the wheat grain (Silva et al., 1996).

According to Mohammed et al. (2018), the neonicotinoid insecticide imidacloprid [1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine] is still effective in suppressing cereal aphid populations in wheat fields throughout the growing season; however, the negative impact of this insecticide on the biological control services and pollinators needs to be considered with caution (Whitehorn et al., 2012; Dicks, 2013; Gibbons et al., 2015; Kang et al., 2018; Lämsä et al., 2018). Although imidacloprid has been banned in several regions (Valavanidis, 2018; Fijian Government, 2019), it has still been largely used in many countries, highlighting the importance of the studies for more appropriate managements and technologies of this insecticide.

For many years of the modern age, little attention was devoted to the sustainability of agriculture, but concerning is rising (Singh and Singh, 2017; Zhang et al., 2017). The growing demands by eco-friendly farming press to decrease the application rates, to reduce the costs and to increase the efficiency of the activities. These demands turn essential the knowledge of the application of crop inputs and parameters that ensure the products will reach the target efficiently, minimizing losses and leading to more sustainable agriculture (Matuo et al., 1989; Ali et al., 2018).

The determination of the most appropriated parameters, such as the application rate and the size of the droplets, is directly related to the quality of the spray application (Matthews et al., 2014). The definition of the spray application rate depends mainly on the type of the target to be reached, the required coverage, the way the pesticide acts and the application technique. The application rate also influences the operational efficiency of the application process because the time used to sprayer reload activities significantly changes the operational capacity of the sprayers (Antuniassi, 2014).

However, the reduction of the application rate requires an enhancement of the application technology regularly used in the field. Thus, there is an increasing need for studies that allow the use of efficient nozzles and appropriate rates (Silva, 1999a). Additionally, beyond the operational gains, it is important to study the possible impacts generated by new technology and procedures on the population of beneficial insects as the natural enemies (predators) of wheat pests. Therefore, the objectives of this study were to evaluate different technologies for applying the imidacloprid insecticide on the wheat crop concerning the chemical control of *S. graminum* and the impacts of these application technologies on natural enemies present in the area.

MATERIALS AND METHODS

Site study

The experiment was conducted in duplicate, Field-1 and Field-2, installed simultaneously; both had irrigation systems via a central pivot and were installed in areas of wheat seed production (wheat cultivar BRS 404). The fields were distant 500 m from each other and located in Maringá Farm, Araguari County, Minas Gerais State, Brazil (18°34'00.23"S; 48°13'03.9"W).

Sowing of wheat crop and cultural practices

The wheat sowing was done in the no-tillage system in April 2016 in Field-1 and Field-2, respectively. The spacing used was 17 cm between rows, with a density of 350 plants m^{-2}. The cropping management followed the indications of the 'Recommendations of the South-Brazilian Commission of Wheat Research' (Recomendações da Comissão Sul-Brasileira de Pesquisa de Trigo, 2000) regarding fertilization, weed control and disease management.

Use of spray nozzles

The spray nozzles (MagnoJet, Brazil) for insecticide treatments application were: (1) MGA 015, hollow cone jet, with 90° angulation and 0.56 L min^{-1} nominal flow; (2) MGA 03, hollow cone jet, with 90° angulation and 1.13 L min^{-1} nominal flow; and (3) AS 7030, asymmetric twin flat fan, with 110° angulation and 0.75 L min^{-1} nominal flow.

Use of adjuvants

The adjuvants used were: lauryl ether sodium sulfate (LESS) - Mirus 400Si® (Superagro, Brazil), concentration of 0.6 mL L^{-1}, characteristics: anti-evaporation, acidifier, anti-drift and adjuvant anti-foaming (adjuvant 01); and copolymer of polyester, silicone and d-limonene (CPSDL) - Orlist 900Li® (Superagro, Brazil), concentration of 1.33 mL L^{-1}, characteristics: spreader, moisturizing, compatibilizer and penetrating adjuvant (adjuvant 02). The spray solutions were prepared in the sprayer tank, adding first the adjuvants in the concentration recommended by the manufacturer, together with the imidacloprid insecticide - 200 g ha^{-1} of the active ingredient.

Treatments and conditions of application

Both experiments were carried out in the strip-plot scheme, with 8 treatments: (1) control (no product application); (2) nozzle AS 7030, 75 L ha^{-1}, no adjuvant (T.1); (3) nozzle MGA 015, 75 L ha^{-1}, no adjuvant (T.2); (4) nozzle MGA 015, 75 L ha^{-1} + adjuvant 01 (T.3); (5) nozzle AS 7030, 75 L ha^{-1} + adjuvant 01 (T.4); (6) nozzle AS 7030, 75 L ha^{-1} + adjuvant 02 (T.5); (7) nozzle MGA 030, 150 L ha^{-1}, no adjuvant (T.6); and, (8) nozzle MGA 03, 150 L ha^{-1} + adjuvant 01 (T.7), each were repeated thrice. The plots had 740 m long and 27 m wide. The usable area assessed corresponded to 1,800 m^2, discarding 10 m at the beginning and the end of the plot and 1 m on each side.

The spray applications occurred when *S. graminum* reached 10% of plant infestation, according to the 'Recommendations of the South-Brazilian Commission of Wheat Research' (Recomendações da Comissão Sul-Brasileira de Pesquisa de Trigo, 2000) and to Cunha et al. (2016). A self-propelled sprayer (Case® Patriot 250 model) was used with 27 m length and nozzles were spaced by 0.5 m. The working speed established was 16 km h^{-1} (4.44 m s^{-1}) for all treatments.

The environmental conditions during the applications were monitored using a thermo-higro-digital anemometer (SKTHAL-01, Skill-Tec, Brazil). During the applications in Field-1, the weather conditions presented a minimum temperature of 25.4°C and a maximum of 29.5°C, relative humidity between 48 and 51%, and wind speeds between 5.8 and 7.9 km h^{-1}. In Field-2, the weather conditions presented a minimum temperature of 30.7°C and a maximum of 32.4°C, relative humidity between 43 and 45%, and wind speeds between 0.8 and 5.2 km h^{-1}.

Insect evaluations

The evaluation of the effectiveness of the spray treatments in the control of *S. graminum* was performed by counting (surveys) of the alive adult insects, before and after each application, using a clashing cloth with 1 m wide by 1 m length. Similarly, the population of *Chrysoperla externa* (Hagen, 1861) and *Orius insidiosus* (Say, 1832) (two important natural enemies of aphids that belong to the orders Neuroptera and Hemiptera, respectively) was evaluated (Parra et al., 2002).

A prior evaluation was performed on the same day of the application of the treatments and, subsequently, other surveys were carried out at 3, 5, 7 and 10 days after the application of the treatments. The percentage of effectiveness of the treatments was calculated by the formula of Henderson and Tilton (1955):

$$E = 1 - \left[\left(\frac{T_b}{T_a} \times \frac{t_a}{t_b}\right)\right] \times 100$$

where E: Efficacy (%); Tb: number of live insects in the control treatment before application; Ta: number of live insects in the control treatment after application; ta: number of live insects in the treatment after application; tb: number of live insects in the treatment before application. The values obtained during the evaluations, after conversion to the percentage of effectiveness, were classified as low efficacy (lower than 80%), good efficacy (from 80 to 90%), and high efficacy (greater than 90%).

The evaluations of the effects of different application technologies on the population density of natural enemies were carried out with the treatments classified in classes of toxicity. According to the International Organization for Biological and Integrated Control (IOBC) (Hassan and Degrande, 1996; Veire et al., 2002), the classes are: class 1- innocuous (<30%), class 2- slightly harmful (30≤T≤80%), class 3- moderately harmful (80≤T≤99%), and class 4- harmful (>99% of mortality); these classes are a function of the average number of adults found in the areas after 3, 5, 7 and 10 days of the spray treatment application. The percentage of toxicity (T) was calculated by the formula proposed by Henderson and Tilton (1955).

Statistical analysis

The results were submitted for the analyses of normality of residue distribution by the test of Kolmogorov-Smirnov and to the homogeneity of variances by the test of Levene (both at 0.01 significance level) before the analysis of variance (0.05 significance level). Student's t-test differentiated the averages of the treatments for each day of the evaluation for independent samples (0.05 significance level).

RESULTS AND DISCUSSION

Evaluation of the control of wheat aphid

The association between the adjuvant 01 and the hollow cone nozzle, for both application rates, and the adjuvant 02 with the asymmetric twin flat fan nozzle (75 L ha^{-1}) improved efficiency in the control of the wheat aphid (Table 1).

The improvement of the control of the *S. graminum* in these treatments can be explained, mainly by the use of adjuvants, which can modify the spray properties and improve the quality of the droplets increasing the spray spread and adhesion on the leaf surface (Kissmann, 1998; Hilz and Vermeer, 2013; Preftakes et al., 2019). Such characteristics may accelerate the absorption of the phytosanitary product, reducing its exposure to degradation/loss factors, such as solar radiation, temperature, and rain. Those characteristics help achieved good efficiency of the insecticide even after five days of spraying, where good control performance on the *S. graminum* was still observed (Cunha and Alves, 2009; Preftakes et al., 2019).

Table 2 shows the effectiveness of control of *S. graminum* at 3, 5, 7 and 10 days after the application of the insecticide. At 3 days after spray application, it could be noted that there was a difference in the *S. graminum* population among the nozzle, adjuvants and application rates. According to the classification proposed by Henderson and Tilton (1955), the treatments that showed high efficiency (> 90%) during the evaluation period were those that contained adjuvants, with emphasis to the associations between the adjuvant 01 and the hollow cone nozzle, both application rates (75 and 150 L ha^{-1}) and the adjuvant 02 with the asymmetric twin flat fan nozzle, at the rate of 75 L ha^{-1}.

Therefore, better control of the *S. graminum* was observed in the associations between the adjuvant LESS and the hollow cone nozzle for both application rates (75 and 150 L ha^{-1}), and the adjuvant CPSDL with the asymmetric twin flat fan nozzle for 75 L ha^{-1} indicating that the reduction of spray volume in the imidacloprid application to *S. graminum* control is possible with no

Table 1. Effect of application technology on the population density of *Schizaphis graminum* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of the nozzle in two wheat fields, in the 2015/2016 harvest season.

Treatment	Average number of adults[1]									
	Before application		3 DAA		5 DAA		7 DAA		10 DAA	
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2
T.1	5.2±1.9[a]	6.2±4.1[a]	2.4±0.9[a]	2.6±1.1[b]	1.4±0.5[b]	1.2±1.3[b]	0.6±0.9[b]	0.4±0.9[b]	1.8±0.8[b]	2.2±0.8[b]
T.2	5.0±3.5[a]	6.0±4.1[a]	2.2±1.9[a]	2.0±2.1[b]	1.2±1.1[b]	1.2±1.3[b]	0.4±0.9[b]	0[c]	1.8±0.8[b]	2.0±0.7[b]
T.3	5.8±4.3[a]	6.8±2.2[a]	1.6±1.5[b]	0.6±0.9[c]	0.6±0.9[b]	0[c]	0[c]	0[c]	0[c]	0[c]
T.4	5.4±4.4[a]	6.4±3.9[a]	2.0±2.1[a]	2.0±1.0[b]	1.0±1.0[b]	0.6±0.9[b]	0.4±2.2[b]	0[c]	1.4±1.3[b]	1.2±0.8[b]
T.5	6.0±2.8[a]	7.0±3.6[a]	1.8±0.8[b]	0.6±0.9[c]	0.8±0.4[b]	0.2±0.4[b]	0[c]	0[c]	0[c]	0[c]
T.6	5.6±2.1[a]	6.6±6.0[a]	1.8±1.5[b]	1.4±1.9[b]	0.8±0.4[b]	0.6±0.5[b]	0.2±0.4[b]	0.2±0.4[b]	1.6±1.1[b]	1.4±0.5[b]
T.7	6.2±4.5[a]	7.2±5.4[a]	1.8±1.3[b]	0.6±0.9[c]	0.6±0.9[b]	0[c]	0[c]	0[c]	0[c]	0[c]
Control	4.8±2.2[1a2]	5.8±5.0[a]	5.0±2.2[a]	7.4±2.3[a]	6.0±1.9[a]	8.2±3.0[a]	8.2±2.5[a]	7.2±1.6[a]	9.2±1.5[a]	10.2±1.6[a]

[1]Averages followed by standard deviation. [2]Averages followed by different letters, in column, differ among treatments by Student's t test ($p < 0.05$). T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

Table 2. Efficacy of control of *Schizaphis graminum* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of the nozzle in two wheat fields, in the 2015/2016 harvest season.

Treatment	Percentage of control[1]							
	3 DAA		5 DAA		7 DAA		10 DAA	
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2
T.1	55.69	67.13	78.46	86.31	93.25	94.80	81.94	79.82
T.2	57.76	73.87	80.80	85.85	95.32	100	81.22	81.05
T.3	73.52	93.08	91.72	100	100	100	100	100
T.4	64.44	75.51	85.18	93.36	97.83	100	86.47	89.34
T.5	71.20	93.28	89.33	97.97	100	100	100	100
T.6	69.14	83.37	88.57	93.57	95.82	97.56	85.09	87.94
T.7	72.13	93.47	92.25	100	100	100	100	100

[1]Low efficacy = lower than 80%; good efficacy = from 80% to 90%; high efficacy = higher than 90%. T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

loss of effectiveness, but the presence of the adjuvant is important to assist this control.

Silva (1999b) studied the efficiency of insecticides without adjuvants on *S. graminum* in corn after applying with spray volumes of 150 or 300 L ha^{-1}, concluded that the largest volume was the most indicated for the efficient control of this pest. The author explains that, when using a hollow cone nozzle, the insecticides are less efficient than the applications with a flat fan nozzle. It is possible that these differences, in the case of the maize crop, are related to the great distance between the point of jet projection and the target, and that fine droplets (hollow cone) are more sensitive to change the trajectory.

Similarly, Cunha et al. (2006) attest that fine droplets are ideal, because, for the same spray volume, droplets of smaller diameter are better distributed on the leaf surface, and provide better coverage of the target and greater penetration into the plant canopy improving the control efficiency. However, as mentioned, very fine droplets are more prone to drift or evaporate and very coarse droplets have problems due to their tendency of outflow and less canopy coverage.

In most cases, there was no difference between the spray volumes tested, analyzing each nozzle and adjuvant in particular. This lack of differences indicates that it is possible to reduce the spray volume of the application without loss of efficiency of the imidacloprid insecticide. It is also important to highlight that the use of

Table 3. Toxicity of spray treatments on *Chrysoperla externa* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of the nozzle in two wheat fields, in the 2015/2016 harvest season.

Treatment	Percentage of toxicity[1]								Class[2]
	3 DAA		5 DAA		7 DAA		10 DAA		
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	
T.1	62.5	76.2	100	100	100	100	100	100	4
T.2	25.0	64.3	100	100	100	100	100	100	4
T.3	100	100	100	100	100	100	100	100	4
T.4	100	100	100	100	100	100	100	100	4
T.5	100	100	100	100	100	100	100	100	4
T.6	62.5	64.3	100	100	100	100	100	100	4
T.7	100	100	100	100	100	100	100	100	4

[1]Low efficacy = lower than 80%; good efficacy = from 80% to 90%; high efficacy = higher than 90%. [2]Class of toxicity from the fifth day after application of the spray treatments: class 1 = innocuous (T<30%), class 2 = slightly harmful (30%≤T≤80%), class 3 = moderately harmful (80%≤T≤99%) and class 4 = harmful (T>99%) (VEIRE et al., 2002). T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

adjuvants improved the quality of the application and maintain a good level of control, even with spray volume reduction (Preftakes et al., 2019).

These results corroborate with those found by Ferrari et al. (2014), who studied the insecticide to control bedbugs on soybean. They observed that the use of adjuvant resulted in the maintenance of the efficiency of control in a terrestrial application with a reduced rate (50 L ha^{-1}). To proceed with the reduction in the spray volume, it is very important to make the correct adjustment of the pressure and choice the nozzle that ensure good deposition on plant leaves, as well as consider environmental factors to reduce losses by drift (action of the wind) or drop extinction (evaporation) due to wrong height of the application boom, to low humidity and/or to high air temperature.

Toxic effects on natural enemies

The presence of two natural enemies, *C. externa* and *O. insidiosus*, was observed before the application of the treatments, and the percentage of toxicity was determined with the observation of natural enemies after the application of the treatments.

C. externa

The treatments with the presence of adjuvants, soon after 3 days from application, showed high toxicity to *C. externa*. In this way, according to the classification of the IOBC, the insecticide imidacloprid proved to be harmful to this species even 5 days after the insecticide application (Table 3), independent of the application technology employed, which compromised the ability of predation of the wheat aphid. The quantities of *C. externa* found in all treatments are presented in Table 4.

In a similar study, it was demonstrated that some neonicotinoids may have a greater capacity to penetrate the cuticle of insects, therefore being more toxic (Tomizawa and Casida, 2005). This fact can affect the development of organisms, as well as compromising the reproduction of subsequent generations, which can be considered as a sublethal effect. Carvalho et al. (2010) obtained results that corroborate those presented in this study, observing differences between the treatments in relation to the survival probability of *C. externa* where imidacloprid resulted in the survival of only 22.7%, which suggests high toxicity of this product to adults of this species. Similar results were obtained by Bueno and Freitas (2003), which found that imidacloprid caused 100% mortality of the first instar larvae of *C. externa*.

Rocha (2008) studied the selectivity of imidacloprid (0.7 g L^{-1} of a.i.) and thiamethoxam (0.5 g L^{-1} of a.i.) at different stages of the biological cycle of *C. externa*, collected in coffee plantation, reported that these compounds caused 100% mortality of larvae of second instar nymphs and adults, making it impossible to carry out assessments of the fertility and viability of eggs. The author also noted that thiamethoxam, imidacloprid, mineral oil, endosulfan, and dimethoate, when applied directly on pupae of *C. externa*, did not affect its cycle, with an average duration of this stage varying from 10.3 to 10.9 days.

The effect on the mortality of predators observed in treatments with imidacloprid may be related to the neurotoxic action, even in low doses (Ware and Whitacre, 2004; Lämsä et al., 2018). These compounds can affect various groups of insects, including natural enemies,

Table 4. Effect of application technology on the population density of *Chrysoperla externa* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of the nozzle in two wheat fields, in the 2015/2016 harvest season.

Treatment	Average number of adults[1]									
	Before application		3 DAA		5 DAA		7 DAA		10 DAA	
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2
T.1	0.4±0.5[a]	0.6±0.9[a]	0.2±0.4[a]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.2	0.2±0.4[a]	0.4±0.5[a]	0.2±0.4[b]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.3	0.4±0.5[a]	0.4±0.5[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.4	0.4±0.5[a]	0.2±0.4[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.5	0.2±0.4[a]	0.6±0.9[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.6	0.4±0.5[a]	0.4±0.5[a]	0.2±0.4[b]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.7	0.4±0.5[a]	0.6±0.9[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Control	0.6±0.5[1a2]	1.0±0.7[a]	0.8±1.1[a]	1.4±0.5[a]	1.6±1.8[a]	2.2±1.3[a]	2.0±1.9[a]	3.0±0.7[a]	2.8±1.6[a]	3.6±0.5[a]

[1]Averages followed by standard deviation. [2]Averages followed by different letters, in column, differ among treatments by Student's t test ($p < 0.05$). T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

Table 5. Toxicity of spray treatments on *Orius insidiosus* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of nozzle in two wheat fields, in the 2015/2016 harvest season.

Treatment	Percentage of toxicity - (T%)[1]								Class[2]
	3 DAA		5 DAA		7 DAA		10 DAA		
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	
T.1	50.0	40.00	100	100	100	100	100	100	4
T.2	66.7	40.00	100	100	100	100	100	100	4
T.3	100	100	100	100	100	100	100	100	4
T.4	100	100	100	100	100	100	100	100	4
T.5	100	100	100	100	100	100	100	100	4
T.6	50.0	70.00	100	100	100	100	100	100	4
T.7	100	100	100	100	100	100	100	100	4

[1]Low efficacy = lower than 80%; good efficacy = from 80% to 90%; high efficacy = higher than 90%. [2]Class of toxicity from the fifth day after application of the spray treatments: class 1 = innocuous ($T<30\%$), class 2 = slightly harmful ($30\%\leq T\leq 80\%$), class 3 = moderately harmful ($80\%\leq T\leq 99\%$) and class 4 = harmful ($T>99\%$) (VEIRE et al., 2002). T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

significantly reducing insect survival (Torres and Ruberson, 2004; Wood and Goulson, 2017).

O. insidiosus

The data presented in Tables 5 and 6 relate to the toxicity and survival of *O. insidiosus*, and resemble those found for *C. externa*. Again, the treatments with the presence of adjuvants, soon after 3 days from application, showed high toxicity to *O. insidiosus*. The insecticide imidacloprid demonstrated, once again, to be toxic to natural enemies studied even 5 days after the insecticide application, regardless of the technology used, impairing their ability to predation of aphids. The quantities of *O. insidiosus* found in all treatments are presented in Table 6.

These results confirm those obtained by other researchers with other species of the genus *Orius*. Delbeke et al. (1997) verified under laboratory conditions, that the 5th instar nymphs of *Orius laevigatus* (Fieber, 1860) (Hemiptera: Anthocoridae), in contact with residues of the insecticide imidacloprid (0.04 mg a.i. L^{-1}) presented 50% of mortality. The high toxicity of insecticides was also observed by Morais et al. (2003), who reported that abamectin, fenpropathrin, and imidacloprid did not allow the survival of adults of *O. insidiosus*. On the other hand, cartap and cyromazine did not affect insect survival significantly. Although such products have been classified

Table 6. Effect of application technology on the population density of *Orius insidiosus* at 3, 5, 7 and 10 days after application (DAA) of imidacloprid, associated or not with adjuvants and types of the nozzle in two wheat fields, in the 2015/16 harvest season.

Treatment	Average number of adults[1]									
	Before application		03 DAA		05 DAA		07 DAA		10 DAA	
	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2	Fd-1	Fd-2
T.1	0.2±0.4[a]	0.2±0.4[a]	0.2±0.4[b]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.2	0.6±1.3[a]	0.2±0.4[a]	0.4±0.9[a]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.3	0.2±0.4[a]	0.2±0.4[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.4	0.2±0.4[a]	0.2±0.4[a]	0.2±0.4[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.5	0.2±0.4[a]	0.2±0.4[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.6	0.2±0.4[a]	0.4±0.9[a]	0.2±0.4[b]	0.2±0.4[a]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
T.7	0.4±0.5[a]	0.2±0.4[a]	0[c]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Control	0.2±0.4[1a2]	0.6±0.9[a]	0.4±0.9[a]	1.0±1.0[a]	1.2±0.8[a]	1.2±0.8[a]	1.6±0.9[a]	1.6±0.9[a]	1.2±0.8[a]	1.4±0.9[a]

[1]Averages followed by standard deviation. [2]Averages followed by different letters, in column, differ among treatments by Student's t test ($p < 0.05$). T.1 = nozzle AS 7030, 75 L ha^{-1}, no adjuvant; T.2 = nozzle MGA 015, 75 L ha^{-1}, no adjuvant; T.3 = nozzle MGA 015, 75 L ha^{-1}, adjuvant 01; T.4 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 01; T.5 = nozzle AS 7030, 75 L ha^{-1}, adjuvant 02; T.6 = nozzle MGA 030, 150 L ha^{-1}, no adjuvant; T.7 = nozzle MGA 03, 150 L ha^{-1}, adjuvant 01. Adjuvant 01: lauryl ether sodium sulfate (LESS). Adjuvant 02: copolymer of polyester, silicone and d-limonene (CPSDL). Fd-1 = Field-1; Fd-2 = Field-2.

in class 4 (harmful), it was possible to observe that abamectin caused a delayed effect, in comparison to the insecticides fenpropathrin and imidacloprid, while the first killed 36.7% of the population was evaluated until 30 days after treatment, the other two caused in the same period, 100% mortality.

Similar results were obtained by Lee et al. (1997) with fenpropathrin, which was sprayed on adults of *Orius sauteri* (Poppius, 1909) (Hemiptera: Anthocoridae) and found no survivors. The harmful effects of imidacloprid were also similar to those observed by Shipp et al. (1992), by confined adults of *O. insidiosus* in cages with leaves of cucumber previously treated and no survivors were identified.

The results found here with imidacloprid approached those found by Elzen (2001), who provided eggs of *Helicoverpa zea* (Boddie, 1850) (Lepidoptera: Noctuidae) previously treated with this insecticide to males and females of *O. insidiosus*, and observed a reduction in the survival of this predator, averaging 52.2 and 37.3% reduction, respectively. Nemoto (1995) aimed at the control of pests of eggplant in field conditions, found that throughout five sprayings of imidacloprid, there was a significant reduction in the density of *O. sauteri* and *Orius minutus* (L., 1758) (Hemiptera: Anthocoridae).

It has been observed, again, that the treatments with adjuvant caused higher toxicity to the natural enemy found in this study. According to Cunha and Alves (2009), the adjuvants, when used properly, can improve the interaction of the insecticide with water and fix some of their characteristics, with positive impacts on the efficiency of insect control targets and not targets (e.g. bees, spiders, and natural enemies).

The adjuvant 2 presents, in its composition the essential oil D-limonene, a terpene monocyclic substance that presents activity against insects, mites, and microorganisms (Hollingsworth, 2005; Hikal et al., 2017). The interest in the use of monoterpenes to control pests is based on the need for insecticides that are less harmful to the environment and which do not have negative impacts on human health, when compared with conventional chemical treatments, with low toxicity to humans, has important commercial appeal and has been appointed as an alternative to synthetic insecticides (Ibrahim et al., 2001; Regnault-Roger et al., 2012).

Therefore, imidacloprid associated with any of the adjuvants tested is harmful to the natural enemies: *C. externa* and *O. insidiosus*, even on the fifth day after application, regardless of the technology employed. It is necessary to find other combinations of insecticides and adjuvants to control the *S. graminum* without compromising the natural enemies.

Imidacloprid constitutes an example of a product from the new generation of insecticides belonging to the group of neonicotinoids, which are compounds that act as agonists of nicotinic receptors of acetylcholine (Ware and Whitacre, 2004; Regnault-Roger et al., 2012) and feature high toxicity to insects and selectivity to man. In the present study, this effect was evident in all treatments, also demonstrating its detrimental effect on natural enemies of the *S. graminum*, *C. externa* and *O. insidiosus* under field conditions. Thus, more studies are necessary to find other options of chemical control, including the adjuvants, to control the *S. graminum* without compromising the natural enemies that are very important to the integrated pest management.

Conclusion

Improved *S. graminum* control was observed in the association between the adjuvant lauryl ether sodium sulfate and the hollow cone nozzle for both application rates (75 and 150 L ha^{-1}) and between the adjuvant copolymer of polyester+silicone+d-limonene and asymmetric twin flat nozzle at low spray rate (75 L ha^{-1}).

The reduction of insecticide spray volume to *S. graminum* control is possible with no loss of effectiveness, improving the efficiency of the process of insecticide application.

The application of this insecticide associated with any one of the adjuvants tested is harmful to *C. externa* and *O. insidiosus*, even on the fifth day after imidacloprid application regardless of the technology employed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Ali S, Akbar MF, Sultan A, Saleem MS (2018). An ecofriendly approach to control wheat aphid (*Schizaphis graminum* (Rondani) by using biorational insecticides as seed treatment and foliar applications. Pakistan Entomologist 40(2):77-84.

Antuniassi UR (2014). Avaliação da cobertura de folhas de soja em aplicações terrestres com diferentes tipos de pontas. In: Simpósio Internacional de Tecnologia de Aplicação de Agrotóxicos, v.3. Botucatu, Anais, Botucatu: FEPAF, pp. 48-51.

Blackman RL, Eastop VF (2000). Aphids on the world's crops: An identfication and information guide. John Wiley & Sons, West Sussex, England.

Bueno AF, Freitas S (2003). Efeito do hexythiazox e imidaclopride sobre ovos larvas e adultos de *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae). Ecossistema 26(1):74-77.

Carvalho GA, Godoy MS, Carvalho BF, Lasmar O (2010). Seletividade fisiológica de inseticidas em duas espécies de crisopídeos. Pesquisa Agropecuária Brasileira 45:1253-1258.

Cunha GR, Caierão E, Rosa AC (2016). Informações técnicas para trigo e triticale - Safra 2016. In: 9ª Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale. Passo Fundo, RS. Embrapa.

Cunha JPAR da, Alves GS (2009). Características físico-químicas de soluções aquosas com adjuvantes de uso agrícola. Interciencia 34(9):655-659.

Cunha JPAR da, Reis EF dos, Santos RO (2006). Controle químico da ferrugem asiática da soja em função de ponta de pulverização e de volume de calda. Ciência Rural 36(5):1360-1366.

Delbeke F, Vercruysse P, Tirry L, Clercq P, Degheele D, De-Clercq P (1997). Toxicity of diflubenzuron, pyroproxyfen, imidacloprido and diafenthiuron to the predatory bug *Orius laevigatus* (Hemiptera: Anthocoridae). Entomophaga 42(3):349-358.

Dicks L (2013). Bees, lies and evidence-based policy. Nature 494:283.

Elzen GW (2001). Lethal effects of insecticide residues on *Orius insidiosus* (Hemiptera: Anthocoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). Journal of Economic Entomology 91(1):55-59.

Ferrari F, Roggia S, Felix LF (2014). Efeito do volume de calda adjuvante e horário de aplicação sobre a eficiência de controle percevejos da soja. In: Jornada Acadêmica da Embrapa Soja, 9, 2014, Londrina. Resumos expandidos.. Embrapa Soja, p. 111-118.

Fijian Government (2019). Paraquat and imidacloprid pesticide banned from 1st jan 2020. Assessed: 12 Dec 2019. Available at: https://www.fiji.gov.fj/Media-Centre/News/paraquat-and-imidacloprid-pesticide-banned-from-1s.

Gassen DN (1984). Insetos associados à cultura do trigo no Brasil.Passo Fundo: EMBRAPA/CNPT, (Circular Técnica).

Gibbons D, Morrissey C, Mineau P (2015). A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Environmental Science and Pollution Research 22:103-118.

Hassan SA, Degrande PE (1996). Methods to test the side effects of pesticides on *Trichogramma*. In: Parra JRP, Zuchi RA (eds.). Curso de controle biológico com Trichogramma. Piracicaba, FEALQ, pp. 63-74.

Henderson CF, Tilton EW (1955). Tests with acaricides against the brown wheat mite. Journal Economic Entomology 48(2):157-161.

Hikal WM, Baeshen RS, Ahl HAH (2017). Botanical insecticide as simple extractives for pest control. Cogent Biology 3:1404274.

Hilz E, Vermeer AWP (2013). Spray drift review the extent to which a formulation can contribute to spray drift reduction. Crop Protection 44:75-83.

Hollingsworth RG (2005). Limonene, a citrus extract, for control of mealybugs and scale insects. Journal of Economic Entomology 98(3):772-779.

Ibrahim MA, Pirjo K, Aflatuni A, Tiilikkala K, Holopainen JK (2001). Insectidal, repellent, antimicrobial activity and phytotoxicity of essential oils with special reference to limonene and its suitability for control of insect pests. Agricultural and Food Science in Finland 10:243-259.

Kang Z-W, Liu F-H, Pang R-P, Tian H-G, Liu T-X (2018). Effect of sublethal doses of imidacloprid on the biological performance of aphid endoparasitoid *Aphidius gifuensis* (Hymenoptera: Aphidiidae) and influence on its related gene expression. Frontiers in Physiology 9:1729.

Kindler SD, Elliott NC, Giles KL, Royer TA, Fuentes-Granados R, Tao F (2002). Effect of greenbugs (Homoptera: Aphididae) on yield loss of winter wheat. Journal of Economic Entomology 95:89-95.

Kissmann KG (1998). Adjuvantes para caldas de produtos fitossanitários. In: Guedes JVC, Dornelles SHB (Eds.). Tecnologia e segurança na aplicação de agrotóxicos. Santa Maria: Departamento de Defesa Fitossanitária, Sociedade de Agronomia de Santa Maria, p. 39-51.

Lämsä J, Kuusela E, Tuomi J, Juntunen S, Watts PC (2018). Low dose of neonicotinoid insecticide reduces foraging motivation of bumblebees. Proceedings of the Royal Society B 285:20180506.

Lee GH, Choi MY, Kim DH (1997). Effects of pesticides on predator *Orius sauteri* Poppius (Hemiptera: Anthocoridae). Journal of Crop Protection 39(2):61-66.

Matthews GA, Bateman R, Miller P (2014). Pesticide application methods. 4th Edition Wiley, Chichester, UK. 517p.

Matuo T, Nakamura SH, Almeida A (1989). Efeito de alguns adjuvantes da pulverização nas propriedades físicas do líquido. Summa Phytopathologica 15(2):163-173.

Morais AA, Carvalho GA, Moraes JC, Godoy MS, Cosme LV (2003). Avaliação de seletividade de produtos fitossanitários utilizados na cultura do crisântemo a adultos de Orius insidiosus (Say, 1832) (Hemiptera: Anthocoridae) em laboratório. Ciência e Agrotecnologia, 27(5):971-977. https://doi.org/10.1590/S1413-70542003000500001

Mohammed AAAH, Desneux N, Fan Y, Han P, Ali A, Song D, Gao X-W (2018). Impact of imidacloprid and natural enemies on cereal aphids: integration or ecosystem service disruption? Entomologia Generalis 37:47-61.

Nemoto H (1995). Pest management systems for eggplant arthropods: a plan to control pest resurgence resulting from the destruction of natural enemies. Journal Agricultural Research Quartely 29(1):25-29.

Parra JRP, Botelho PSM, Correa-Ferreira BS, Bento JMS (2002). Controle biológico no Brasil: parasitóides e predadores. Editora Manole, São Paulo.

Preftakes CJ, Schleier JJ, Kruger GR, Weaver DK, Peterson RK (2019). Effect of insecticide formulation and adjuvant combination on agricultural spray drift. Peer Journal 7:e7136.

Recomendações da Comissão Sul-Brasileira de Pesquisa de Trigo (2000). In: Anais, XXXII Reunião da Comissão Sul-Brasileira de Pesquisa de Trigo. Cruz Alta. 90 p.

Regnault-Roger C, Vincent C, Arnason T (2012). Essential oils in insect control: low-risk products in a high-stakes world. Annual Review of Entomology 57:405-424.

Rocha LCD (2008). Seletividade fisiológica de inseticidas utilizados em cultura cafeeira sobre os predadores *Chrysoperla externa* (Hagen, 1861) (Neuroptera: Chrysopidae) e *Cryptolaemus montrouzieri* Mulsant, 1853 (Coleoptera: Coccinellidae). 133 p. (PhD Thesis) - Universidade Federal de Lavras, Brazil.

Royer TA, Pendleton BB, Elliott NC, Giles KL (2015). Greenbug (Hemiptera: Aphididae) biology, ecology, and management in wheat and sorghum. Journal of Integrated Pest Management 6(1):19.

Salvadori JR, Salles LAB (2002). Controle biológico dos pulgões do trigo. In: Parra JRP, Botelho PSM, Ferreira BSC, Bento JMS (eds.) Controle biológico no Brasil: parasitóides e predadores. São Paulo: Manole, pp. 427-447.

Salvadori JR, Tonet GEL (2001). Manejo integrado dos pulgões de trigo. Passo Fundo: EMBRAPA/CNPT, (Circular Técnica).

Salvadori JR (1999). Controle biológico de pulgões de trigo: o sucesso que perdura. Revista Plantio Direto 46:25-31.

Shipp JL, Zariffa N, Ferguson G (1992). Spatial patterns of and sampling methods for *Orius* spp. (Hemiptera: Anthocoridae) on greenhouse sweet pepper. Canadian Entomologist 124(5):887-894.

Silva DB da, Guerra AF, Rein TA, Anjos J de RN dos, Alves RT, Rodrigues GC, Silva IAC (1996). *Trigo para o abastecimento familiar: do plantio à mesa*. Embrapa-SPI Brasília, Embrapa-CPAC Planaltuba.

Silva OC (1999a). Tecnologia de aplicação de fungicadas. In: Canteri MG, Pria MD, Silva OC (eds.). Principais doenças fúngicas do feijoeiro. UEPG Ponta Grossa, pp. 127-137.

Silva MTB (1999b). Fatores que afetam a eficiência de inseticidas sobre *Schizaphis graminum* em milho. Ciência Rural 29(3):383-387.

Singh R, Singh GS (2017). Traditional agriculture: a climate-smart approach for sustainable food production. Energy, Ecology and Environment 2(5):296-316.

Tomizawa M, Casida JE (2005). Neonicotinoid insecticide toxicology: mechanisms of selective action. Annual Review Pharmacology Toxicology 45:247-248.

Torres JB, Ruberson JR (2004). Toxicity of thiamethoxam and imidacloprido to *Podisus nigrispinus* (Dallas) (Heteroptera: Pentatomidae) nymphs associated to aphid and whitefly control in cotton. Neotropical Entomology 33(1):099-106.

Valavanidis A (2018). Neonicotinoid insecticides. Banned by the European Union in 2018 after scientific studies concluded that harm honey bees. Scientific Reviews. Available at: http://chem-tox-ecotox.org/?s=Neonicotinoid+insecticides.

Van-Emden HF, Harrington R (2007). Aphids as crop pests. CABI, USA, 752 p.

Veire Van de, Sterk G, Staaij M Van de, Ramakers PMJ, Tirry L (2002). Sequential testing scheme for the assessment of the side-effects of plant protection products on the predatory bug *Orius laevigatus*. BioControl 47(1):101-113.

Ware GW, Whitacre DM (2004). *An introduction to insecticides*. 4rd ed. Tucson, Arizona. Accessed in: 10 Jul 2017. Available at: <http://ipmworld.umn.edu/chapters/ware.htm>

Whitehorn PR, O'Connor S, Wackers FL, Goulson D (2012). Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science 336:351-352.

Wood TJ, Goulson D (2017). The environmental risks of neonicotinoid pesticides: a review of the evidence post 2013. Environmental Science and Pollution Research International 24(21):17285-17325.

Zhang Y, Min Q, Li H, He L, Zhang C, Yang L (2017). A conservation approach of globally important agricultural heritage systems (GIAHS): improving traditional agricultural patterns and promoting scale-production. Sustainability 9(2):295.