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Fighting off the sucking pests of soybean: managing stink bugs and whiteflies

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Abstract

Stink bugs and whiteflies are major concerns for pest management in Brazilian soybean fields, causing severe economic losses to soybean growers and leading to excessive insecticide applications per crop cycle. Despite biological differences, these two sap-sucking pests often co-occur in soybean fields and can be successfully managed with the same insecticide spray, reducing operational costs to the growers. The aim of this work was to evaluate the efficacy of eleven insecticides in the control of stink bugs and whiteflies. Two insecticide sprays were made with an interval of 14 days between them. The results from ANOVA and Tukey post-hoc test ($P \leq 0.05$) revealed significant differences among treatments. Acetamiprid + bifenthrin (75 + 75 g a.i. ha^{-1}) was the most efficient treatment for the control of stink bugs, reaching 97.8% of insect mortality. Cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) was the most efficient treatment for the control of whiteflies, reaching 78.8% of insect mortality. This treatment also presented the highest combined control of stink bugs and whiteflies, reaching 83.5% of insect mortality.

Keywords: *Bemisia tabaci*; control efficacy; *Euschistus heros*; *Glycine max*; pest management.

Introduction

Sap-sucking pests are a major concern for pest management in soybean fields in Brazil. Stink bugs (Hemiptera: Pentatomidae) and whiteflies (Hemiptera: Aleyrodidae) stand out in economic importance. Expansion of land area grown with soybeans and abusive use of non-selective insecticides (Vieira et al., 2012) have enabled these insects to become increasingly dispersed and difficult to control, causing severe economic losses to soybean growers throughout the country (Marques et al., 2019; Arnemann et al., 2019).

The neotropical brown stink bug (*Euchistus heros* [F.]) and the green-belly stink bug (*Diceraeus furcatus* [F.]) are the main stink bug species found in Brazilian soybean fields, but the red-banded stink bug (*Piezodorus guildinii* [Westwood]) and the southern green stink bug (*Nezara viridula* [L.]) are also common (Guedes et al., 2016). These insects feed on soybean pods, leading to smaller seeds and reduced yield (Corrêa-Ferreira et al., 2009). Neonicotinoid, organophosphate and pyrethroid insecticides are the main control strategy for these pests in Brazil, often combined to enhance control efficacy (Sosa-Gómez and Omoto, 2012; Marques et al., 2019). Nonetheless, control failures of *E. heros* have been reported in Brazil (Sosa-Gómez and Silva, 2010; Tuelher et al., 2017), with field populations becoming increasingly less susceptible to pyrethroids (Somavilla et al., 2020). Brazilian soybean growers currently use two to four foliar insecticide sprays to manage stink bugs (Bueno et al., 2015).

The whitefly (*Bemisia tabaci* [Gennadius]) can injury soybeans throughout its whole cycle (Lima et al., 2002). Currently, over 38 cryptic species are recognised within the *B. tabaci* species complex (Elfekih et al., 2021), many of which were previously referred to as biotypes due to being morphologically indistinguishable (de Barro et al., 2011). The MEAM1 species ('Middle-East Asia Minor 1', previously known as 'B-biotype') predominates in Brazilian soybean fields (de Moraes et al., 2018), but the MED species ('Mediterranean', previously known as 'Q-biotype') has been recently detected in the country as well. Although more common in greenhouse crops, the MED species transmits the cowpea mild mottle virus (CPMMV; carlavirus) more efficiently (Bello et al., 2021) and has evolved resistance to novel insecticides more rapidly than MEAM1 (McKenzie et al., 2012; Pozebon et al., 2020).

Whiteflies damage soybean plants both directly (due to sap sucking and toxin injection) and indirectly (acting as vector for viruses and precursor for the growth of sooty mold fungi) (Hirose et al., 2015). When left unmanaged, whiteflies can result in yield losses as high as 31 kg ha^{-1} for a population density of one whitefly $trifoliate^{-1}$ (Padilha et al., 2021). Although whitefly adults are easily controlled, the nymphs remain sheltered in the middle and lower segments of the soybean canopy, preventing direct contact with insecticides. This allows population growth shortly after foliar insecticide applications (Pozebon et al., 2019), requiring up to six insecticide sprays to halt whitefly infestation (Petroli, 2017).

Control failures and lack of updated information regarding the management of sap-sucking pests have led Brazilian soybean growers to raise excessively the number of insecticide sprays per crop cycle, increasing control costs and compromising the long-term sustainability of this management strategy (Arnemann et al., 2019; Pozebon et al., 2020; Somavilla et al., 2020). We evaluated the efficacy of chemical insecticides in the control of stink bugs and whiteflies in two crop seasons. Our results will help farmers to establish the most efficient strategy for the management of sap-sucking pests when populations reach the economic threshold levels.

Results and Discussion

First cropping season (2019/20)

Stink bug control

The population of stink bugs infesting the soybean plants in the first cropping season was composed of *E. heros* (71 %), *P. guildinii* (20 %), *N. viridula* (8 %) and other species (1 %). The treatments were sprayed at a population density of 4.4 stink bugs m^{-2}. Adults and nymphs were evaluated as a single variable.

All treatments where the combination of cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) or cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) were used in the first spray presented stink bug mortality (adults + nymphs) >90 % at 3 days after the first spray (DA1S), and maintained satisfactory control efficacy (> 80 %) until 14 days (Table 1). With the exception of acetamiprid + pyriproxyfen (20 + 40 g a.i. ha^{-1}) and sulfoxaflor + lambda-cyhalothrin (30 + 45 g a.i. ha^{-1}), all treatments kept the population density below two stink bugs m^{-2} until 14 DA1S, which is considered the control threshold for stink bugs in soybeans (Corrêa-Ferreira and Panizzi, 1999).

Control efficacy for stink bugs at 3 days after the second spray (DA2S) was >80 % in all treatments, with the exception of acetamiprid + pyriproxyfen (20 + 40 g a.i. ha^{-1}), which controlled only 50 % of the infesting population (Table 1). This lack of knockdown effect is probably related to the absence of a pyrethroid given that they are extremely fast-acting insecticides (Salgado, 2013).

Two sprays of cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) and two sprays of acetamiprid + bifenthrin (75 + 75 g a.i. ha^{-1}) reduced the infesting population to zero stink bugs m^{-2} at 3 DA2S, maintaining 100% of control efficacy until 14 DA2S. Acetamiprid + bifenthrin (two sprays) presented the highest level of stink bug mortality across all evaluations (97.8 %). All treatments containing cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) or cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) in the first spray also presented high control efficacy for stink bugs (near 90 % or higher; see Table 1). Cyantraniliprole is a second-generation anthranilic diamide (ryanodine receptor modulator) that offers cross-spectrum foliar and systemic activity against chewing and sucking insects (Salgado, 2013). However, its use in Brazil is still limited by its high costs (Benevia®; US$ 90.00 ha^{-1} on average; Arnemann et al., 2019).

The highest control efficacies considering all treatments were obtained at 14 DA2S, when six treatments reduced the infesting population to zero stink bugs m^{-2}. Similar results were observed by Marques et al. (2019), with 84.8 % mortality after two sprays of lambda-cyhalothrin + thiamethoxam (35.25 + 26.5 g a.i. ha^{-1}). The same treatment provided 86.5 % of control efficacy in our study (Table 1) and is cheaper (US$ 10.00 ha^{-1} on average) than products containing cyantraniliprole, for instance. Thiamethoxam is a highly systemic neonicotinoid whose absorption by plants peaks around 72 h after the application (Gazzoni, 2008), providing high mobility within soybean plants and long residual activity (Cui et al., 2010), whereas lambda-cyhalothrin presents faster knockdown effect when compared to other pyrethroids (Marques et al., 2019).

Whitefly control

Whitefly population in the first cropping season averaged 2.6 adults $trifoliate^{-1}$ and 8.0 nymphs $trifoliate^{-1}$ at the moment of the first spray (Table 2). Adults and nymphs were evaluated as separate variables and presented susceptibility to different active ingredients.

Significant differences among the treatments were observed for whitefly adults. Sulfoxaflor + lambda-cyhalothrin (two sprays) presented the lowest control efficacy (average 72.3 %), and the highest infesting population (average 3.4 adults $trifoliate^{-1}$) among the insecticide treatments. Cyantraniliprole + bifenthrin (two sprays) presented the highest control percentage (90.8 %) with populations below 1.0 adult $trifoliate^{-1}$ at all evaluations (Table 2).

None of the treatments reached 60 % of control efficacy at 14 DA1S for whitefly nymphs, with the infesting populations increasing rather than decreasing in several treatments (Table 2). Control levels increased only at 10 DA2S, when all treatments surpassed 70 % of nymph mortality. Average control efficacy across all evaluations was <70 %. Cyantraniliprole + bifenthrin+ carbosulfan (two sprays) provided 66.7 % of insect mortality and reduced whitefly population to less than 1.0 nymph $trifoliate^{-1}$, which is considered the control threshold for whiteflies in soybean (Padilha et al., 2021). Arnemann et al. (2019) also pointed out cyantraniliprole an efficient tool for whitefly control. Nymph mortality for treatments containing cyantraniliprole + bifenthrin increased when carbosulfan was added to the first spray (see the evaluation at 14 DA2S in Table 2).

Overall, all treatments presented higher control efficacy for whitefly adults than whitefly nymphs. The reason for this discrepancy lies in the feeding behaviour of both life stages. Whitefly nymphs are commonly found in the middle and lower segments of the soybean plants, in the underside of the leaflets (Czepak et al., 2018; Pozebon et al., 2019), while adults feed and oviposit in the upper (i.e. younger) leaves of soybean plants, remaining more exposed to direct contact with insecticide sprays. Thus, adults can be easily controlled by sequential sprays of fast-acting pyrethroids, whereas the control of nymphs relies on the long residual action and plant systemicity of neonicotinoids (Stamm et al., 2016, Arnemann et al., 2019).

Combined control

For the growing conditions of the first cropping season (2019/20), the highest combined control of stink bugs and whiteflies (adults + nymphs) was provided by two sprays of cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}), with an average of 83.2 % of insect mortality. Two sprays of cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}), one spray of cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) followed by one spray of bifenthrin + carbosulfan (30 + 90 g a.i. ha^{-1}), and two sprays of acetamiprid + bifenthrin (75 + 75 g a.i. ha^{-1}) also reached 80 % of average control efficacy for stink bugs and whiteflies. The lowest combined control was provided by two sprays of sulfoxaflor + lambda-cyhalothrin (30 + 45 g a.i. ha^{-1}; average 58.9 %).

The three treatments containing cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) in the first spray presented the highest yields, differing significantly from the others (Supplementary Table 4). The untreated control presented yield reduction of 326.7 kg ha^{-1} due to damage by stink bugs and whiteflies, when compared to the highest-yielding treatment (two sprays of cyantraniliprole + bifenthrin + carbosulfan). Although not reaching 80 % of control efficacy, two sprays of thiamethoxam + lambda-cyhalothrin (35.25 + 26.5 g a.i. ha^{-1}) resulted in yield similar to the treatments with highest insect mortality. This might be related to the bioestimulation properties of thiametoxam, as described by Gazzoni (2008).

Second cropping season (2020/21)

The population of whiteflies in the second cropping season reached the same control level of the first cropping season (≥10 whiteflies $trifoliate^{-1}$) before stink bugs could naturally infest the experimental plots. Insecticide sprays maintained stink bug infestation negligible, and it was not quantified in the second cropping season. The insecticide treatments were first sprayed when whitefly populations reached 4.4 adults and 6.4 nymphs $trifoliate^{-1}$, respectively (Supplementary Table 2).

Similarly to the first cropping season, all treatments presented control efficacy of whitefly adults near or higher than 80 % (Supplementary Table 2). When considering all evaluations, only cyantraniliprole + bifenthrin + carbosulfan (followed by one spray of cyantraniliprole) presented <80 % of average adult mortality, differing significantly from the other treatments ($P \leq 0.05$). Two sprays of thiamethoxam + lambda-cyhalothrin (35.2 + 26.5 g a.i. ha^{-1}) resulted in the highest mean of control efficacy for whitefly adults (90.2 %).

The overall mortality of whitefly nymphs in the second cropping season (2020/21) was lower than observed for adults, although higher than observed for nymphs in the first cropping season (2019/20). Suitable climatic conditions for this pest during the 2020/21 summer season (i.e. low air humidity and high mean temperatures; Sharma et al., 2013), allowed whitefly populations to grow as high as 49.3 nymphs $trifoliate^{-1}$ in the untreated control (Supplementary Table 2 at 10 DA2S). All insecticide treatments kept nymph population <3.0 nymphs $trifoliate^{-1}$ at 10 DA2S, surpassing 95 % of control efficacy. The highest mean of control efficacy for whitefly nymphs considering all evaluations was provided by two sprays of cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}; average 79.3 %).

As observed in the first cropping season (2019/20), the treatments containing cyantraniliprole were among the most efficient in controlling whitefly nymphs. The satisfactory performance of this active ingredient is probably related to its physicochemical characteristics, such as low Log Pow and high solubility in water (Barry et al., 2014), providing great mobility within soybean plants (Pes et al., 2020). Cyantraniliprole presents upward translocation through xylem tissues when applied via seed treatment or in the soil (Selby et al., 2016) and translaminar and acropetal movements when applied as a foliar spray (Barry et al., 2014). This mobility within the plant may reach whitefly nymphs located in the underside of soybean leaves. While few treatments presented satisfactory control of whitefly nymphs after the first spray, all reached 90 % of insect mortality at 10 DA2S. Sequential sprays are particularly important for the performance of pyrethroids, which rely on fast knockdown effect and provide little to none residual action (Salgado, 2013). The untreated control presented yield reduction of 1281.7 kg ha^{-1} when compared with the highest-yielding treatment (one spray of cyantraniliprole + bifenthrin, followed by one spray of bifenthrin). This substantial yield loss is related to the high pressure of whiteflies in the second cropping season (reaching 20.5 adults $trifoliate^{-1}$ and 49.3 nymphs $trifoliate^{-1}$ in the untreated plots; Supplementary Table 2) and the high potential to cause damage in soybeans (31 kg ha^{-1} of yield reduction for a population density of one whitefly $trifoliate^{-1}$; Padilha et al., 2021).

Two-seasons analysis

The variations observed in the infestation levels of stink bugs and whiteflies between the two cropping seasons offered a chance to evaluate the performance of the same insecticide treatments under two distinct field conditions: high pressure of stink bugs with moderate presence of whiteflies in the first season (2019/20), and high pressure of whiteflies with absence of stink bugs in the second season (2020/21). The population growth of whiteflies in the untreated control plot illustrates this difference in pressure between the two seasons (see Table 2 and Supplementary Table 2). The absence of stink bugs in the second cropping season might be linked to a late migration of the first colonizing insects into the soybean plots, when compared to the previous season; thus, when the insecticide treatments were applied to control the already established whitefly population, the first stink bug settlers were also suppressed, indirectly preventing the establishment of the infesting population. The results from the first season support this hypothesis, as all treatments provided stink bug mortality >80 %. The only exception (two sprays of acetamiprid + pyriproxyfen 20 + 40 g a.i. ha^{-1}) includes the active ingredient pyriproxifen in its composition, which knowingly controls whiteflies but has little effect upon stink bugs and other pests (Salgado, 2013). This juveline hormone mimic provides an antimetamorphic effect, preventing the insect to reach its adult stage; as such, it does not control adult insects or early stages, requiring a precise spray timing to reach satisfactory control efficacy.

Considering the averages between the two seasons, all insecticide treatments provided mortality of adult whiteflies ≥80 %, whereas nymph mortality did not reach 70 % (Supplementary Table 3 and Figure 1). This outcome reinforces the conclusion that whiteflies nymphs are much harder to control than adults. Aside from the treatments containing cyantraniliprole, the only treatment to reach 60 % or more of average nymph mortality was thiamethoxam + lambda-cyhalothrin (two sprays). When stink bugs and whiteflies were analysed together as a single variable, all treatments presented control efficacy equal or higher than 70 % in the average between the two seasons (Supplementary Table 3). Cyantraniliprole + bifenthrin (two sprays) provided the highest combined control of whitefly adults and nymphs and stink bugs (up to 83.5 %). However, two sprays of cyantraniliprole + bifenthrin +

Table 1. Mean number (M) of living stink bug adults and nymphs m^{-2} and control efficacy (CE%), in the first summer cropping season (2019/20). The active ingredients used in each treatment are presented in Supplementary Table 1. Santa Maria, RS, Brazil.

Treatment	0 DA1S[1]	3 DA1S		10 DA1S		14 DA1S		3 DA2S		7 DA2S		10 DA2S		14 DA2S		Mean CE%
	M[2]	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	
1	4.7 a	0.5 b	93.5	0.5 c	91.3	0.7 b	88.5	0.5 b	90.9	0.5 b	92.0	0.2 b	93.3	0.0 c	100.0	92.8 a
2	5.7 a	0.7 b	90.3	0.7 bc	87.0	0.5 b	92.3	1.0 b	81.8	2.0 b	68.0	0.0 b	100.0	0.0 c	100.0	88.5 a
3	4.0 a	0.2 b	96.8	0.2 c	95.7	0.7 b	88.5	0.2 b	95.4	0.2 b	96.0	0.0 b	100.0	0.2 c	95.8	95.4 a
4	4.0 a	0.7 b	90.3	0.5 c	91.3	0.7 b	88.5	0.0 b	100.0	0.0 b	100.0	0.0 b	100.0	0.0 c	100.0	95.7 a
5	5.0 a	0.5 b	93.5	0.2 c	95.7	0.2 b	96.1	0.5 b	90.9	1.7 b	72.0	0.7 b	80.0	0.2 c	95.8	89.2 a
6	6.5 a	0.0 b	100.0	0.2 c	95.7	0.2 b	96.1	0.0 b	100.0	0.5 b	92.0	0.2 b	93.3	0.0 c	100.0	96.7 a
7	4.7 a	1.7 b	77.4	1.7 bc	69.6	2.5 ab	61.5	2.7 ab	50.0	1.0 b	84.0	1.0 b	73.3	3.2 ab	45.8	66.0 b
8	2.5 a	2.2 b	71.0	0.5 c	91.3	2.7 ab	57.7	0.7 b	86.34	0.5 b	92.0	0.0 b	100.0	1.0 bc	83.3	83.1 a
9	3.0 a	0.2 b	96.8	0.7 bc	87.0	1.2 b	80.8	0.0 b	100.0	0.0 b	100.0	0.2 b	93.3	0.0 c	100.0	94.0 a
10	4.7 a	0.2 b	96.8	0.5 c	91.3	0.2 b	96.1	0.0 b	100.0	0.0 b	100.0	0.0 b	100.0	0.0 c	100.0	97.8 a
11	2.7 a	1.0 b	87.1	2.5 b	56.5	1.5 b	76.9	0.0 b	100.0	0.0 b	100.0	0.2 b	93.3	0.5 c	91.7	86.5 a
12	5.0 a	7.7 a	—	5.7 a	—	6.5 a	—	5.5 a	—	6.2 a	—	3.7 a	—	6.0 a	—	—
CV (%)[3]	18.3	31.5	—	22.0	—	38.0	—	77.7	—	40.1	—	27.8	—	35.2	—	10.4

Note. [1]DAS = Days after first (1) and second (2) spray.[2]Means followed by the same letter in the column do not differ among themselves by the Tukey test (P≤0.05). [3]CV (%) = Coefficient of variation.

Table 2. Mean number (M) of living whitefly adults and nymphs per soybean trifoliate and control efficacy (CE%) of whitefly adults and nymphs in the first summer cropping season (2019/20). The active ingredients used in each treatment are presented in Supplementary Table 1. Santa Maria, RS, Brazil.

Treatment	0 DA1S[1]	3 DA1S		10 DA1S		14 DA1S		3 DA2S		7 DA2S		10 DA2S		14 DA2S		Mean CE%
	M[2]	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	M	CE%	
Adults																
1	2.8 a	0.2 b	90.2	0.4 c	87.8	0.5 bc	83.6	0.1 c	98.6	0.1 c	98.5	0.6 b	86.2	0.9 f	90.8	90.8 a
2	2.6 a	0.1 b	96.1	0.5 c	85.1	0.5 bc	82.0	0.4 c	89.2	0.3 bc	91.1	1.8 ab	60.6	1.3 cdef	86.1	84.3 ab
3	2.5 a	0.2 b	92.2	0.8 bc	78.4	0.3 bc	88.5	0.8 bc	78.4	0.6 bc	80.6	3.2 ab	31.9	1.7 bcdef	82.1	76.0 ab
4	2.5 a	0.2 b	92.2	0.6 c	82.4	0.3 bc	88.5	0.1 c	98.6	0.2 bc	94.1	1.3 b	72.3	0.9 f	90.8	88.4 ab
5	2.5 a	0.1 b	96.1	0.6 c	82.4	0.5 bc	82.0	0.3 c	90.5	0.2 bc	94.1	1.1 b	77.7	1.1 def	88.2	87.3 ab
6	2.6 a	0.2 b	92.2	0.8 bc	78.4	0.6 bc	80.3	0.3 c	91.9	0.7 bc	79.1	0.7 b	84.1	1.0 ef	89.7	85.1 ab
7	2.4 a	0.3 b	86.3	0.6 c	82.4	0.6 bc	78.7	0.2 c	94.6	0.1 c	98.5	0.5 b	88.3	2.8 bc	70.8	85.6 ab
8	2.8 a	0.5 b	78.4	0.6 c	82.4	0.8 b	72.1	1.8 ab	51.3	1.1 b	67.1	0.5 b	89.4	3.4 b	65.1	72.3 b
9	2.7 a	0.1 b	98.1	0.6 c	83.8	0.3 bc	88.5	0.5 c	86.5	0.6 bc	82.1	2.0 ab	57.4	2.5 bcd	74.4	81.5 ab
10	2.5 a	0.0 b	100.0	0.8 c	78.4	0.1 c	96.7	0.4 c	89.2	0.4 bc	86.6	1.1 b	76.6	1.7 bcdef	82.6	87.1 ab
11	2.8 a	0.5 b	78.4	1.8 b	51.3	0.7 bc	75.4	0.6 bc	83.8	0.8 bc	76.1	0.5 b	89.4	2.4 bcde	74.9	75.6 ab
12	2.7 a	2.5 a	—	3.7 a	—	3.1 a	—	3.7 a	—	3.3 a	—	4.7 a	—	9.8 a	—	—
CV (%)[3]	7.4	36.4	—	19.2	—	24.6	—	30.5	—	27.9	—	40.8	—	15.6	—	12.2
Nymphs																
1	5.2 a	2.7 cde	72.4	2.9 a	60.1	7.7 a	0.0	2.8 a	54.1	2.3 ab	70.9	0.1 a	98.3	0.8 ab	89.0	63.5 a
2	19.5 a	4.1 bcde	58.2	5.2 a	29.1	6.3 a	0.0	6.1 a	2.4	1.4 ab	81.6	2.3 a	73.9	1.1 ab	84.1	47.0 b

3	11.9 a	10.8 ab	0.0	5.9 a	20.3	6.6 a	0.0	2.4 a	61.3	7.8 a	1.3	0.4 a	95.0	1.7 ab	75.9	36.2 b
4	4.8 a	1.9 e	80.6	5.6 a	23.6	5.5 a	0.0	1.2 a	80.6	0.3 b	96.2	1.1 a	87.2	0.1 b	98.6	66.7 a
5	3.7 a	2.6 cde	73.5	4.0 a	45.9	3.3 a	35.9	5.0 a	19.3	2.8 ab	64.6	2.2 a	75.0	0.2 ab	97.2	58.8 a
6	4.0 a	5.8 abcde	40.9	3.6 a	51.3	5.1 a	1.9	2.3 a	62.1	1.7 ab	77.8	0.7 a	91.7	0.1 ab	97.9	60.5 a
7	6.8 a	11.5 a	0.0	6.3 a	14.2	3.1 a	39.8	4.1 a	34.7	2.8 ab	63.9	0.3 a	96.1	0.7 ab	90.3	48.4 b
8	3.4 a	4.9 abcde	50.0	11.4 a	0.0	5.8 a	0.0	6.8 a	0.0	7.1 a	10.1	2.2 a	75.6	0.6 ab	91.1	32.4 b
9	7.3 a	7.3 abcd	25.5	8.0 a	0.0	2.1 a	59.2	2.8 a	54.1	5.9 ab	24.7	1.3 a	85.0	4.6 ab	35.9	40.6 b
10	10.9 a	2.3 de	76.5	7.4 a	0.0	2.8 a	44.7	2.9 a	53.2	1.6 ab	79.1	1.6 a	82.2	0.1 ab	97.9	61.9 a
11	8.9 a	8.0 abc	18.4	5.8 a	20.9	2.5 a	51.5	5.2 a	15.3	0.9 ab	88.6	0.3 a	96.7	0.4 ab	93.8	55.0 a
12	9.5 a	9.8 ab	—	7.4 a	—	5.1 a	—	6.2 a	—	7.9 a	—	9.0 a	—	7.2 a	—	—
CV (%)	26.8	22.2	—	31.2	—	48.7	—	43.7	—	45.4	—	84.9	—	76.2	—	44.5

Note. [1]DAS = Days after first (1) and second (2) spray.[2]Means followed by the same letter in the column do not differ among themselves by the Tukey test (P≤0.05). [3]CV (%) = Coefficient of variation.

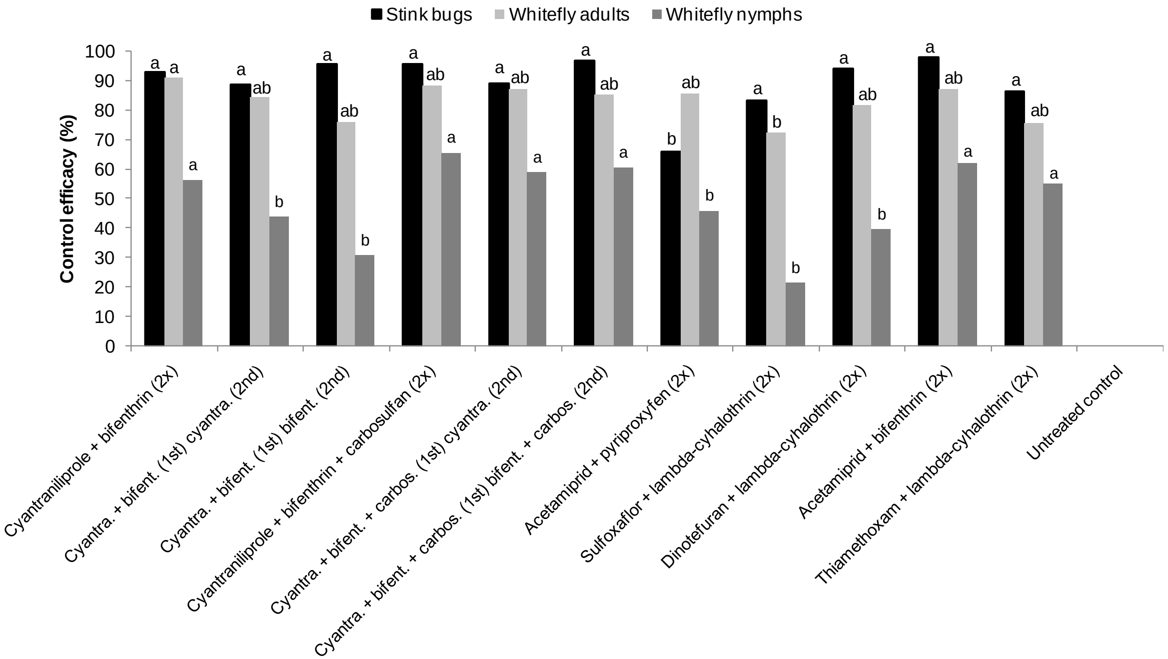

Figure 1. Average control efficacy (CE ± SD) of stink bug and whiteflies, in the first (1st) and second (2nd) insecticide sprays on soybeans (summer cropping season 2019/20). Same active ingredients in the two sprays are indicated by: (2x). Cyantra. (cyantraniliprole), bifent. (bifenthrin) and carbos. (carbosulfan). Santa Maria, RS, Brazil.

carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) also provided high combined control of both pest species (82.7 %), and had the highest yield among all treatments and seasons (Supplementary Table 4). Marques et al. (2019) and Arnemann et al. (2019) also highlighted the importance of sequential sprays to reach satisfactory mortality levels of stink bugs and whiteflies, respectively. Therefore, for conditions of high population pressure such as those under which these two experiments were carried out, two sprays of cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) or two sprays of cyantraniliprole + bifenthrin + carbosulfan (50 + 30 + 90 g a.i. ha^{-1}) beginning when infestation by each pest reach their respective economic threshold levels are recommended. Insecticide sprays in conditions of low infestation could unnecessarily increase control costs and indirectly affect natural enemies, potentially jeopardizing the management strategy as a whole. Future efforts should be focused on including novel formulations of chemical and biological insecticides to provide an economically efficient and environmentally sustainable management program for sap-sucking pests in soybeans.

Materials and Methods

Experiment conditions and plant material

Two field experiments were carried out in Santa Maria-RS/Brazil (29º42'48" S, 53º43'59" W, 119 meters a.s.l.) over two summer cropping seasons (2019/20 and 2020/21). We used the soybean cultivar TMG 7063 IPRO with a population density of 300,000 plants ha^{-1}, and a row spacing of 0.5 meters. The sowing dates were January 1st, 2020 (first cropping season) and December 10th, 2020 (second cropping season). In both cropping seasons, 250 kg $hectare^{-1}$ of fertilizer NPK 00-20-20 were used. Weeds were controlled prior to sowing (glyphosate 1,040 g a.e. ha^{-1} + 2,4-D 1,005 g of a.e. ha^{-1}), and at V3 soybean growth stage with a foliar spray of glyphosate (1,040 g of a.e. ha^{-1}). Seeds were treated with carbendazim + thiram (30 + 70 g a.i. ha^{-1}) and three foliar sprays of azoxystrobin (60 g a.i. ha^{-1}) + cyproconazole (24 g a.i. ha^{-1}) were made for disease control at the reproductive stages R1, R4 and R5.4. Defoliating caterpillars were controlled by the expression of insecticide Cry proteins in the Bt soybean plants.

Treatments

The experimental design was randomized blocks with four replicates, including eleven insecticide treatments and one untreated control plot (Supplementary Table 1). Each plot consisted of 12 rows 12 m long (72 m²). Treatments were chosen based on the insecticides commonly used by soybean growers and recommended by field technicians in Brazil to control stink bugs and whiteflies on soybeans. Two insecticide sprays were made with an interval of 14 days between them, using a spraying volume of 150 L ha^{-1}. The sprays were carried out using a CO_2-pressurized backpack sprayer, TJ XR-110015 nozzles, with a spray boom 2 meters long and 0.5 meters between nozzles. The soybean plants were at growth stage R1 at the moment of the first insecticide spray, in both cropping seasons.

Evaluations

Infestation by stink bugs and whiteflies occurred naturally in both experiments. Evaluations were made at 3, 10, 14 days after the first spray (DA1S) and at 3, 7, 10, 14 days after the second spray (DA2s), in the first cropping season; at 3, 5, 7, 10, 14 DA1S and at 3, 7, 10, 14 DA2S, in the second cropping season. Stink bugs (adults and nymphs) were quantified using a vertical beat sheet (Guedes et al., 2006), with a sampling area of 1 m² per experimental unit, followed by morphological identification of the stink bug species.
Whitefly adults were counted on site in the underside of 20 trifoliate leaves $plot^{-1}$, randomly selected in the upper canopy segment of soybean plants from the five central rows of each plot. Whitefly nymphs were quantified by sampling five leaflets $plot^{-1}$ (20 leaflets $treatment^{-1}$), randomly selected in the middle and lower canopy segments of soybean plants. The choice for sampling whitefly adults in the upper segment and nymphs in the middle and lower segments of the canopy was based on the distribution pattern of *B. tabaci* in soybean plants (Pozebon et al., 2019). Harvest was performed in 6 m² $plot^{-1}$, and was used to estimate yield ha^{-1}.

Statistical analysis

Whitefly adults and nymphs were analysed separately due to differences in their biology and behaviour. Stink bug adults and nymphs were combined as a single variable due to similarities between the two life stages. Control efficiency for each insecticide treatment was assessed through the equation of Abbott (1925):

$$\mathrm{C.E.}\,(\%) = \left(1 - \frac{Pt}{Pc}\right) \times 100$$

where C.E. is the control efficiency or corrected insect mortality (%) in each treatment, P_c is the mean number of individuals alive in the control plot, and P_t is the mean number of individuals alive in the treatment plot. Data were submitted to analysis of variance (ANOVA), and Tukey post-hoc test (P≤0.05) was conducted. All statistical analyses were carried out using the Software SASM-Agri (Canteri et al., 2001).

Conclusion

(1) Acetamiprid + bifenthrin (75 + 75 g a.i. ha^{-1}) was the most efficient treatment for the control of stink bugs in soybeans, reaching 97.8 % of insect mortality.
(2) Cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) was the most efficient treatment for the control of whiteflies in soybeans, reaching 78.8 % of insect mortality.
(3) Cyantraniliprole + bifenthrin (50 + 50 g a.i. ha^{-1}) presented the highest combined control of stink bugs and whiteflies with 83.5 % of insect mortality.

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