Volunteer soybean *(Glycine max)* interference in bean *(Phaseolus vulgaris)* crops: ethoxysulfuron and halosulfuron critical level of damage and selectivity

Interferencia de la soja *(Glycine max)* voluntaria en el cultivo del frijol *(Phaseolus vulgaris)*: nivel crítico de daño y selectividad de los herbicidas etoxysulfuron y halosulfuron

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Abstract

This study aimed to determine the negative impact of volunteer soybean plants on bean crop yield and the tolerance of bean genotypes to the herbicides ethoxysulfuron and halosulfuron. To determine the impact of volunteer soybean plants on bean crops, a field experiment was developed, with sub-sub-plots, and four replications. The main plots contained two bean cultivars, while the sub-plots received two soybean sowing times (0 and 7 days after the beans had been sown), while the sub-sub-plots contained five soybean plant densities (0, 5, 10, 20, and 40 plants m^{-2}). The tolerance of the bean genotypes was evaluated with two experiments in a completely randomized design with three replications. They were arranged in a 28 x 3 factorial design (bean genotypes x herbicide doses). Each soybean plant per m^2 reduced bean crop yield by 4%. The recommended doses of ethoxysulfuorn and halosulfuorn resulted in tolerance levels above 70% for all the studied bean genotypes.

Keywords
competitive interference • volunteer soybean • tolerance • herbicides

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Resumen

Este estudio determinó el impacto negativo de las plantas voluntarias de soja en el rendimiento del frijol y la tolerancia de genotipos de frijol a los herbicidas etoxysulfuron y halosulfuron. Para determinar el impacto de la soja en el cultivo de frijol, se desarrolló un experimento de campo, en sub-sub-parcelas, con cuatro repeticiones. Las parcelas principales contenían dos cultivares de frijol; las subparcelas tenían dos tiempos de siembra de soja (0 y 7 días después del frijol); las sub-subparcelas contenían 5 densidades de soja (0, 5, 10, 20 y 40 plantas m^{-2}). La tolerancia de los genotipos de frijol se evaluó con dos experimentos en un diseño completamente al azar con tres repeticiones, en un factorial 28 x 3 (genotipos de frijol x dosis). Cada planta de soja por m^2 redujo un 4% el rendimiento del frijol. Las dosis recomendadas de etoxysulfuron y halosulfuron resultaran niveles de tolerancia superiores al 70%.

Palabras clave
interferencia competitiva • soja voluntaria • tolerancia • herbicidas

Introduction

Bean crops are among the most commonly cultivated species in the world. According to the FAO (2022), in 2020 bean cultivation occupied 34.8 million ha, with a total production of 27.55-million-tons. This resulted in a mean global yield of 791.5 kg ha^{-1} (8), even though some genotypes have a potential yield of over 4 ton ha^{-1} (5). Low productivity, in many of the areas where bean crops are cultivated, can be a result of the poor adaptation of some genotypes and environmental conditions, such as extreme temperature and drought stress, but it is mainly due to grain loss from pests, diseases and weeds.

Bean plants present a fast development cycle and a low ability to accumulate biomass, which makes them susceptible to competition from weed plants. The literature reports that a mixed infestation of weeds can reduce grain yield by up to 80% (3, 9), in addition to lowering the commercial quality of bean grains.

The importance of intensive farming systems has increased in regions with suitable soil and climatic conditions, since they improve the use of these areas, creating the possibility of cultivating more than one crop per year. In Brazil, the use of early and very early soybean cultivars as the first and second crop in a rotation is becoming more normal. Fallow, as a practice to prevent the effects of Asian soybean rust (*Phakopsora pachyrhizi*) in some Brazilian states, has constrained the sowing of off-season soybean, which results in the intensification of maize, sorghum and bean crops in this period. Natural soybean grain dehiscence or the incorrect adjustment of the harvesting machine can result in the emergence of soybean plants in the middle of a bean crop (second crop), which can interfere with crop growth and yield.

Volunteer corn plants can reduce bean yield between 27 and 35% per corn plant m^{-2} emerging at the same time as the bean plants. Between 4.6 and 9.7 plants / m^{-2} can reduce bean yield by 50% (1). To date, the impact generated by volunteer soybean plants competing with bean plants is unknown, but they are suspected to have the potential to be highly competitive since there are many morphological similarities between the two species, which could intensify the competition for the same ecological niche (20). In addition, chemical management in this situation is hampered by the high selectivity of the herbicides for both cultures.

The herbicides ethoxysulfuron and halosulfuron, which inhibit the acetolactate synthase (ALS) enzyme, are registered in Brazil for the control of volunteer soybean plants in bean crops (4) and are considered efficient (16). The success of these herbicides depends on how selective they are for different bean cultivars and how efficiently they can control soybean plants presenting greater genetic variability. The identification of the bean genotype response to herbicides is fundamental to determining its use in weed management; it is also essential for improvement programs aimed at the selection of herbicide-tolerant genotypes.

The objective of this study was to determine the impact of the interference of soybean plants on the grain yield of different bean genotypes and the tolerance of these bean genotypes to the herbicides ethoxysulfuron and halosulfuron.

Materials and methods

Experimental site

The experiments were carried out in a greenhouse and in the field at the Federal University of Technology - Paraná, Campus Pato Branco (UTFPR-PB) (26°10'31.6'' S and 52°42'28.01'' W) at an altitude of 740m. The climatic region is considered a climatic transition between the cfa/cfb climates (both rainy and hot temperate climates, the former is humid in all seasons and hot in the summer; while the latter is humid in all seasons with moderately hot summers), according to the Köppen climate classification (12). The soil used in both experiments is classified as an Oxisol (table 1).

Table 1. Physicochemical characteristics of the soil where the experiments were carried out.

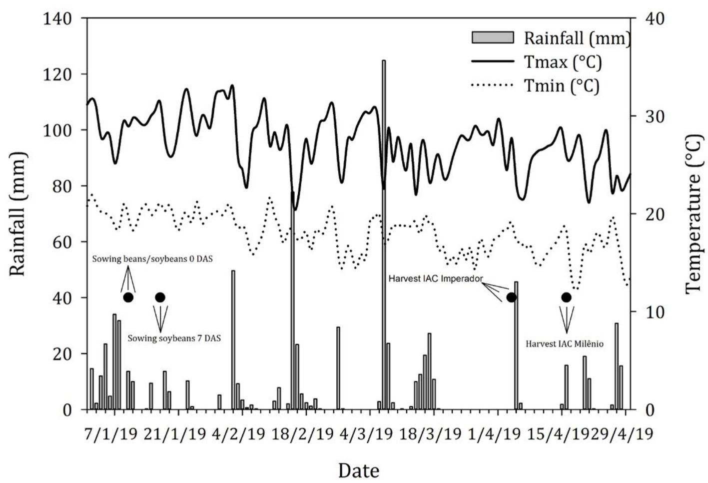
Tabla 1. Características físico-químicas del suelo donde se llevaron a cabo los experimentos.

Granulometric distribution		Chemical components	
Clay	55.7	MO[1/]	49.6
Sand	3.0	P[2/]	8.9
Silt	41.3	K[3/]	0.7
		CIC[4/]	13.8
		pH[5/]	4.8
		H+Al[6/]	5.8

[1/] Organic Matter (g dm^{-3}); [2/] Phosphorus (mg dm^{-3}); [3/] Potassium (cmolc dm^{-3}); [4/] Cation exchange capacity; [5/] Soil pH; [6/] Exchangeable acidity (cmolc dm^{-3}).

[1/] Materia Orgánica (g dm^{-3}); [2/] Fósforo (mg dm^{-3}); [3/] Potasio (cmolc dm^{-3}); [4/] Capacidad de intercambio catiónico; [5/] pH del suelo; [6/] Acidez intercambiable (cmolc dm^{-3}).

For the greenhouse experiments, the collected soil was sieved in a 5 mm mesh sieve and deposited in 5L polyvinyl chloride (PVC) pots. Irrigation was carried out manually twice a day. The greenhouse conditions during the experimental period were 20 to 30°C and 60 to 90% relative air humidity. For the field experiment, the climate conditions during the experimental period are presented in figure 1.



Source: Simepar (Meteorological System of Paraná).

Fuente de información: Simepar (Sistema Meteorológico de Paraná).

Figure 1. Rainfall (■), Minimum (-) and maximum (---) temperature during the development of the experiment in 2019 in Pato Branco, PR, Brazil.

Figura 1. Lluvia (■), temperatura mínima (-) y máxima (---) durante el desarrollo del experimento en 2019 en Pato Branco, Paraná, Brasil.

Soybean plant interference in bean plants

A field experiment was set up, using a randomized block experimental design with sub-sub plots and four repetitions. In the main plots, two bean genotypes were implanted with distinct morphophysiological characteristics: IAC *Imperador*, with a determinate growth habit, upright position and a 75-day cycle; and IAC *Milênio*, with an indeterminate growth habit, semi-upright position and a 95-day development cycle. The sub-plots comprised two soybean sowing times, 0 and 7 days after bean sowing, and in the sub-sub-plots, five soybean plant densities were implemented (0, 5, 10, 20 and 40 plants per m^{-2}). The soybean plant genotype used was P95R51, with an indeterminate growth habit and a 120-day development cycle.

The sub-sub-plots consisted of five 5m long lines, with a 0.45m interval between them. The usable area of the sub-sub-plots was composed of the three central lines, excluding 0.5 m at each end. Bean sowing was carried out using a no-till sower, with a desired plant density of 280.000 pl ha^{-1} for both genotypes. The seeds were treated with a 100g i.a. dose of fipronil + pyraclostrobin + thiophanate-methyl per 100 kg of seeds. The base fertilization used was 269 kg ha^{-1} of the 8-28-16 (N-P_2O_5-K_2O) formulation. When the plants were in the V_4 phase, topdressing was carried out with 60 kg ha^{-1} urea (46% N). Soybean sowing was carried out manually and after the plants had emerged, excess plants were removed to homogenize the densities set for the treatments.

Weeds were manually removed during the experimental period. Insect control was carried out with thiamethoxan+lambda-cyhalothrin (30.87 g i.a. ha^{-1}), acefate+ aluminum silicate (975,5 g i.a. ha^{-1}), and beta-cyfluthrin+imidacloprid (81.37 g i.a. ha^{-1}). Disease control was carried out with fentin hydroxide (250 g i.a. ha^{-1}), prothioconazole+trifloxystrobin (162,5 g i.a. ha^{-1}), and mancozebe (2250 g i.a. ha^{-1}).

When the bean plants were fully grown, 10 plants from the usable area (5.4 m^2) of each sub-sub plot were selected to determine plant height (ESTm), first pod insertion height (AIPV), number of pods per plant (NVP), number of grains per pod (NGV) and 1000-grain mass (MMG). Bean grain yield (REND) for each genotype was determined by harvesting and then threshing the plants of the usable area of each sub-sub-plot, the resulting grains were weighed and the grain mass humidity determined and corrected to 13%.

Tolerance of the bean genotypes

In the greenhouse, two experiments were set up in a completely randomized experimental design, with three replications and two factors. The first experiment was developed with the herbicide ethoxysulfuron, while the second investigated the herbicide halosulfuron. In both experiments, the first factor contained 28 bean genotypes, which included: IAC *Imperador*, IAC *Milênio*, *Jalo Precoce*, BRS *Radiante*, ANFP 110, IPR *Colibri*, BRS *Esteio*, IPR *Uirapuru*, IPR *Tuiuiú*, IAC *Harmonia*, BRS *Esplendor*, IPR *Campos Gerais*, IPR *Tiziu*, IPR *Juriti*, BRS *Talismã*, IPR *Siriri*, IPR *Tangará*, IAPAR 81, IPR *Andorinha*, IPR *Corujinha*, IPR *El dourado*, IPR *Grauna*, IPR *Chopim*, IPR *Saracura*, IPR *Garça*, IPR *Maracanã*, ANFC 9, and IPR *Gralha*. The second factor was defined by the doses of each herbicide applied to each experiment. The doses applied of the herbicide ethoxysulfuron were 0, 45, and 90 g ha^{-1}, while the doses applied of halosulfuron were 0, 80, and 160 g ha^{-1}. Four seeds were placed in each pot; after emergence and establishment, excess plants were removed leaving only two plants.

Herbicide was applied when 50% or more plants presented an expanded third trifoliate leaf, using a CO_2 pressurized back sprayer equipped with XR 110.02 flat-fan nozzles. The volume of the mixture used was 200 L ha^{-1}, with a 3.6 km h^{-1} application speed. For the herbicide halosulfuron, the mixture included a nonylphenol ethoxylate surfactant at a 0.5% v/v concentration.

Twenty-eight days after application, the tolerance of the bean plants was determined using a scale in which 100 corresponded to the absence of herbicide symptoms and 0 corresponded to plant death. intermediate values were ascribed according to discolouration, atrophy and growth reduction.

Statistical analysis

The data were submitted to variance analysis ($p \leq 0.05$) using the R language (2018). For the bean tolerance evaluation experiments, the means were grouped using the Scott-Knott test ($p \leq 0.05$), using the R language (2018). For the competition experiment, when the means of the qualitative data were significant, they were compared using the Tukey ($p \leq 0.05$) test (21), while the means of quantitative data were fitted to a linear polynomial (Equation 1), three-parameter logistic (Equation 2) and rectangular hyperbola (Equation 3) models, using the Sigmaplot software version 12.0 (24).

$$Y = A * B + X \quad (1)$$

$$Y = A / [1 + (X / D_{50}) ^\wedge B] \quad (2)$$

$$YL = (A * X) / (D_{50} + X) \quad (3)$$

where
Y = the dependent variable
X = the soybean density
A = the Y value when the X value tends to 0
B = the curve slope
D_{50} = the soybean plant density needed to reduce the dependent variable by 50%
YL = the grain yield loss (%).

For the rectangular hyperbola model, the relation between parameters A and D_{50} results in the i parameter, which represents the yield loss when the soybean density is 1 plant m^{-2} and is considered the critical damage level (6).

Results and discussion

Interference of soybean plants in bean plants

The variance analysis indicated significance for only the bean genotype isolated factor regarding the ESTm, GVG, and MMG variables. For the AIPV variable, significance was observed for the simple effects of bean genotype and soybean density, while the VAG variable presented significance for the simple effects of bean genotype, soybean density and soybean establishment time. For the REND variable, significance was observed for soybean density, bean genotype interaction and the simple effect of soybean establishment time.

An increase in bean AIPV was observed with the increase in soybean density, which was 20% in relation to the control, without plants, when the soybean density was 40 pl m^{-2} (figure 2, page 113).

However, the number of pods per plant reduced with the increase in soybean plant density, reaching a 30% reduction with the 40 pl m^{-2} density. As reported by Machado *et al.* (2015), increased weed density negatively impacted the number of pods per bean plant, which was a result of the reduction in the number of branches per plant. Competition between plants promotes a greater search for light, favouring etiolation and the development of branches in the upper third of the plant to the detriment of the lower third, which causes a higher AIPV.

The IAC *Imperador* genotype presented lower ESTm (46%) and AIPV (61%) when compared with IAC *Milênio*, while the IAC *Milênio* genotype presented lower GVG, MMG and VAG (8, 17, and 32%, respectively) in comparison with IAC *Imperador* (table 2, page 113).

A) first pod insertion height (cm), B) Pods per plant (number), C) Grain yield (%), (D) Bean yield loss (%). Each point represents a mean of three replications and the bars represent the mean standard error. Parameters are presented in table 2. and table 3 (page 114).

A) altura de inserción de la primera vaina (cm), B) Vainas por planta (número), C) Rendimiento de grano (%), (D) Pérdida de rendimiento (%) de frijol. Cada punto representa la media de tres repeticiones y las barras representan el error estándar medio. Los parámetros se presentan en la tabla 2 y tabla 3 (pág. 114).

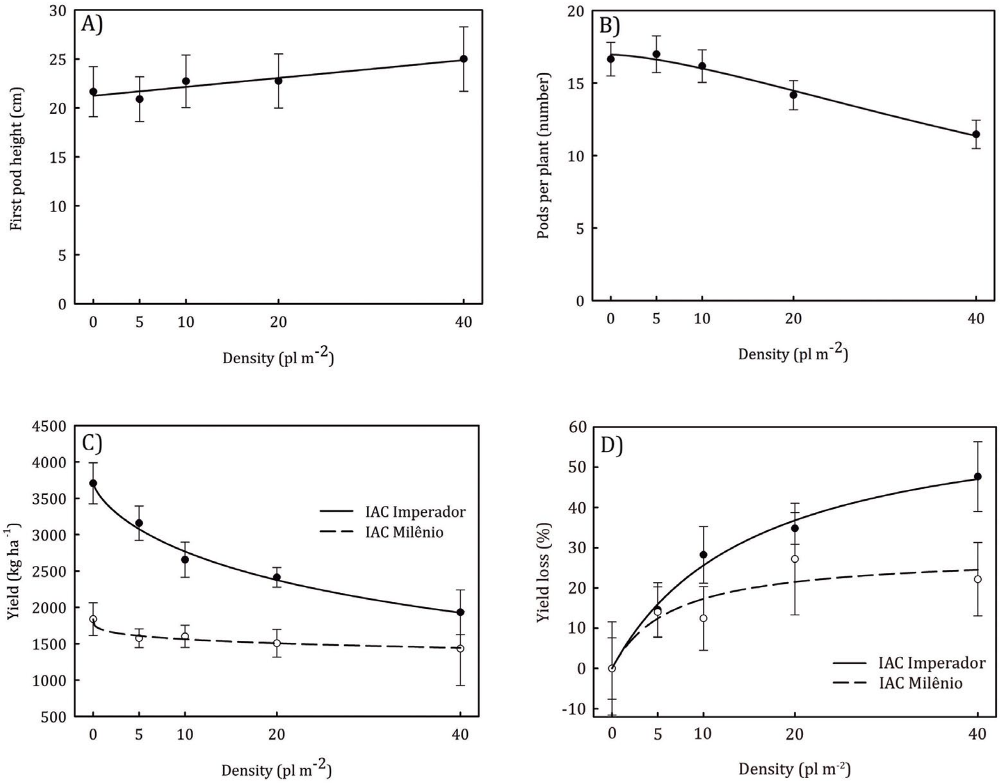


Figure 2. Impact of soybean plant density, with two different establishment times (0 and 7 days after bean sowing) and of two bean cultivars (IAC *Milênio* and IAC *Imperador*).

Figura 2. Impacto de la densidad de plantas de soja, de dos tiempos de establecimiento (0 y 7 días después de la siembra del frijol) y de dos cultivares de frijol (IAC Milênio e IAC Imperador).

Table 2. Height of adult plants (cm) (ESTM), First pod insertion height (cm) (AIPV), Grains per pod (n) (GVG), 1000 grain mass (g) (MMG) and Pods per plant (n) (VAG) for beans plants of the cultivars IAC *Imperador* and IAC *Milênio*.

Tabla 2. Altura de las plantas maduras (cm) (ESTM), Altura de inserción de la primera vaina (cm) (AIPV), Granos por vaina (n) (GVG), Masa de mil granos (g) (MMG), Vainas por planta (n) (VAG) de plantas de frijol de los cultivares IAC Imperador e IAC Milênio.

Cultivar	EST_M	AIPV	GVG	MMG	VAG
IAC *Imperador*	67.99 b	12.74 b	4.16 a	207.85 a	17.99 a
IAC *Milênio*	125.36 a	32.67 a	3.81 b	173.13 b	12.21 b

[1/] Means followed by the same letter in the same column did not differ according to the Tukey test (p≤0.05). The data represents the means of all densities and times of soybean sowing.

[1/] Medias seguidas de la misma letra en la misma columna no difieren en la prueba de Tukey (p≤0,05). Los datos representan las medias de todas las densidades y épocas de siembra de soja.

The differences observed between the genotypes are due to the intrinsic characteristics of each material. When the soybean plants were established simultaneously with the bean plants, lower NVAG (14%) and REND (21%) were observed when compared with the results obtained from soybean plants established 7 days after the bean sowing (table 3). The weed interference potential tends to be greater when these plants are established in the area simultaneously or before the commercial crop plants, as has been observed in several works on different species both cultivated and weeds (14, 18). The plants that establish first in the environment present some advantages regarding the allocation of resources, guaranteeing a greater competitive potential (20).

Table 3. Pods per plant (n) (VAG) and grain yield (Kg ha^{-1}) (REND) of beans with two different times of soybean crop establishment.

Tabla 3. Vainas por planta (n) (VAG) y rendimiento de grano (Kg ha^{-1}) (REND) de frijol en dos tiempos de establecimiento del cultivo de soja.

Time of establishment	NVAG	REND
0 DAS[1/]	14.15 b[2/]	1999.58 b
7 DAS	16.10 a	2421.99 a

[1/] Days after soybean sowing.
[2/] Means followed by the same letter in the same column did not differ in the Tukey test (p≤0.05).
The data represents the means of all densities and the bean cultivars.
[1/] Dias después de la siembra de soja.
[2/] Medias seguidas de la misma letra en la misma columna no difieren en la prueba de Tukey (p≤0,05).
Los datos representan las medias de todas las densidades y los cultivares de frijol.

The maximum grain yield values for each of the bean genotypes were distinct, as revealed by the "*a*" parameter value (table 4). The maximum yield of the IAC *Imperador* genotype was 3716 kg ha^{-1}, and was reduced by 48% with a soybean density of 40 pl m^{-2}. The IAC *Milênio* genotype presented a maximum grain yield of 1836 kg ha^{-1}, lower than that of IAC *Imperador*, however, it was reduced by only 22% with the maximum soybean density (figure 2D, page 113).

Table 4. Equation parameters to determine the impact of soybean plant densities on the first pod insertion height (AIPV) (cm), number of pods per plant (VAG) and grain yield (REND) (kg ha^{-1}) of bean plants.

Tabla 4. Parámetros de la ecuación para determinar el impacto de las densidades de plantas de soja en la altura de inserción de la primera vaina (AIPV) (cm), número de vainas por planta (VAG) y rendimiento de grano (REND) (kg ha^{-1}) de plantas de frijol.

Variable		Parameters			R^2	QME	p
		a	b	D_{50}			
AIPV[1/]	-	21.24 (0.42)*	0.09 (0.02)**	-	0.82	0.41	0.02
VAG[2/]	-	16.96 (0.36)**	1.52 (0.32)*	63.57 (8.32)*	0.96	0.18	0.01
REND[2/]	IAC Imperador	3716.55 (100.91)**	0.72 (0.10)*	44.28 (6.97)*	0.99	10316.42	0.01
	IAC Milênio	1835.98 (36.95)**	0.31 (0.10)	2566.86 (3994.22)	0.97	1367.11	0.03

* and ** significant at 5 and at 1% probability, respectively;
[1/] Linear polynomial model.
[2/] Three-parameter logistic model.
* y ** significativos al 5 y al 1% de probabilidad, respectivamente;
[1/] Modelo de polinomio lineal.
[2/] Modelo logístico de tres parámetros.

The NCD of soybean plant interference in the beans crop was higher than that caused by the interference of the *Brachiaria plantaginea* (0.4 to 0.7) (11), but similar to that caused by *Euphorbia heterophylla* (2.4 to 5.5) (14), and lower than that caused by maize plants to beans (27 to 35) (1). This highlights the high damage caused by soybean plants to bean crops. As reported by Radosevich *et al.* (2007), the higher the morphologic similarity between the plants is, the higher the competition between them. In the soybean crop, for example, the NCD can vary from 0.97 to 36.42, depending on the weed type and its establishment time (18).

Despite the different potentials for soybean plant interference in the bean genotypes, the level of damage (NCD) observed was similar between them, that is, a soybean plant per m^2 was able to reduce the grain yield of both genotypes by approximately 4% (table 5). This occurred because the NCD value (parameter *i*) corresponds to the tangent of the rectangular hyperbola angle in the curve region where the infesting density is close to zero (6). Therefore, parameter *i* does not detect the negative impact on the gain yield at higher densities, and this impact is greater in the cultivar IAC *Imperador* than IAC *Milênio*. However, *i* is still a useful parameter, since it estimates losses at low densities, which are usually close to the economic damage level (18).

Table 5. Equation parameters for determining the impact of soybean plant densities on grain yield loss (%) in bean plants.

Tabla 5. Parámetros de la ecuación para determinar el impacto de las densidades de plantas de soja en la pérdida de rendimiento de grano (%) de las plantas de frijol.

Variable	Parameters			R^2	p
	A	D_{50}	i		
IAC Imperador	65.22 (5.96)**	15.46 (3.31)*	4.22	0.99	0.0004
IAC Milênio	28.49 (7.35)*	6.48 (5.61)^{ns}	4.40	0.85	0.02

* and ** significant at 5 and 1% probability, respectively;

1/ Rectangular hyperbola.

* e ** significativos al 5 y al 1% de probabilidad, respectivamente;

1/ Hipérbola rectangular.

Bean genotype tolerance

A significant effect was observed for the interaction between dose and bean genotype for both herbicides. Regardless of the herbicide, reduced tolerance was observed for all the genotypes with the increase in herbicide dose. With the 45 g ha^{-1} dose of ethoxysulfuron, the genotypes IAC *Harmonia*, IPR *Campos gerais*, IPR *Chopim* and IPR *Tiziu* stood out for having high tolerance levels, over 95%, compared with the other genotypes (figure 3, page 116). When the dose was increased to 90 g ha^{-1}, only the genotypes IPR *Chopim* and IPR *Tiziu* presented high tolerance levels, over 90%. With the 45 g ha^{-1} dose of ethoxysulfuron, the genotype IPR *Garça* showed lower tolerance than the others, 75%. When the dose was increased to 90 g ha^{-1}, the genotypes BRS *Radiante*, IPR 81, IPR *Andorinha*, IPR *Colibri*, IPR *Garça* and IPR *Maracanã* showed greater sensitivity to the herbicide, with a 70% maximum tolerance.

With both doses of the herbicide halosulfuron, 80 and 160 g ha^{-1}, the genotypes ANFC 9, IAC *Milênio*, IPR *Gralha* and IPR *Tuiuiu* stood out for presenting a higher tolerance than the other gynotypes, reaching over 90% (figure 4, page 116). It is necessary to highlight that none of the genotypes that showed higher tolerance to ethoxysulfuron presented the same reaction to halosulfuron. However, some genotypes such as IAC *Harmonia* and IPR *Tiziu* presented a high tolerance to ethoxysulfuron, and an intermediate tolerance to halosulfuron. Only the genotypes BRS *Radiante* and IPR *Garça* presented a low tolerance to halosulfuron in the 80 g ha^{-1} dose, reaching the 75% level. When the dose was increased to 160 g ha^{-1}, the genotypes IPR *Andorinha*, IPR *Garça*, IPR *Saracura*, and IPR *Tangará* showed lower tolerance than the other genotypes, which was either equal to or lower than 65%.

*Uppercase letters compare cultivars within each dose, while lowercase letters compare doses within each cultivar using the Scott-Knott test ($p \leq 0.05$).

*Las letras mayúsculas comparan los cultivares dentro de cada dosis, mientras que las letras minúsculas comparan las dosis dentro de cada cultivar usando la prueba de Scott-Knott ($p \leq 0,05$).

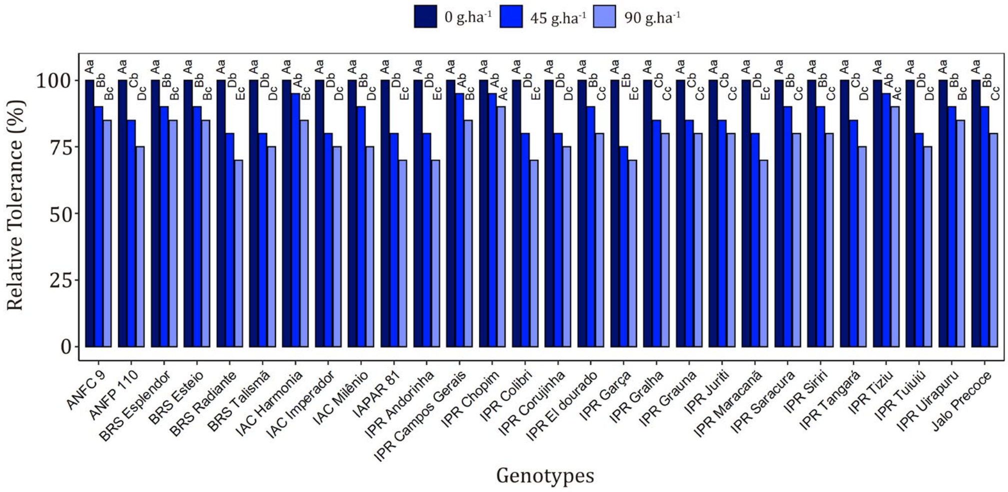


Figure 3. Relative tolerance (%) of 28 bean cultivars to the different doses of the herbicide ethoxysulfuron 28 days after application (DAA).

Figura 3. Tolerancia relativa (%) de 28 cultivares de frijol a diferentes dosis de ethoxysulfuron 28 días después de su aplicación (DAA).

*Uppercase letters compare cultivars within each dose, while lowercase letters compare doses within each cultivar using the Scott-Knott test ($p \leq 0.05$).

*Las letras mayúsculas comparan los cultivares dentro de cada dosis, mientras que las letras minúsculas comparan las dosis dentro de cada cultivar usando la prueba de Scott-Knott ($p \leq 0,05$).

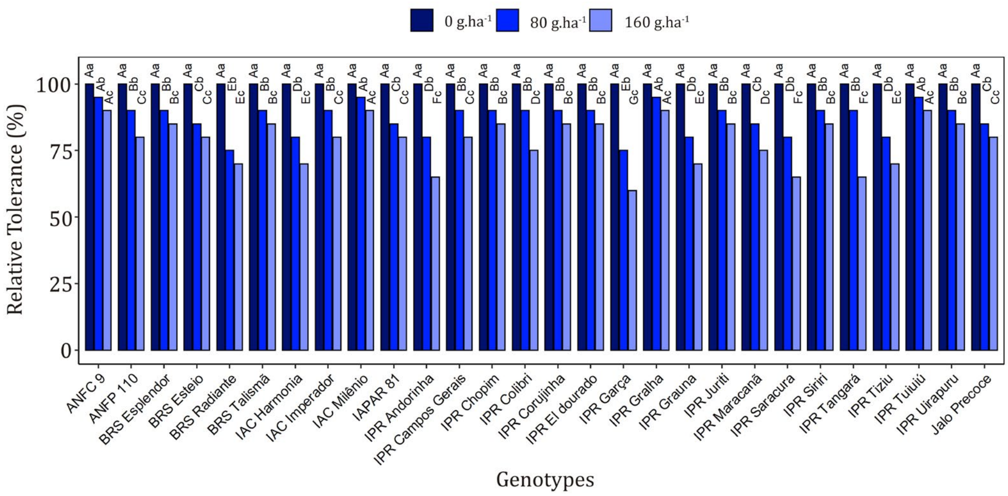


Figure 4. Relative tolerance (%) of 28 bean cultivars to different doses of the herbicide halosulfuron 28 days after application (DAA).

Figura 4. Tolerancia relativa (%) de 28 cultivares de frijol a diferentes dosis de halosulfuron 28 días después de su aplicación (DAA).

Highly variable responses to both herbicides were observed for the bean genotypes, similar results were found by Soltani *et al.* (2015) for the same herbicides. In that study, the authors observed that the level of injury provided by halosulfuron would barely pass 15%, however, the damage to some genotypes resulting from ethoxysulfuron could reach 70%. In the present study, the mean tolerance to ethoxysulfuron for all the genotypes was 86.07±5.83 (mean ± standard deviation) (45 g ha^{-1}) and 78.39±6.24 (90 g ha^{-1}) and the mean tolerance to halosulfuron was 87.14±5.84 (80 g ha^{-1}) and 78.75±8.78 (160 g ha^{-1}). This shows that there was a similar mean tolerance to both herbicides; however, differences were observed between the cultivars. In addition, the standard deviation for the herbicide halosulfuron for the 160 g ha^{-1} dose was the highest, suggesting a greater response variability by the genotypes to the higher doses of this herbicide when compared with ethoxysulfuron.

The differential tolerance of bean genotypes to different herbicides such as saflufenacil, sulfentrazone, clomazone, dimethenamid, and metolachlor, applied pre-emergence (7, 10, 17, 22, 23) or to the herbicides chlorimuron and imazethapyr applied post-emergence (19) has also been observed. The differential tolerance between genotypes could be related mainly to the tolerance mechanism. The main mechanism involved in the tolerance of cultivated plants is metabolization through enzymes belonging to the cytochrome P450. In fact, the involvement of these proteins has been suggested in bean tolerance to the herbicides ethoxysulfuron and halosulfuron (13). However, differences regarding the interception and absorption of herbicides, mainly related to the plant morphology (leaf angle, quantity and quality of the epicuticular wax), as well as differences regarding translocation between plants may also justify the differential tolerance between genotypes (2, 15).

Increased doses resulted in a reduction in plant tolerance to both herbicides in all genotypes. This suggests that suitable management practices must be adopted to prevent a reduction in the tolerance of the cropped species. Situations that require increased doses, such as the management of a difficult control plant inside the crop, must be avoided. Likewise, taking care when applying the herbicides, by not overfilling the spray bar, for example, is a recommended practice to prevent loss of herbicide selectivity.

It is very difficult to estimate the threshold of injury to the plants in the vegetative phase, the level over which grain yield loss occurs, since the correlation between an early level of damage and yield loss is influenced by several factors, such as the herbicide action mechanism, environmental conditions that determine plant recovery, and management practices adopted, among others. If we consider that the plants can recover from an observed injury at 28 DAA of the herbicide up to the tolerance threshold of 70%, it could be assumed, given the data presented in this study, that the use of the label recommended dose of both herbicides, ethoxysulfuron and halosulfuron, would allow the recovery of the plants without hampering their productive potential. However, ethoxysulfuron doses greater than the ones recommended on the label would not be tolerated by the genotypes BRS *Radiante*, IPR *Colibri*, IPR 81, IPR *Andorinha*, IPR *Garça* and IPR *Maracanã*. Likewise, halosulfuron doses over the ones recommended would not be tolerated by the genotypes BRS *Radiante*, IAC *Harmonia*, IPR *Tiziu*, IPR *Tangará*, IPR *Andorinha*, IPR *Graúna*, IPR *Saracura* and IPR *Garça*, since they could harm the productive potential of the plants.

In the tests that evaluated the tolerance of bean genotypes, a highly variable response to the herbicides was observed. This highlights the importance of a good management plan that considers the tolerance of bean genotypes to herbicides when cropping beans and soybean in succession. The cultivation of bean genotypes with lower tolerance to the herbicides (BRS *Radiante*, IPR *Colibri*, IPR 81, IPR *Andorinha*, IPR *Garça* and IPR *Maracanã* to ethoxysulfuron and BRS *Radiante*, IAC *Harmonia*, IPR *Tiziu*, IPR *Tangará*, IPR *Andorinha*, IPR *Graúna*, IPR *Saracura* and IPR *Garça* to halosulfuron) could result in grain losses. However, field experiments comparing bean genotypes have to be performed to obtain further information on grain yield.

According to the data analysis, the impact of soybean plants on bean grain yield is high. Among the genotypes used in the competition study, IAC *Milênio* presented a comparatively high tolerance to halosulfuron; however, its tolerance to ethoxysulfuron can be considered intermediate to low, depending on the dose used. The genotype IAC *Imperador* presented intermediate tolerance to halosulfuron; however, its tolerance to ethoxysulfuron was low.

The behavioural difference of bean genotypes in relation to the different herbicides should be highlighted. Despite the mean behaviour of all genotypes being similar in relation to the herbicides (86 and 87% for the label recommended dose and 78 and 79% for double the recommended dose, respectively, for ethoxysulfuron and halosulfuron), different responses from the same genotype to each of the herbicides were observed. This occurred for the genotype IPR *Tiziu*, which presented high tolerance to ethoxysulfuron, but had a low tolerance to halosulfuron, when compared to the other genotypes. This emphasizes the importance of knowing the tolerance of the genotype before choosing the herbicide.

Conclusions

Each soybean plant is capable of causing a 4% reduction in bean plant grain yield, regardless of the establishment time of the soybean plants or the bean genotype. Calculating the level of economic damage by considering both economic and biological variables is recommended to assist with decision-making to control soybean plants infesting bean crops.

The bean genotypes displayed a highly variable response to the herbicides ethoxysulfuron and halosulfuron; however, when the label recommended dose of the herbicides was used, the tolerance levels observed were over 70%. Knowledge of this variable response to the herbicides is important as a warning to farmers and technicians and can be used in bean breeding programs. An increase in each of the herbicide doses promotes an increase in bean plant damage. Therefore, care should be taken when applying herbicides, mainly by avoiding over-spraying.

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