Selectivity of latifolicides associated with glyphosate applied in postemergence on soybean (*Glycine max*) cultivars

Selectividad de latifolicidas asociados con glifosato aplicados en post-emergencia en cultivares de soja (*Glycine max*)

Jhonatan Coradin[1], Guilherme Braga Pereira Braz[1], Alessandro Guerra da Silva[1], Sérgio de Oliveira Procópio[2], Guilherme Sales Vian[1], Paulo Victor Leão Lima Chavaglia[1], Marco Antonio Rodrigues Goulart[1], Matheus de Freitas Souza[1]

Originales: Recepción: 03/03/2022 - Aceptación: 13/02/2023

Abstract

The genetic improvement of soybean cultivars over the years has focused on increasing the yield potential and tolerance to some abiotic and biotic factors. However, during the transfer of genes of interest, some genes responsible for a lower tolerance to herbicides can be integrated into the genome of the new cultivar. Thus, the objective of this study was to evaluate the selectivity of herbicide associations applied in the postemergence period of three soybean cultivars. The experiment was conducted in a randomized completely block design, with four replications. The selected cultivars were M7110 IPRO®, Foco IPRO®, and Bônus IPRO®. The herbicides and the respective doses (g a.i. ha^{-1}) used were glyphosate (1176), glyphosate + bentazon (1176 + 600), glyphosate + fomesafen (1176 + 175), glyphosate + lactofen (1176 + 120), glyphosate + imazethapyr (1176 + 100), glyphosate + chlorimuron (1176 + 10), glyphosate + cloransulam (1176 + 39.5), and a control without herbicide application. The visual note of intoxication was evaluated for each treatment. The components of growth and yield evaluated were height, stand, weight of one hundred grains, and yield. The application of postherbicide herbicides did not alter the plant stands of soybean cultivars. Additionally, these herbicides did not reduce the yield of the M7110 IPRO® and Foco IPRO® cultivars. Glyphosate isolated and in association with lactofen or imazethapyr reduced the grain yield of the Bônus IPRO® cultivar.

Keywords
Chemical control • *Glycine max* • herbicides • phytointoxication

1 Graduate Program in Plant Production. Universidade de Rio Verde. Rio Verde (Goiás), Brazil. Zip code: 75901-970. guilhermebrag@gmail.com
2 Research Department. EMBRAPA Meio Ambiente. Jaguariúna (São Paulo), Brazil. Zip code: 13918-110.

Resumen

El mejoramiento genético de los cultivares de soja a lo largo de los años se ha centrado en aumentar la capacidad productiva y la tolerancia a algunos factores abióticos y bióticos. Sin embargo, durante la transferencia de genes de interés, algunos genes responsables de una menor tolerancia a los herbicidas pueden integrarse en el genoma del nuevo cultivar. El objetivo de este estudio fue evaluar la selectividad de las asociaciones de herbicidas aplicadas en la post-emergencia de tres cultivares de soja. El diseño experimental utilizado fue un bloque completamente al azar, con cuatro repeticiones. Los cultivares seleccionados fueron M7110 IPRO®, Foco IPRO® y Bônus IPRO®. Los herbicidas y las respectivas dosis (g a.i. ha^{-1}) utilizados fueron: glyphosate (1176), glyphosate + bentazon (1176 + 600), glyphosate + fomesafen (1176 + 175), glyphosate + lactofen (1176 + 120), glyphosate + imazethapyr (1176 + 100), glyphosate + chlorimuron (1176 + 10), glyphosate + cloransulam (1176 + 39,5), y un control sin aplicación de herbicida. Se hizo una nota visual de intoxicación para cada tratamiento. Los componentes de crecimiento y rendimiento evaluados fueron: altura, rodal, peso de cien granos y rendimiento. La aplicación de herbicidas en post-emergencia no alteró la masa vegetal de los cultivares de soja. Además, estos herbicidas no redujeron el rendimiento de los cultivares M7110 IPRO® y Foco IPRO®. Tanto el glifosato aislado como mezclado con lactofen o imazethapyr redujeron el rendimiento del cultivar Bônus IPRO®.

Palabras clave

Control químico • *Glycine max* • herbicidas • fitointoxicación

Introduction

The repetitive use of the same herbicide can generate risks to the sustainability of agricultural systems, as it causes important changes in the composition of the weed community present in agricultural areas. The emergence of herbicide-resistant weed biotypes is among the main concerns related to plant protection globally (5, 14).

Due to the large-scale adoption of Roundup Ready® (RR®) technology, which gives plants tolerance to glyphosate, postemergence applications of this herbicide have become quite frequent in large crops such as soybeans (17). This fact significantly contributed to the increase in the population of weed species tolerant (13) to this herbicide in the cultivated areas, in addition to accelerating the selection of resistant biotypes. This change in the weed community has led to the need to complement chemical control, especially with the application of latifolicides in soybean crops (1).

The association among herbicides with different modes of action has become an important strategy for the control of a wider spectrum of weed species (21), in addition to mitigating the occurrence of weed resistance to herbicides (18). Currently, ALS (*e.g.*, imazethapyr, chlorimuron) and PPO (*e.g.*, fomesafen, lactofen) inhibitors are among the most widely used herbicides in postemergence soybean crops and are used mainly in association with glyphosate. Despite showing satisfactory control for several weed species, especially broadleaves, these herbicides can cause injuries to soybean plants, with internal chlorosis and leaf tissue necrosis as the most frequent visual symptoms, which can negatively affect crop yield (2).

In a study by Alonso *et al.* (2011), it was observed that the use of glyphosate isolated and in association with other postemergence herbicides provided visual symptoms of injuries in RR® soybean plants, causing a reduction in crop yield components. The most common symptom caused by the isolated application of glyphosate on RR® soybean is the chlorosis of the trifoliated leaves positioned in the upper portion of the plants; however, other negative effects were observed in studies with this herbicide, such as reduced nutrient absorption and plant growth (6, 22).

The postemergence herbicide applications in soybean crops are more effective in weed control when carried out at the early stages of development. Fornazza *et al.* (2011) reported that some combinations of herbicides applied in the initial postemergence of soybean can affect the grain yield due to the low selectivity observed for some cultivars. The selectivity of herbicides for soybean cultivars, mainly related to the use of these products in associations, is an aspect to be carefully observed, mainly due to the current use in Brazil of genotypes with great phenotypic variation, highlighting relevant aspects, such as maturation groups, growth types, leaflet area, leaf inclination angle, and pubescence. The correct choice of soybean cultivars can avoid losses in grain yield resulting from low tolerance to herbicides.

In this context, the objective was to study the selectivity of latifolicides in association with glyphosate applied in the postemergence period of three RR® soybean cultivars in the Midwest region of Brazil.

Materials and methods

Three experiments were carried out in the field in the same plot located in the municipality of Rio Verde (Goiás State), Brazil (17°52'05"S and 50°55'36"W; altitude: 741 m), from November 18th, 2020 to March 18th, 2021. In each experiment, the selectivity of herbicides applied postemergence to a soybean cultivar of indeterminate growth type and with great representation in terms of cultivated area in the Midwest region of Brazil was evaluated. The evaluated cultivars were M7110 IPRO® (maturity group - MG: 6.8), Focus IPRO® (MG: 7.2), and Bônus IPRO® (MG: 7.9).

According to Köppen's classification, the climate of the municipality where the experiments were carried out is of the Aw type, which is called "tropical with the dry season", characterized by more intense rainfall in summer than in winter. In figure 1, there are climatological data related to temperature and relative humidity of the air, luminosity, and rainfall during the period of conducting the experiments.

Source: INMET - Instituto Nacional de Meteorologia. Collection station: Rio Verde (Goiás State).

Fuente: INMET - Instituto Nacional de Meteorología. Estación de recolección: Rio Verde (Estado de Goiás).

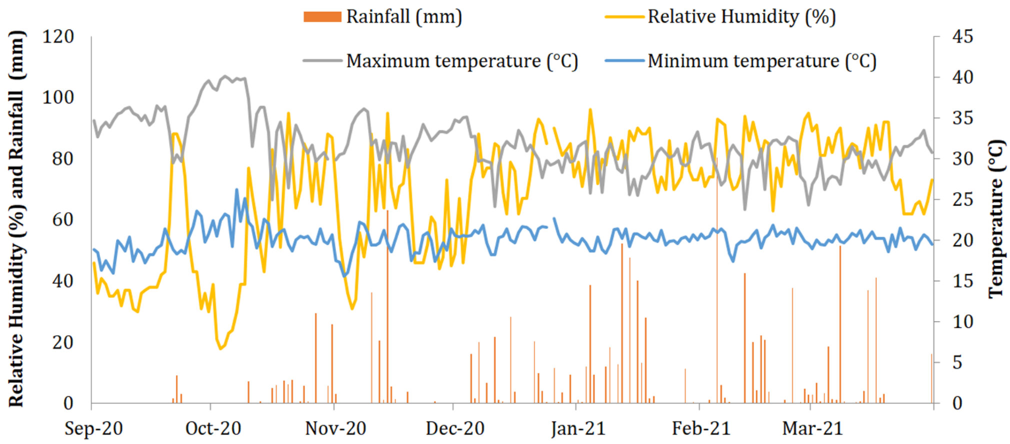

Figure 1. Data on temperature and relative air humidity, luminosity and rainfall during the period of conducting the experiments. Rio Verde (Brazil), 2020/2021.

Figura 1. Datos sobre temperatura y humedad relativa del aire, luminosidad y precipitación durante el período de realización de los experimentos. Rio Verde (Brasil), 2020/2021.

Before the installation of the experiments, the analysis of soil samples collected at depths from 0 to 20 cm was carried out, which revealed the following physicochemical properties: pH in $CaCl^2$ of 4.8; 5.0 $cmol_c\ dm^{-3}$ of $H^+ + Al^{+3}$; 2.78 $cmol_c\ dm^{-3}$ of Ca^{2+}; 1.09 $cmol_c\ dm^{-3}$ of Mg^{+2}; 0.11 $cmol_c\ dm^{-3}$ of K^+; 4.3 mg dm^{-3} of P; 30.2 g dm^{-3} organic matter; 42% sand; 7% silt and 51% clay (sandy clay texture). Before sowing, the weeds present in the experimental area received two herbicide applications (burndown desiccation), the first being carried out ten days before sowing (November 8th, 2020) with the application of glyphosate (720 g a.e. ha^{-1}) and the second on the day of sowing (November 18th, 2020), with the application of glyphosate + flumioxazin (900 + 20 g a.i. ha^{-1}) in association with the addition of Joint Oil® (0.5% V/V).

Soybean sowing was carried out mechanically, adopting a spacing of 0.5 m between rows. Twenty-two, 16, and 10 seeds of soybean were distributed per linear meter for the cultivars M7110 IPRO®, Foco IPRO®, and Bônus IPRO®, respectively. The seeds used in the experiments received industrial treatment with fungicides and insecticides. Fertilization was carried out at sowing time, with application in the furrow of the equivalent of 400 kg ha^{-1} of 02-20-28 (N-P-K). The emergence of soybean seedlings of the three cultivars occurred on November 25th, 2020.

In all experiments, a randomized complete block design was used, evaluating eight treatments with four replications. The treatments consisted of the evaluation of herbicide associations applied in the postemergence period of soybean (table 1). It is worth noting that no adjuvants were added to the application of any of the treatments; this criterion was adopted because all the associations contained a glyphosate-based product in their composition. The experimental units consisted of six sowing lines, with a length of 5.0 m (15.0 m^2). Only the four central lines of each experimental unit were considered useful areas for the evaluations, excluding 0.5 m from each end.

Table 1. Treatments evaluated in post-emergence applications of soybean cultivars. Rio Verde (Brazil), 2020/2021.

Tabla 1. Tratamientos evaluados en aplicaciones de post-emergencia de cultivares de soja. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})*	Mode of action**
Check without herbicide	-	-
Glyphosate	1176	EPSPs inhibitor
Glyphosate + bentazon	1176 + 600	EPSPs inhibitor + PSII inhibitor
Glyphosate + fomesafen	1176 + 175	EPSPs inhibitor + PPO inhibitor
Glyphosate + lactofen	1176 + 120	
Glyphosate + imazethapyr	1176 + 100	EPSPs inhibitor + ALS inhibitor
Glyphosate + chlorimuron	1176 + 10	
Glyphosate + cloransulam	1176 + 39.5	

1/ For glyphosate 1176 g of active ingredient (a.i.) ha^{-1} corresponds to 960 g of acid equivalent (a.e.) ha^{-1}. 2/ EPSPs = 5-enolpyruvylshikimate-3-phosphate synthase; PSII = photosystem II; PPO = protoporphyrinogen oxidase; ALS = acetolactate synthase.

1/ Para el glifosato 1176 g de ingrediente activo (i.a.) ha^{-1} corresponde a 960 g de ácido equivalente (e.a.) ha^{-1}. 2/ EPSPs = 5-enolpiruvilshikimato-3-fosfato sintase; PSII = fotosistema II; PPO = protoporfirinógeno oxidase; ALS = acetolactato sintase.

The treatments application in the three experiments was carried out on December 18th. 2020 (23 days after emergence- DAE). On this occasion, the soybean plants were at stage V5 (5 trifoliated leaves) for the cultivars M7110 IPRO® and Foco IPRO® and at V4 (4 trifoliated leaves) for the Bônus IPRO® cultivar, with plant height varying between 15 and 18 cm. At the time of application, the soil was wet, the temperature and relative humidity, minimum and maximum, were 23.1 and 25.1 °C and 60 and 64%, respectively, and the sky had the presence of few clouds and wind speed at values close to 1.2 km h^{-1}. The applications were carried out using a CO_2 pressurized back sprayer equipped with a boom fitted with 6 fan-type spray tips XR-110.015 spaced 50 cm apart and regulated to a pressure of 0.24 MPa. These application conditions provided an application rate equivalent to 150 l ha^{-1}.

To ensure that the soybean plants were only exposed to the effect of herbicide treatments, manual weeding of the species that made up the weed community of all experimental units was carried out throughout the entire crop cycle. In addition, during the development of soybean, cultural practices were carried out following the recommendations of Embrapa (2013), to control pests and diseases without letting them negatively influence the development of the crop. All phytosanitary applications, except for the herbicide treatments that were the object of evaluation, were carried out using a tractor sprayer machine, adopting an application rate equivalent to 150 l ha^{-1}.

Injury level evaluations of soybean cultivars were carried out at 7 and 28 days after herbicide application (DAA), using for this evaluation the scale proposed by the SBCPD (1995), which presents grades ranging from 0% to 100%, where 0% means the absence of symptoms and 100% represents the death of all plants present in the useful area. Plant height assessments (cm) were carried out at 50 DAE and at harvest time with the aid of a graduated measuring tape, measuring the distance from the soil surface to the apex in 5 plants per experimental unit. In addition, at the time of harvest, an evaluation of the plant stand was carried out, counting the number of plants present in a 3 m row, with the data for this variable presented as the number of plants per linear meter (plants m^{-1}).

Additionally, in harvest, the yield components, number of pods per plant, and mass of 100 grains were evaluated. To evaluate the number of pods per plant, the count of pods present in 5 plants per experimental unit was performed. In the evaluation of 100 grain masses, 100 grains were counted and weighed on a precision scale, correcting the humidity content to 13%. To determine the grain yield, all plants present in the useful area of each experimental unit were plucked manually (M7110 IPRO® and Foco IPRO®, harvested on March 13th, 2021; Bônus IPRO®, harvested on March 18th, 2021), where this material was later submitted to threshing, packaging, identification, weighing and grain humidity correction processes to 13%.

Statistical analyses were performed using SISVAR software (2011). Data from all experiments were submitted to analysis of variance by the F test ($p \leq 0.05$), and when there was a significant effect, the Scott–Knott mean grouping criterion ($p \leq 0.05$) was applied.

Results and discussion

Experiment I: Selectivity of herbicide associations applied postemergence to the soybean cultivar M7110 IPRO®

Observing the phytotoxicity results for the cultivar M7110 IPRO® at 7 DAA, it can be seen that the levels of injuries caused by the herbicides varied from 11.25 and 14.50%, with no significant difference among the herbicide treatments; however, all differed from the control without herbicide application (table 2). Furthermore, it is worth emphasizing that, in this evaluation, the latifolicides associated with glyphosate postemergence did not enhance injury levels compared to the application of glyphosate isolated.

Table 2. Injury level of soybean (cultivar: M7110 IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 2. Fitointoxicación de la soja (cultivar: M7110 IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Injury level (%)			
		7 DAA		28 DAA	
Control without herbicide	-	0.00	a	0.00	a
Glyphosate	1176	11.25	b	2.50	a
Glyphosate + bentazon	1176 + 600	11.25	b	3.75	a
Glyphosate + fomesafen	1176 + 175	12.50	b	5.00	a
Glyphosate + lactofen	1176 + 120	14.50	b	7.50	b
Glyphosate + imazethapyr	1176 + 100	11.25	b	3.75	a
Glyphosate + chlorimuron	1176 + 10	13.25	b	8.25	b
Glyphosate + cloransulam	1176 + 39.5	11.25	b	2.50	a
F_{Value}		14.80*		3.85*	
CV (%)		21.81		66.60	

a.i. = active ingredient; DAA = days after application. * Significant by F test ($p \leq 0.05$). Means followed by different letters in the column differ from each other by the Scott-Knott test ($p \leq 0.05$).

i.a. = ingrediente activo; DAA = días después de la aplicación. * Significativo por prueba F ($p \leq 0,05$). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott ($p \leq 0,05$).

In the evaluation carried out at 28 DAA, the highest percentages of injury levels were seen in soybean plants that received postemergence applications of the association's glyphosate + chlorimuron and glyphosate + lactofen, which presented values of 8.25% and 7.50%, respectively (table 2). In a study by Alonso *et al.* (2010), it was observed that the association glyphosate + lactofen did not present selectivity for the soybean cultivar CD 214 RR®. In this final evaluation, except for the treatments mentioned above, no differences were observed between the other treatments and the control without herbicide application in terms of injury levels, which demonstrates the crop's ability to recover from the negative effects caused by these herbicides.

The evaluation of plant height showed a direct relationship with the results of injury levels, since the treatments that provided higher percentages of injuries promoted a reduction in soybean size at 50 DAE (table 3, page 91). On this occasion, the combination of glyphosate + chlorimuron and glyphosate + lactofen directly affected the plant size of this cultivar, providing reductions of 9.66% and 6.02%, respectively, for the height values measured in the control without herbicides. The low levels of foliar injuries found in the last phytotoxicity evaluation in the other treatments were not able to induce a reduction in the growth of soybean plants, since the height values were similar to the control without herbicide application.

Table 3. Height and stand of soybean plants (cultivar: M7110 IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 3. Altura y soporte de plantas de soja (cultivar: M7110 IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Plant height (cm)				Stand (plants m^{-1})	
		50 DAE		Harvest		50 DAE	
Control without herbicide	-	79.70	a	103.95	a	19.24	a
Glyphosate	1176	79.85	a	103.50	a	19.33	a
Glyphosate + bentazon	1176 + 600	78.70	a	103.05	a	19.16	a
Glyphosate + fomesafen	1176 + 175	78.75	a	100.00	b	19.24	a
Glyphosate + lactofen	1176 + 120	72.00	b	98.50	b	20.58	a
Glyphosate + imazethapyr	1176 + 100	76.55	a	103.20	a	18.24	a
Glyphosate + chlorimuron	1176 + 10	69.10	b	98.35	b	20.41	a
Glyphosate + cloransulam	1176 + 39.5	74.90	a	102.75	a	19.41	a
F_{Value}		6.02*		3.14*		0.73^{ns}	
CV (%)		4.19		2.58		8.88	

a.i. = active ingredient; DAE = Days after emergence. * and ^{ns} Significant and non-significant, respectively, by the F test (*p≤0.05*). Means followed by different letters in the column differ from each other by the Scott-Knott test (*p≤0.05*).

i.a. = ingrediente activo; DAE = Días después de la emergencia. * y ^{ns} Significativo y no significativo, respectivamente, por la prueba F (*p≤0,05*). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott (*p≤0,05*).

At harvest, the PPO inhibitor herbicides fomesafen and lactofen and the ALS inhibitor chlorimuron, all in association with glyphosate, promoted significant reductions in plant height compared to the control without herbicide (table 3). The average reduction in height value imposed by these treatments reached values of 4.81%, with no differences among these three herbicide treatments. The other herbicide treatments did not differ from the control regarding the final plant height. It is noteworthy that the height of plants can influence certain parameters of the soybean crop, such as the potential for plant lodging or yield losses in the mechanized harvesting operation due to the presence of pods at lower heights concerning the height work of the harvester cutting deck (8).

None of the herbicide treatments applied postemergence resulted in decreases in the range of plants evaluated at harvest (table 3). In general, when the herbicide is registered for use in the crop and its positioning is followed correctly, it is unlikely that the plants will die, causing reductions in the final population of the crop. Regarding the evaluations of yield components, as well as soybean grain yield, there were no significant differences among treatments (table 4). In this sense, it is observed that the occurrence of foliar injuries associated with the reduction in the size of plants caused by some herbicide treatments was not enough to affect the productive response of soybean cultivar M7110 IPRO®.

Table 4. Number of pods per plant (NPP), the mass of 100 grains (M100G), and soybean grain yield (cultivar: M7110 IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 4. Número de vainas por planta (NPP), masa de 100 granos (M100G) y rendimiento de grano de soja (cultivar: M7110 IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	NPP		M100G (g)		Yield (kg ha^{-1})	
Control without herbicide	-	30.90	a	18.62	a	4177	a
Glyphosate	1176	27.10	a	18.85	a	4390	a
Glyphosate + bentazon	1176 + 600	27.50	a	18.51	a	3776	a
Glyphosate + fomesafen	1176 + 175	28.67	a	18.71	a	4075	a
Glyphosate + lactofen	1176 + 120	25.60	a	18.95	a	4314	a
Glyphosate + imazethapyr	1176 + 100	32.50	a	18.78	a	4008	a
Glyphosate + chlorimuron	1176 + 10	30.90	a	18.62	a	4238	a
Glyphosate + cloransulam	1176 + 39.5	29.05	a	18.89	a	4135	a
F_{Value}		1.84^{ns}		0.10^{ns}		0.86^{ns}	
CV (%)		11.65		4.95		9.98	

a.i. = active ingredient. ^{ns} Not significant by the F test (*p≤0.05*).

i.a. = ingrediente activo. ^{ns} No significativo por la prueba F (*p≤0,05*).

This fact can be explained by the regular rainfall in the months after spraying the treatments (figure 1, page 88), which may have promoted greater crop recovery capacity after light foliar stresses caused by the herbicides used in the experiment, preserving the yield components (number of pods per plant and mass of 100 grains), as well as grain yield. Work carried out by Alonso *et al.* (2010, 2011, 2013) also demonstrated the selectivity of these herbicides to soybean crops. Despite this, selectivity studies are always necessary, since genetic variations of cultivars are one of the main factors influencing the greater or lesser tolerance of plants to a particular active ingredient (19).

Based on the results obtained in the study with this cultivar, it is evident that all herbicide associations applied postemergence showed selectivity for M7110 IPRO® at the doses and application stage in which they were used. In addition, it appears that the cultivar M7110 IPRO® has good adaptability to cultivation in the region where the experiment was conducted since it presented high yield levels.

Experiment II: Selectivity of herbicide associations applied postemergence to the soybean cultivar Foco IPRO®

Cultivar Foco IPRO® showed differential susceptibility to the variable injury level, with significant differences among herbicide treatments and the control without application (table 5). In the evaluation carried out at 7 DAA, glyphosate in association with lactofen, as well as in association with ALS-inhibitors herbicides, imazethapyr, chlorimuron, and cloransulam, provided the highest percentage of injuries to soybean plants, at levels ranging from 8,75 to 12.50%. The application of glyphosate isolated and the associations of this herbicide with bentazon or fomesafen at 7 DAA resulted in lower levels of intoxication than the other herbicide treatments but were still higher than the control.

Table 5. Injury level of soybean (cultivar: Foco IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 5. Fitointoxicación de la soja (cultivar: Foco IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Injury level (%)			
		7 DAA		28 DAA	
Control without herbicide	-	0.00	a	0.00	a
Glyphosate	1176	3.75	b	1.25	a
Glyphosate + bentazon	1176 + 600	5.00	b	0.00	a
Glyphosate + fomesafen	1176 + 175	6.25	b	2.50	a
Glyphosate + lactofen	1176 + 120	10.25	c	6.25	b
Glyphosate + imazethapyr	1176 + 100	12.50	c	10.00	c
Glyphosate + chlorimuron	1176 + 10	10.75	c	5.75	b
Glyphosate + cloransulam	1176 + 39.5	8.75	c	5.75	b
F_{Value}		12.98*		14.75*	
CV (%)		32.37		47.15	

a.i. = active ingredient; DAA = Days after application. * Significant by F test (*p≤0.05*). Means followed by different letters in the column differ from each other by the Scott-Knott test (*p≤0.05*).

i.a. = ingrediente activo; DAA = días después de la aplicación. * Significativo por prueba F (*p≤0,05*). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott (*p≤0,05*).

Regarding the results obtained in the evaluation carried out at 28 DAA, the association of glyphosate with imazethapyr provided the highest level of injury for this cultivar (10.00%) (table 5), with leaf chlorosis being the main observed visual symptom. Following the treatments with higher levels of injuries, lactofen, chlorimuron, and cloransulam were all applied in association with glyphosate. Furthermore, in this evaluation, the ability of the cultivar Foco IPRO® to recover from the phytotoxicity caused by these previously mentioned herbicides inhibiting PPO and ALS was evident. According to Oliveira Jr. *et al.* (2008), the effects of applying glyphosate to soybeans with RR® technology may vary according to the genotype, the time of application, and the dose of herbicide used.

The data referring to the evaluations of plant height (50 DAE and harvest) and plant stand at harvest are presented in table 6 (page 93). Regarding the evaluation of plant height, the herbicide treatments did not cause changes in the plant height of soybean (cultivar Focus IPRO®) in both evaluations, with no significant differences from the control without application. With the above, there is a quick recovery of the stresses promoted by the herbicides applied postemergence, detected in the visual evaluations of injury levels, allowing that the vegetative growth of the plants was not negatively affected.

Table 6. Height and stand of soybean plants (cultivar: Foco IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 6. Altura y soporte de plantas de soja (cultivar: Foco IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Plant height (cm)				Stand (plants m^{-1})	
		50 DAE		Harvest		50 DAE	
Control without herbicide	-	69.35	a	105.10	a	13.61	a
Glyphosate	1176	67.20	a	104.45	a	13.38	a
Glyphosate + bentazon	1176 + 600	66.35	a	104.20	a	13.88	a
Glyphosate + fomesafen	1176 + 175	66.00	a	102.80	a	13.46	a
Glyphosate + lactofen	1176 + 120	63.45	a	102.20	a	13.08	a
Glyphosate + imazethapyr	1176 + 100	60.85	a	101.35	a	13.77	a
Glyphosate + chlorimuron	1176 + 10	63.80	a	104.00	a	14.10	a
Glyphosate + cloransulam	1176 + 39.5	66.75	a	104.35	a	13.16	a
F_{Value}		2.53^{*}		0.64^{ns}		0.44^{ns}	
CV (%)		5.07		3.11		7.79	

a.i. = active ingredient; DAE = Days after emergence. * and ^{ns} Significant and non-significant, respectively, by the F test ($p\leq0.05$). Means followed by different letters in the column differ from each other by the Scott-Knott test ($p\leq0.05$).

i.a. = ingrediente activo; DAE = Días después de la emergencia. * y ^{ns} Significativo y no significativo, respectivamente, por la prueba F ($p\leq0,05$). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott ($p\leq0,05$).

The final stand of the plants was also not affected by the herbicide treatments (table 6), which demonstrates, once again, the safety regarding the use of these herbicides for the soybean cultivar Foco IPRO®. The evaluated herbicides did not influence yield components (number of pods per plant and weight of 100 grains) or grain yield, not showing significant differences from the control without application (table 7). Marchi *et al.* (2013) reported that the association of glyphosate (1176 g a.i. ha^{-1}) with chlorimuron (10 g a.i. ha^{-1}) applied to soybean plants at stage V2-V3 resulted in a significant reduction in the mass of 100 grains but without an impact on the grain yield. Regular and expressive rainfall observed mainly in the months of January and February favored the cultivar Foco IPRO® in the aspect of reestablishing foliar intoxication initially promoted by the herbicides, favoring the demonstration of herbicide selectivity. The cultivar Foco IPRO® presented, regardless of the herbicide treatments, yields ranging from 3,510 to 4,067 kg ha^{-1}, which demonstrates its good adaptability to the southwestern region of Goiás State.

Table 7. Number of pods per plant (NPP), mass of 100 grains (M100G) and soybean grain yield (cultivar: Focus IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 7. Número de vainas por planta (NPP), masa de 100 granos (M100G) y rendimiento de grano de soja (cultivar: Focus IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	NPP		M100G (g)		Yield (kg ha^{-1})	
Control without herbicide	-	45.70	a	16.76	a	3879	a
Glyphosate	1176	47.60	a	16.28	a	3935	a
Glyphosate + bentazon	1176 + 600	46.70	a	16.02	a	4067	a
Glyphosate + fomesafen	1176 + 175	47.05	a	16.06	a	3510	a
Glyphosate + lactofen	1176 + 120	50.00	a	16.05	a	3715	a
Glyphosate + imazethapyr	1176 + 100	45.60	a	15.92	a	3889	a
Glyphosate + chlorimuron	1176 + 10	48.40	a	16.36	a	3835	a
Glyphosate + cloransulam	1176 + 39.5	49.80	a	15.89	a	4017	a
F_{Value}		0.57^{ns}		1.54^{ns}		1.02^{ns}	
CV (%)		9.36		2.87		9.05	

a.i. = active ingredient. ^{ns} Not significant by the F test ($p\leq0.05$).

i.a. = ingrediente activo. ^{ns} No significativo por la prueba F ($p\leq0,05$).

Experiment III: Selectivity of herbicide associations applied postemergence to the soybean cultivar Bônus IPRO®

The injury level caused by the herbicide treatments for the Bônus IPRO® soybean cultivar is shown in table 8. As seen for the other cultivars, more accentuated levels of phytotoxicity occurred in the first evaluation (7 DAA), with a partial or complete recovery of most soybean plants in the later evaluation (28 DAA).

Table 8. Injury level of soybean (cultivar: Bônus IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 8. Fitointoxicación de la soja (cultivar: Bônus IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Injury level (%)			
		7 DAA		28 DAA	
Control without herbicide	-	0.00	a	0.00	a
Glyphosate	1176	2.50	a	0.00	a
Glyphosate + bentazon	1176 + 600	6.25	b	1.25	a
Glyphosate + fomesafen	1176 + 175	12.50	c	3.75	a
Glyphosate + lactofen	1176 + 120	13.75	d	5.00	b
Glyphosate + imazethapyr	1176 + 100	11.25	c	2.50	a
Glyphosate + chlorimuron	1176 + 10	16.25	d	10.00	b
Glyphosate + cloransulam	1176 + 39.5	10.75	c	7.00	b
F_{Value}		22.97*		6.73*	
CV (%)		25.93		73.71	

a.i. = active ingredient; DAA = Days after application. * Significant by F test ($p \leq 0.05$). Means followed by different letters in the column differ from each other by the Scott-Knott test ($p \leq 0.05$).

i.a. = ingrediente activo; DAA = días después de la aplicación. * Significativo por prueba F ($p \leq 0,05$). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott ($p \leq 0,05$).

At 7 DAA, the PPO and ALS inhibitors lactofen and chlorimuron, respectively, both associated with glyphosate, presented the highest percentages of injury levels to the soybean cultivar Bônus IPRO®, with averages of 13.75% and 16,25%, respectively, differing significantly from the other treatments and the control without herbicide application. These data corroborate the results presented by Alonso *et al.* (2010), who verified that the association of herbicides with PPO and ALS modes of action to glyphosate present symptoms of foliar phytotoxicity to soybean plants superior to other tested mixtures in evaluations carried out at 7 and 15 DAA.

The initial leaf symptoms observed after the application of these herbicides were similar to those described by Alonso *et al.* (2013), including chlorimuron chlorosis followed by necrosis in the apical leaves and chlorosis with subsequent necrosis and wrinkling for lactofen. Even at 7 DAA, the associations of glyphosate with cloransulam, imazethapyr, or fomesafen showed intermediate levels of injuries, with phytotoxicity varying from 10.75 to 12.50%, not differing from each other. The PSII inhibitor bentazon, in association with glyphosate, promoted mild injury symptoms (6.25%), characterized by small and few chlorotic and necrotic spots on the leaves.

At 28 DAA, the soybean plants of the Bônus IPRO® cultivar already showed good recovery from the symptoms of injuries; however, higher levels of injuries were observed in treatments involving the association of glyphosate with lactofen, chlorimuron, and cloransulam, where the levels were in the range of 5.00 to 10.00%. The other herbicide treatments evaluated did not show significant differences among them, with a maximum percentage of injuries of 3.75%, and were statistically equivalent to the control, which was without application.

At 50 DAE, a significant reduction was observed in the soybean plant size of the Bônus IPRO® cultivar that received a postemergence application of the association glyphosate + chlorimuron, with an average decrease of 18.31% in plant height when compared to the control without herbicide application (table 9, page 95). The glyphosate + imazethapyr and glyphosate + lactofen treatments also resulted in a lower plant height of soybean, but at a lower magnitude, with an average reduction of 7.42%. All other herbicide treatments did not significantly affect the size of soybean plants when compared to the control without herbicide application. Of the morphological variables, plant height was the most affected by herbicides applied postemergence and is an important parameter for measurement in selectivity experiments (12).

At harvest, plants of the cultivar Bônus IPRO® recovered for the variable height, with no more differences among the glyphosate + imazethapyr and glyphosate + lactofen associations and the control without herbicide application (table 9). Only the glyphosate + chlorimuron treatment provided a lower final plant height, with an average reduction of 9.56%, compared to the average height of soybean plants present in the control treatment plots without herbicides. Correia and Durigan (2007), evaluating the selectivity of eight commercial formulations of glyphosate-based products to two RR® soybean cultivars, found that none of the herbicides influenced the plant height.

Table 9. Height and stand of soybean plants (cultivar: Bônus IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 9. Altura y soporte de plantas de soja (cultivar: Bônus IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	Plant height (cm)				Stand (plants m^{-1})	
		50 DAE		Harvest		Harvest	
Control without herbicide	-	62.15	a	122.05	a	7.69	a
Glyphosate	1176	63.20	a	120.40	a	7.30	a
Glyphosate + bentazon	1176 + 600	61.50	a	117.35	a	8.33	a
Glyphosate + fomesafen	1176 + 175	61.25	a	122.05	a	7.72	a
Glyphosate + lactofen	1176 + 120	56.70	b	116.70	a	7.47	a
Glyphosate + imazethapyr	1176 + 100	57.65	b	115.85	a	6.80	a
Glyphosate + chlorimuron	1176 + 10	50.45	c	107.75	b	8.14	a
Glyphosate + cloransulam	1176 + 39.5	60.70	a	117.60	a	8.25	a
F_{Value}		9.66*		4.50*		1.43^{ns}	
CV (%)		4.53		3.69		11.29	

a.i. = active ingredient; DAE = Days after emergence. * and ^{ns} Significant and non-significant, respectively, by the F test ($p≤0.05$). Means followed by different letters in the column differ from each other by the Scott-Knott test ($p≤0.05$).

i.a. = ingrediente activo; DAE = Días después de la emergencia. * y ^{ns} Significativo y no significativo, respectivamente, por la prueba F ($p≤0,05$). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott ($p≤0,05$).

The final stand of plants for the Bônus IPRO® cultivar remained statistically the same for all treatments, with no significant reduction occurring among the experimental units that received the herbicides and the control (table 9). This result consolidates the results found for the cultivars M7110 IPRO® and Foco IPRO®, where it is verified that the evaluated herbicide treatments did not reduce the plant stand. For the variables number of pods per plant and mass of 100 grains, negative changes were not verified in the soybean plants of the cultivar Bônus IPRO® due to the application of postemergence herbicides (table 10, page 96). This result differs from the study carried out by Alonso *et al.* (2011), where it was verified that the association of glyphosate and lactofen promoted a significant reduction in the mass of 100 grains.

Regarding grain yield, the treatments isolated glyphosate, glyphosate + lactofen, and glyphosate + imazethapyr provided significant reductions in this parameter of 8.99%, 6.62%, and 9.67%, respectively, compared to the grain yield recorded in the control without herbicide application (table 10, page 96). These results demonstrate the lack of selectivity of these herbicide treatments for use in production areas that use this cultivar. According to Constantin *et al.* (2016), the attenuation of negative effects, such as foliar injuries, caused by the herbicide glyphosate in genetically modified soybean cultivars (RR®) can be minimized, maintaining the crop's yield potential through the use of biostimulant products. The other herbicide treatments did not damage the grain yield of the cultivar Bônus IPRO®, which presented yields ranging from 3,288 to 3,903 kg ha^{-1}, regardless of the evaluated herbicide treatments.

Table 10. Number of pods per plant (NPP), mass of 100 grains (M100G) and soybean grain yield (cultivar: Bônus IPRO®) after application of post-emergence herbicide associations. Rio Verde (Brazil), 2020/2021.

Tabla 10. Número de vainas por planta (NPP), masa de 100 granos (M100G) y rendimiento de grano de soja (cultivar: Bônus IPRO®) después de la aplicación de asociaciones de herbicidas de postemergencia. Rio Verde (Brasil), 2020/2021.

Treatments	Doses (g a.i. ha^{-1})	NPP		M100G (g)		Yield (kg ha^{-1})	
Control without herbicide	-	69.70	a	22.00	a	3694	a
Glyphosate	1176	66.65	a	20.25	a	3288	b
Glyphosate + bentazon	1176 + 600	60.90	a	22.50	a	3903	a
Glyphosate + fomesafen	1176 + 175	60.50	a	20.25	a	3707	a
Glyphosate + lactofen	1176 + 120	60.40	a	21.00	a	3449	b
Glyphosate + imazethapyr	1176 + 100	64.80	a	21.25	a	3337	b
Glyphosate + chlorimuron	1176 + 10	57.85	a	21.75	a	3607	a
Glyphosate + cloransulam	1176 + 39.5	68.55	a	21.00	a	3746	a
F_{Value}		1.31^{ns}		0.79^{ns}		2.51*	
CV (%)		11.94		8.48		7.54	

a.i. = active ingredient. * and ^{ns} Significant and non-significant, respectively, by the F test ($p≤0.05$). Means followed by different letters in the column differ from each other by the Scott-Knott test ($p≤0.05$).

i.a. = ingrediente activo. * y ^{ns} Significativo y no significativo, respectivamente, por la prueba F ($p≤0,05$). Medias seguidas de letras diferentes en la columna difieren entre sí por la prueba de Scott-Knott ($p≤0,05$).

Conclusion

The stand of plants at harvest of soybean cultivars M7110 IPRO®, Foco IPRO®, and Bônus IPRO® was not decreased by postemergence applications of glyphosate, either isolated or in association with bentazon, fomesafen, lactofen, imazethapyr, chlorimuron, and cloransulam.

None of the evaluated herbicide treatments caused a reduction in the grain yield of cultivars M7110 IPRO® and Foco IPRO®; however, the herbicides lactofen and chlorimuron, in association with glyphosate, were the ones that caused the highest levels of phytotoxicity to M7110 IPRO®, and the combination of glyphosate with imazethapyr caused greater phytotoxicity in the cultivar Foco IPRO®.

Post-emergence application of glyphosate was isolated, and the associations of glyphosate + lactofen and glyphosate + imazethapyr decreased the grain yield of the Bônus IPRO® soybean cultivar.

The results of the present work reinforce the need for care in choosing the soybean cultivar and the selection of the herbicides to be applied postemergence, as the genetics of the material are decisive for the response in terms of sensitivity to the applied herbicides.

References

1. Albrecht, L. P.; Albrecht, A. J. P.; Moreira Silva, A. F.; Ramos, R. A.; Rodrigues da Costa, K. Y.; Viana de Araújo, G.; Mundt, T. T.; Colombari, C. 2022. Sequential application of herbicide options for controlling *Conyza sumatrensis* in soybean pre-sowing. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 54(2): 83-93.
2. Alonso, D. G.; Constantin, J., Oliveira Jr., R. S.; Biffe, D. F.; Raimondi, M. A.; Gemelli, A.; Blainski, E.; Carneiro, J. 2010. Selectivity of glyphosate in tank mixtures for RR soybean in sequential applications with mixtures only in the first or second application. Planta Daninha. Brazil. 28(4): 865-875.
3. Alonso, D. G.; Constantin, J.; Oliveira Jr., R. S.; Arantes, J. G. Z.; Cavalieri, S. D.; Santos, G.; Rios, F. A.; Franchini, L. H. M. 2011. Selectivity of glyphosate tank mixtures for RR soybean. Planta Daninha. Brazil. 29(4): 929-937.
4. Alonso, D. G.; Constantin, J.; Oliveira Jr., R. S.; Santos, G.; Dan, H. A.; Oliveira Neto, A. M. 2013. Seletividade de glyphosate isolado ou em misturas para soja RR em aplicações sequenciais. Planta Daninha. Brazil. 31(1): 203-212.
5. Beckie, H. J. 2011. Herbicide-resistant weed management: focus on glyphosate. Pest Manag. Sci. 67(9): 1037-1048.
6. Bott, S.; Tesfamariam T.; Candan, H.; Cakmak, I.; Römheld, V.; Neumann, G. 2008. Glyphosate induced impairment of plant growth and micronutrient status in glyphosate-resistant soybean (*Glycine max* L.). Plant and Soil. 312(1): 85-194.

7. Constantin, J.; Oliveira Jr., R. S.; Gheno, E. A.; Biffe, D. F.; Braz, G. B. P.; Weber, F.; Takano, H. K. 2016. Prevention of yield losses caused by glyphosate in soybeans with biostimulant. Afr. Jour. Agri. Res. 11(18): 1601-1607.
8. Constantin, J.; Braz, G. B. P.; Oliveira Jr., R. S.; Andrade, C. L. L.; Pereira, B. C. S.; Machado, F. G. 2020. Performance of RR soybean submitted to postemergence application of glyphosate with a foliar elicitor product. Arquiv. Inst. Biol. Brazil. 87: e0492019.
9. Correia, N. M.; Durigan, J. C. 2007. Seletividade de diferentes herbicidas à base de glyphosate a soja RR. Planta Daninha. Brazil. 25(2): 375-379.
10. Embrapa. Tecnologias de Produção de Soja. 2013. Região Central do Brasil. Londrina, PR: Embrapa Soja. 265 p.
11. Ferreira, D. F. 2011. Sisvar: a computer statistical analysis system. Ciên. Agr. Brazil. 35(6): 1039-1042.
12. Fornazza, F. G. F.; Constantin, J.; Machado, F. G.; Oliveira Jr.; R. S.; Silva, G. D.; Rios, F. A. 2018. Selectivity of pre-and post-emergence herbicides to very-early maturing soybean cultivars. Comum. Sci. 9(4): 649-658.
13. Galon, L.; Konzen, A.; Bagnara, M. A. M.; Brunetto, L.; Aspiazú, I.; da Silva, A. M. L.; Brandler, D.; Linsingen Piazzetta, H. V.; Radünz, A. L.; Perin, G. F. 2022. Interference and threshold level of *Sida rhombifolia* in transgenic soybean cultivars. Revista de la Facultad de Ciencias Agrarias Universidad Nacional de Cuyo. Mendoza. Argentina. 54(2): 94-106.
14. López-Ovejero, R. F.; Penckowski, L. H.; Podolan, M. J.; Carvalho, S. J. P.; Christoffoleti, P. J. 2006. Alternativas de manejo químico da planta daninha *Digitaria ciliaris* resistente aos herbicidas inibidores da ACCase na cultura de soja. Planta Daninha. Brazil. 24(2): 407-414.
15. Marchi, S. R.; Borgoni, D.; Biazzi, L.; Bellé, J. R. 2013. Associações entre glifosato e herbicidas pósemergentes para o controle de trapoeraba em soja RR®. Rev. Bras. Her. Brazil. 12(1): 23-30.
16. Oliveira Jr., R. S.; Dvoranen, E. C.; Constantin, J.; Cavalieri, S. D.; Franchini, L. H. M.; Rios, F. A.; Blainski, E. 2008. Influência do glyphosate sobre a nodulação e o crescimento de cultivares de soja resistente ao glyphosate. Planta Daninha. Brazil. 26(4): 831-843.
17. Osipe, J. B.; Oliveira Jr., R. S.; Constantin, J.; Biffe, D. F.; Rios, F. A.; Franchini, L. H. M.; Gheno, E. A.; Raimondi, M. A. 2014. Seletividade de aplicações combinadas de herbicidas em pré e pósemergência para a soja tolerante ao glyphosate. Bio. Jour. Brazil. 30(3): 623-631.
18. Owen, M. D. K.; Zelaya, I. A. 2005. Herbicide-resistant crops and weed resistance to herbicides. Pest Manag. Sci. 61(3): 301-311.
19. Priess, G. L.; Norsworthy, J. K.; Roberts, T. L.; Gbur Jr., E. E. 2020. Impact of postemergence herbicides on soybean injury and canopy formation. Weed Tech. 34(5): 727-734.
20. Sociedade Brasileira da Ciência Das Plantas Daninhas (SBCPD). 1995. Procedimentos para instalação, avaliação e análise de experimentos com herbicidas. Londrina: SBCPD. 42 p.
21. Vieira Júnior, N. S.; Jakelaitis, A.; Cardoso, I. S.; Rezende, P. N.; Moraes, N. C.; Tavares, C. J. 2015. Associação de herbicidas aplicados em pós emergência na cultura do milho. Global Sci. and Tech. 8(1): 1-8.
22. Zobiole, L. H. S.; Oliveira Jr., R. S.; Huber, D. M.; Constantin J.; Castro, C.; Oliveira F. A.; Oliveira Júnior, A. 2010. Glyphosate reduces shoot concentrations of mineral nutrients in glyphosate resistant soybeans. Plant and Soil. 328: 57-69.

Acknowledgements

Thanks to the *Universidade de Rio Verde* (UniRV), *Fundação de Amparo à Pesquisa do Estado de Goiás* (FAPEG), and *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) for the financial research support of this research (Process number: 201810267001546).