Advances in Weed Science
formerly Planta Daninha

RESEARCH ARTICLE

Accessions to glyphosate and ACCase-inhibiting herbicides in Argentina. Sorghum halepense response to herbicides

Julio A. Scursoni[a], Juan P. Morello[a], María S. Muñoz[a], Gabriel Fantin[a], Daniela Medina Herrera[a], Brenda Seco[a], Facundo Villanueva[a]

[a] Facultad de Agronomía UBA Buenos Aires, Ciudad Autónoma de Buenos Aires, Argentina. Cátedra de Producción Vegetal. Facultad de Agronomía. U.B.A.

Abstract: **Background**: Johnsongrass (Sorghum halepense) is an important weed in summer crops of Argentina. In 2005, the first population resistant to glyphosate was identified and in 2015 one multiple resistant to glyphosate and haloxyfop methyl was registered. Another population with multiple resistance to glyphosate, haloxyfop methyl and clethodim was also identified in 2020. This study represents the first complete survey of herbicide resistant populations of johnsongrass in Argentina.

Objective: The objective was to quantify the presence and distribution of ACCase and glyphosate resistant johnsongrass populations. In addition, the resistance factor (RF) was estimated for some populations, and the target site resistance mechanism was also studied. Methodology: From 2014 to 2023, a set of experiments was performed with the aim of studying the responses of 392 populations of johnsongrass to glyphosate, clethodim and haloxyfop-methyl. Survival was assessed 30 days after herbicide applications. One population known as susceptible to each herbicide was included. The applications were made with a CO2- powered backpack sprayer when seedling plants had four to six expanded leaves.

Results: Glyphosate resistance was prevalent (70%). The frequency of populations showing survival with haloxyfop-methyl (15%) was greater than that with clethodim (7%). Eight percent were cross resistant (haloxyfop-methyl + clethodim), and 19% multiple resistance to glyphosate + ACCase inhibitors. Mutation W2027C was identified in one population resistant to haloxyfop methyl and glyphosate. Mutation W1999G was identified in a population with multiple resistance to haloxyfop-methyl, clethodim and glyphosate from Santa Fe, and mutations W2027C and G2096A occurred in another population from Córdoba.

Keywords: Resistance, Clethodim, haloxifop methyl

Journal Information:
ISSN - 2675-9462
Website: http://awsjournal.org
Journal of the Brazilian Weed Science Society

How to cite: Scursoni JA, Morello JP, Muñoz MS, Fantin G, Herrera DM, Seco B, Villanueva F. Accessions to glyphosate and ACCase-inhibiting herbicides in Argentina Sorghum halepense response to herbicides. Adv Weed Sci. 2026;44:e020250021. https://doi.org/10.51694/AdvWeedSci/2026;44:0007

Approved by:
Editor in Chief: Carol Ann Mallory-Smith
Associate Editor: Rafael Munhoz Pedroso

Conflict of Interest: The authors declare no conflict of interest regarding the publication of this manuscript.

Received: March 11, 2025
Approved: February 26, 2026

* Corresponding author:
<scursoni@agro.uba.ar>

This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided that the original author and source are credited.

Copyright: 2022

1. Introduction

Johnsongrass (*Sorghum halepense L. Pers*) is one of the most problematic weeds in the world. It is present in 53 countries in a broad range of latitudes from 45° S to 55° N (Holm et al., 1977). In Argentina, it is also present in different cropping systems from irrigated crops in the Rio Colorado Valley (36° S) to extensive soybean and maize crops in northern Salta province (22°S) (Leguizamón 2012). According to surveys performed by De la Fuente (2021), Conyza bonariensis L. (Cronquist), Amaranthus hybridus L., Eleusine indica L. Gaertn, Sorghum halepense and Amaranthus palmeri (S. Wats), are the five main herbicide resistant weeds in the country. Likewise, and in agreement with estimations of REM AAPRESID (2023), the area covered by glyphosate- resistant johnsongrass in 2023 was slightly more than twelve million ha. The area covered by ACCase resistant biotypes is significantly lower than with glyphosate resistant biotypes, but they are present in 50% of the states where there is presence of glyphosate resistant biotypes (Asociación Argentina de Productores en Siembra Directa, 2023).

From the 1995/96 growing season, glyphosate-resistant soybean (RR, Roundup Ready) began to be sown in Argentina. This technology was massively adopted by farmers, reaching almost 100% of the total soybean area in eight years from its introduction. In addition, only few years after RR soybean was adopted, RR corn (Zea mays L.) and RR cotton (Gossypium hirsutum L.) were introduced, and their planted areas rapidly expanded (Consejo Argentino para la Información y el Desarrollo de la Biotecnología, 2023).

The adoption of GM crops brought a high increase of use of glyphosate, representing 70% of the total herbicide market of Argentina. The efficacy and versatility of glyphosate added to the economic advantage of this technology, which explains its massive adoption by farmers. In addition to the introduction of glyphosate-resistant crops, other important changes in crop production were the adoption of direct seeding systems, replacing tillage with herbicides during the fallow (i.e., chemical fallow). In these conditions, glyphosate was the most applied herbicide mixed with residual herbicides such as atrazine or metsulfuron methyl and postemergence auxinic herbicides (2,4 D; dicamba) (Scursoni et al., 2021).

Ten years after the introduction of RR technology, the first case of glyphosate resistance in Argentina was recorded in Johnsongrass (Vila Aiub et al., 2007). Two years after, Lolium perenne L. glyphosate resistance was also identified. So far there are several herbicide resistant biotypes registered in Argentina, namely 31 for glyphosate, 16 for ALS inhibitors, nine for ACCase inhibitors, six for auxinic herbicides and one for PPO inhibitors. Moreover, 15 biotypes are resistant to multiple herbicides (REM AAPRESID 2024). The increase of Johnsongrass populations resistant to glyphosate led to the use of ACCase- inhibiting herbicides, particularly haloxyfop methyl and clethodim. In 2015, a population resistant to haloxyfop methyl and another one with multiple resistant to haloxyfop methyl and glyphosate were identified. In addition, another population with multiple resistance to haloxyfop methyl, clethodim and glyphosate was documented in 2020 (Heap 2025). Regarding the cases of johnsongrass resistance worldwide, there are seven biotypes resistant to glyphosate including one with multiple resistance (glyphosate-ACCasa inhibitors); twelve that are resistant to ALS inhibitors, including one with multiple resistance to nicosulfuron and fluazifop butyl; and eleven that are resistant to ACCase inhibitors. With respect to the ALS inhibitors, there are more cases of resistance to sulfonylureas than to other chemical families. In addition, for the ACCase inhibitors, there are more cases of resistance to aryloxyphenoxypropionates (FOPS) than cyclohexanediones (DIM) and phenylpyazoles (DEN). Interestingly there is only one case of resistance to pendimethalin (Heap 2025).

Given the economic importance of johnsongrass in soybean production in Argentina, the objective of this study was to conduct a national survey to quantify the frequency and distribution of ACCase and glyphosate resistance in the country. In addition, the resistance factor index (RF) was calculated for some populations and the target site resistance mechanism was studied. This is the first detailed survey of resistant populations of johnsongrass in Argentina.

2. Materials and methods

From the 2014-15 to 2022-23 growing seasons, johnsongrass seeds were collected in soybean production fields with the aim of studying the response to glyphosate, haloxyfop methyl and clethodim. The seed collection sites encompassed the main soybean crop production areas of Argentina representing about twenty million hectares (Figure 1). The areas covered were the northwest and northeast of Argentina (NWA, Salta province and NEA, Chaco), and Cordoba, Santa Fe and Buenos Aires provinces from the core zone.

During all the growing seasons 471 populations were collected and 392 (83%) were treated with the herbicides (Table 1).

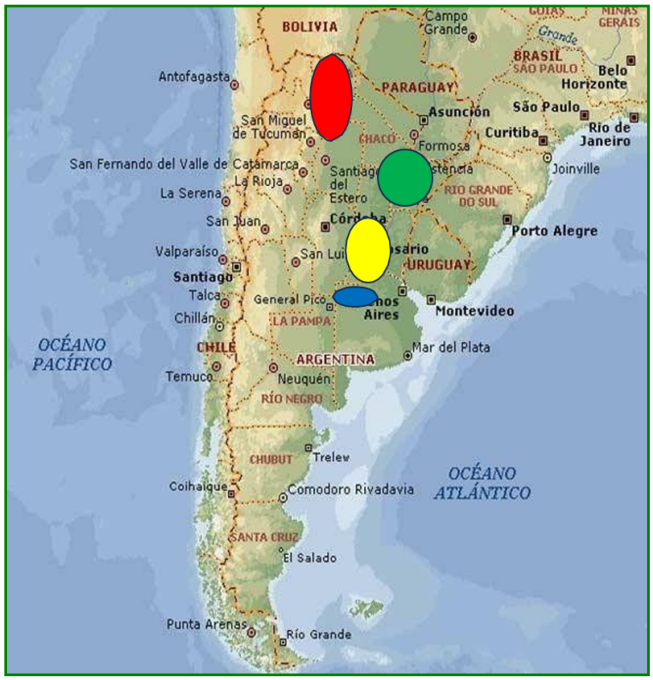


Figure 1 - Areas from seeds collection. NWA (red) NEA (green) Core Zone, Santa Fe and Córdoba (yellow), Buenos Aires (Blue)

Table 1 - Number of populations harvested and treated with herbicides from different areas

AREA	N°TREATED	N°HARVESTED	TREATED/ HARVESTED (%)
Buenos Aires	66	79	84
Santa Fe	117	142	83
Cordoba	105	154	85
NWA	76	102	75
NEA*	27	24	113
Total	392	471	83

*Some populations from NEA were treated more than one time.

2.1 Seed collection

Johnsongrass seeds were collected from the fields when most of the seeds were mature during February, March and April of each year. The seeds were collected in soybean crops in which individuals of johnsongrass were observed before the crop harvest. At each field, mature inflorescences were randomly collected from an average of 50 individuals. The samples were kept at room temperature in paper bags until their threshing in May, June and July of each year.

2.2 Seedling establishment

Collected seeds were sown during October/November/December of each growing season. Sowing was done directly in 40x30 cm trays containing substrate composed of soil,

peat, and perlite. Trays were kept in optimum humidity conditions until seedlings emerged. Subsequently, seedlings were transplanted into 0.6 L pots, totaling 4 or 5 plants/pot. After transplanting, the pots were irrigated and maintained at field capacity in outdoor conditions. Preventive control of diseases and insects was performed by applications of difenoconazole + pydiflumetofen and chlorantraniprole + lambda cyhalothrin, respectively.

2.3 Herbicide Treatments and plant survival evaluation

Five replications arranged in a completely randomized design were established for each treatment in each accession. The experimental unit consisted of a pot with four or five plants (depending on the number of seedlings available). The herbicides and rates used in each treatment were those recommended for johnsongrass seedlings on the label (Table 2). In addition, a control treatment (untreated plants) was included. At the 4-6 leaf stage, plants were treated using a backpack sprayer at 18 kg pressure and a volume of 140 l ha. Survival was assessed 30 days after treatment. Individuals were recorded as alive if they were actively growing after treatment and dead if there was no presence of photosynthetically active tissue. Survival was expressed as the proportion of surviving individuals in relation to the total number of treated plants.

For all the experiments, a susceptible population to all the herbicides was included. Based on plant survival, populations were classified as susceptible (0% survival), resistance in progress (>0 to <10%), low resistant (10% - <30% survival) and resistant (=> 30% survival).

2.4 Dose response curves

In order to quantify the resistance level of some populations with high survival to different treatments, dose-response experiments were performed for each herbicide. For each population, seven rates of herbicides were applied, three rates below (0.125, 0.250 and 0.500 x) and three rates (2, 4 and 8x) above the recommended field rate of the herbicide. For each rate, three replications of four plants per pot were established and survival was evaluated as described above.

Table 2 - Herbicides Treatments applied on different growing seasons. *Half rates were applied from 2014–2018 and 2022–2023

Treatments	Formulated % e.a/i.a.	Rates (cm^3/ha)	Rates (cm^3 a.i./ha)
Glyphosate	50.6	1.750	875
Haloxyfop methyl	54	80	43.2
Haloxyfop methyl	54	40*	21.6
Clethodim	24	400	96
Clethodim	24	200*	48

2.5 Statistical analysis

Plant survival (%) response to the herbicides in each accession was used to obtain descriptive statistics (mean, median, quartile 25% and quartile 75%), using INFOSTAT software (Di Rienzo et al., 2011). This analysis was conducted to evaluate the sensitivity of johnsongrass populations to glyphosate, haloxyfop methyl and clethodim.

2.6 Dose response

Survival data and herbicide rates were subjected to nonlinear regression analysis in R software v. 1.0.143 using the dose response curve with a log-logistic equation proposed by Seefeldt et al. (1995):

$$Y = C + \frac{D - C}{1 + \left(\frac{x}{DL50}\right)^b} \quad (1)$$

Where C = the lower limit, D = 5 the upper limit, b = the slope at the DL50, and DL50 = the herbicide rate required for 50% survival reduction.

The level of resistance (R) for a population was determined by the resistance ratio (R/S), which was calculated as the DL50 of the R population divided by the DL50 of the susceptible control (S) population.

2.7 Mechanism of resistance

The ACCase gene was sequenced for some johnsongrass populations that were found to be resistant to clethodim or haloxyfop in the whole plant pot test. For each plant, one centimeter of leaf tissue was harvested and placed in a 96-well plate and lyophilized in a freeze dryer for three consecutive days and then shipped to Syngenta, Research Triangle Park, North Carolina, USA for DNA extraction and Sanger sequencing. Genomic DNA was extracted using the MagMAX™ Plant DNA Isolation Kit (Thermo Scientific™, Waltham, Massachusetts, USA) and quantified using a Nano Drop 8,000 (Thermo Fisher Scientific Waltham, Massachusetts, USA). Polymerase chain reaction targeted a fragment that encompassed ACCase codons 1,651 to 2,109 ensuring the genotyping of codons 1,781, 1,999, 2,027, 2,041, 2,078, 2,088 and 2,096, which are important for the binding of ACCase herbicides to the target enzyme. The forward and reverse primers were 5'ATGTCAACACCTGAATTTCCC3' and 5'CTGAACTTGATTTCAATTAACCC3', respectively. PCR was performed in 25 µL reaction volume containing 5.0 µL of GoTaq Buffer, 0.5 µL of 10 mM dNTPs, 1.5 µL of 25 mM MgCl2, 0.5 µL of 10 µM of each forward and reverse primers, 0.2 µL of GoTaq G2 Hot Start Polymerase (Promega, Madison, Wisconsin, USA) and 14.8 µL of ultrapure nuclease-free water (Sigma-Aldrich, Burlington, Massachusetts, USA). PCR cycling conditions were as follows: an initial step of 95°C for 2 min, 35 cycles at 94°C for 1 min, 58°C for 30 s, 72°C for 90 s and final extension step of 72°C for 10 min. The PCR products were run on 1.0%

Table 3 - Frequency (%) of populations susceptible (0% survival) to each herbicide treatment in different areas

	Haloxifop methyl		Clethodim		Glyphosate	
Area	N° and Freq.	N° pop. Treated	N° and Freq.	N° pop. Treated	N° and Freq.	N° pop. Treated
Bs. Aires	41 (62%)	66	51 (77%)	66	32 (52%)	61
Córdoba	60 (57%)	105	75 (71%)	105	26 (26%)	100
Santa Fe	57 (52%)	117	84 (72%)	117	18 (17%)	107
NWA	42 (55%)	76	57 (75%)	76	21 (29%)	73
NEA	21 (81%)	26	23 (85%)	27	16 (61%)	26
Total	225 (57%)	390	290 (74%)	391	113 (31%)	367

agarose gel to verify presence of the respective amplicons. The amplified DNAs were purified and sequenced on a Genetic Analyzer 3,500 instrument (Applied Biosystems, Thermo Fisher, Waltham, Massachusetts, USA) following the manufacturer's instructions. The chromatograms were manually read using Geneious Prime 2020.1.2.

3. Results and Discussion

There were more populations susceptible to clethodim (290, 74%) than to haloxyfop- methyl (225, 57%) and glyphosate (113, 31%) (Table 3). In addition, 75 populations (19%) were susceptible to all treatments. These results correspond to the level of adoption of each of the three different herbicides. Sensitive populations to glyphosate were more frequent in Buenos Aires and NEA than in the other zones. This may be related to more crop rotation practiced in Buenos Aires than at the core area (Santa Fe and Cordoba) and NWA, where soybean monoculture is prevalent. Crop rotation is an agronomic practice that should be used by farmers to prevent the resistance evolution (Norsworthy et al., 2012). The frequency of susceptible populations to glyphosate is higher than what is considered by farmers. The conditions at which the herbicides were applied in the experiment are those recommended on the label, both in terms of plant size and environmental conditions. In farm fields, however, herbicides often are applied to plants at very advanced stages of growth, and resulting poor control is sometimes mistakenly attributed to resistance.

3.1 Resistance in progress (survival >0-<10%)

Overall, resistance in progress was higher for haloxyfop-methyl and clethodim than for glyphosate. The number of populations showing resistance in progress were 46, 39 and 14 for haloxifop-methyl, clethodim and glyphosate, respectively representing 12%, 10% and 4% of the populations treated with each herbicide. These results reflect the replacement in the use of glyphosate by graminicides because of the increase of glyphosate-resistant biotypes.

3.2 Resistant populations

Regarding all the populations, areas, and growing seasons, frequency (%) of resistant populations (survival ≥ 10%) to glyphosate was higher than to ACCase inhibitors and, in addition, there were more resistant populations to haloxyfop methyl than to clethodim (Figure 2).

Average survival for each treatment was higher for glyphosate than for the ACCase inhibitors. Moreover, median, Q1 and Q3 values are higher for glyphosate than for ACCase inhibitors (Table 4). In addition, frequency of populations with high survival (>50%) was higher for glyphosate than for the other treatments (Table 5). Fifty percent of the populations showed high survival to glyphosate applications while 12% and 3% showed high survival to haloxyfop- methyl and clethodim treatments, respectively. Most of the populations with high resistance to haloxyfop-methyl and clethodim were recorded on the core zone (Santa Fe and Córdoba). On the other hand, regarding high resistance to glyphosate, lower frequencies were recorded in Buenos Aires (9%) and NEA (1.6%).

3.3 Cross and Multiple Resistance

About 8% of the populations (32) were resistant (survival ≥ 10%) to haloxyfop-methyl and clethodim, and most of them

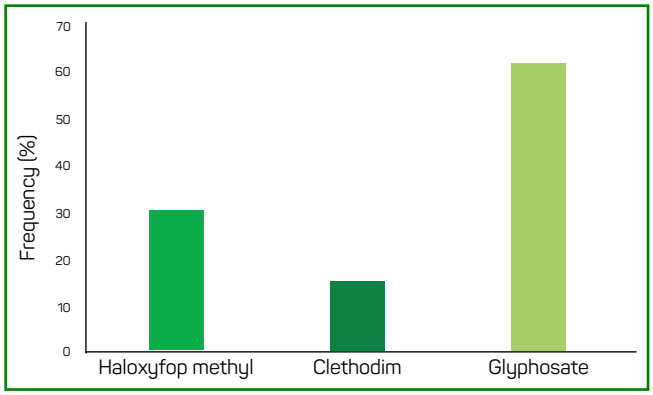


Figure 2 - Overall frequency (%) of populations with survival ≥ 10%

Table 4 - Statistical summary (average, median, standard deviation, minimum and maximum, first quartile (Q1) and third quartile (Q3) of the populations resistant to the different herbicide treatments

	Haloxifop-methyl	Clethodim	Glyphosate
Number of populations	119	62	240
Average survival (%)	43	31	67.7
Median	37.5	25	75
Std Dev.	28.6	20	15.4
Min	10	10	10
Max	100	83	100
Q1	17	13	50
Q3	65	44	90

Table 5 - Number and frequency (%) of populations with low (≥10-<30 survival), medium (≥30-<50 survival) and high resistance (≥50 survival) to each treatment

	Low Resistance	Medium Resistance	High Resistance
Haloxyfop methyl	52 (13%)	19 (5%)	48 (12%)
Clethodim	35 (9%)	15 (4%)	12 (13%)
Glyphosate	31 (8%)	26 (7%)	183 (50%)

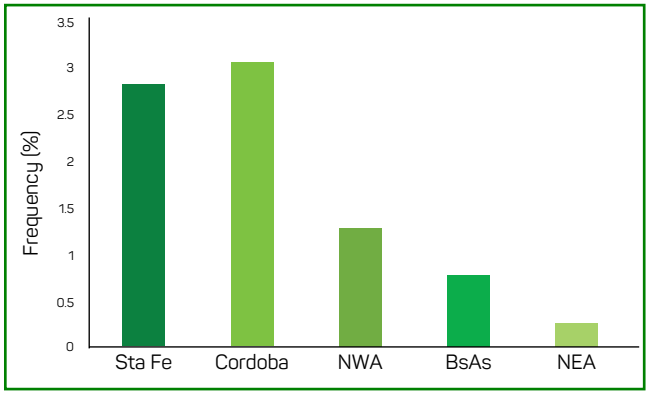


Figure 3 - Frequency (%) of cross resistance (haloxyfop-methyl + clethodim) populations for each surveyed area

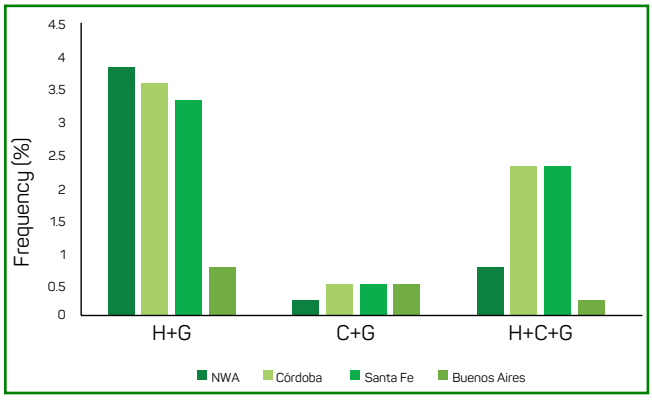


Figure 4 - Frequency of multiple resistance to combinations of haloxyfop-methyl (H), glyphosate (G), and clethodim (C) of johnsongrass populations for each surveyed area

were from the core zone (Córdoba and Santa Fe) (Figure 3). I nterestingly, 64 populations were resistant to haloxyfop-methyl while susceptible to clethodim. On the other hand, 12 populations were resistant to clethodim but susceptible to haloxyfop-methyl. Ten and seven populations were resistant to haloxyfop-methyl or clethodim and susceptible to glyphosate, respectively. However, only two populations were resistant to both ACCase inhibitors but susceptible to glyphosate. Populations with multiple resistance to haloxyfop + glyphosate were prevalent over populations with multiple resistance to clethodim + glyphosate and haloxyfop-methyl + clethodim + glyphosate (Figure 4).

The results agree with the tendency of post-emergence herbicide use to control johnsongrass in soybean crops. The first and most prevalent herbicide was glyphosate until the cases of resistance began to increase. Then, ACCase inhibitors were applied in replacement of glyphosate. Haloxyfop-methyl began to be used before clethodim.

However, due to the appearance of cases of resistance to haloxyfop-methyl, the area treated with clethodim is growing.

3.4 Resistance mechanism

The results showed that there are more populations resistant to haloxyfop-methyl than to clethodim. Target site resistance to these herbicides is regulated by different genetic mutations on the ACCase gene. The target site mechanism was studied in a few populations that were

identified as resistant in field experiments. Some resistant populations did not contain known resistant mutations whilst, in others different mutations in the ACCase gene were identified. Although the samples showed resistance to glyphosate, one of them showed resistance to clethodim, haloxyfop-methyl and glyphosate, while the remaining were resistant only to haloxyfop-methyl and glyphosate (Table 6, Figure 5). Interestingly, one of the samples from Santa Fe showed high survival to clethodim at label rate (96 gai/ha), but not when the rate was increased to 240 gai. /ha.

There are seven mutations that confer resistance to ACCase herbicides but while most of them have been identified conferring resistance to aryloxyphenoxypropionates, a few have been identified as bestowing resistance to cyclohexanediones. Only two mutations (D2078G and C2088R) confer broad resistance to all the herbicides. The resistance levels and herbicide spectra depend on the resistance mutation, the number of alleles (homozygous/heterozygous) the weed species, the growth stage of the plant, and the herbicidal chemical nature (Kaundun, 2014; Yu et al., 2007). Scarabel et al. (2014) recorded the presence of the Ile 2041Asn mutation in johnsongrass populations from northern Italy with high resistance index for aryloxyphenoxypropionate herbicides (including haloxyfop) and low for cyclohexanediones (including clethodim). In addition, Bradley et al. (2001) suggested the greater activity of the ACCase enzyme as a mechanism of resistance to aryloxyphenoxypropionates and cyclohexanediones. Burke et al. (2006) recorded target site resistance to clethodim in a Mississippi population with moderate to high levels of resistance to both aryloxyphenoxypropionate and cyclohexanedione herbicides. Kaloumenos and Eleftherohorinos (2009) identified a population resistant to aryloxyphenoxypropionates (not haloxyfop) in Greece,

Table 6 - Survival (%) in response to different herbicides and resistance mechanisms of populations with multiple resistance to ACCase herbicides and glyphosate

Location	Clethodim (%)	Haloxyfop-methyl (%)	Glyphosate (%)	Glyphosate / ACCase Mutations
Córdoba (Idiazabal)	0	67	50	W2027C
Santa Fe (El Trebol)	42	50	100	W1999G
Córdoba (Etruria)	75	90	95	W2027C G2096A C2088R

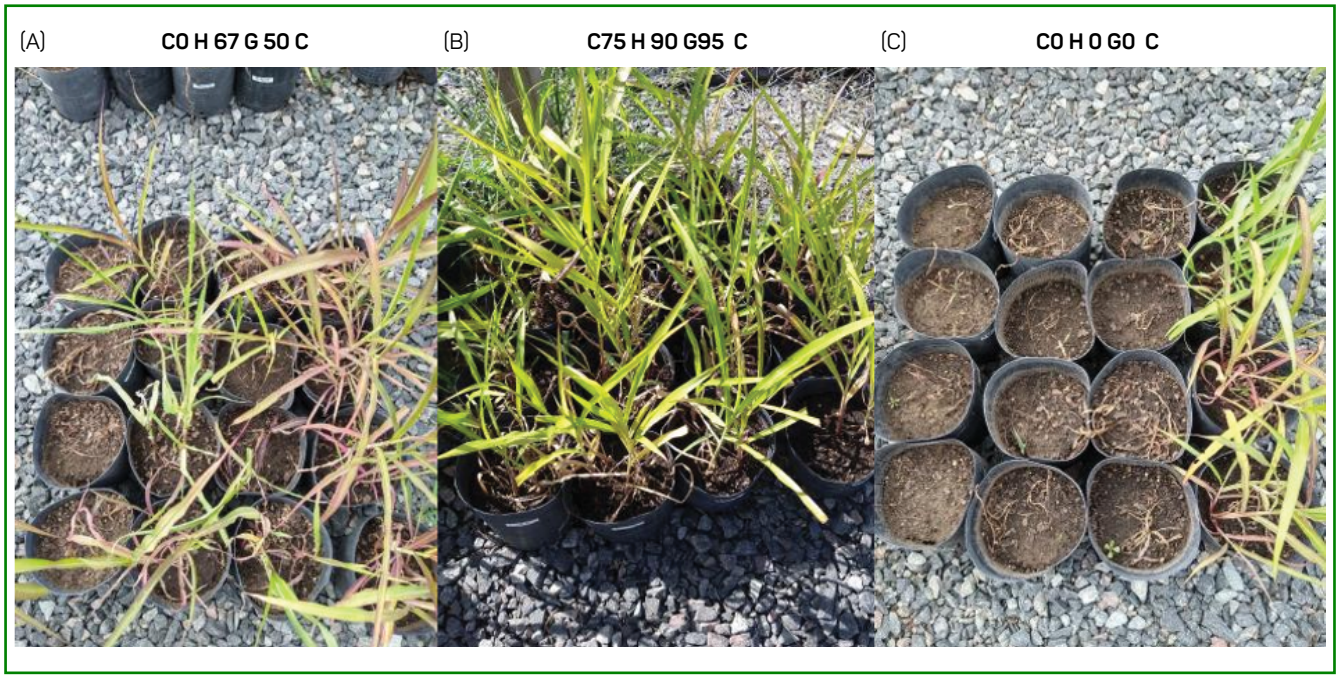


Figure 5 - Populations resistant to haloxyfop-methyl and glyhosate (A), clethodim, haloxyfop-methyl and glyphosate (B) and susceptible to all treatments (C). Atop each image values are listed for percent survival to C (clethodim), H (haloxyfop-methyl), G (glyphosate) and C (untreated control)

recording a higher level of resistance in individuals generated from rhizomes compared to those from seeds.

The Trp-2027-Cys mutation was identified in populations of Sorghum sp. resistant to Fops herbicides (Kershner et al., 2012), and Rubin (2016) identified this mutation in a population from Israel resistant to both fluazifop butyl and clethodim (Heap 2025). Martinatto (2020) recorded a population resistant to haloxyfop- methyl and glyphosate but susceptible to clethodim, identifying the mutations Ile-2041- Asn, Gly-2096-Ala and another mutation not previously identified (unpublished). Interestingly, in the present study there were two mutations that were not recorded previously in Johnsongrass, W1999G and C2088R.

Although NTS (non-target site) resistance is predominant for ACCase inhibitors in other species, there are no reports of NTS mechanisms for this group of herbicides in johnsongrass (Martinatto 2020). NTS resistance is mostly caused by the metabolization of aryloxiphenoxipropionates, phenylpyrazoles, and cyclohexanediones by cyp P450 and GST enzyme complexes (Kaundun 2014). However, no such resistance mechanism was recorded with clethodim and only one case was reported with haloxyfop-methyl in Alopecurus myosuroides (Letouzé and Gazquez (2003) as cited in Martinatto (2020)).

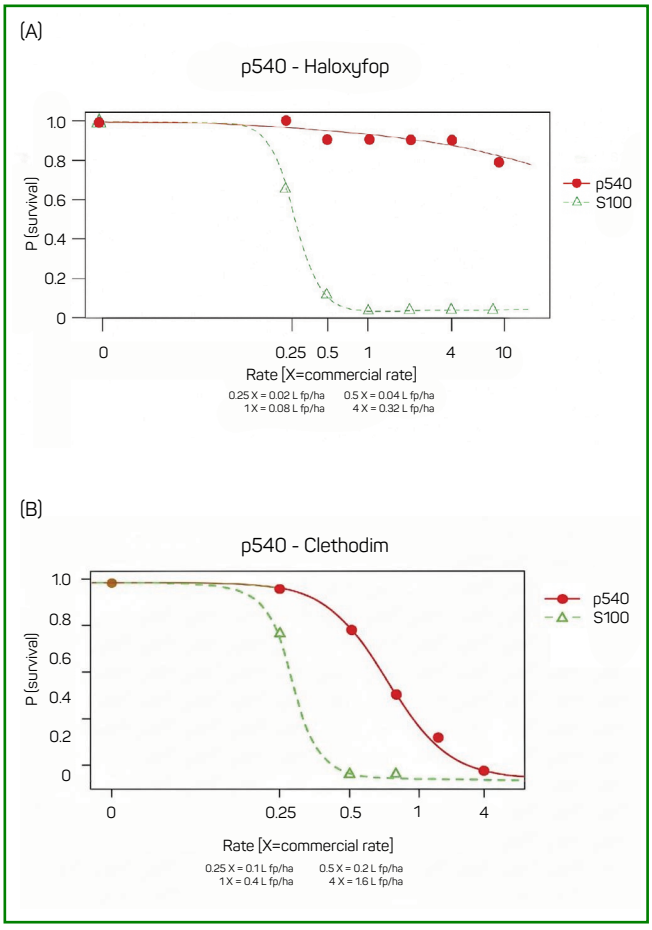


Figure 6 - Dose responses to haloxyfop methyl (A) and clethodim (B) for population p540 with multiple resistance and susceptible population p120. Lethal doses for 50% control (DL50) with haloxyfop-methyl were 0.29 and 199.50 for p120 and p540, respectively; and with clethodim lethal doses were 0.29 and 1.52 for the same populations

3.5 Dose response studies

The dose response studies were conducted in populations with different responses to the herbicides evaluated. The population with multiple resistance to both ACCase inhibitors + glyphosate revealed different RF depending on the herbicide evaluated (Figure 6) The resistant population compared to the susceptible population was 688 and 5,2 times more tolerant to haloxyfop-methyl and clethodim, respectively.

4. Conclusions

The current studies covered an unprecedented number of johnsongrass populations, distributed in different production regions of Argentina. These studies clearly showed the prevalence of glyphosate resistance and the advance of resistance to ACCase inhibiting herbicides. The geographic areas with the greatest predominance of soybean monoculture were those with the greatest abundance of resistance cases. The methodology applied in the present study was necessary to ascertain the evolution of resistance to different herbicides, identifying not only the cases already present but also possible problems for the future.

Author Contributions

All authors read and agreed to the published version of the manuscript. JS: Conceptualization of the manuscript and development of the methodology, data collection, data analysis, data interpretation, funding acquisition and resources, and project administration, and supervision, writing the original draft of the manuscript: writing, review, and editing. JPM: Data collection, data analysis and data interpretation MSM: data collection, data analysis and data interpretation GF: data analysis and data interpretation. DMH: Data analysis and data interpretation1 BS: data analysis and data interpretation. FV: Data analysis and data interpretation.

Acknowledgements

We thank the Syngenta Global Company for the support provided in conducting this study, particularly our colleagues Deepak Kaundun, Raul Moreno, Ian Zelaya, Federico Venier and Nicolás Bongiorni. Research partially supported by UBACYT 20020220200025BA (2023) and 20020170100404BA (2018). We also thank all colleagues who provided support in terms of seed collection and students who collaborate with experiments. In particular, we thank Samuele Pinton (student from Italy), Ignacio

Gatica, Lujan Rodriguez and Pablo T. Herrera (students from FAUBA) for their collaboration in field experiments.

Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to confidentiality agreements with the project sponsors. The data is available at the following repository: [https://drive.google.com/drive/folders/1w4vX_BSuOhnZ__lKUNW0kMqU_rZSDGIv?usp=drive_link] and may be accessed upon reasonable request and with permission from the authors and the funding entity. This data should be handled with care and is not intended for unrestricted public distribution.

References

Asociación Argentina de Productores en Siembra Directa – Aapresid. [PMN - Pest Management Network]. Rosario: Asociación Argentina de Productores en Siembra Directa; 2023[access Sept 1, 2024]. Spanish. Available from: https://www.aapresid.org.ar/rem

Bradley KW, Wu J, Hatzios KK, Hagood Jr ES. The mechanism of resistance to aryloxyphenoxypropionate and cyclohexanedione herbicides in a johnsongrass biotype. Weed Sci. 2001;49(4):477-84. Available from: https://doi.org/10.1614/0043-1745(2001)049[0477:TMORTA]2.0.CO;2

Burke IC, Thomas WE, Burton JD, Spears JF, Wilcut JW. A seedling assay to screen aryloxyphenoxypropionic acid and cyclohexanedione resistance in johnsongrass (*Sorghum halepense*). Weed Technol. 2006;20(4):950-5. Available from: https://doi.org/10.1614/WT-05-160.1

Consejo Argentino para la Información y el Desarrollo de la Biotecnología - Argenbio. [Genetically modified crops]. Buenos Aires: Consejo Argentino para la Información y el Desarrollo de la Biotecnología; 2024[access Apr 24, 2026]. Spanish. Available from: https://www.argenbio.org/cultivos-transgenicos

De la Fuente E, Oreja F, Duarte Vera A, Kruk B, Scursoni J. [Weed management practices in Argentina]. In: Actas del III Congreso Argentino de Malezas (ASACIM); 2021 jun 9-10; Rosario, Argentina. Rosario: ASACIM; 2021. Spanish.

Di Rienzo JA, Casanoves F, Balzarini MG, Gonzalez L, Tablada M, Robledo CW. [InfoStat: statistical software version 2011]. Córdoba: Universidad Nacional de Córdoba; 2011[access Apr 24, 2026]. Spanish. Available from: http://www.infostat.com.ar

Heap I. The international survey of herbicide resistant weeds. Weedscience. 2025[access Apr 24, 2026]. Spanish. Available from: https://www.weedscience.org/In.asp

Holm JP, LeRoy G, Plucknett DL, Pancho JV, Herberger JP. The world's worst weeds: distribution and biology. Honolulu: University of Hawaii Press; 1977.

Kaloumenos NS, Eleftherohorinos IG. Identification of a johnsongrass (*Sorghum halepense*) biotype resistant to ACCase-inhibiting herbicides in Northern Greece. Weed Technol. 2009;23(3):470-6. Available from: https://doi.org/10.1614/WT-08-187.1

Kaundun SS. Resistance to acetyl-CoA carboxylase–inhibiting herbicides. Pest Manag Sci. 2014;70(9):1405-17. Available from: https://doi.org/10.1002/ps.379

Kershner KS, Al-Khatib K, Krothapalli K, Tuinstra MR. Genetic resistance to acetyl-coenzyme A carboxylase-inhibiting herbicides in grain sorghum. Crop Sci. 2012;52(1):64-73. Available from: https://doi.org/10.2135/cropsci2011.02.0082

Leguizamón ES. [Johnsongrass: *Sorghum halepense* (L.) Persoon: basis for its management and control in production systems]. Rosario: Asociación Argentina de Productores en Siembra Directa; 2012. Spanish.

Martinatto A. [Characterization of the mechanism responsible for resistance to haloxyfop-p-methyl and glyphosate in *Sorghum halepense*] [tese]. Rosario: Universidad Nacional de Rosario; 2020. Spanish.

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM et al. Reducing the risk of herbicide resistance: best management practices and recommendations. Weed Sci. 2012;60(SP1):31-62. Available from: https://doi.org/10.1614/WS-D-11-00155.1

Scarabel L, Panozzo S, Savoia W, Sattin M. Target-site ACCase-resistant johnsongrass (*Sorghum halepense*) selected in summer dicot crops. Weed Technol. 2014;28(2):307-15. Available from: https://doi.org/10.1614/WT-D-13-00137.1

Scursoni JA, Duarte Vera A, Oreja F, de la Fuente EB, Kruk BC. [Use of herbicides in grain crop production systems in Argentina]. In: Actas del III Congreso Argentino de Malezas (ASACIM); 2021 jun 9-10; Rosario, Argentina. Rosario: ASACIM; 2021[access Apr 24, 2026]. Spanish. Available from: http://www.malezas2021.com.ar

Seefeldt SS, Jensen JE, Fuerst EP. Log-logistic analysis of herbicide dose-response relationships. Weed Technol. 1995;9(2):218-27. Available from: https://doi.org/10.1017/S0890037X00023253

Vila Aiub MM, Balbi MC, Gundel PE, Ghersa CM, Powles SB. Evolution of glyphosate-resistant johnsongrass (*Sorghum halepense*) in glyphosate-resistant soybean. Weed Sci. 2007;55(6):566-71. Available from: https://doi.org/10.1614/WS-07-053.1

Yu Q, Jalaludin A, Han H, Chen M, Sammons RD, Powles SB. Evolution of a double amino acid substitution in the EPSP synthase in Eleusine indica conferring high level glyphosate resistance. Plant Physiol. 2015;167(4):1440-7. Available from: https://doi.org/10.1104/pp.15.00146