Revista Mexicana de
Ciencias Agrícolas
REMEXCA

DOI: https://doi.org/10.29312/remexca.v15i7.3506

Article

Acetolactate synthase and acetyl coenzyme A carboxylase inhibiting herbicides in *Avena fatua*

Andrés González-Ruiz[1]
Carlos Enrique Ail-Catzim[2]
Carlos Alfonso López-Orona[1]
Raymundo Medina-López[1]
Mitzi Dayanira Estrada-Acosta[1]
Guadalupe Alfonso López-Urquídez[1,§]

1 Universidad Autónoma de Sinaloa-Facultad de Agronomía. Carretera Culiacán-Eldorado km 17.5, Culiacán, Sinaloa, México. CP. 80398. (ag-ruiz2009@hotmail.com; clopezorona@uas.edu.mx; raymedinalop@hotmail.com; mitziestrada@uas.edu.mx).

2 Universidad Autónoma de Baja California-Instituto de Ciencias Agrícolas. Carretera Delta Oaxaca s/n, Ejido Nuevo León, Mexicali, Baja California. CP. 21705. (carlos.ail@uabc.edu.mx).

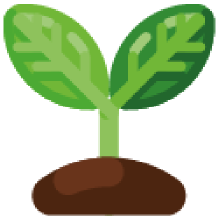
Autor para correspondencia: alfonsolopezurquidez@uas.edu.mx

Abstract

Avena fatua is a very important weed in wheat worldwide. This also occurs in the Mexicali Valley, BC., where acetolactate synthase- and acetyl coenzyme A carboxylase-inhibiting herbicides are used to control this grass. In the search for the best alternative for the producer, this research aimed to estimate the efficiency of these two groups of herbicides to control *Avena fatua*. The trials were carried out during the 2021-2022 autumn-winter cycle in three ejidos in said Valley (República Mexicana, Nayarit, and Sombrerete). The experiments included herbicides representative of each group. Acetolactate synthase was composed of iodosulfuron, flucarbazone, and pyroxsulam and acetyl coenzyme A carboxylase was integrated by fenoxaprop and pinoxaden. The experiments were arranged in randomized complete blocks with four replications. An analysis of variance was carried out for weed control and density and crop yield; the effectiveness of herbicides was measured using a non-linear regression model. Weed control efficiency and weed index were estimated. The results indicate that the best group of herbicides was acetyl coenzyme A carboxylase. For example, in the projection of the level of damage, in the República Mexicana experiment, we have fenoxaprop= 77.16+0.78*DAA-0.009*DAA^2, that is, the damage to the weed increases slightly over time, at least until the 56 DAA. On the contrary, mesosulfuron loses efficiency of 6.41% daily in the second stage of the evaluated period: 138.20-6.41*DAA+0.07*DAA^2. In efficiency at the same site, fenoxaprop has 83.15% and Iodosulfuron only 37.5%.

Keywords:

biological effectiveness, resistance, weed control, yield.



Introduction

Wild oat (*Avena fatua* L.) is one of the weed species that most affects winter crops worldwide (Tidemann *et al*., 2021). It is also one of the main weeds in the Mexicali Valley region in wheat crops (Herrera Andrade *et al*., 2010). Different strategies are used to solve this problem in crops, including the use of synthetic chemicals (Gao and Su, 2024). To control *Avena fatua* in wheat, several herbicides are applied, which are concentrated in two groups. On the one hand, there are Acetolactate Synthase (ALS) inhibitors and on the other, Acetyl Coenzyme A Carboxylase (ACCase) inhibitors (Cobb and Reade, 2010).

ALS inhibitors are used for their high efficacy, low environmental impact, and wide crop selectivity (Heap, 2020). Nonetheless, there are many biotypes resistant to APPs (aryloxyphenoxypropionates) and CHDs (cyclohexanediones) (Tafoya-Razo *et al*., 2022). This is due to a mutation in ACCase that reduces their sensitivity to the herbicide (Hassanpour-bourkheili *et al*., 2021). There are also weeds resistant to ALS-inhibiting herbicides, which, in most cases, is caused by a mutation at the site of action (Lonhienne *et al*., 2022), although, in some cases, it can be caused by limited absorption, translocation, and sequestration of the herbicide in the vacuoles (Yu and Powles, 2014).

For their part, Cruz-Hipólito *et al*. (2011) evaluated two biotypes of *A. fatua*, one from Mexico and the other from Chile, which were susceptible to pinoxaden, with a lethal concentration of 50. In addition, Torres-García *et al*. (2018) identified a mutation within the ALS enzyme and indicate that it is likely to cause resistance in *A. fatua* biotypes in Mexico. Based on the above, the effect of ALS- and ACCase-inhibiting herbicides on *Avena fatua* in wheat in the Mexicali Valley, BC., was evaluated.

Materials and methods

The study was carried out in three ejidos in the wheat-growing area of the Mexicali Valley, BC., during the autumn-winter 2020-2021 cycle, on farms with a history of herbicide application that has been deficient in controlling *A. fatua*. Ejido República Mexicana is located north of the Mexicali Valley, 60.931 km from the city, the agricultural plot was located at 32° 38’ 38.19” north latitude, 114° 48’ 50.4” west longitude, at 34 masl.

Ejido Nayarit is located in the central part, 39.426 km from the city, the farm was located at 32° 8’ 50.02” north latitude, 115° 16’ 44” west longitude, at 13 masl. Ejido Sombrerete is located south of the Valley at 63.41 km from the city, the agricultural plot was located at 32° 9’ 28.15” north latitude, 115° 3’ 48.19” west longitude, at 9 masl. The experiments were conducted with average maximum and minimum temperatures of 29.33 °C and 10.53 °C and the lowest rainfall of the year (SIMARBC, 2022). The crop was managed according to the farmers’ cultural practices, except for the application of herbicides.

In ejido República Mexicana, the herbicide was applied on December 27, 2020 (average height of *A. fatua* of 9.48 cm); in Ejido Nayarit, the herbicides were applied on January 17, 2021 (average weed height of 10.45 cm); in ejido Sombrerete, it was established on February 19, 2021 (average weed height of 11.37 cm) and the wheat in full tillering. This was what determined the moment of the application of the herbicide.

Herbicides were evaluated at recommended commercial doses (Table 1). In the application of the herbicides, a 25 L Forza 25 K2P2L two-stroke motorized sprayer was used, which was equipped with a 1.2 m distance spray boom with TeeJet 80.02 flat fan nozzles (uniform opening of 80° and an expenditure of 0.2 gallons min^{-1}), calibrated at an expenditure of 295.5 L ha^{-1}. Similarly, the application broth was adapted according to the optimal pH based on the herbicide and an average electrical conductivity of 1.31 dS m^{-1}, for which a HO9812 g meter was used.

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Table 1. ALS- and ACCase-inhibiting herbicides evaluated on *A. fatua*.

Active ingredient	Brand	Dose	pH	Chemical family	MOA
Iodosulfuron-methyl-sodium	Sigma Forte (OD 1.2%)	1.5 L ha^{-1}	8.28	Sulfonylureas	ALS
Flucarbazone sodium	Everest® 70 WDG (70% w/w DG)	30 g ha^{-1}	6.1	Sulfonyl-amino-carbonyl-triazolinones	ALS
Pyroxsulam	Across (OD 2.9%)	0.5 L ha^{-1}	7.03	Triazolopyrimidine	ALS
Fenoxaprop-p-ethyl	Puma Super (oil in water emulsion 6.5%)	1 L ha^{-1}	8.26	Aryloxy-phenoxy-propionates	ACCase
Pinoxaden	Axial (5%w/v EC)	1.2 L ha^{-1}	7.55	Phenylpyrazoles	ACCase

Information collected from the technical data sheets of the commercial herbicides used in the present study. ALS= acetolactate synthase; ACCase= acetyl coenzyme A carboxylase; WDG= water dispersible granules; MOA= mechanism of action.

An experimental design of randomized complete blocks with four replications was applied. The experimental unit was 41.53 m^2. The usable area was 18.96 m^2. It was divided into four sampling units. Plant height, weed density, and herbicide control efficacy were evaluated. At each sampling point, five plants were randomly selected (20 per experimental unit).

The plant height was measured from the soil surface with a tape measure; to record the density of oats, the total plants per m^2 and the grain yield in kg m^{-2} were counted; the damage was measured by visual observation using the scale of 1 to 9 of the European Weed Research Society. Data were obtained at 14, 28, 42, and 56 days after herbicide application (DAA). Weed control efficiency was calculated according to Mani *et al*. (1973); for this purpose, the following formula was applied:

$$\mathrm{WCE\%}=\frac{\mathrm{BMc\text{-}BMt}}{\mathrm{BMc}}\mathrm{x}100$$

Where: WCE= weed control efficiency (%); BMc= density of *A. fatua* plants m^{-2} in the control plot; BMt= density of *A. fatua* plants m^{-2} in the treated plot. The calculation of the weed index (WI) was carried out using the formula proposed by Gill and Kumar (1969):

$$\mathrm{WI}=\frac{\mathrm{X\text{-}Y}}{\mathrm{X}}\mathrm{x}100$$

Where: X= yield (t ha^{-1}) of the treatment of least competition of weeds; and Y= yield (t ha^{-1}) of the experimental unit of the treatment evaluated.

An analysis of variance and a comparison of means between the treatments using Tukey's test ($p< 0.05$) were performed; it was verified that the data had normal distribution using Shapiro's test; it was also confirmed that the treatments had equal variances with Levene's test. In addition, an analysis of the loss of biological effectiveness of herbicides was carried out based on the percentage of control reported each week. To this end, the second-order polynomial nonlinear regression model was applied. Statistical analyses were performed with the XLSTAT program, version 2022 (Addinsoft, 2022).

Results and discussion

Biological effectiveness of the herbicides evaluated

In the trial conducted in ejido República Mexicana, all treatments were highly effective on *A. fatua* at 14 DAA (Table 2). However, herbicides belonging to the ACCase group, pinoxaden and fenoxaprop-p-ethyl, were better, with a damage percentage of 88.12 and 86.12%. The effect of these two herbicides remained constant during the experiment. In contrast, the herbicides of the ALS group (pyroxsulam, flucarbazone, and iodosulfuron) decreased their effectiveness after 14 DAA.

Table 2. Percentage of damaged *A. fatua* plants ±SE in the ejido República Mexicana experiment.

Treatments	DAA 14	DAA 28	DAA 42	DAA 56
Control	0 ±0e	0 ±0d	0 ±0d	0 ±0c
Flucarbazone	71.75 ±4.24c	18.43 ±13.02c	3 ±0.87cd	1 ±0c
Pyroxsulam	80 ±1.84b	53.12 ±4.4b	3.87 ±1.48c	2.25 ±0.95c
Pinoxaden	88.12 ±1.89a	91.68 ±0.3a	90 ±3.35b	88.87 ±4.22b
Iodosulfuron-methyl-sodium	64.68 ±1.87d	8.18 ±3.95c	1.53 ±0.26cd	1 ±0c
Fenoxaprop-p-ethyl	86.12 ±2.49a	92.68 ±0.9a	93.75 ±0.51a	93.43 ±0.31a

Values with different letters in a column are statistically different (Tukey $p < 0.05$). SE= standard error; DAA= days after application.

With the nonlinear regression analysis, it was obtained that: fenoxaprop= 77.16+0.78*DAA-0.009*DAA^2; pinoxaden= 83.67+0.42*DAA-0.006*DAA^2; pyroxsulam= 137-4.27*DAA+0.03*DAA^2; flucarbazone= 144.61-6.21*DAA+0.065*DAA^2; iodosulfuron= 138.20-6.41*DAA+0.07*DAA^2. This indicates that the herbicides belonging to ACCase have a uniform trend over time. On the other hand, the herbicides of the ALS group, iodosulfuron and flucarbazone, had a daily loss of efficiency of 6.41 and 6.21%, respectively in the stage of 14 to 28 DAA.

In the ejido Nayarit experiment, herbicides had a high efficiency at 14 DAA, which increased slightly at 28 and 42 DAA for all herbicides, except for iodosulfuron and flucarbazone. In contrast, at 56 DAA, all herbicides caused less damage to the weed, but it was greater in ALS herbicides (Table 3).

Table 3. Percentage of damaged *A. fatua* plants ±SE in the ejido Nayarit experiment.

Treatments	DAA 14	DAA 28	DAA 42	DAA 56
Control	0 ±0c	0 ±0c	0 ±0d	0 ±0b
Flucarbazone	69.68 ±0.6b	66.56 ±3.93b	64.37 ±2.42c	12.18 ±2.62b
Pyroxsulam	77.18 ±3.04a	82.18 ±1.18a	84.37 ±1.49ab	55 ±4.48a
Pinoxaden	73.12 ±1.8ab	85.93 ±3.2a	90.5 ±3.56a	72.37 ±11.13a
Iodosulfuron-methyl-sodium	71.87 ±4.35ab	72.18 ±3.44b	68 ±3.78c	9.37 ±1.56b
Fenoxaprop-p-ethyl	71.87 ±1.08ab	73.75 ±1.69b	81.87 ±5.83b	61.87 ±17.95a

Values with different letters in a column are statistically different (Tukey $p < 0.05$). SE= standard error; and DAA= days after application.

The nonlinear regression analysis shows that: fenoxaprop= 48.2+2.03*DAA-0.033*DAA^2; pinoxaden= 36.61+3.21*DAA-0.05*DAA^2; pyroxsulam= 41.7+3.19*DAA-0.055*DAA^2; flucarbazone= 25.3+4.11*DAA-0.08*DAA^2; Iodosulfuron= 17.03+5.08*DAA-0.099*DAA^2. This means that pinoxaden would have an effectiveness of 77.29% at 50 DAA, iodosulfuron would have 24.36% on those same days. On the other hand, ACCase herbicides would have an effectiveness of 77.29% in pinoxaden and 67.34% in fenoxaprop.

In ejido Sombrerete, all herbicides had a suppressive effect at 14 DAA, which was maintained at 28 DAA and even increased in all treatments, although it was lower in flucarbazone. There was also a decrease at 42 DAA and a pronounced drop in the effectiveness of all treatments at 56 DAA (Table 4). In addition, the projection at 50 DAA, yielded with the nonlinear regression analysis, shows that pyroxsulam has an efficacy of 28.05%, pinoxaden of 27.68%, flucarbazone of 24.1%, fenoxaprop of 30.6%, and iodosulfuron of 28.59%.

Table 4. Percentage of damaged *A. fatua* plants ± SE in the ejido Sombrerete experiment.

Treatments	DAA 14	DAA 28	DAA 42	DAA 56
Control	0 ±0b	0 ±0b	0 ±0b	0 ±0c
Flucarbazone	69.68 ±0.31a	63.75 ±4.3b	46.87 ±6.18a	4 ±1b
Pyroxsulam	65.62 ±3.17a	67.81 ±1.8ab	54.37 ±5.96a	4 ±1b
Pinoxaden	69.03 ±0.6a	68.12 ±0.63a	52.18 ±5.69a	4.93 ±3.13ab
Iodosulfuron-methyl-sodium	69.68 ±0.31a	70.93 ±1.44a	55 ±5.03a	4.31 ±1.14b
Fenoxaprop-p-ethyl	69.68 ±0.31a	70 ±0.51a	56.56 ±3.44a	7.18 ±2.19a

Values with different letters in a column are statistically different (Tukey $p< 0.05$). SE= standard error; DAA= days after application.

These results are consistent with Scursoni *et al*. (2011), who found that fenoxaprop-p-ethyl and pinoxaden provided similar control with values of 96 and 98% on *A. fatua* in wheat. This is because both inhibit the synthesis of fatty acids from narrow-leaved species (Rosales-Robles, 2006), stopping membrane synthesis, which is required for cell synthesis (Takano *et al*., 2020). On the other hand, herbicides that inhibit the acetolactate synthase enzyme inhibit the biosynthesis of branched-chain amino acids essential for weed growth and development.

In addition, plant death is not only due to starvation of these amino acids since the herbicide inhibits cell division as there is an accumulation of α-ketobutyrate and a decrease in phloem translocation (Cobb and Reade, 2010).

Effect of herbicides on wild oat plant density

The plant density in the ejido República Mexicana trial decreased from 28 DAA in all treatments compared to the control and maintained this decrease in the fenoxaprop and pinoxaden treatments in stages 42 and 56 DAA. The Table 5 shows that herbicides belonging to the ACCase group were more efficient over time.

Table 5. Efficiency of treatments (% control) and plant density of *A. fatua* ± SE in the Ejido República Mexicana experiment.

Treatments	Variable	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Control	Density	362 ±75.5a	527 ±104.6a	722 ±108.8a	807 ±132.91a	743 ±60.5a
	WCE (%)	0	0	0	0	0
Flucarbazone	Density	466 ±31.9a	554 ±30.94a	704 ±44.72a	716 ±81.24bc	659 ±62.6a
	WCE (%)	-28.8	-5.1	2.4	11.3	11,4
Pyroxsulam	Density	433 ±72.9a	482 ±16.09a	552 ±52.9ab	618 ±63.88b	769 ±35.5a
	WCE (%)	-19.5	8.5	23.6	23.4	-3.4
Pinoxaden	Density	365 ±36.7a	359 ±40.28a	338 ±43.23b	295 ±78.53c	216 ±63.8b
	WCE (%)	-0.7	31.9	53.1	63.5	71
Iodosulfuron-methyl-sodium	Density	404 ±72.5a	368 ±61.6a	550 ±131.78ab	636 ±126.9ab	632 ±33a
	WCE (%)	2.4	36.9	21.1	25.7	12.5
Fenoxaprop-p-ethyl	Density	354 ±91.4a	393 ±73.41a	322.92 ±74.1b	256 ±116.27c	148 ±97.5b
	WCE (%)	-9	22.4	50.6	56.1	68.6

Values with different letters in a column are statistically different (Tukey $p< 0.05$). SE= standard error; DAA= days after application; WCE= weed control efficiency.

In the experiment carried out in ejido Nayarit, the difference between the two groups of herbicides is also marked, although in this case, the herbicides belonging to the ACCase group only prevented the increase in the population, since in the case of fenoxaprop-p-ethyl, the density decreased 1.1 plants per day on average, while pinoxaden had a decrease of 1.66 plants per day (Table 6).

Table 6. Efficiency of treatments (% control) and plant density of *A. fatua* ± SE in the ejido Nayarit experiment.

Treatment	Variable	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Control	Density	414 ±81.9a	553 ±80.9a	669 ±74.8a	768 ±129.8a	852 ±144.3a
	WCE (%)	0	0	0	0	0
Flucarbazone	Density	454 ±179.7a	470 ±147.9a	535 ±112ab	686 ±213.2a	692 ±181.2ab
	WCE (%)	-9.8	15	20	10.7	18.8
Pyroxsulam	Density	477 ±89.5a	341 ±73.6a	413 ±90.8ab	590 ±117.7ab	632 ±231.9abc
	WCE (%)	-15.3	38.3	38.2	23.2	25.9
Pinoxaden	Density	513 ±85.2a	308 ±20.21a	347 ±35.4b	274 ±4.1b	255 ±46.5c
	WCE (%)	-23.9	44.3	48.1	64.3	70.1
Iodosulfuron-methyl	Density	525 ±51.2a	420 ±18.3a	453 ±4.2ab	566 ±54.6ab	610 ±27.8bc
	WCE (%)	-26.8	24.1	32.2	26.3	28.4
Fenoxaprop-p-ethyl	Density	462 ±56.1a	404 ±37.7a	443 ±97.2ab	432 ±77.4ab	355 ±72.9bc
	WCE (%)	-11.7	27	33.7	43.8	58.3

Values with different letters in a column are statistically different (Tukey $p< 0.05$). SE= standard error; DAA= days after application; WCE= weed control efficiency.

In the experiment carried out in ejido Sombrerete, the density of plants in the different evaluations was not statistically different ($p< 0.5$) in all treatments. Nevertheless, at 56 DAA, the pinoxaden and fenoxaprop-p-ethyl treatments maintained lower plant density compared to the control, where the population gradually increased (Table 7).

Table 7. Efficiency of treatments (% control) and plant density of *A. fatua* ± SE in the ejido Sombrerete experiment.

Treatments	Variable	DAA 0	DAA 14	DAA 28	DAA 42
Control	Density	361 ±75.93a	415 ±85.66a	439 ±75.66a	392 ±28.23a
	WCE (%)	0	0	0	0
Flucarbazone	Density	294 ±56.09a	301 ±41.85a	319 ±29.89a	305 ±3045a
	WCE (%)	18.6	27.4	27.3	22.2
Pyroxsulam	Density	276 ±56.28a	311 ±51.02a	310 ±61.46a	320 ±46.65a
	WCE (%)	23.5	25.1	29.3	18.2
Pinoxaden	Density	390 ±66.68a	307 ±39.25a	328 ±24.62a	350 ±59.01a
	WCE (%)	-8	25.9	25.3	10.7
Iodosulfuron-methyl	Density	325 ±78.05a	402 ±49.54a	386 ±64.68a	374 ±51.77a
	WCE (%)	10.1	3.1	12.0	4.5
Fenoxaprop-p-ethyl	Density	383 ±88.64a	368 ±68.71a	315 ±18.32a	291 ±37.04a
	WCE (%)	-6	11.3	28.2	25.8

Values with different letters in a column are statistically different (Tukey $p< 0.05$). SE= standard error; DAA= days after application; WCE= weed control efficiency.

These results coincide with those obtained by Scursoni *et al*. (2011), who point out that with pinoxaden and fenoxaprop-p-ethyl, the density of *A. fatua* in barley decreased. For their part, Baghestani *et al*. (2008) found that with the fenoxaprop and Iodosulfuron herbicides, the population of *Avena ludoviciana* (Diureu) decreased by 97.5%. Likewise, Scursoni *et al*. (2011) observed that with pinoxaden and fenoxaprop-p-ethyl, the density of *A. fatua* plants in wheat decreased.

Effect of the herbicides evaluated on plant height in *A. fatua*

Regarding the height of the *A. fatua* plant, in the ejido República Mexicana experiment (Table 8), the control had the tallest plants in all stages of sampling; however, in the treatments of fenoxaprop-p-ethyl and pinoxaden, they were smaller in the last two evaluations.

Table 8. Plant height of *A. fatua* (cm) ±SE in the ejido República Mexicana experiment.

Treatment	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Control	9.3 ±0.4a	26.7 ±1.2a	53.9 ±3.3a	72.8 ±2.7a	101 ±3.9a
Iodosulfuron-methyl	9.7 ±0.7a	19.4 ±0.9b	47.4 ±1.9b	68.6 ±3.9a	92.4 ±3.5b
Flucarbazone sodium	10.1 ±1.1a	16.9 ±1.4bc	41.6 ±2.4bc	65.9 ±1.4a	91.5 ±3.6bc
Pyroxsulam	9.3 ±0.9a	11.1 ±0.98d	39.1 ±1.8c	63.6 ±1.5a	89.1 ±2.8c
Pinoxaden	9.4 ±0.8a	11 ±0.5d	12.9 ±1d	24.9 ±4.1b	27.9 ±3d
Fenoxaprop-p-ethyl	9.1 ±0.9a	12.9 ±0.8cd	12.6 ±0.7d	22.3 ±3b	26.3 ±3.1d

Values with different letters in a column are statistically different (Tukey p< 0.05). SE= standard error; DAA= days after application.

In the ejido Nayarit trial, there was the same trend as the results obtained in the experiment in ejido República Mexicana (Table 9).

Table 9. Plant height of *A. fatua* (in cm) ±SE in the ejido Nayarit experiment.

Treatment	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Control	10.5 ±0.8a	13.8 ±1.6a	27.9 ±2.4a	43.9 ±3.8a	77.6 ±3.98a
Flucarbazone sodium	11.4 ±1.5a	9.6 ±1ab	16.3 ±2.3b	33.8 ±3.9ab	59.5 ±3.92b
Fenoxaprop-p-ethyl	10.8 ±0.9a	9.9 ±1ab	13.6 ±1.2b	25.6 ±3.5bc	53.1 ±5.32bc
Iodosulfuron-methyl	10.5 ±1.3a	9.6 ±0.9ab	15.8 ±2.8b	20.1 ±3b	59.4 ±4.7b
Pyroxsulam	9.7 ±0.2a	7.6 ±0.6b	10.1 ±0.7b	24.7 ±1bc	49.3 ±1.97bc
Pinoxaden	9.8 ±0.8a	8.6 ±0.7b	9.1 ±1.3b	16.7 ±2.8c	43 ±6.27c

Values with different letters in a column are statistically different (Tukey p< 0.05). SE= standard error; DAA= days after application.

In the ejido Sombrerete experiment, the plants of all the treatments were shorter than the control at 28 and 42 DAA, while at 56 DAA, the treatments that showed a decrease in growth were iodosulfuron, pyroxsulam and fenoxaprop (Table 10). Nonetheless, at 14 DAA, the flucarbazone and control treatments had the same behavior. At 28 and 42 DAA, the plant height in all herbicide treatments was lower than in the control.

Table 10. Plant height of *A. fatua* (cm) ±SE in the ejido Sombrerete experiment.

Treatment	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Control	11.6 ±1.9a	14.9 ±1.4a	36.5 ±3.3a	54.7 ±4.5a	94.6 ±5.7a
Flucarbazone sodium	13.7 ±2.5a	14.5 ±1.6a	27.8 ±4b	46.2 ±5.2ab	89.5 ±8a
Pinoxaden	10.2 ±1.4a	10.7 ±1.2a	25.3 ±2.5b	42.6 ±5b	89.6 ±5.7a

Treatment	DAA 0	DAA 14	DAA 28	DAA 42	DAA 56
Fenoxaprop-p-ethyl	10 ±0.9a	11.3 ±1a	25.9 ±1.9b	44.1 ±4.7ab	82.9 ±5.5a
Pyroxsulam	12.3 ±2a	9.6 ±1.4a	24.3 ±2.7b	43.6 ±5.1ab	81.9 ±7.7a
Iodosulfuron-methyl	10.4 ±0.7a	9.3 ±0.9a	22.2 ±1.5b	41.8 ±1.7b	77.9 ±30a

Values with different letters in a column are statistically different (Tukey $p < 0.05$). SE= standard error; DAA= days after application.

Effect of herbicide application on grain yield of wheat

The highest efficiency occurred in the treatments of the ACCase group, with pinoxaden having 84.54% and fenoxaprop having 83.15% in the trial developed in ejido República Mexicana, while those belonging to the ALS group had an efficiency of less than 45%. Similarly, in the ejido Nayarit experiment, the efficiency was lower than what occurred in most of the treatments of ejido República Mexicana, except for the pyroxsulam treatment, which went from 28.57 to 57.5%.

In ejido Sombrerete, the efficacy of herbicides was very low, with the fenoxaprop treatment having the highest efficiency, with 32.6%. Likewise, in the experiments where the herbicides of the ALS group were applied, the yields are similar to those obtained in the control of the three experiments. In addition, the effect of the herbicides of the ACCase group is high since the difference between yields is significant ($p < 0.05$) (Table 11).

Table 11. Wheat efficiency (%) and yield ± standard error in the experiments.

Treatment	Ej. Rep. Mexicana		Ej. Nayarit		Ej. Sombrerete	
	(t ha^{-1})	Efficiency	(t ha^{-1})	Efficiency	(t ha^{-1})	Efficiency
Control	1.5 ±0.26b	0	2 ±0.4b	0	4.2 ±0.63b	0
Flucarbazone	2.6 ±0.3b	42.31	2 ±0.24b	19.05	3.9±0.53b	-7.69
Pyroxsulam	2.1 ±0.28b	28.57	5 ±0.6a	57.5	4.4 ±0.08b	4.55
Pinoxaden	9.7 ±1.02a	84.54	4 ±0.24a	65.31	4.5 ±0.77ab	6.67
Iodosulfuron-methyl	2.4 ±0.13b	37.5	2 ±0.12b	26.09	4.9 ±0.09ab	14.29
Fenoxaprop-p-ethyl	8.9 ±0.31a	83.15	5 ±1.07a	67.31	6.2 ±0.74a	32.26

Values with different letters in a column are statistically different (Tukey $p < 0.05$).

Pinoxaden and fenoxaprop-p-ethyl treatments were the best and there was no significant difference between them ($p < 0.05$), which coincides with Scursoni *et al*. (2011), who did not find differences in yield in barley either when comparing these two herbicides. The herbicides of the ACCase group (fenoxaprop-p-ethyl and pinoxaden) influenced the control of *A. fatua* to the extent that this benefited the development of the crop.

This result reflects that *A. fatua* is a factor that limits the development and yield of wheat crops in the Mexicali Valley. Likewise, the yields obtained in these tests reflect the effect exerted by the density and height of the weeds and the action of herbicides (Herrera Andrade *et al*., 2010). On the other hand, the difference between trials, having higher percentages in ejido República Mexicana and lower in ejido Sombrete, is related to the height of the weeds at the time of herbicide application, especially the ALS group.

This statement is based on the fact that, in the ejido República Mexicana trial, the plants of *A. fatua* had a height of 9.48 cm at the time of application, while those of the Sombrerete trial had an average height of 11.37 cm; that is, a height greater than that recommended for the application of some herbicides evaluated.

Conclusions

Under the conditions in which this research was conducted, it is concluded that: a) all the herbicides evaluated cause damage to *A. fatua*, decrease its density and affect its height, at least until the first week after application; b) the fenoxaprop-p-ethyl and pinoxaden herbicides (ACCase group) had greater biological effectiveness on *A. fatua* than the herbicides of the ALS group, which was reflected in the yield of wheat; c) the level of efficacy of the herbicides evaluated affects wheat yields; and d) the herbicides of the ACCase group can be applied as an alternative control of *A. fatua* in the Mexicali Valley, BC., following the recommendations for their use.

Acknowledgements

Andrés González Ruiz is a student of the Doctoral Program in Agricultural Sciences of the Autonomous University of Sinaloa and has received a grant for his studies from CONAHCYT; for this reason, these institutions are thanked for the support provided.

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Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 July 2024
Date accepted: 01 October 2024
Publication date: 04 December 2024
Publication date: Oct-Nov 2024
Volume: 15
Issue: 7
Electronic Location Identifier: e3506
DOI: 10.29312/remexca.v15i7.3506

Categories

Subject: Articles

Keywords:

Keywords:

biological effectiveness
resistance
weed control
yield

Counts

Figures: 0
Tables: 11
Equations: 2
References: 19
Pages: 0