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Research paper

Influence of herbicides-based weed management in chickpea

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ABSTRACT

Weeds are one of the most problematic factors for chickpea cultivation due to their negative effects on yield reduction in Iran. In the present investigation, new PRE-herbicide (flumioxazin) with different rates as IBS (incorporated before sowing), PRE, and Early-post with previously used herbicides were compared for controlling weeds and subsequently increasing in grain yield of chickpea. Results showed that PRE flumioxazin at rates 50, 75, and 100 g ai ha^{-1}, oxyflourfen and flumioxazin + pyridate reduced total dry weed biomass 79 to 83.2%. These reductions (total dry weed biomass) were 59 to 73% by application of PRE flumioxazin at 50, 75 and 100 g ai ha^{-1}, oxyfluorfen, flumioxazin + pyridate and pyridate in Kurdistan and 70 to 74.5% in Hamedan by application of IBS and PRE flumioxazin at 50, 75 and 100 g ai ha^{-1}, oxyfluorfen, flumioxazin + pyridate. The grain yield of chickpea was greatest [Kermanshah (1489.5 kg ha^{-1}), Hamedan (312 kg ha^{-1}), and Kurdistan (2015 kg ha^{-1})] in PRE flumioxazin at 50 g ai ha^{-1} application after hand weeding. According to the results, PRE flumioxazin at 50 g ai ha^{-1} is the most suitable treatment to control broadleaf weeds and increase yield in autumn-sown chickpea.

Key words: Biomass, Grain yield, Flumioxazin, weeds, chickpea

INTRODUCTION

Weeds are one of the most important limiting factors in the production of chickpea (*Cicer arietinum*) in Iran, especially in autumn sown chickpea. Chickpeas, with 37.8% of the total production of pulses, ranked first in Iran and produced 168142.5 t ha^{-1} in 439872 ha^{-1} of area harvested (FAOSTAT 2021). The largest area under cultivation of chickpea is located in Kermanshah, Kurdistan and Lorestan provinces in Iran (154000, 82000 and 62000 ha, respectively) (Anonymous 2022). Reducing weed density may increase yield by reducing inter-plant competition, proper radiation distribution, and improvement of space microclimate (Canevary 2006). Lack of weed control in chickpea fields reduces its grain yield by 85-100%. (Gaur *et al*. 2010, Mousavi 2004). In this regard, this decrease has been estimated at 94% in South Asia (Saxena 1996) and in Iran at 48-66.4% and 58% in two reports (Mohammadi *et al*. 2005, Ahmadi 1998). In addition to yield reduction, the presence of weeds such as False carrot (*Turgenia latifolia* (L.) Hoffm. Bt Rach), three-horn bedstraw (*Galium tricornutum* Dandy.) and field bindweed (*Convolvulus arvensis* L.) also interfere with chickpea harvesting. The density level of weeds in autumn-sown chickpeas is high. According to the previous finding, the density of weeds in autumn-sown is 6.54 and 2.5 times higher than in spring-sown in Kurdistan (Fathi *et al*. 2016) and Lorestan (Mousavi *et al*. 2007), respectively. Although weed density is reduced in spring-sown due to plowing before planting, water stress in this growing season lowers chickpea yield. For this reason, in recent years, leading farmers have turned to autumn-sown chickpeas.

Mansourian *et al*. (2021) stated that weeds observed in chickpea fields in Kurdistan were 52 species, mainly from *Asteraceae*, *Poaceae*, *Apiaceae*, and *Caryophyllaceae* families, and the predominant broadleaf weeds were catchweed bedstraw (*Galium aparine* L.), field bindweed (*Convolvulus arvensis* L.), shepherd׳s needle (*Scandix pecten veneris* L.), salsify (*Tragopogon graminifolius* DC.), dove-foot geranium (*Geranium molle* L.) and great bur parsley (*Turgenia latifolia* (L.) Hoffm). The most problematic weeds in chickpea fields in Kermanshah, Kurdistan, and Hamedan were stinking chamomile (*Anthemis cotula* L.), hoary cress (*Cardaria draba* (L.) Desv.), Syrian cephalaria (*Cephalaria syriaca* (L.) Roemer & Schultes), henbit (*Lamium amplexicaule* L.), chicory (*Cichorium intybus* L.), cow soapwort (*Vaccaria hispanica* (Mill) Rauschert), field bindweed, winter vetch (*Vicia villosa* Roth.), prostrate knotweed (*Polygonum aviculare* L.), prickly lettuce (*Lactuca* *serriola* L.) and drug fumitory (*Fumaria officinalis* L.) (Veisi *et al*. 2022, Veisi *et al*. 2019, Chalechale *et al*. 2014). Various strategies for weed management can be used in autumn-sown chickpea, including the application of inter-row cultivators, crop management (crop rotations), and application of herbicides. Herbicide can be considered as one of the effective measures to reduce weed damage in chickpea.

Like other pulses, chickpea is more likely damaged by post-herbicides than PRE-herbicides (Solh and Pala 1990). This indicates the limitations of herbicides, especially post-emergence herbicides for broadleaf weeds in chickpea (Solh and Pala 1990). Currently, only a few herbicides are recommended for chickpea in Iran. The availability of post herbicides in Iran, for instance, pyridate (the only post herbicide registered for chickpeas in Iran), is limited due to high cost. Previous research indicates that the weed control efficiency of oxyfluorfen for autumn-sown chickpeas was 69 to 76% (Veisi *et al*. 2022). Farmers in Iran prefer to manage weeds, by hand weeding or using cultivators between rows, due to the potential risk of herbicide damage, the high cost involved in herbicide applications, and limited herbicide options for selective weed control.

Flumioxazin, a *N*-phenyl phthalimide herbicide, is registered for pre-control of broadleaf weeds in soybean (*Glycine max*) (Ferrier 2023). Flumioxazin is a soil-applied herbicide with a unique mode of action (protoporphrinogen oxidase inhibition) and is classified as a Weed Science Society of America (WSSA) Group 14, that chloroplast is the initial site of action of flumioxazin (Ferrier 2023). In a study conducted in Missouri, flumioxazin alone provided 92% and 89% control of common cocklebur and common ragweed respectively (Niekamp *et al*. 1999). Due to the spectrum of weeds controlled by flumioxazin, this herbicide has been most commonly used in the peanut fields in the United States (Grey *et al*. 2003, Scott *et al*. 2002). Flumioxazin is effective in reducing broadleaf weeds including *Amaranthus* species, common lambsquarters (*Chenopodium album* L.), Eastern black nightshade (*Solanum ptychanthum* Dunal), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), velvetleaf (*Abutilon theophrasti* Medik,) and common ragweed (*Ambrosia artemesiifolia* L.) (Anonymous 2019, Herrmann *et al*. 2017).

Considering the wide range of weed species in chickpeas in different regions of Iran, autumn-sown requires herbicides that provide a broader spectrum of weed control. Furthermore, the prevention of weed resistance to herbicides makes it necessary to increase the diversity of herbicides. In this regard, the purpose of this study was to compare new PRE-herbicide (flumioxazin) with different rates as IBS, PRE, and Early-post with previously used herbicides, in terms of weed control and subsequently increase grain yield of chickpea.

MATERIALS AND METHODS

In this study, three field experiments were carried out in Kermanshah (46.50° E, 34.16° N, 1346 meters above sea level (asl), Kurdistan (47.8° E, 35.40° N, 2010 meters asl), and Hamedan (48.32° E, 34.52° N, 1741.5 meters above sea level) provinces of Iran, during growing year 2020-2021. The three studied locations were different regarding climate, chickpea cultivars (Table 1), and weed diversity (Table 2). Experimental fields with a history of sufficient infestation of the annual broadleaf weeds in each location were selected in the fall. Fields were conventionally prepared (moldboard ploughing, and disking) before planting. Fertilizers, 20, 20, and 25 kg N, and 50, 40, and 50 kg P_2O_5 were broadcasted based on soil test recommendations at Kermanshah, Kurdistan, and Hamedan, respectively. Chickpea cultivars (Table 1) were planted in three sites from 22nd October to 19th November 2020. Cultivars and descriptions of each location, including soil pH, texture, percentage of organic matter, clay, sand, and silt content are given in Table 1.

Monthly meteorological data, including accumulated monthly rainfall and mean temperature, were collected from stations located in research locations (Figure 1).

Plot size was 8 m long by 3 m wide to include five sowing rows with a 0.5 m row spacing. The average density of dominant weeds in the whole field was determined (Table 2).

Table 1. The climate, soil textures, pH, and percentage of organic matter (OM) at three experimental chickpea locations during 2020-2021

Location	Research station	Cultivar	Climate	Texture	Sand%	Silt %	Clay %	pH	OM %
Kermanshah	Mahidasht	Adel	Semi-dry	Silt clay	12	46	42	7.8	0.73
Kurdistan	Saral	Saed	Semi-dry cold	Clay	19	31	45	7.42	0.74
Hamedan	Azad	Adel	Semi-dry cold	Sandy loam	35	40	24.4	8.08	0.40

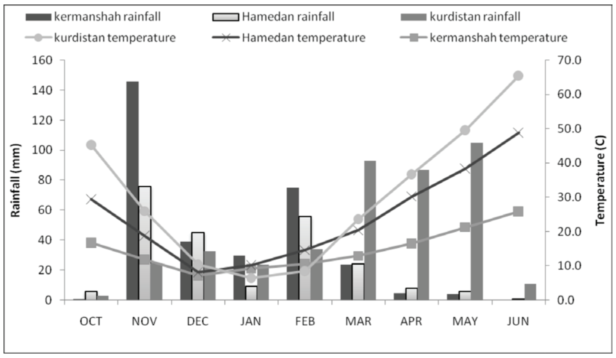

Fig. 1. Monthly average temperature (°C; *solid line*) and total rainfall (mm; *bold bar*) were recorded from each location (Kurdistan, Kermanshah, and Hamedan) during 2020-2021

Other weeds species includes the species with an average density of less than two plants per square meter. Standard errors of densities shown in parenthesis.

The experiments were conducted with nine herbicide treatments (IBS, PRE, early POST, and POST applications) as well as weed-free checks, arranged in a randomized complete block design with four replications (Table 3).

Herbicides were applied at a spray volume of 300 L ha^{-1} at 250 kPa using a battery-operated backpack sprayer equipped with one flooding nozzle. The IBS-treatment was first sprayed on the bare soil and then incorporated with the soil by the seeder. In this way, the toxic soil was transferred from the cultivation rows to inter-row spacing. The PRE-herbicides were sprayed three days after sowing. Early POST-herbicide was applied at cotyledon to 2 leaf stages of weeds. POST- herbicides were sprayed at 2 to 4 leaf stages of weeds and 4 to 6 leaf stages of chickpea. Half of each plot was sprayed, and the other half was used as an untreated control (Zand *et al.* 2007). Grasses were controlled by haloxyfop R-methyl (Galant Super 10.8% EC) (108 g ai ha^{-1}) at three to five leaf stages in the whole field. Two quadrats were randomly thrown in the untreated

Table 2. Average density of weed species per square meter across the three locations (2020-2021 growing season).

Weed species	**Weed density (Weed no. m^{-2})**		
	Kermanshah	**Kurdistan**	**Hamedan**
Alyssum spp.	-	-	9.6 (0.5)
Amaranthus retroflexus L.	-	-	10 (0.4)
Carthamus oxycantha M. Bieb.	15 (1)	-	-
Cephalaria syriaca (L.) Roemer & Schult.	13 (1.8)	16.5(1.9)	-
Cichorium intybus L.	7.8 (0.4)	-	-
Conringia orientalis (L.) Dumort.	23 (1.5)	-	-
Descurainia Sophia (L.) Webb.ex Prantl.	-	-	13.5 (0.7)
Fumaria officinal L.	-	-	9.5 (1.3)
Galium tricornatum Dandy.	8.5 (1.1)	6.5 (1.6)	3.2 (0.4)
Rapistrum rugosum (L.) All.	6.2 (0.5)	-	-
Lamium amplexicaule L.	6.1 (0.5)	-	-
Picnomon acarna (L.) Cass.	-	10.2 (0.2)	-
polygonum aviculare L.	25.4(1.8)	18.3(1.6)	-
Stizolophus balsamita (Lam.) Cass.ex. Takht.	11.5 (1.5)	-	-
Tragopogon major Jacq.	5.8 (0.5)	4.2 (1.1)	-
Vicia villosa	7.2 (0.7)	-	-

and treated plots, and weeds were counted by species. In these quadrats, weed density and biomass were recorded eight weeks after PRE herbicides and four weeks after POST herbicides. Weeds were cut at ground level and oven-dried at 75ºC for 48 hours. The percentage reductions in density and biomass of weeds by species were calculated.

At four and eight weeks after PRE and POST treatments (WAT), crop phytotoxicity in comparison to untreated crops was evaluated regarding the scales of EWRC (European Weed Research Society), which is related to visual injury of herbicides to chickpea (scores from 1 to 9 (1 = no visible injury and 9 = death of all plant) (Zheliazkov *et al.* 2017). Chickpea yield was determined after harvest (from June 15 to July 1, 2021). Whole plant and grain yield of chickpea were manually harvested at the physiological crop maturity stage in an area of 2 m^2 (1 m by 2 m) in treated and untreated plots.

Table 3. Treatments applied in autumn-sown chickpea at three locations in 2020-2021

Treatments		**Timing**	**Rate (g ai ha^{-1})**	**Formulation**	**Herbicide rate in active ingredient**
Common name	**Commercial name**				
Flumioxazin	Clean sheet	IBS	75	WP	50%
Flumioxazin	Clean sheet	PRE	25		
			50		
			75		
			100		
Oxyfluorfen	Goal	PRE	168	EC	24%
Flumioxazin	Clean sheet	early POST	25	EC	50%
Flumioxazin +pyridate	Clean sheet+ Lentagran	PRE + POST	100 + 1200	WP + EC	50%+ 60%
Pyridate	Lentagran	POST	1200	EC	60%

All data were analyzed using analysis of variance (PROC GLM) in SAS portable 9.1 statistical software. The assumptions of variance analysis were tested by ensuring that the residuals were random and homogenous, with a normal distribution about a mean of zero. Means comparison was based on Duncan's Multiple Range Test at p=0.05 level.

RESULTS AND DISCUSSION

Herbicide treatment points (e.g. flu 50) close to species vectors (e.g. Ces) indicate an association between the treatment and percentage reduction in weed species density. Importantly, changes in species composition are more strongly associated with individual herbicide treatments, with a strong trend in flumioxazin treatments (Fig 2). Proximity of a species vector to herbicide indicates a strong positive correlation, suggesting a high effect of herbicide. For example, flumioxazin 50, 75, and 100 g ai ha^{-1} are strongly associated with *G. tricornutum* reduction (Fig. 2). In contrast, pyridate, flumioxzain 25, early post flumioxazin, oxyfluorfen, and IBS flumioxazin are strongly negatively correlated with weeds reductions.

At Kermanshah, herbicide treatments

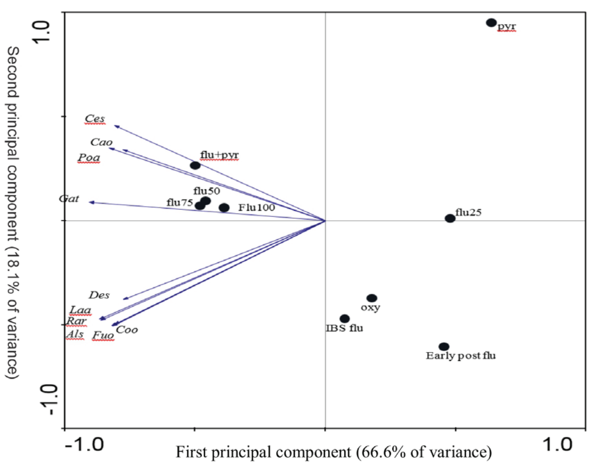

Fig. 2: Principal component analysis (PCA) of the first two canonical varieties describing the relationship of percentage reduction in weed density and herbicide applications, four weeks after treatments. Vectors represent the main explanatory variables: Intensification index of herbicide application. Herbicide code: IBS flumioxazin (IBS flu), flumioxazin 25, 50, 75 and 100 g ai ha^{-1} (flu25, 50, 75 and 100), species codes: Ces (*Cephalaria syriaca*), Cao (*Carthamus oxycantha*), Poa (*Polygonum aviculare*), Gat (*Galium tricornutum*), Des (*Descurania sophia*), Laa (*Lamium amplexicaule*), Rar (*Rapistrum rugosum*), Als (*Alyssum* spp.), Fuo (*Fumaria officinalis*) and Coo (*Conringia orientalis*

significantly affected the density and biomass of weeds in chickpea. The density and biomass of broadleaf weeds were reduced by applications of PRE flumioxazin (50, 75, and 100 g ai ha^{-1}) 79 to 87%, flumioxazin+pyridate (83%), IBS flumioxazin 75 g ai ha^{-1} (70 to 76%) and oxyfluorfen (80 to 81%) compared to untreated control. In contrast, the poorest control of weed densities (63 to 64%) occurred with pyridate (Table 4). Flumioxazin 100 g ai ha^{-1} reduced total biomass and density of weeds by 83 to 87%, and no significant difference was observed, with flumioxazin PRE (50 and 75 g ai ha^{-1}), flumioxazin + pyridate and oxyfluorfen.

At Kurdistan, all herbicide treatments showed a significant decrease compared to untreated control. Observations showed that the greatest reductions (69 to 80.5%) in density and biomass of total weeds occurred with flumioxazin+pyridate, PRE flumioxazin at 50, 75, and 100 g ai ha^{-1}. On the contrary, IBS, Early POST, and PRE-flumioxazin at 25 g ai ha^{-1}, pyridate and oxyfluorfen gave poor weed control (dry biomass and density) (Table 4).

At Hamedan, the application of herbicides reduced dry biomass and density of weeds significantly compared to non-treated plots. The highest reduction (100%) in the density of total weeds was due to flumioxazin 75 and 100 g ai ha^{-1}, which was not significantly different from PRE flumioxazin 50 and 75 g ai ha^{-1} (80.5%) and IBS flumioxazin (80%). Meanwhile, the application of IBS flumioxazin, PRE flumioxazin 50, 75, and 100 g ai ha^{-1}, PRE oxyfluorfen, as well as flumioxazin+pyridate provided the greatest reductions in the total dry biomass of weeds (70-74%). At the same time, pyridate had the least effect (58%) on reducing the total dry biomass of weeds (Table 4).

Some herbicide treatments caused visible injury to chickpea at three locations. Compared with other herbicide treatments, PRE flumioxazin at 100 g ai ha^{-1} caused the most crop injury (EWRS score 4 to 5) including discoloration and stunting at three sites. At Kermanshah, the results of the observations by the visual logarithmic scale of EWRS show that phytotoxic effects on chickpea, eight WAT, were very weak (score 1) after flumioxazin + pyridate, IBS and PRE flumioxazin (25 and 50 g ai ha^{-1}) were applied (Table 5). Visible injury caused by PRE flumioxazin at 75 g ai ha^{-1} was present as a signs of leaf chlorosis, as well as stunting, but the phytotoxicity symptoms decreased with time due to plant regrowth (Table 5).

At Kurdistan, no injury was observed by

Table 4. Reduction of density and dry biomass of weeds, nine weeks after the PRE and four weeks after the POST treatments at three locations

Treatments	Rate (g ai ha^{-1})	Timing	Kermanshah				Kurdistan				Hamedan			
			DB		D		DB		D		DB		D	
			%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
Flumioxazin	75	IBS	70 c	4.5	76 c	1.4	25 c	14.5	41 cd	31.7	74.5 a	1.0	80 a	3.9
	25	PRE	66 cd	3.3	69 d	1.7	39 bc	16.5	39 d	29.9	65 b	3.5	67 c	3.5
	50	PRE	79 ab	4.2	83 ab	1.2	70.5 a	16.6	72 ab	14	72 a	3.6	78 ab	2.3
	75	PRE	81 ab	1.7	83 ab	2.9	73 a	14.6	69 abc	18	72.5 a	1.5	80.5 a	2.3
	100	PRE	83 a	1.8	87 a	4.9	71 a	10	70 abc	16	72 a	4.2	81 a	1.0
	100	Early POST	70 c	1.0	71 d	1.1	29 c	10.4	45 bcd	20.1	64 b	2.8	72 bc	2.4
Oxyfluorfen	168	PRE	80 ab	3.8	81 ab	5.7	59 b	18.7	50 bcd	36	70 ab	4.3	74.5ab	2.7
Flumioxazin+pyridate	100+1200	PRE+POST	83 a	4.1	83 ab	4.2	70 a	70.2	80.5 a	20	70 ab	4.6	77 ab	1.1
Pyridate	1200	POST	64 d	2.0	63 e	1.3	60 b	11	50 bcd	37	58 c	2.5	57 d	6.8

DB dry biomass, *D* density, SD standard deviation, % percentage reduction

*Means followed by the different letters are significantly different according to Duncan's Multiple Range Test (p< 0.05))

PRE flumioxazin (25 and 50 g ai ha^{-1}) as well as flumioxazin+pyridate, though more injury (EWRS score 5) occurred by PRE flumioxazin (100 g ai ha^{-1}) (plant stunting) and pyridate (Table 5).

At Hamedan, no injury attributable to herbicides was noted in chickpea treated with IBS and PRE flumioxazin (25, 50 and 75 g ai ha^{-1}), flumioxazin+pyridate as well as pyridate eight weeks after treatment. Conversely, when PRE flumioxazin at 100 g ai ha^{-1} was applied Early POST, caused the highest (EWRS score 4.6) injury (leaf necrosis and plant stunting).

Yield attribute and grain yield of chickpea were significantly influenced by herbicide treatments. At Kermanshah, among the herbicide treatments, the highest grain yield of chickpea occurred in flumioxazin 50 g ai ha^{-1} (1489.5 kg ha^{-1}), flumioxazin 75 g ai ha^{-1} (1470 kg ha^{-1}), IBS flumioxazin (1448 kg ha^{-1}) and flumioxazin + pyridate. Similarly, the highest plant dry biomass of chickpea (398, 386, 379, and 355 g m^{-2}) was attributed to the treatments mentioned above, respectively. In contrast, pyridate, Early POST flumioxazin, as well as PRE flumioxazin at 25 and 100 g ai ha^{-1} gave the lowest grain yield and plant dry biomass. Furthermore, the maximum plant height (44 cm) was found with the application of PRE flumioxazin 50 g ai ha^{-1} and oxyfluorfen (Table 8). Due to the difference in weed control and crop injuries by herbicide treatments, yield traits also showed significant differences. At Kurdistan, hand weeding followed by PRE flumioxazin at 50 g ai ha^{-1} and flumioxazin+pyridate resulted in the highest grain yield (2000 to 2485 kg ha^{-1}), plant dry biomass (351 to 430 kg ha^{-1}) and plant height (32.2 cm) compare to other treatments (Table 6).

At Hamedan, herbicide treatments significantly affected the grain yield, plant dry weight, and plant height of chickpea. Application of PRE flumioxazin 50 and 75 g ai ha^{-1}, IBS flumioxazin, flumioxazin+pyridate, and hand weeding produced the highest grain yield (678 kg ha^{-1}) and plant dry biomass (up to 178 g m^{-2}), whereas PRE flumioxazin at 25 g ai ha^{-1} produced lowest. Maximum plant height of chickpea (49 to 50 cm) was obtained using

Table 5. Herbicide injury to chickpea, using 1 to 9 scale: 1= no visible damage and 9= death of all plant tissues, when evaluated four and eight weeks after treatments

Treatments	Rate (g ai ha^{-1})	Timing	Kermanshah		Kurdistan		Hamedan	
			4WAT	SD	4WAT	SD	4WAT	SD
Flumioxazin	75	IBS	1 d	0.0	1 cd	0.5	1 c	0.0
	25	PRE	1 d	0.0	1 e	0.0	1 c	0.0
	50	PRE	1 d	0.0	1 e	0.0	1 c	0.0
	75	PRE	2 b	0.0	2 bc	0.0	1.3 bc	0.5
	100	PRE	4 a	0.0	5 a	0.0	5 a	0.0
	100	Early POST	1.9 bc	0.0	2 bc	0.5	2 b	0.0
Oxyfluorfen	168	PRE	1.5 c	0.5	2.2 bc	0.5	2 b	0.0
Flumioxazin+pyridate	100+1200	PRE+POST	1 d	0.5	1.2 de	0.5	1 c	0.0
Pyridate	1200	POST	2.5 b	0.0	2.5 ab	0.57	2 b	1

Table 6. Impact of herbicides on height, grain yield and plant dry biomass of chickpea at three locations

Treatments	Rate (g ai ha^{-1})	Timing	Grain yield (kg ha^{-1}) Kerm GY	Kerm SD	Kurd GY	Kurd SD	Hame GY	Hame SD	Plant dry biomass (g m^{-2}) Kerm PD	Kerm SD	Kurd PD	Kurd SD	Hame PD	Hame SD	Height (cm) Kerm H	Kerm SD	Kurd H	Kurd SD	Hame H	Hame SD
Flumioxazin	75	IBS	1448 ab	269	1485 bc	645.1	625 ab	4.2	379 a	31	272 cd	106	164 ab	1.1	43.5 bc	1.3	27.5 c	3.4	49.7 bc	0.5
	25	PRE	1041 cd	48	1340 c	424.9	546 d	9	273 bc	3	253 d	52.4	144 d	2.4	41 e	0.9	28 c	0.5	48.3 bc	0.5
	50	PRE	1489.5 ab	105.5	2015 ab	328.0	623 ab	1.3	398 a	4	351 abc	72.3	163 abc	0.3	44 ab	1.4	32 ab	0.8	49 abc	1
	75	PRE	1470 ab	61	1785 bc	342.7	639 ab	3.7	386 a	12	324 bcd	47.1	168 a	3.7	43.4 bc	0.6	31 b	0.4	49.3 ab	1
	100	PRE	971 cd	243.5	1740 bc	240.6	572 bcd	8.2	257 bc	36	319 bcd	39.3	147 cd	8.2	41.2 de	1	27 c	1	48.7 bc	0.5
	100	Early POST	896 d	72	1175 c	304.8	563 cd	3.6	236 c	13	286 bcd	56.9	148 bcd	3.6	42 cde	0.9	26 c	2.3	48 c	0
Oxyfluorfen	168	PRE	1199 bc	515	1370 c	438.3	553 cd	2.5	313 abc	68	234 d	44.3	145.5 d	2.5	44 ab	0.8	27 c	1.7	48.3 bc	0.5
Flumioxazin+ pyridate	100+1200	PRE+ POST	1348 ab	245	2000 ab	415.1	619 ab	0.3	355 ab	37	368 ab	67.9	164 ab	1.3	43 bcd	0.9	32 ab	1.2	49.3 ab	0.5
Pyridate	1200	POST	875 d	251	1480 bc	852.1	555 cd	82	230 c	35	277 bcd	136	150 bcd	24.1	42 cde	1.3	27.9 c	2.6	48.3 bc	0.5
Hand weeding	-	-	1643 a	100	2485 a	312.1	678 a	29	396 a	11	430 a	45.8	178 a	7.5	45.5 a	0.9	35 a	2.9	50 a	0

Kerm Kermanshah, *Kurd* Kurdistan, *Hame* Hamedan, *SD* standard Deviation, *GY* Grain yield, *PD* Plant dry biomass, *H* Height

*Means followed by the different letters are significantly different according to Duncan's Multiple Range Test ($p< 0.05$)

PRE flumioxazin 50 and 75 g ai ha^{-1} as well as hand weeding (Table 6) (Figure 3).

The results in the three experimental locations showed that pyridate did not have the necessary efficiency in controlling weeds in chickpea fields may be due to the low quality of the herbicide. Meanwhile, the PRE flumioxazin treatment (100 g ai ha^{-1}) also caused a decrease in chickpea yield and yield attributes due to crop injury despite the favorable control of weeds. Besides, flumioxazin applied after the emergence of chickpea (Early POST) caused damage to chickpea, hence which naturally reduced the yield and yield attributes of chickpea. Increased crop injury has been reported after flumioxazin applied Early POST (McNaughton *et al*. 2014). Similarly, Sridhara *et al*. (2019) and Wilson *et al.* (2002) reported that PRE flumioxazin at 50 g ai ha^{-1} reduced total weeds (density and dry matter) up to 90%.

The results confirmed the findings of previous studies by Harmohinder (2021) in which IBS flumioxazin controls the broad-leaved weeds up to 91%. Although, Sudan's study showed that oxyfluorfen reduced the grassy weeds (by up to 90%) and broadleaf weeds (only 62%) in chickpea (Mohammed 2016). Also, the results showed that increasing the rate of flumioxazin, did not affect increasing its efficiency. In visual assessment, PRE flumioxazin at 100 g ai ha^{-1} controlled weeds up to 84%.

PRE flumioxazin at 100 g ai ha^{-1} and hand weeding was not significantly different in terms of grain yield, plant dry biomass, and plant height of chickpea, and there was no significant increase in chickpea yields with higher flumioxazin levels, in such a way that even higher levels (200 g ai ha^{-1}) caused phytotoxicity and grain yield reduction of chickpea. In confirmation of these findings, Vasilakoglou *et al*. (2013) reported that flumioxazin (110 g ai ha^{-1}) is the most appropriate option for controlling the dominant weeds with the lowest crop injury in chickpea. Richardson and Zandstra (2006) also pointed out that flumioxazin reduced Common ragweed (*Ambrosia artemisiifolia* L.) by up to 92%. Flumioxazin reduced the biomass of broadleaf weeds by more than 90% (Wilson *et al.* 2002)

At Kurdistan, the total density of weeds in the experimental field was sufficiently reduced (up to 73%) by flumioxazin 50, 75, and 100 g ai ha^{-1} as well as flumioxazin + pyridate. All treatments (except for Early POST flumioxazin) had favorable effects on reducing the density and dry biomass of *C. syriaca* (L.) Roemer & Schult. Flumioxazin + pyridate had the greatest effect on reducing the density of *P. aviculare* L., followed by flumioxazin 50, 75, and 100 g ai ha^{-1}. Kumari *et al*. (2021) in India and Melo *et al*. (2019) have also reported that the control efficiency of broadleaf weeds by flumioxazin in peanut and onion is 95% and 90%, respectively. Flumioxazin 50 g ai ha^{-1}, flumioxazin + pyridate as well as hand weeding had more grain yield, dry biomass and plant height of chickpea compared to other treatments without any damage to the chickpea. These results are in accordance with Vasilakoglou *et al*. (2013), who found that the application of PRE flumioxazin at 55 g ai ha^{-1} provided the least phytotoxicity to chickpea. Despite proper weed control by PRE flumioxazin at 150 and 200 g ai ha^{-1}, they had lower yield traits than the above-mentioned treatments, which may be due to herbicide damage at higher rates.

The results in Hamedan showed that PRE flumioxazin 50 g ai ha^{-1} with the greatest effect on total weeds, as well as the dominant weeds such as *D. sophia* (L.) Webb.ex Prantl., *F. officinalis* L., *Alyssum* spp., *Amaranthus retroflexus* L., and *Galium tricornutum* Dandy. (96-100%), was the most suitable treatment due to its low rate and higher weed control efficiency. Furthermore, higher levels of flumioxazin had no significant effects in reducing the density and dry biomass of weeds. Jha and Kumar (2017) also mentioned that PRE flumioxazin at 53 g ai ha^{-1} reduced up to 98% of weeds in chickpea fields, which is consistent with the results of this research. PRE flumioxazin 200 g ai ha^{-1} followed by oxyfluorfen and pyridate had adverse effects on chickpea. Whereas PRE flumioxazin 50 g ai ha^{-1} was the most suitable treatment for Hamedan due to the lack of adverse effects on chickpeas and high weed control level as well as grain yield.

Although oxyfluorfen reduced 59 to 80% of total weed dry biomass in three locations, it had a lower grain yield than flumioxazin 50 g ai ha^{-1}. This may be due to poor control of some weeds, such as wild *C. oxycantha* M. Bieb. and *P. aviculare* L., which increased crop-weed competition. Previous findings have also shown that oxyfluorfen is safe and effective in increasing chickpea yield, compared to untreated control (Veisi *et al*. 2022). Reddy *et al*. (2022) also reported that the weed control efficiency of PRE oxyfluorfen (42%) increased (82%) by adding one-hand weeding. In this regard, Rastgoi *et al*. (2021) mentioned that the application of PRE oxyfluorfen 100 g ai ha^{-1} + Imazethapyr 50 g ai ha^{-1} + one-hand weeding seems better for higher productivity and profitability of chickpea crop**.**

CONCLUSION

Considering the high damage caused by broad-leaved weeds in autumn-sown chickpea cultivation and the strategy of increasing the herbicide package to reduce weed resistance to herbicides, this study provides the most suitable broad-leaved herbicides for autumn-sown chickpea. Based on the results, among the herbicide treatments, pre-emergence application of flumioxazin at 50 and 75 g ai ha^{-1} was the most effective treatment for broadleaf control in chickpea. Furthermore, there was no significant difference between the application of different amounts of flumioxazin (50 and 75 g ai ha^{-1}) as well as flumioxazin + pyridate, in terms of weed control and increase in chickpea yield. According to findings, pre-emergence flumioxazin with a rate of 50 g ai ha^{-1} was the most effective (70.5 to 79% dry biomass of weeds) and lowest amount of herbicide was considered to be recommended to farmers to control broadleaf weeds in autumn-sown chickpea fields. Flumioxazin allows growers to shift chickpea cultivation from spring to autumn in order to use more rainfall and consequently higher grain yield. The application of flumioxazin may be one of the strategies to be incorporated in integrated weed management programs.

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