Efficiency of herbicides for weed control in chickpea and effect of their residues on wheat growth

Eficacia de herbicidas para el control de malezas en garbanzo y efecto de sus residuos en el crecimiento del trigo

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ABSTRACT

In order to determine the best time to use and the adequate dose of four herbicides to control weeds in dryland chickpea (*Cicer arietinum* L.) fields, we performed the present experiment in 4 × 5 m plots. Fourteen treatments were carried out that from 1 to 9 included trifluralin. Treatments 1, 2, and 3 were with increasing doses of trifluralin (480, 720, and 960 g ai ha^{-1}) applied 30 d before planting. Treatments 4, 5, and 6 included increasing doses of trifluralin (480, 720, and 960 g ai ha^{-1}) applied 15 d before planting. Treatments 7, 8 and 9 consisted of increasing doses of trifluralin (480, 720, and 960 g ai ha^{-1}) applied at the time of planting. Treatments 10, 11, and 12 included pyroxasulfone (85 g ai ha^{-1}), flumioxazin (51 g ai ha^{-1}) and imazethapyr (100 g ai ha^{-1}), respectively. These last three treatments were carried out at the time of planting; treatments 13 and 14 were: weed-infested (without weed control) and weed-free (manual weeding during the entire season). Flumioxazin 66% and pyroxasulfone 57% (mean of two samples) reduced weed dry weight compared to uncontrolled treatment. The results showed that the treatments were significantly different for 100-seed weight, biological yield, and seed yield of chickpea. Weed-infested and weed-free plants had the lowest and highest grain yield, respectively. Herbicide treatments of flumioxazin, trifluralin 960 g ai ha^{-1}, and pyroxasulfone at planting produced 55%, 44%, and 40% higher grain yield, respectively, than the weed-infested plots. Also, none of the herbicide treatments reduced chickpea yield and biomass. The herbicide residues had no adverse effect on wheat growth in the next crop season.

Key words: dryland conditions, flumioxazin, imazethapyr, rotation, trifluralin.

RESUMEN

Con el fin de identificar el mejor momento de uso y la dosis adecuada de cuatro herbicidas para el control de malezas en campos áridos de garbanzo (*Cicer arietinum* L.), el presente experimento se realizó en parcelas de 4 × 5 m. Se realizaron 14 tratamientos donde, del 1 al 9 incluyeron trifluralina; los tratamientos 1, 2 y 3 fueron con dosis crecientes de trifluralina (480, 720, and 960 g ia ha^{-1}) aplicada 30 d antes de la siembra; los tratamientos 4, 5 y 6 incluyeron dosis crecientes de trifluralina (480, 720, y 960 g ia ha^{-1}) 15 d antes de la siembra. Los tratamientos 7, 8 y 9 consistieron en dosis crecientes de trifluralina (480, 720, y 960 g ia ha^{-1}) al momento de la siembra. Los tratamientos 10, 11 y 12, incluyeron piroxasulfona (85 g ia ha^{-1}), flumioxazina (51 g ia ha^{-1}) e imazetapir (100 g ia ha^{-1}) respectivamente. Estos tres últimos tratamientos se realizaron al momento de la siembra; los tratamientos 13 y 14 fueron: infestado de maleza (sin control de maleza) y libre de maleza (desmalezado manual durante toda la temporada). La flumioxazina al 66% y la piroxasulfona al 57% (media de dos muestras) redujeron el peso seco de las malezas en comparación con la parcela infestada de malezas. Los resultados mostraron que los tratamientos fueron significativamente diferentes para el peso de 100 semillas, el rendimiento biológico y el rendimiento de semillas de garbanzo. Las plantas infestadas de malezas y libres de malezas tuvieron el rendimiento de grano más bajo y alto respectivamente. Los tratamientos con herbicidas flumioxazina, trifluralina 960 g ia ha^{-1}, y piroxasulfona en la siembra, mostraron un rendimiento de grano 55%, 44% y 40% mayor, respectivamente, que las parcelas infestadas de malezas. Además, ninguno de los tratamientos con herbicida redujo el rendimiento y la biomasa del garbanzo. Los residuos del herbicida no tuvieron efecto adverso sobre el crecimiento del trigo en la siguiente temporada de cultivo.

Palabras clave: condiciones áridas, flumioxazina, imazetapir, rotación, trifluralina.

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Introduction

According to FAO statistics, the primary producers of chickpea worldwide are India, Turkey, and Russia, and the chickpea grain yield average is 1,038 kg ha^{-1} worldwide (FAO, 2021). The area under cultivation of chickpea in Iran is about 456 thousand ha, with an average grain yield of 439 kg ha^{-1}, which is very low compared to the global average yield.

Weeds are the biggest challenge to food production worldwide and reduce crop yields due to high competitiveness (Naghib *et al*., 2020). The competitive capacity of chickpea is lower than other crops compared to weeds, so productivity is seriously affected by weeds (Abdulahi *et al*., 2012). There are different reports of weed damage to chickpea fields under the free control of weeds. Some studies reported a 92% reduction in performance and a damage rate of up to 97% (Paolini *et al*., 2006; Mousavi *et al*., 2007). In western Iran (Kurdistan), a 77.5% reduction in yield because of weed interference is estimated (Fathi *et al*., 2017). Another research estimates the amount of damage in weed-free control as 48.3% in Kermanshah and 66.4% in Tabriz (Mohammadi *et al*., 2005). Due to the long growing season and rainfall in autumn and winter, weeds are a massive problem in winter cultivation of chickpeas and sometimes heavy weed infestations can cause 88% crop failure, while in spring cultivation with plowing before planting, a large volume of weeds are controlled (Knott & Halila, 1988). Important and dominant broadleaf weeds of chickpea fields in Kermanshah were chicory (*Cichorium intybus* L.), bindweed (*Convolvulus arvensis* L.), stickywilly (*Galium aparine* L.), Jeweled distaff thistle (*Carthamus oxyacantha* M. Bieb.), and cowcockle (*Vaccaria pyramidata* Medik.). The narrow leaf weeds were wild barley (*Hordeum spontaneum* Koch.), wild oat (*Avena ludoviciana* Durieu.), and bermuda grass (*Cynodon dactylon* L. Pers.) (Chalechale *et al*., 2015).

The dinitroaniline chemical group has the aniline construction as a basis containing NO_2 molecules. Trifluralin and pendimethalin belong to this group with more than ten different herbicides. Trifluralin has been used in agriculture since 1963 (Grover *et al*., 1997). This herbicide is registered in various countries for controling weeds separately or in mixtures, and it is used in the following crops: *Glycine max*, citrus, *Gossypium hirsutum*, *Arachis hypogaea*, *Phaseolus vulgaris*, and *Allium sativum* (Rodrigues & Almeida, 2018). Its application at pre-planting mixed alone with soil or in combination with the post-emergent herbicides is one of the standard methods to control weeds in bean crops (Rouse *et al*., 2018). Pyroxasulfone is a herbicide that inhibits the biosynthesis of very-long-chain fatty acids (VLCFAs) (Tanetani *et al*., 2009). This herbicide is a pre-emergent discovered amongst several herbicidal 3-sulfonylisoxazoline derivatives (Ito *et al*., 2015). Another pre-emergent herbicide imazethapyr belongs to the imidazolinone group, a class of herbicides that inhibits acetohydroxyacid synthase in synthesizing branched-chain amino acids in plants (Tan *et al*., 2005). Imazethapyr is used in weed control of soybeans, alfalfa, corn, rice, and peanuts (Barnett & Brundage, 2010). The pre-emergent herbicide flumioxazin is an herbicide that blocks protoporphyrinogen oxidase (PPO) activity (Iwashita *et al*., 2022). Flumioxazin is used in the Fabaceae family since it provides a wide range of protective action against weeds (Norsworthy *et al*., 2012).

Providing available, effective, low-cost control solutions for the presence of weeds has economic importance in chickpea cultivation. The number of herbicides introduced to control chickpea weeds in Iran and other countries is not comparable to cereal products. Hence, this study was conducted to estimate the appropriate dose and time of application of trifluralin and evaluates the effect of three other herbicides at planting: imazethapyr, pyroxasulfone, and flumioxazin for weed control in chickpea under dryland conditions. Also, possible residual growth effects on wheat growth and yield have been studied.

Materials and methods

The experiment was conducted in the dryland agricultural research sub-institute-Sararood in Kermanshah, Iran (34º20'N, 47º19'E, 1351 m a.s.l.) during the 2018-19 growth season. The climate at the experimental site was semi-arid and moderately cold with long-term total annual rainfall and maximum and minimum rainfall of 449 and 171 mm. The average annual temperature was 13.8°C, the absolute minimum temperature was -24°C, and the absolute maximum temperature was 44°C. Total rainfall during the experimental conduction (2018-2019) was 783 mm. Figure 1 shows the monthly precipitation of Sararood station in 2018-2019.

The experiment was performed in a randomized complete block design with four replicates. Treatments applied in 4 x 5 m plot size included trifluralin (48%) applications 30 d before planting (DBP) (480, 720, and 960 g ai ha^{-1} for treatments 1, 2, and 3); trifluralin applied 15 DBP (480, 720, and 960 g ai ha^{-1} for treatments 4, 5, and 6); trifluralin applied at planting time (480, 720, and 960 g ai ha^{-1} for treatments 7, 8, and 9); pyroxasulfone (85%) at planting time (85 ai g ha^{-1} for treatment 10); flumioxazin (51%) at planting (51 g ai ha^{-1} for treatment 11); imazethapyr (10%) at planting time (100 g ai ha^{-1} for treatment 12); weed-infested and weed-free (treatment 13 and 14) (Tab. 1). A Matabi backpack sprayer was used to spray herbicides with calibrated nozzles based on 300 L ha^{-1} of water. At each stage, immediately after applying the herbicide, a surface disking operation was performed to mix the herbicide with the surface layer of the soil.

Chickpea seeds (cv. Mansour) were planted mechanically using an Aske 2200 (Sazeh Kesht Bukan Company, Iran) on March 19, 2019. Each plot consisted of seven rows with 35 cm row-spacing. The distance between chickpea seeds on planting rows was 8 cm, and the planting depth was 5 cm (35 plants/m^2). During two stages, one at the beginning of the growing season and another at the chickpea flowering stage, weeds were manually removed from the plots as weeding check treatment. No control operations were performed in weed-infested (WI) plots. Chickpea harvest was done manually, and seeds and straw were separated and measured manually.

Chickpea growth traits

Measurements were taken at two different chickpea growth stages, in the 8-10 leaf stage (May 8, 2019) and at the beginning of pod formation (May 24, 2019), using a quadrat (with dimensions of 70 x 50 cm) that included two rows of planting with a length of 50 cm. Biologic yield (total biomass + yield), grain yield, plant height, number of pods m^{-2}, number of seeds per plant, 100-seed weight, plant dry weight (stems+leaves) at two sampling stages, number of seeds per pod, and plant density of chickpea were measured. In order to measure weed density and dry weight, samples were taken separately from each plot in each treatment. After collecting the samples, weeds were counted per species. Then, to determine the dry weight of the weeds, the samples were dried separately in an oven at 75°C for 48 h.

Wheat traits

These consisted of the visual assessment of the effects of herbicides on wheat growth. The assessment of possible herbicidal effects on the plants was done using a scoring method with a range of 0 to 100. A score of 0 indicated no adverse effect, and a score of 100 indicated plant death. At the end of the growth season, after the complete wheat growth (growth stage 22 according to the Zadox method), the number of tillers was measured in five randomly selected plants in each plot. To measure the 100-seed weight and grain yield, the plot area was harvested and weighed by considering the marginal plot effect at the time of full ripening, and the data were registered in kg ha^{-1}.

Statistical analysis

To determine the richness, the Shannon-Wiener diversity index and their relative frequency at two chickpea growth stages (8-10 leaves) were used using a frame (70 × 50 cm) contained two rows of crop. After collecting the samples, weed plants were counted by species. The samples were then placed in an oven with a temperature of 75ºC for 48 h to determine the weed dry weight. Weed species richness, Shannon-Wiener diversity index, and their relative frequency were calculated as follow:

A) Weed species richness indicates the number of weed species present in each treatment (Poggio, 2005); B) Relative frequency of weeds is the ratio of each weed in the sample to the total number of weeds multiplied by 100 (Booth *et al.*, 2003); C) Shannon-Wiener Diversity Index was calculated using the following equations:

$$H = -\Sigma[pi(lnpi)] \text{ and } pi = ni/N$$

where ni is the number of weeds (i) in the sample, and N is the total number of weeds in the sample.

One-way ANOVA procedure was applied using SAS software (Version 8.1) to assess all effects. Significant differences among treatment means were identified by least significant differences test (LSD) (P<0.05) (SAS Institute, 1998).

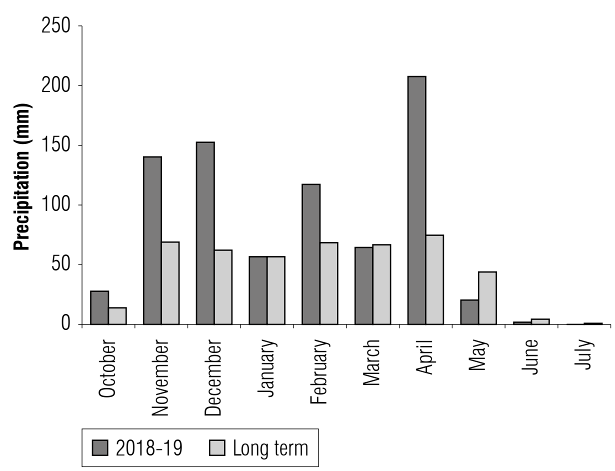

FIGURE 1. Monthly precipitation at Sararood station (Iran) in 2018-19 and comparison with monthly long-term precipitation.

TABLE 1. List of herbicides and characteristics used in the experiment.

Common name	Trade name	Chemical group	Recommended dose, g ha^{-1}	ai† and formulation	Mode of action
Trifluralin	Treflan	Dinitroanilines	720	48% EC⁑	Inhibitors of microtubule assembly
Imazethapyr	Pursuit	Imidazolinone	100	10% SL	ALS, AHAS Inhibitor of biosynthesis of amino acids
Pyroxasulfone	Sakura	Pyrazole	85	85% WG	Blocking heme and chlorophyll biosynthesis
Flumioxazin	Chateau	N-phenyl phthalimide	21	51% WDG	PPO inhibition

† Active ingredient.

⁑ EC, emulsion concentrate; SL, soluble liquid; WG, wettable granule; WDG, water dispersible granule.

Results and discussion

Weeds

Hare's ear (*Bupleurum rotundifolium* L.) had the highest relative frequencies in all treatments (average 25%), followed by bitter bean (*Sophora alopecuroides* L.) (average 11%), field bindweed (*Convolvulus arvensis* L.) (average 10%), syrian cephalaria (*Cephalaria syriaca* L.) (average 7%), chicory (*Cichorium intybus* L.) (average 8%), and prickly lettuce (*Lactuca scariola* L.) (average 7%). Moreover, other weeds with relatively low frequencies were present in some treatments (Tab. 2). Pyroxasulfone had the lowest relative frequency for hare's ear, although no significant difference was generally observed in relative frequency in different treatments. Researchers stated that the herbicide trifluralin could control lemongrass properly (Mirkamali & Maddah, 1974); also, they reported better control of lemongrass by trifluralin than imazethapyr (Moradi, 2009).

Results of analysis of variance in the first stage of weed sampling showed that the effect of treatments on the richness of weed species was insignificant (Tab. 3). Most species richness was related to weed-infested plants. On the other hand, treatments 10 and 11 (pyroxasulfone and flumioxazin) had the lowest species richness (Tab. 3). Analysis of weed species richness variance in the second sampling stage showed a significant difference (P<0.01) between treatments. The herbicide treatment of trifluralin 960 g ai ha^{-1} at planting had the loweste species richness. The pyroxasulfone and flumioxazin were in the next class, and other treatments were not different from the weed-infested (WI) plot (Tab. 4). Changes in the management of field activities may

TABLE 2. Relative frequencies of weed species in treatments 30 d after herbicide application. The data is the mean of four replicates.

	Treatments												
Weeds	1	2	3	4	5	6	7	8	9	10	11	12	13
Bupleurum rotundifolium	0.28	0.29	0.40	0.22	0.35	0.21	0.24	0.36	0.38	0.00	0.15	0.08	0.32
Sophora alopecuroides	0.08	0.18	0.09	0.05	0.04	0.23	0.07	0.15	0.10	0.08	0.15	0.18	0.05
Cichorium intybus	0.09	0.20	0.09	0.15	0.05	0.08	0.03	0.08	0.05	0.08	0.00	0.00	0.17
Convolvulus arvensis	0.10	0.02	0.05	0.00	0.20	0.07	0.00	0.00	0.32	0.19	0.06	0.18	0.08
Glycyrrhiza glabra	0.06	0.09	0.01	0.06	0.00	0.03	0.08	0.13	0.00	0.23	0.00	0.27	0.00
Lactuca scariola	0.05	0.08	0.02	0.06	0.07	0.06	0.12	0.07	0.00	0.20	0.00	0.09	0.10
Triticum aestivum	0.00	0.04	0.00	0.07	0.00	0.08	0.00	0.00	0.00	0.07	0.06	0.00	0.00
Anthemis cotula	0.02	0.04	0.06	0.04	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.04
Cephalaria syriaca	0.14	0.00	0.03	0.14	0.08	0.03	0.22	0.05	0.05	0.15	0.00	0.00	0.10
Erodium multifida	0.00	0.02	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Lathyrus sp.	0.02	0.00	0.00	0.01	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.04	0.00
Cynodon dactylon	0.00	0.00	0.07	0.11	0.00	0.00	0.00	0.00	0.08	0.00	0.38	0.04	0.00
Carthamus oxyacantha	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00
Galium aparine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Cardaria draba	0.03	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Euphorbia helioscopia	0.00	0.00	0.00	0.00	0.20	0.15	0.14	0.00	0.00	0.00	0.00	0.00	0.02
Tragopogon major	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vicia sp.	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Neslia apiculata	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.07
Adonis aestivalis	0.05	0.03	0.00	0.06	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.05

1, 2, and 3: trifluralin 30 d before planting (480, 720, and 960 g ai ha^{-1}), 4, 5, and 6: trifluralin 15 d before planting (480, 720, and 960 g ai ha^{-1}), 7, 8 and 9: trifluralin applied at planting time (480, 720, and 960 g ai ha^{-1}), 10, 11 and 12: pyroxasulfone, flumioxazin, and imazethapyr at planting time, and 13: weed-infested (no weed control).

change the species richness in the field. Field operations may create the conditions for the invasion of one species and make the conditions unfavorable for the presence of other species (Liebman *et al*., 2001). Managing various factors, especially the chemical management of weeds causes a change in the species richness of the field (Liebman *et al*., 2001). The combination of various weeds in the field indicates the presence of plants with different abilities in the utilization of water and nutrients that makes it more difficult for the crop to compete with the weeds and then restricts the crop growth (Mousavi *et al*., 2005).

The effect of different treatments on the Shannon diversity index at the first stage of sampling was insignificant, and vice-versa was significant in the second stage of sampling. Flumioxazin and trifluralin at 960 g ai ha^{-1} had the lowest effects at planting treatments, indicating that these treatments effectively reduced weed diversity. An investigation by examining the diversity index in imazethapyr, trifluralin, and control plots (without herbicide) reported that the value of this index in different stages of chickpea growth in check and imazethapyr was more than trifluralin herbicide treatment (Abbasian, 2011).

Weed density in both sampling stages was affected by herbicides (Tab. 5). In the first stage of sampling, pyroxasulfone, flumioxazin, and trifluralin 960 g ai ha^{-1} applications at planting produced the lowest number of weeds. These herbicides had 67, 51, and 48% reduction compared to the WI. The other treatments with WI were in the same class. Weed control in two sampling stages has no significant difference in weed density by the chemical control method (Nourbakhsh, 2013). Pyroxasulfone and flumioxazin followed by trifluralin 960 g ai ha^{-1} at planting resulted in the lowest weed dry weight (Fig. 2) and the lowest weed density (Fig. 3).

TABLE 3. ANOVA for weeds richness and Shannon's index.

Source of variation	Degree of freedom	Mean square			
		Richness1‡	Richness2⁑	Shannon1‡	Shannon2⁑
Replicate	3	1.25^{ns}	0.173^{ns}	0.123^{ns}	0.0037^{ns}
Treatment	12	1.91	3.67**	0.13	0.288**
Residual	36	1.67	0.90	0.17	0.102
Total	51	1.70	1.51	0.15	0.140
CV%		34	23	38	26

‡ First stage (8-10 leaf stage of chickpea).

⁑ Second stage (the beginning of chickpea pod formation).

ns, no significant difference; ** significant difference at $P<0.01$.

TABLE 4. Mean comparison of Richness and Shannon's index in different treatments at two sampling stages.

Treatments	Treatment	Richness 1‡	Richness 2⁑	Shannon 1‡	Shannon 2⁑
Trifluralin 480 g ai ha^{-1} 30 DBP†	1	4.3	5.3	1.1	1.6
Trifluralin 720 g ai ha^{-1} 30 DBP	2	3.8	5.0	1.1	1.4
Trifluralin 960 g ai ha^{-1} 30 DBP	3	3.3	4.5	1.0	1.2
Trifluralin 480 g ai ha^{-1} 15 DBP	4	4.3	5.5	1.2	1.6
Trifluralin 720 g ai ha^{-1} 15 DBP	5	3.8	3.3	1.1	1.0
Trifluralin 960 g ai ha^{-1} 15 DBP	6	3.8	4.3	1.3	1.3
Trifluralin 480 g ai ha^{-1} at planting	7	4.5	3.8	1.2	1.2
Trifluralin 720 g ai ha^{-1} at planting	8	3.3	3.8	0.9	1.1
Trifluralin 960 g ai ha^{-1} at planting	9	3.5	2.8	1.1	0.9
Pyroxasulfone 85 g ai ha^{-1} at planting	10	2.8	3.0	0.9	1.1
Flumioxazin 51 g ai ha^{-1} at planting	11	2.5	3.3	0.7	0.8
Imazethapyr 100 g ai ha^{-1} at planting	12	3.8	3.3	1.1	1.0
Weed-infested (WI)	13	5.0	5.3	1.3	1.6
LSD 0.05		1.9	1.4	0.6	0.5

† Days before planting.

‡ First stage (8-10 leaf stage of chickpea).

⁑ Second stage (the beginning of chickpea pod formation).

TABLE 5. ANOVA of weeds density and weeds weight in 2 sampling stages.

Source of variation	Degree of freedom	Weed density 1‡	Weed dry weight 1‡	Weed density 2⁑	Weed dry weight 2⁑
Replicate	3	0.538^{ns}	0.739^{ns}	0.974^{ns}	10.392^{ns}
Treatment	12	23.840**	3.290**	61.244**	58.547**
Error	36	6.18	0.975	6.363	9.277
CV%		27	26.7	25.1	26.4

‡ First stage (8-0 leaf stage of chickpea).

⁑ Second stage (the beginning of chickpea pod formation).

^{ns}, no significant difference; ** significant difference at $P<0.01$.

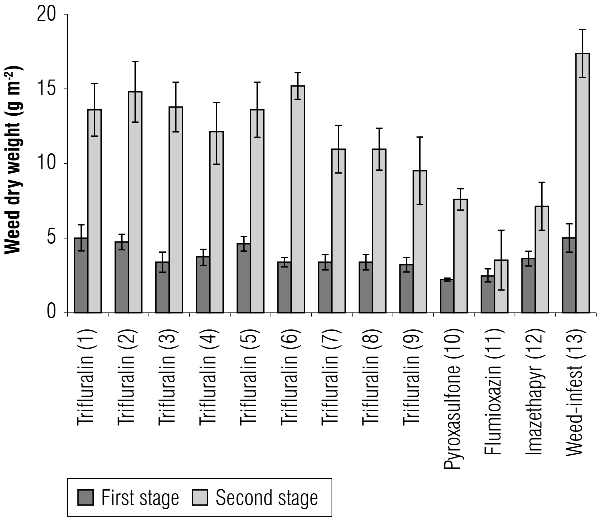

FIGURE 2. Weed dry weight (g m^{-2}) in treatments at two sampling stages (bars represent standard error). 1, 2, and 3: trifluralin 30 d before planting (480, 720, and 960 g ai ha^{-1}), 4, 5, and 6: trifluralin 15 d before planting (480, 720, and 960 g ai ha^{-1}), 7, 8 and 9: trifluralin applied at planting time (480, 720, and 960 g ai ha^{-1}), 10, 11 and 12: pyroxasulfone, flumioxazin, and imazethapyr at planting time, and 13: weed-infested (no weed control).

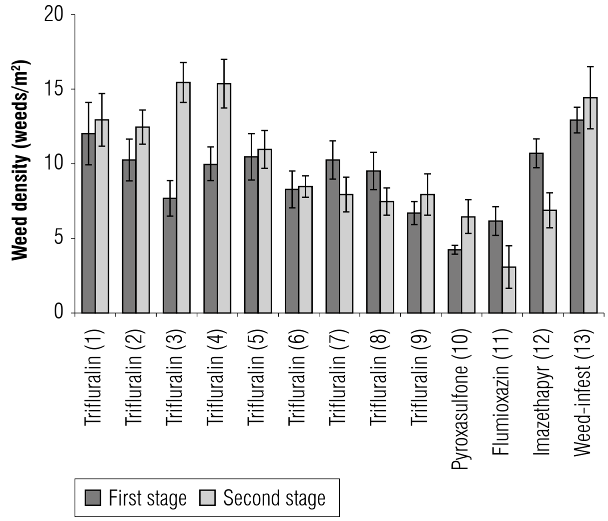

FIGURE 3. Weed density (weeds/m^2) intreatments at two sampling stages (bars represent standard error). 1, 2, and 3: trifluralin 30 d before planting (480, 720, and 960 g ai ha^{-1}), 4, 5, and 6: trifluralin 15 d before planting (480, 720, and 960 g ai ha^{-1}), 7, 8 and 9: trifluralin applied at planting (480, 720, and 960 g ai ha^{-1}), 10, 11 and 12: pyroxasulfone, flumioxazin, and imazethapyr at planting time, and 13: weed-infested (no weed control).

TABLE 6. ANOVA for biologic yield (BioY), grain yield (GY), plant height (PH), number of pods per m^2 (NSM), number of seeds per plant (NSP), 100-seed weight (100-SW), plant weight at two sampling stages (PW1, PW2), number of seeds per pod (NSpod), plant density (PD) of chickpea in different treatments.

Source of variation	DF	BioY	GY	PH	NSM	NSP	100-SW	PW1	PW2	NSpod	PD
Replication	3	30628.2^{ns}	4600.75^{ns}	13.64*	502.97^{ns}	3.089^{ns}	4.755^{ns}	0.260*	0.329^{ns}	0.010^{ns}	1.93^{ns}
Treatment	13	24811*	7497.17**	1.683^{ns}	300.72^{ns}	2.572^{ns}	5.971*	0.0053^{ns}	0.173^{ns}	0.061*	1.8^{ns}
Error	39	12536.1	1737	2.957	389.3	3.57	2.41	0.013	0.140	0.029	1.400
CV%		14.7	13.2	7.4	19.7	21.9	4.3	18.1	18.7	12.5	7.4

^{ns}, no significant difference; * significant difference at $P<0.05$. ** significant difference at $P<0.01$.

Chickpea

The effect of treatments was significant only for the 100-seed weight, biologic yield, and grain yield (Tab. 6). The one hundred seed weight is one of the characteristics related to the quality of chickpea seeds and is essential in terms of marketability and price, since the higher the seed weight, the greater is the chickpea marketability (Abdulahi *et al.*, 2012). The lowest and the highest of 100-seed weight was related to WI and weed-free at 34.2 and 38.2 g. Pyroxasulfone and trifluralin 960 g ai ha^{-1} at planting were also in this class (Tab. 7). Another study showed that the highest amount of 100-seed weight of chickpea was obtained under weed-free conditions followed by pyridate herbicide, and the lowest 100-seed weight was related to WI (Shahsavari, 2017). When increasing the number of pods and consequently increasing the number of seeds

TABLE 7. Mean comparisons of biologic yield (BioY), grain yield, and 100-SW of chickpea in different treatments.

Treatments	Biologic yield (kg ha^{-1})	100-SW‡ (g)	Grain yield (kg ha^{-1})
Trifluralin 480 g ai ha^{-1} 30 DBP	745 abcd†	36.5 abc	278 de
Trifluralin 720 g ai ha^{-1} 30 DBP	700 bcd	35.6 abc	296 cde
Trifluralin 960 g ai ha^{-1} 30 DBP	634 d	34.8 bc	284 de
Trifluralin 480 g ai ha^{-1} 15 DBP	749 abcd	35.9 abc	289 cde
Trifluralin 720 g ai ha^{-1} 15 DBP	737 abcd	36.8 abc	286 cde
Trifluralin 960 g ai ha^{-1} 15 DBP	750 abcd	36.5 abc	318 bcd
Trifluralin 480 g ai ha^{-1} at planting	818 abcd	34.9 bc	311 cde
Trifluralin 720 g ai ha^{-1} at planting	798 abcd	35.9 abc	310 cde
Trifluralin 960 g ai ha^{-1} at planting	784 abcd	37.6 a	354 abc
Pyroxasulfone 85 g ai ha^{-1} at planting	837 abc	37.7 a	344 abcd
Flumioxazin 51 g ai ha^{-1} at planting	861 ab	37.1 ab	380 ab
Imazethapyr 100 g ai ha^{-1} at planting	674 bcd	34.9 bc	315 bcd
Weed-infested	653 cd	34.2 c	245 e
Weed-free	901 a	38.2 a	408 a

† Means with the same letter in the same column are not significantly different according to test LSD ($P<0.05$).
‡ Seed weight.

per plant, the 100-seed weight decreased (Samaei *et al.*, 2006). This may be due to the limitations of photosynthetic compounds produced and stored. In this experiment, probably due to drought stress (Tab. 1), the number of seeds per plant was reduced in all treatments, but 100-seed weight of chickpeas was normal and similar to average climatic conditions, and this agrees with the results of others that the sensitivity of this trait to the number of seeds per plant and drought stress is lower (Samaei *et al.*, 2006; Yousefi *et al.*, 2006).

The highest grain yield was found in the weed-free plots with 408 kg ha^{-1}, and the lowest yield was found in the WI with 245 kg ha^{-1}. The flumioxazin, trifluralin 960 g ai ha^{-1} at planting, and pyroxasulfone produced 55%, 44%, and 40% higher grain yields than the WI. Many researchers have reported the decreased yield of chickpea in weed competition conditions (Nezami *et al.*, 1997; Mousavi *et al.*, 2007; Nasari, 2010; Abdulahi *et al.*, 2012; Mahmoudi *et al.*, 2012; Nourbakhsh, 2013; Shahsavari, 2017). Another study stated that no herbicide alone can achieve the same grain yield as a weed-free crop (Moradi, 2009); and, therefore, the use of herbicides in this study alone was not sufficient and could not be equivalent to grain yield in a weed-free treatment. Consequently, including a weeding step in the weed management program is necessary.

Wheat growth

Wheat plants in the tillering stage were examined by visual evaluation for residual herbicide effect. None of the herbicide treatments had any adverse effect on wheat growth. Analysis of variance of wheat tiller number per plant, 1000 grain weight, number of plants per m^2, and grain yield of wheat showed that the effect of treatments on these traits was not significant.

Conclusions

Several pre-emergent and pre-planting herbicides have been applied in chickpea crops that helped to control many broadleaf weeds. Even if pre-emergent herbicides control the initial wave of weed growth at the beginning of the growing season, the persistence period of the herbicide may not be able to control the weeds later in the season; late-emerging weeds make it especially difficult to harvest. Therefore, control of broadleaf weeds in chickpea cultivation requires pre-planting herbicides and the subsequent use of post-emergent herbicides or other management methods to control the remaining weeds. Applications of flumioxazin, trifluralin 960 g ai ha^{-1} at planting, and pyroxasulfone reduced weed number and subsequently resulted in higher grain yields in chickpea. The study of herbicide residual on wheat growth in the next cropping seasons showed no adverse effect.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contributions

SB and SKM designed the experiments, SL and AA carried out the field and laboratory experiments, SB, PS and IT contributed to the data analysis, SB and SL wrote the article. All authors have read and approved the final version of the manuscript.

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