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Research Article

Evaluating the effectiveness of various herbicides for managing broadleaf weeds in faba bean (*Vicia faba* L.)

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ABSTRACT- Faba bean growth and yield are constrained by weeds. Thus, field experiments were conducted in Khorramabad, Iran in 2020-2021 to evaluate the effect of trifluralin 960 g ai ha^{-1} pre-plant applications (PPI), imazethapyr 100 g ai ha^{-1} pre-plant applications (PPI), imazethapyr 100 g ai ha^{-1} plus one hand weeding (OHW), imazethapyr100 g ai ha^{-1} POST (post-emergence herbicide), bentazon 960 g ai ha^{-1} POST, oxyflorfen 192 g ai ha^{-1} preemergence (PRE), oxyflorfen PRE + OHW, diclosulam 21 g ai ha^{-1} PRE, diclosulam PRE plus OHW, one or two hand weeding on weed control and yield in faba bean. Weeds, such as safflower, wild mustard, cow cockle, and three-horn bedstraw were dominant in both years. Weed biomass in uncontrolled plots was 173 g m^{-2} in 2020 and 145 g m^{-2} in 2021. The lowest weed biomass was observed in diclosulam PRE + OHW, bentazon POST, and two hand weeding treatments. Imazethapyr PPI, trifluralin PPI, and imazethapyr POST herbicides negatively affected faba bean yield. In 2020 and 2021, Diclosulam + OHW decreased total weed density by 85% and 82%, respectively, compared to the untreated sample (control). These ideas resulted in 53% and 61% yield reductions in the weedy check plots compared to the weed-free control plots in 2020 and 2021, respectively. All herbicides resulted in minor damage to the beans, with diclosulam and OHW + diclosulam exhibiting the least impact.

INTRODUCTION

Faba bean (*Vicia faba* L.) is a major legume used for direct human consumption worldwide. It is the third essential food grain legume in area and production, after soybeans and peas (Sujayanand et al. 2018). Faba bean is generally consumed as dry beans, and their pods are an essential source of protein, similar to the total grain crop value of rice and corn. In addition, faba bean is a valuable source of dietary fiber, vitamins, and minerals (Calışkanturk et al. 2017).

Faba bean can improve soil nitrogen through the symbiosis in their roots with nitrogen-fixing bacteria, for example, *Rhizobium* and *Azospirillum* (Graham and Vance, 2003; Gentzbittel et al., 2015). Thus, rotating it with cereals helps adapt to temperate and subtropical climates while maintaining and improving soil fertility (Rojas et al., 2023). Adding legumes to the production systems can aid in the fight against climate change by decreasing greenhouse gas emissions and soil carbon sequestration (Lina et al., 2023). Australia, China, Ethiopia, the United Kingdom, and Germany are the five leading producers of faba bean (FAO, 2017).

In recent years, there has been a significant increase in faba bean cultivation, up to 12.7 million ha in 2014, resulting in 120 million kg harvested (FAO, 2017). The area under faba bean cultivation in Iran was 36,000 ha, with an average yield of 1278 kg ha^{-1} in 2016, less than the global average yield of 1800 kg ha^{-1} (FAO, 2017).

In 2019, the world production of faba bean was estimated at 5.43 million tons, highlighting about 25% growth compared to 4.35 million tons in 1990 (Dhull et al. 2021).

Weeds are often considered the main factor limiting the growth and yield of faba bean (Poggio et al. 2004). The presence of weeds can detrimentally affect the growth and productivity of faba bean, as they are highly susceptible to weed competition. Kumari and Makkou (2007) showed that up to 80% of weed competition can reduce faba bean yield. As a result, effective weed management strategies are crucial for optimal yields in faba bean. Frenda et al. (2013) also reported 60% reduction in faba bean yield in plots infested with weeds. Early weed control is critical for maximizing faba bean yield. Studies in the Mediterranean region have suggested that the critical period for weed control falls between 28 and 33 days after crop emergence (Frenda et al., 2013). However, hand weeding, the primary method employed in Iran's significant faba bean production areas like Lorestan province, is labor-intensive and expensive, especially for large-scale farms. Therefore, adopting

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more advanced weed control strategies is crucial to ensure efficient and sustainable faba bean production. Chemical weed management is a better supplement to conventional methods and vital to modern integrated crop production.

Limited studies have been conducted to identify suitable herbicides for faba beans in Iran and the World. Various herbicides, including trifluralin, bentazon, and imazethapyr are used in weed control by faba bean growers in Iran. Bean cultivation has few options for post-emergence herbicides. Bentazone is effective against various broadleaf weeds and disrupts photosynthesis at the photosystem II level. Studies have indicated that applying two to three liters of bentazone per hectare can significantly reduce broadleaf weed (*Sinapis arvensis*, *Chenopodium album*, *Abutilon theophrasti*, *Amaranthus retroflexus*, *Portulaca oleracea*, *Raphanus raphanistrum*, *Datura stramonium*, *Xanthium strumarium*, and *Capsella bursa-pastoris*) infestation in bean fields ((Abou-Khater et al., 2021). Imazethapyr, a systemic herbicide in the IMI class, works by inhibiting acetolactate synthase (ALS) to reduce branched-chain amino acids and control weeds. Hence, imazethapyr is effective against broomrape and annual weeds like *Chenopodium album*, *Amaranthus retroflexus*, *Sinapis arvensis*, *Abutilon theophrasti*, *Polygonum convolvulus*, *Stellaria media* (Dor et al., 2017; Rubiales & Fernández-Aparicio, 2012), and annual weeds (Tan et al., 2005). This herbicide is designed explicitly for legumes without causing damage to the plants, and its selectivity is due to its breakdown process within the plant. Once absorbed, the herbicide undergoes hydroxylation and subsequently binds to glucose, rendering it inactive (Ahmadi et al., 2016). Therefore, this research evaluates the effectiveness of herbicide application methods (pre-planting as well as pre- and post-emergence) in controlling weeds, while minimizing crop injury motivated by the challenge of broadleaf weeds in faba bean production.

MATERIALS AND METHODS

Experimental site

The experimental site was in Khorramabad city, Lorestan province, Iran (32.3°N, 46.21°E, 1,100 meters above sea level). The climate was arid to semiarid, with an average annual air temperature and rainfall of 17.2 °C and 504 mm, respectively. Table 1 presents the monthly average air temperatures and precipitation during the faba bean growing seasons of 2020 and 2021 at the experimental site. The soil type was clay loam, with a pH of 7.5 in 2020 and 8.0 in 2021. The soil organic matter content was 0.87% in 2020 and 1.05% in 2021. Table 2 provides the observed primary soil characteristics (up to a depth of 30 cm). There was an existing populace of broadleaf weed species where wheat was produced before the study was initiated. Each year, tillage included moldboard plowing to a depth ranging from 20 to 25 cm, followed by disking before seedling faba bean. 'Barakat' variety of faba beans was planted on October 16, 2020, and November 1, 2021, at a density of 15 seeds m^{-2}. Seeds were disinfected with Vitavax fungicide at a 0.2% concentration.

Table 1. The monthly air temperatures and rainfall data were collected at the experimental sites in Khorramabad throughout the faba bean growth season in 2020 and 2021.

Month	Temperature (°C)						Total rainfall (mm)	
	2020			2021			2020	2021
	Mean	Min.	Max.	Mean	Min.	Max.		
Oct	22.6	11.8	31.2	21.9	11.9	32.0	0.31	0.00
Nov	14.7	5.9	23.6	14.3	6.8	21.8	0.38	1.12
Dec	8.9	3.6	14.3	9.6	3.1	16.3	5.44	2.98
Jan	6.6	-1.0	14.3	5.9	-0.9	12.7	0.16	1.01
Feb	8.1	0.6	15.6	4.5	-0.6	11.9	2.91	1.01
Mar	10.0	2.9	17.1	10.4	3.6	17.2	1.83	1.15
Apr	13.1	6.4	19.7	16.1	6.9	25.1	1.25	0.20
May	18.9	10.3	27.6	22.2	12.2	32.1	0.38	0.07
June	26.0	15.4	36.6	15.2	6.6	37.6	0.00	0.07
Jul	29.5	19.6	39.5	30.1	19.9	41.7	0.00	0.00

Table 2. Physicochemical properties of the experimental site soil (depth of 0-30 cm)

Year	Sand (%)	Silt (%)	Clay (%)	Organic C(%)	Available N(%)	Available P(ppm)	Available K (ppm)	EC (ds/m)
2020	32	34	28	0.87	0.07	11.9	175	1.45
2021	30	35	32	1.05	0.055	13.6	190	1.72

Herbicide treatments and experimental design

The experimental design was a randomized complete block with four replicates. The treatments consisted of 1) trifluralin (Treflan®, SC 45%), 2) Bazargan Kala Corp., Tehran, Iran), 3) imazethapyr (Pursuit®, SL 10%, BASF Corp., Tehran, Iran), 4) oxyfluorfen (Goal®, SL EC 24%, Ariashimi Corp., Tehran, Iran), 5) diclosulam (Strongarm®, WDG 84%), and 6) bentazon (Basagran®, SL 48%, Ariashimi, Tehran, Iran) with two control plots weed-free and weed-infested throughout the crop cycle. The PPI (pre plant herbicide) treatments were applied the day before sowing, the PRE (pre emergence herbicide) treatments were applied two days before planting, and the POST (post emergence herbicide) treatments were applied at the two to four leaves. The pre-plant applications (PPI) was trifluralin at 960 g ai ha^{-1} and imazethapyr at 100 g ai ha^{-1}. Herbicides applied PRE included imazethapyr at 100 g ai ha^{-1} and diclosulam at 21 g ai ha^{-1}. Herbicides applied POST included oxyflorfen at 192 g ai ha^{-1} and bentazon at 960 g ai ha^{-1} (Boyd, 2015).

During the study, various cultural treatments were evaluated for weed management. A weedy and weed-free treatments were also included one or two hand weedings. In plots that were weeded once or twice, weeds were removed either at post-emergence herbicide application or two weeks after.

The field was plowed vertically twice using a reversible plow to prepare the land for planting in November 2020. A disk harrow was then used to break up clods, promoting seed germination and growth. Land preparation and the first spraying (pre-cultivation) were performed at the end of November. The length of each experimental plot was 4 m, and the width of each plot was 3 m. Each experimental plot had five planting lines with a distance of 45 cm from each other, and the distance between plants on the planting line was 10 cm, with a density of 22 plants per square meter (Aboali & Saeedipour, 2015). The distance between the blocks and the test plots were 3 and 1 m, respectively. In the non-weed treatments, weeds were removed by hand weekly during the growing season.

All herbicides were sprayed with an Elegance 12 electric knapsack sprayer equipped with a flooding nozzle and calibrated to deliver 250 L ha^{-1} of spray solution at a pressure of 2.5 bar. Applications comprised a pre-planting treatment one week before sowing, a pre-emergence treatment before the emergence of bean seedlings, and a post-emergence treatment at the 4-5 leaf stage following the end of winter conditions.

Weed density and biomass reduction were assessed using Eq. (1), which involved counting weeds within two permanent quadrats (each measuring 0.25 m^{-2}) in each plot three weeks after the POST herbicide application (May 5th, 2020 and May 12th, 2021). The dry weight was measured after being placed in an oven at 75 ºC for 48 h and determining the number of weeds in the laboratory (Ahmadi et al. 2016).

$$WR (\%) = [1 - (WT/WC)] * 100 \qquad \text{Eq. (1)}$$

WR is a percentage that reflects the weed density and biomass reduction relative to the weedy plot. WT refers to the amount of weed biomass (g m^{-2}) remaining after the weed control method is applied. WC is the initial weed biomass (g m^{-2}) before implementing weed control.

Morphological traits and yield components were also determined based on ten plants randomly selected from each plot in the final harvest stage. Additionally, the faba bean yield and its components were measured by harvesting plants from a central 2 m^{-2} area within each plot at maturity to evaluate the impact on the crop (Karimmojeni et al., 2015). Sandral et al. (1997) randomly selected 20 faba bean plants from each plot and calculated their height, number of pods per plant, number of seeds per pod, and the weight of 100 seeds. The faba beans were evaluated visually for signs of injury. This assessment happened 40 days after sowing for PPI and PRE herbicides and 15 and 30 days after POST treatments. A rating scale of 1 to 9 was used, with 1 signifying no injury and 9 indicating plant death.

Statistical analysis

The data were subjected to an analysis of variance using SAS. Means were compared using an LSD Multiple Range test at a $P < 0.05$ level of significance.

RESULTS AND DISCUSSION

Weed density and biomass

The analysis of variance indicated that weed density reduction (WDR, %), weed biomass reduction (WBR, %), height, 100-seed weight, and grain yield (GY) were significantly affected by different experimental treatments (Table 3). The composition of weeds in the faba bean fields remained consistent between 2020 and 2021. The dominant weed species observed in both years were wild safflower, wild mustard, cowcockle, and threehorn bedstraw. Other weed species found in the fields included common vetch, buttercup, and chamomile. Density in the weedy check plots showed that the average densities of wild safflower were 12 plant m^{-2} in 2020 and 6 plant m^{-2} in 2021, while wild mustard's were 11 and 8 plant m^{-2} in 2020 and 2021, respectively. Cow cockle densities were 7 plant m^{-2} in 2020 and 9 plant m^{-2} in 2021, while three horn bedstraw densities were 5 plant m^{-2} in 2020 and 4 plant m^{-2} in 2021. The effectiveness of herbicide treatments on weed control can be found in Table 3 and Table 4. This information probably encompasses the percentage reduction in weed density and biomass. The results indicated significant variations between the years and treatments for wild safflower and wild mustard regarding density and biomass reductions (Table 4 and Table 5).

Table 3. Analysis of variance for weed density reduction (WDR, %), weed biomass reduction (WBR, %), height, 100-seed weight, and grain yield (GY) under different treatments during the growing seasons in 2020 and 2021 at Khoramabad (Lorestan province, Iran)

Source of variation	DF	WDR	WBR	Height (cm)	100-seed weight (g)	GY kg ha^{-1}
Replication	3	1.54^{ns}	2.49 ^{ns}	21.08**	4.84 ^{ns}	18005.2 ^{ns}
Treatment	12	1.73 **	45.29 **	47.28**	149.2**	796539.3**
Error	36	0.34	9.95	10.12	7.9	576321.9

Mean square values are presented for each independent variable and interaction term.

ns: not significant.

** Treatment effects significant at $P < 0.01$.

Table 4. Weed density reductant at 21 days after application in 2020 and 2021

Treatment	Timing	Rate (g ai ha^{-1})	Density reduction (%)				Cow cockle	Three-horn bedstraw	Total weed density	
			Wild safflower		Wild mustard					
			2020	2021	2020	2021			2020	2021
Trefluralin	PPI	960	60^{c}	65^{c}	67^{d}	74^{bcd}	70^{ab}	65^{b}	13^{abc}	9^{b}
Imazethapyr	PPI	100	62^{c}	65^{c}	70^{cd}	65^{d}	60^{bc}	65^{b}	17^{a}	14^{b}
Imazethapyr+OHW	PPI	100	70^{bc}	75^{b}	70^{cd}	78^{abcd}	75^{ab}	72^{ab}	11^{bcde}	9^{b}
Imazethapyr	POST	100	75^{ab}	80^{ab}	78^{b}	75^{abcd}	70^{ab}	80^{ab}	9^{cdef}	7^{b}
Bentazon	POST	100	85^{a}	80^{ab}	80^{b}	90^{a}	85^{a}	85^{a}	6^{ef}	5^{b}
Oxyflorfen	PRE	192	75^{ab}	80^{ab}	65^{d}	70^{cd}	70^{ab}	65^{b}	9^{cdef}	12^{b}
Oxyflorfen+OHW	PRE	192	85^{a}	80^{ab}	75^{bc}	85^{abc}	80^{ab}	85^{a}	7^{def}	8^{b}
Diclosulam	PRE	21	74^{ab}	80^{ab}	75^{bc}	80^{abcd}	78^{ab}	75^{ab}	12^{abcd}	10^{b}
Diclosulam+OHW	PRE	21	85^{a}	82^{ab}	90^{a}	80^{abcd}	80^{ab}	85^{a}	6^{ef}	5^{b}
OHW	–	–	45^{d}	35^{d}	45^{e}	30^{e}	45^{c}	45^{c}	15^{ab}	13^{b}
THW	–	–	80^{ab}	88^{a}	95^{a}	88^{ab}	85^{a}	80^{ab}	5^{f}	4^{b}
Weed infested	–	–	–	–	–	–	–	–	39	28^{a}
P-value	–	–	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Abbreviations: PPI, herbicide applied immediately before planting; PRE, three to four days after planting; POST, applied at the 4-6-leaf stage of the weeds; OHW, one-hand weeding; THW, two-hand weddings.

Data were pooled for 2020 and 2021.

In 2020-2021, weed density and biomass significantly decreased by 55-90% across various herbicide treatments. Wild safflower density and biomass were reduced from 55% for trifluralin to 90% for two-hand weeding and diclosulam, followed by one-hand weeding treatments in both years. Trifluralin PPI or imazethapyr PPI resulted in the least effective control of wild safflower among all other treatments (Table 4 and Table 5).

Wild mustard control ranged from 67-95%. However, none of the herbicide treatments outperformed two-hand weddings for wild mustard (Table 4 and Table 5). Bentazon and diclosulam herbicides, followed by manual weeding (one-hand weeding), were the most effective treatments in reducing wild mustard density and biomass. The same herbicides (bentazon and diclosulam) were also effective against cow cockle and three-horn bedstraw during the 2020 and 2021 growing seasons, reducing their density and biomass from 45% to 95%. Over two years, bentazon POST, oxyflorfen PRE followed by one-hand weeding, diclosulam followed by one-hand weeding, and two-hand weedings provided 80% or more cow cockle and three-horn bedstraw control. Table 3 and Table 4 present that trifluralin and imazethapyr may be less successful in controlling these weeds.

Manual weeding is a time-consuming and expensive task, especially for large-scale operations, which reduces overall weed density and biomass by 80% to 95% and 30% to 50%, respectively (Table 4 and Table 5). Previous research has shown that hand weeding is an effective method for controlling weeds in legumes, such as peas (Lyon and Wilson, 2005; Shahbazi et al., 2019) and lentils (Karimmojeni et al., 2015; Ahmadi et al., 2016). Kumar et al. (2017) also reported that multiple hand-weeding times yielded better results. Hand weeding reduces weeds' density and dry weight in faba bean fields, following no hand weeding (Badr & El-Sayed, 2016). Broadleaf weeds and grasses biomass was reduced by 60% and 73% in faba bean hand weeding (Ghanbari-Bonjar et al. 2015).

In a two-year study, unweeded plots (weedy check) exhibited significant weed biomass at 173 g m^{-2} in 2020 and 145 g m^{-2} in 2021. All weed control methods reduced weed biomass compared to the weedy check in both years. Two manual weedings achieved the lowest total weed biomass, at 15 g m^{-2} in 2020 and 13 g m^{-2} in 2021, followed by bentazon POST, diclosulam PRE, and one-hand weeding (Table 4 and Table 5).

Trifluralin PPI (47 g m^{-2}) and imazethapyr PPI (46 g m^{-2}) herbicide treatments resulted in the least effective weed control in 2020 and 2021. The total weed densities were 39 and 28 plants m^{-2} for weed-infested treatment in 2020 and 2021, respectively (Table 4). Research has indicated that applying 0.4 L ha^{-1} of imazethapyr on faba bean fields was ineffective in weed control (Aboali and Saeedipour, 2015). However, 50 g ai ha^{-1} of imazethapyr post-emergence can effectively control broadleaf weeds in pinto beans throughout the season (Blackshaw and Esau, 1991). The need for different doses of imazethapyr indicated that weed management in bean cultivation depends on the existing weed species.

On the other hand, the two-hand weedings (5 and 4 plants m^{-2}), bentazon (6 and 5 plants m^{-2}), and diclosulam + one-hand weeding (6 and 5 plants m^{-2}) had the lowest weed densities in 2020 and 2021. Meanwhile, higher weed densities were observed in imazethapyr PPI at 14.8 and 21.2 in 2020 and 2021, respectively (Table 4).

Crop injury

Crop injury was evident across all treatments, ranging from 20-60% (Table 6). The lowest level of crop injury (20%) was observed in diclosulam, bentazon, and diclosulam plus hand weeding in both years of the study. In comparison, the highest level of crop injury (60%) was observed in imazethapyr POST. Previous studies have reported significant levels of injury to legume plants from POST applications of imazethapyr (Taran et al. 2013; Shahbazi et al. 2019). Faba bean burning was significantly lower when herbicides were applied before crop plant germination than after planting, indicating greater safety pre-emergence than post-emergence. These results were consistent with those of Mousavi et al. (2011), in which the herbicide imazetapir in bean cultivation has a rate of 0.7 L ha^{-1}. Imazethapyr is a broad-spectrum herbicide, which can cause injury to legume plants due to its mode of action and inhibits the biosynthesis of branched-chain amino acids. Legumes are particularly sensitive to this type of herbicide, leading to significant injury when exposed to POST applications of imazethapyr.

Yield and yield components

The statistical analysis revealed a relationship between herbicide use and faba bean plant height changes. The interaction between year and treatment did not affect plant height (Table 7). The highest plant height was observed with the post-emergence application of diclosulam herbicide followed by hand weeding, the pre-planting application of oxyfluorfen herbicide, and the post-emergence application of bentazone herbicide (Table 7). Several factors can influence the height of crops, including crop and weed density. Plant height often increases under high populations due to the changes in the quality of light received R/FR(red to far-red) and nutrient uptake (Arabi and Saffari, 2015; Rohrig and Stutzel, 2001). High crop and weed density can increase competition for light and nutrients. Plants may grow taller to access more light for photosynthesis and outcompete neighboring plants for resources in response to this competition. Additionally, changes in the quality of light, such as the ratio of red (R) to far-red (FR) light, can trigger plant responses that promote vertical growth to optimize light capture. A total of 100 faba bean seed weights varied from 65 g in weed-infested plots to 102 g in weed-free plots in 2020 and 2021. Diclosulam POST + one hand weeding and imazethapyr PRE + one hand weeding resulted in higher weights for 100 faba bean seeds than other herbicide treatments across the various herbicide treatments. All herbicide treatments increase faba bean yields compared to weed-infested checks. Crop yield was reduced by 53% and 61% compared to the weed-free control plots in the weedy check in 2020 and 2021. As shown in Table 6, plots treated with one-hand weeding had a 20% yield increase in 2020 and 2021 compared to the weedy checks. In 2021, the faba bean yield was higher in weed-free treatments than in 2020, with respective yields of 3,190 and 2,830 kg ha^{-1}, respectively.

Table 5. Weed biomass reductant at 21 days after application of herbicides in 2020 and 2021.

Treatment	Timing	Rate (g ai ha^{-1})	Biomass reduction (%)						Total weed biomass (g m^{-2})	
			Wild safflower		Wild mustard		Cow cockle	Three-horn bedstraw		
			2020	2021	2020	2021			2020	2021
Trefluralin	PPI	960	60^{c}	68^{d}	72^{cd}	76^{abc}	70^{a}	67^{cd}	47^{bc}	39^{bcd}
Imazethapyr	PPI	100	55^{c}	63^{d}	70^{d}	65^{bc}	67^{a}	64^{de}	43^{bc}	46^{b}
Imazethapyr+OHW	PPI	100	65^{bc}	72^{cd}	70^{d}	65^{bc}	75^{a}	74^{bcd}	31^{cd}	40^{bc}
Imazethapyr	POST	100	75^{ab}	78^{bc}	82^{b}	75^{abc}	78^{a}	79^{bcd}	18^{d}	22^{ef}
Bentazon	POST	100	85^{a}	80^{bc}	90^{a}	85^{ab}	85^{a}	80^{abc}	17^{d}	12^{f}
Oxyflorfen	PRE	192	75^{ab}	82^{ab}	68^{d}	75^{abc}	65^{ab}	70^{cd}	31^{cd}	30^{cde}
Oxyflorfen+OHW	PRE	192	85^{a}	82^{ab}	78^{bc}	85^{ab}	80^{a}	80^{abc}	22^{d}	25^{def}
Diclosulam	PRE	21	78^{a}	85^{ab}	75^{bcd}	80^{abc}	75^{a}	78^{bcd}	16^{d}	13^{f}
Diclosulam+OHW	PRE	21	85^{a}	90^{a}	90^{a}	80^{abc}	80^{a}	88^{ab}	18^{d}	22^{ef}
OHW	–	–	43^{d}	36^{e}	45^{de}	32^{d}	45^{b}	50^{e}	59^{b}	48^{b}
THW	–	–	80^{a}	90^{a}	95^{a}	88^{a}	85^{a}	95^{a}	15^{d}	13^{f}
Weed infested	–	–	–	–	–	–	–	–	173^{a}	14^{5a}
P-value	–	–	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Abbreviations: PPI, applied incorporated application of herbicide applied immediately before planting; PRE, at two to three days after planting; POST, applied at the two- to four-leaf stage of the weeds; OHW, one-hand weedings; THW, two-hand weedings.
Data were pooled for 2020 and 2021.

Table 6. Visual faba bean injury affected by selected herbicide treatments in 2020 and 2021

Treatment	Timing	Rate (g ai ha^{-1})	Injury (%)					
			2020			2021		
			15 DAT	30 DAT	40 DAT	15 DAT	30 DAT	40 DAT
Trefluralin	PPI	960	0^{c}	0^{c}	3^{a}	0^{c}	0^{c}	3^{a}
Imazethapyr	PPI	100	0^{c}	0^{c}	3^{a}	0^{c}	0^{c}	4^{a}
Imazethapyr+OHW	PPI	100	0^{c}	0^{c}	3^{a}	0^{c}	0^{c}	3^{a}
Imazethapyr	POST	100	6^{a}	6^{a}	0^{c}	5^{a}	6^{a}	0^{c}
Bentazon	POST	100	2^{b}	3^{b}	0^{c}	2^{b}	2^{b}	0^{c}
Oxyflorfen	PRE	192	0^{c}	0^{c}	4^{a}	0^{c}	0^{c}	3^{a}
Oxyflorfen+OHW	PRE	192	0^{c}	0^{c}	4^{a}	0^{c}	0^{c}	3^{a}
Diclosulam	PRE	21	0^{c}	0^{c}	2^{a}	0^{c}	0^{c}	2^{a}
Diclosulam+OHW	PRE	21	0^{c}	0^{c}	2^{a}	0^{c}	0^{c}	2^{a}
P-value	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Injury (plant injury rating scale from 1-9): 1 no visible injury and 9 plant death.

Abbreviations: DAT, days after treatment; PPI, Pre-planting; PRE, Pre-emergence; POST, Post-emergence; OHW, one-hand weedings; THW, two-hand weedings.

Table 7. Height, weight of 100 seeds, and faba bean yield under different treatments in 2020 and 2021.

Treatment	Timing	Rate (g ai ha^{-1})	Height (cm)	100-seed weight		Grain yield (kg ha^{-1})	
				2020	2021	2020	2021
Trefluralin	PPT	960	68.0^{cd}	85.0^{c}	86.2^{cd}	1550.0^{fg}	1705.8^{def}
Imazethapyr	PPI	100	68.5^{bcd}	91.4^{abc}	89.9^{bcd}	1650.5^{ef}	1750.8^{def}
Imazethapyr+OHW	PRE	100	68.7^{bcd}	94.6^{ab}	95.0^{abcd}	2156.0^{c}	1970.9^{d}
Imazethapyr	POST	100	63.2^{d}	86.0^{bc}	84.7^{d}	1450.5^{gh}	1610.8^{f}
Bentazon	POST	100	73.2^{abc}	89.5^{abc}	90.0^{bcd}	2390.5^{b}	2680.6^{b}
Oxyflorfen	PPI	192	67.3^{cd}	85.7^{bc}	89.5^{bcd}	1810.3^{de}	1640.2^{ef}
Oxyflorfen+OHW	PPI	192	73.0^{abc}	90.6^{abc}	88.5^{bcd}	2391.4^{b}	2350.0^{c}
Diclosulam	POST	21	68.3^{cd}	90.1^{abc}	92.0^{abcd}	1960.4^{cd}	1908.5^{de}
Diclosulam+OHW	POST	21	74.4^{ab}	94.0^{abc}	97.6^{abc}	2510.0^{b}	2675.6^{b}
OHW	POST	1500	66.9^{d}	75.7^{d}	88.8^{bcd}	1670.5^{ef}	1564.6^{f}
THW	POST	960	77.3^{a}	96.7^{a}	100.0^{ab}	2550.0^{b}	2872.4^{b}
Weed free			78.4^{a}	98.3^{a}	102.7^{a}	2825.4^{a}	3190.5^{a}
Weed infested	POST	300	33^{e}	69.5^{d}	65.3^{e}	1325.7^{h}	1258.3^{g}
P-value	–	–	<0.05	<0.05	<0.05	<0.05	<0.05

Note: PPI, Pre-planting of herbicide; PRE, Pre-emergence of herbicide; POST, Post-emergence of herbicide; OHW, one-hand weedings; THW, two-hand weedings.
The data were pooled for 2020 and 2021.

CONCLUSION

Based on the studies, effective weed control is critical for maximum yields in fava beans. Overall, all herbicide treatments provided adequate weed control compared to the weedy check. Diclosulam and oxyfluorfen enhanced yield with minimal damage to the faba bean plants, but they are not registered for use on faba beans. In contrast, imazethapyr POST resulted in severe phytotoxicity to the faba bean. The PPI-applied herbicides did not provide satisfactory weed control. POST and PRE herbicides generally led to more significant injury in faba beans than PPI treatments. In conclusion, two-hand hoeing, bentazone POST, diclusulam PRE followed by one-hand weeding, and oxyflurfen followed by one-hand weeding were highly effective treatments. They outperformed the control weed-infested treatment season after season regarding height, biological yield, and seed output, and the difference was not statistically significant.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Abdolreza Ahmadi, Saeed Shahbazi, and Yousef Filizadeh; Methodology: Abdolreza Ahmadi, Saeed Shahbazi; Software: Abdolreza Ahmadi and Saeed Shahbazi; Validation: Abdolreza Ahmadi; Formal analysis: Abdolreza Ahmadi and Saeed Shahbazi; Investigation: Abdolreza Ahmadi, Saeed Shahbazi, and Yousef Filizadeh; Resources: Saeed Shahbazi; Data curation: Abdolreza Ahmadi and Saeed Shahbazi; Writing—original draft preparation: Abdolreza Ahmadi, Saeed Shahbazi, and Yousef Filizadeh; Writing—review and editing: Abdolreza Ahmadi and Yousef Filizadeh; Supervision: Abdolreza Ahmadi; Funding acquisition: Abdolreza Ahmadi, Saeed Shahbazi, and Yousef Filizadeh.

DECLARATION OF COMPETING INTEREST

The author discloses no apparent personal relationships or financial ties that could have biased the research results.

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