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RESEARCH ARTICLE

Influence of weed management practices on weed dynamics, productivity and economics in summer greengram under different agroclimatic zones of Punjab, India

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ABSTRACT

A field experiment was conducted during three consecutive summer seasons (2022, 2023 and 2024) at different agroclimatic zones of Punjab, India, to study the effect of weed management practices on weeds and on summer greengram productivity and economics. A randomised block design comprising of 8 treatments with 4 replications was used. Hand weeding (HW) twice resulted in the lowest weed density and biomass, highest weed control efficiency (86.6% at 40 DAS and 84.0% at harvest) and highest greengram yield, which was statistically at par with post-emergence application (PoE) of imazethapyr 75 g/ha at 15 and 25 days after seeding (DAS). However, net return was higher with imazethapyr 75 g/ha PoE at 15 DAS and 25 DAS than HW twice. Imazethapyr 75 g/ha PoE at 15 DAS recorded the highest B:C (3.16). The residues of imazethapyr 50–75 g/ha PoE in grains at harvest were below the quantification limit (0.01 µg/g), confirming the safety of imazethapyr usage at recommended doses. It was concluded that effective and economical weed management in summer greengram, under different agroclimatic zones of Punjab, can be achieved, without any residual effects, with imazethapyr 75 g/ha PoE at 15 or 25 DAS.

Keywords: Greengram, Herbicide residues, Imazethapyr, Economics, Weed management

INTRODUCTION

Pulses are a rich source of protein (20–25%) and serve as a major source of dietary protein, especially because a large proportion of the Indian population is vegetarian. Among the grain legumes, greengram [*Vigna radiata* (L.) Wilczek], also known as mungbean is an important short-duration crop that can be grown year-round. One of the major constraints in greengram production is weed competition, which severely limits productivity (Mishra *et al.* 2016). Due to its slow initial growth, weeds establish rapidly during the early stages and compete vigorously with the crop for nutrients, moisture, sunlight, and space, thereby causing considerable yield reduction. The loss of greengram yield due to weeds ranges from 58.2 to 76.2% (Barik *et al*. 2024, Hirani *et al.* 2024). Besides reducing crop yield, weeds also deteriorate crop quality, compete for nutrients, moisture, and light, and adversely affect soil nutrient status. Weed management plays a crucial role in the successful cultivation of summer greengram.

Traditionally, weed control by hand weeding is expensive and labour-intensive. However, weed control using herbicides was found to be a convenient, economical, and efficient (Verma and Kushwaha 2020). Hand weeding twice at 4 and 6 weeks after sowing (WAS) was recommended for effective weed control in summer greengram. However, often labour non availability for controlling weeds particularly at the critical period, is a major concern. Therefore, there was a need to find out effective weed management strategy. Herbicides were found to be very helpful in efficiently controlling weeds when labour is scarce (Virk *et al*. 2018). Hence, a field experiment was conducted to study the efficacy of imazethapyr at different doses and times

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of application to manage weeds in summer greengram under different agroclimatic zones of Punjab.

MATERIALS AND METHODS

The present study was carried out at the research farm of the Pulses Section, Department of Plant Breeding and Genetics, PAU Ludhiana (LDH) and Regional Research Stations (RRS) at Abohar (ABH), Faridkot (FDK) during summer season of 2022, 2023 and 2024, Gurdaspur (GSP) during summer 2023 and 2024, Bathinda (BTD) during summer 2022, Ballowal Saunkhri (BS) during summer 2024 to study the effect of imazethapyr on weeds and on greengram growth and grain yield. Eight treatments (**Table 1**) were tested in a randomized complete block design (RCBD with 4 replications, at all the locations. The tested treatments include: weedy check, hand weeding (HW) twice at 4 and 6 weeks after sowing (WAS), post-emergence application (PoE) of imazethapyr 50 g/ha at 15 days after sowing (DAS), imazethapyr 50 g/ha PoE at 25 DAS, imazethapyr 75 g/ha PoE at 15 DAS, imazethapyr 75 g/ha PoE at 25 DAS, pre-emergence application (PE) of imazethapyr 50 g/ha and imazethapyr 75 g/ha PE. PE herbicide was applied after sowing using 500 L of water per ha and PoE herbicide was applied using 375 L of water per ha according to the treatments at 15 or 25 DAS. The herbicides were applied by using knapsack sprayer fitted with a flood jet nozzle for PE application and flat fan nozzle for post-emergence application.

The greengram variety SML 1827 was sown at all the locations. The greengram was sown on 28 March 2022, 29 March 2023 and 27 March 2024 at Ludhiana, 6 April 2022, 10 April 2023 and 1 April 2024 at Abohar, 30 March 2023 and 26 March 2024 at Gurdaspur, 24 March 2024 at Ballowal Saunkhri, 25 March 2022, 11 April 2023 and 15 April, 2024 at Faridkot and 14 April 2022 at Bathinda. A seed rate of 30 kg/ha was used for sowing greengram in a row spacing of 22.5 cm. The greengram was raised as per the recommended package of practices. The crop was harvested on second to third week of June at all locations.

Weed density from each plot was recorded at 40 DAS with the help of quadrat. Dry weight of weeds (weed biomass) was recorded at 40 DAS and at harvest stages. For recording weed biomass, weed plants were removed from ground level by using quadrat of 50 cm × 50 cm, these samples were first sun dried and then dried in an oven to attain a constant weight. After drying, weed biomass was recorded and expressed as g/m^2. Weed control efficiency (WCE) was calculated at 40 DAS and at harvest with the help of formula given below:

$$\text{WCE (\%)} = \frac{X-Y}{X} \times 100$$

Where
X = Weed biomass in weedy check
Y = Weed biomass in the treatment

At harvest, plant height, number of branches/ plant and pods/plant were recorded by randomly selected five plants from each plot and average was worked out. Number of seeds per pod was recorded at harvest by counting the number of seeds of ten randomly selected pods and average was taken. A composite sample of seed from each net plot was drawn from the shelled pods and the 100 seeds were weighed separately for each net plot by electronic balance. After harvest of the crop, the biological yield/ plot was recorded. Then after threshing of the harvested produce, grain yield/plot was recorded and grain yield was converted into t/ha. The economics of summer greengram was calculated based on prevailing market price. To calculate the net returns for each treatment, total cost of cultivation was subtracted from the gross returns. Benefit-cost ratio was calculated by dividing net returns with cost of cultivation.

A pooled analysis of location-wise data was performed. Data on weed density was subjected to square-root transformation before statistical analysis to normalize their distribution. Data were subjected to analysis of variance (ANOVA) in a randomized complete block design following standard procedures. All statistical comparisons among treatments were made at the 0.05 probability level (P = 0.05). Residues of imazethapyr in summer greengram at harvest were extracted as described by Sondhia *et al*. (2015) and quantified using Agilent HPLC coupled with a diode array detector (DAD) with ëmax of 225nm. Separation was performed on C-18 column (250×4.6mm) using Acetonitrile: 0.1% formic acid (80:20) as mobile phase at 0.8 mL min^{-1} flow rate.

RESULTS AND DISCUSSION

Weed dynamics

Weed flora of experimental fields was predominated by annual dicot and monocot weeds. The major weeds in greengram at different locations include: *viz., Digitaria sanguinalis, Cyperus rotundus* and *Trianthema portulacastrum* at Ludhiana, *Dactyloctenium aegyptium, Cyperus rotundus* and

Trianthema portulacastrum at Abohar, *Digera muricata* and *Cyperus rotundus* at Gurdaspur, *Cyperus rotundus, Cynodon dactylon* and *Sorghum halepense* at Ballowal Saunkhri, *Echinochloa crusgalli, Dactyloctenium aegyptium, Cyperus rotundus, Digera arvensis, Trianthema portulacastrum* at Faridkot and *Digera muricata, Cyperus rotundus* and *Trianthema portulacastrum* at Bathinda.

Significantly highest weed density and biomass (**Table 1** and **2**) was recorded in weedy check. Hand weeding twice at 4 and 6 weeks after sowing (WAS) recorded the lowest weed density at all locations (**Table 1**) as also observed by Kumar *et al.* (2019). The lowest weed density was also observed with imazethapyr 50 g/ha PoE at 15 and 25 DAS, imazethapyr 50 and 75 g/ha PE and was at par with imazethapyr 75 g/ha PoE at 15 and 25 DAS. The initial slow growth of weeds was due to herbicides which reduced the weed density, thereby minimizing competition and ensuring better crop–weed balance as reported by Meena *et al.* (2019) in pulses and by Kumar *et al.* (2020) in greengram.

Hand weeding twice recorded significantly lower weed biomass than the other treatments at 40 DAS at Ludhiana, Abohar and Gurdaspur. However, at Ballowal Saunkhri and Faridkot, HW twice recorded significantly lower weed biomass than weedy check, which was, however, at par with imazethapyr. At harvest, the lowest weed biomass was recorded with hand weeding twice at Ludhiana, which was statistically at par with imazethapyr 50 and 75 g/ha PE, while at Ballowal Saunkhri, the weed biomass with HW twice, imazethapyr 50 and 75 g/ha at 15 DAS, imazethapyr 50 and 75 g/ha PE, at Gurdaspur, HW twice and imazethapyr 75 g/ha at 15 DAS and at Abohar, two HW twice, imazethapyr 50 and 75 g/ha at 15 and 25 DAS were at par with each other. Most of the weeds were removed with HW twice and only a few weeds emerged after 6 WAS and was statistically at par with imazethapyr 75 g/ha PoE at 15 and 25 DAS. This effectiveness could be attributed to the action of imazethapyr, which inhibits both root and shoot growth of weeds by inhibiting the enzyme acetolactate synthase (ALS). ALS is essential to produce branched-chain amino acids in plants; its inhibition leads to a disruption in protein synthesis, ultimately arrests plant growth and leading to weed mortality.

On an average, the lowest weed density was observed with HW twice, which was significantly lower than weedy check, imazethapyr 50 g/ha at 15 and 25 DAS, imazethapyr 50 and 75 g/ha as PE and at par with imazethapyr 75 g/ha at 15 and 25 DAS. Singh *et al.* (2014) also reported that imazethapyr at 75 and 100 g/ha at 25 DAS gave good control of weeds and the weed control efficiency was comparable to that of HW twice.

The highest weed control efficiency was recorded with HW twice (86.6 and 84.0%), which was significantly higher than other treatments, but it was statistically at par with imazethapyr 75 g/ha PoE at 15 DAS (80.4 and 76.5%) and imazethapyr 75 g/ha PoE at 25 DAS (82.0 and 75.7%) at 40 DAS and at harvest, respectively (**Table 2**). The comparable performance of imazethapyr with hand weeding suggests that the herbicide was effective in managing the major weeds during the critical crop–weed competition period as reported by Singh *et al.* (2018) and Yadav *et al.* (2017).

Effect on greengram

Greengram plant height was not significantly influenced by various weed management treatments at Abohar, Bathinda and Ballowal Saunkhri (**Table 3**). However, the highest plant height was recorded with HW twice, but it was statistically at par with imazethapyr 50 g/ha PoE at 15 and 25 DAS,

Table 1. Weed density as influenced by weed control treatments in summer greengram (pooled mean)

Treatment	Weed density (no./m^2)						
	LDH	ABH	GSP	BS	FDK	BTD	Mean
Weedy check	15.27 (117.0)	12.2 (151.7)	16.1 (51.2)	10.53 (40.0)	12.32 (151.7)	10.01 (101.0)	9.83 (102.1)
Hand weeding twice at 4 and 6 WAS	3.30 (4.7)	5.7 (35.3)	7.0 (8.3)	7.41 (18.0)	3.61 (12.3)	5.08 (26.0)	3.97 (17.4)
Imazethapyr 50 g/ha PoE at 15 DAS	7.33 (26.0)	8.8 (84.0)	11.1 (23.3)	6.00 (12.0)	5.49 (29.4)	6.32 (40.0)	5.71 (35.7)
Imazethapyr 50 g/ha PoE at 25 DAS	8.07 (28.7)	8.8 (81.7)	9.1 (14.8)	5.17 (7.4)	5.84 (33.2)	6.32 (40.0)	5.49 (34.2)
Imazethapyr 75 g/ha PoE at 15 DAS	7.53 (26.3)	7.7 (62.7)	10.4 (20.3)	5.43 (9.0)	3.80 (13.8)	5.90 (35.0)	5.03 (27.8)
Imazethapyr 75 g/ha PoE at 25 DAS	9.43 (41.0)	7.6 (58.7)	8.6 (13.3)	5.02 (7.0)	4.42 (18.8)	6.07 (37.0)	5.12 (29.3)
Imazethapyr 50 g/ha PE	6.20 (17.0)	9.8 (97.3)	13.2 (34.5)	6.79 (14.0)	7.38 (54.0)	6.43 (41.5)	6.23 (43.0)
Imazethapyr 75 g/ha PE	5.53 (13.7)	8.5 (73.7)	12.6 (31.0)	6.44 (12.0)	6.83 (46.2)	5.19 (27.0)	5.55 (33.9)
LSD (p=0.05)	2.7	1.8	1.7	0.8	0.8	0.9	1.3

Original data on weed density given in parentheses were subjected to square root transformation $\sqrt{x+0.5}$ before analysis; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing

Abbreviation used: LDH: Ludhiana; ABH: Abohar; GSP: Gurdaspur; BS: Ballowal Saunkhri; FDK: Faridkot; BTD: Bathinda

imazethapyr 50 and 75 g/ha PE at Ludhiana, with imazethapyr 75 g/ha PoE at 15 and 25 DAS at Faridkot and Gurdaspur. On an average, HW twice recorded significantly higher plant height than weedy check, imazethapyr 50 g/ha at 15 DAS and 75 g/ha as PE and at par with other treatments of imazethapyr. The minimum plant height was recorded under weedy check plots at all locations, except at Ludhiana, where imazethapyr 75 g/ha PoE at 15 DAS recorded the lowest plant height. Application of imazethapyr at higher dose (75 g/ha) PoE at 15 DAS showed phytotoxic effects on crop, which resulted in reduction of plant height. Imazethapyr caused slight phytotoxicity in summer greengram, with an injury score of 8–9% on the 0–100% scale, from which the crop fully recovered within 15-20 days. The highest number of branches/plant was recorded with HW twice at 4 and 6 WAS at Abohar, Faridkot and Gurdaspur, while, imazethapyr 50 g/ha PoE at 15 DAS, imazethapyr 75 g/ha PoE at 25 DAS and imazethapyr 75 g/ha PE recorded the highest number of branches/plant at Ludhiana, Bathinda and Ballowal Saunkhri, respectively (**Table 3**). The application of herbicides whether as pre-emergence or post-emergence and hand weeding effectively minimized weed interference, enabling better uptake of growth resources. As a result, the plants exhibited improved crop growth as reported by Rupareliya *et al.* (2017).

The highest number of pods/plant was recorded with HW twice at 4 and 6 WAS at all locations (**Table 3**). Among herbicidal treatments, imazethapyr 50 g/ha PoE at 15 DAS at Ludhiana, imazethapyr 75 g/ha PoE at 25 DAS at Abohar and Bathinda, imazethapyr 50 g/ha PoE at 25 DAS at Faridkot and imazethapyr 75 g/ha PoE at 15 DAS at Gurdaspur and Ballowal Saunkhri recorded the highest number of pods/plant

Table 2. Weed biomass and weed control efficiency as influenced by weed control treatments in summer greengram (pooled mean)

Treatment	LDH	ABH	GSP	BS	FDK	BTD	Mean	WCE (%)
Weed biomass at 40 DAS (g/m^2)								
Weedy check	10.1 (50.5)	6.6 (53.3)	13.1 (169.7)	10.0 (101)	6.1 (41.6)	11.1 (124)	8.4 (84.6)	-
Hand weeding twice at 4 and 6 WAS	1.3 (1.0)	2.2 (5.0)	4.1 (17.3)	5.1 (26)	2.7 (7.1)	7.8 (61.2)	2.9 (11.3)	86.6
Imazethapyr 50 g/ha PoE at 15 DAS	3.7 (13.7)	4.4 (27.7)	5.7 (32.6)	6.3 (40)	3.6 (12.7)	4.9 (24.7)	4.3 (20.7)	75.5
Imazethapyr 50 g/ha PoE at 25 DAS	4.0 (15.8)	4.2 (25.3)	6.4 (41.0)	6.3 (40)	3.8 (14.6)	3.7 (13.7)	4.3 (20.6)	75.7
Imazethapyr 75 g/ha PoE at 15 DAS	3.7 (13.4)	3.7 (19.7)	4.4 (19.5)	5.9 (35)	3.6 (12.6)	4.6 (22.0)	3.9 (16.6)	80.4
Imazethapyr 75 g/ha PoE at 25 DAS	4.1 (16.6)	3.2 (13.3)	5.4 (21.8)	6.1 (37)	3.2 (9.9)	3.6 (13.2)	3.8 (15.2)	82.0
Imazethapyr 50 g/ha PE	3.3 (11.7)	5.1 (38.3)	7.8 (61.6)	6.4 (41)	2.6 (13.7)	6.0 (36.2)	4.7 (26.8)	68.3
Imazethapyr 75 g/ha PE	3.5 (13.1)	4.0 (23.3)	7.2 (52.4)	5.1 (27)	3.8 (14.4)	5.6 (32.2)	4.3 (21.2)	74.9
LSD (p=0.05)	0.7	0.9	0.9	3.3	2.1	3.1	1.1	7.2
Weed biomass at harvest (kg/ha)								
Weedy check	31.4 (1007)	25.3 (713)	42.7 (1727)	9.6 (93)	23.7 (571)		31.3 (1108)	-
Hand weeding twice at 4 and 6 WAS	7.7 (105)	15.1 (237)	16.4 (221)	4.7 (22)	10.9 (200)		12.3 (178)	84.0
Imazethapyr 50 g/ha PoE at 15 DAS	15.0 (229)	19.8 (517)	23.1 (486)	5.6 (31.7)	17.7 (314)		17.5 (364)	67.2
Imazethapyr 50 g/ha PoE at 25 DAS	18.7 (356)	18.8 (500)	24 (536)	6.4 (41)	16.9 (283)		18.1 (390)	64.8
Imazethapyr 75 g/ha PoE at 15 DAS	13.9 (198)	17.1 (373)	16.8 (237)	5.4 (30)	17.0 (291)		14.9 (260)	76.5
Imazethapyr 75 g/ha PoE at 25 DAS	15.7 (256)	14.6 (280)	20.1 (355)	6.3 (40)	17.2 (296)		15.4 (269)	75.7
Imazethapyr 50 g/ha PE	11.6 (156)	23.5 (673)	28.8 (784)	4.9 (24)	17.4 (312)		19.1 (455)	58.9
Imazethapyr 75 g/ha PE	10.3 (120)	20.0 (477)	26.8 (682)	4.8 (23)	17.0 (307)		17.4 (367)	66.9
LSD (p=0.05)	4.3	5.2	3.4	1.5	4.2		3.6	10.1

Original data on weed density given in parentheses were subjected to square root transformation $\sqrt{x+0.5}$ before analysis; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing
Abbreviation used: LDH: Ludhiana; ABH: Abohar; GSP: Gurdaspur; BS: Ballowal Saunkhri; FDK: Faridkot; BTD: Bathinda

Table 3. Plant height, branches/plant and pods/plant of summer greengram as influenced by weed control treatments (pooled mean)

Treatment	Plant height (cm)						Branches/plant						Pods/plant					
	LDH	ABH	GSP	BS	FDK	BTD	LDH	ABH	GSP	BS	FDK	BTD	LDH	ABH	GSP	BS	FDK	BTD
Weedy check	59.5	48.7	57.3	29.3	47.8	66.3	5.99	4.34	7.24	4.31	4.11	4.08	20.6	13.6	14.6	15.0	21.3	13.5
Hand weeding twice at 4 and 6 WAS	62.9	54.5	64.2	30.8	57.7	69.6	6.17	5.84	11.69	5.40	6.06	5.30	25.3	25.2	20.3	18.6	29.7	20.8
Imazethapyr 50 g/ha PoE at 15 DAS	61.7	50.9	62.0	30.2	55.3	68.0	6.61	4.96	10.24	4.72	4.94	5.15	26.0	21.1	19.3	17.9	28.2	17.8
Imazethapyr 50 g/ha PoE at 25 DAS	61.1	51.7	61.9	33.4	54.8	69.7	6.34	5.20	10.09	4.40	4.91	5.38	22.7	22.1	19.7	17.7	29.0	19.5
Imazethapyr 75 g/ha PoE at 15 DAS	58.9	52.6	63.4	32.8	55.6	69.8	6.16	5.40	11.15	5.10	5.04	5.34	24.4	23.1	20.3	18.5	27.0	19.3
Imazethapyr 75 g/ha PoE at 25 DAS	59.3	53.2	63.4	33.7	55.5	70.0	6.40	5.58	10.85	4.82	5.44	5.45	21.6	24.4	19.7	18.2	28.8	20.3
Imazethapyr 50 g/ha PE	61.1	50.3	60.4	34.8	54.8	69.3	6.28	5.07	9.79	5.10	5.28	5.13	22.6	18.2	19.9	18.0	27.4	17.5
Imazethapyr 75 g/ha PE	61.3	49.6	60.1	31.4	54.4	69.5	6.22	4.46	9.34	5.45	5.01	5.20	23.2	15.4	20.0	18.0	25.7	18.0
LSD (p=0.05)	3.1	NS	1.9	NS	2.4	NS	0.70	0.56	1.40	NS	0.78	0.64	1.8	4.3	2.3	NS	4.3	2.2

Abbreviation used: LDH: Ludhiana; ABH: Abohar; GSP: Gurdaspur; BS: Ballowal Saunkhri; FDK: Faridkot; BTD: Bathinda; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing

in greengram. Number of seeds/pod was not significantly affected by different weed management practices at Ludhiana, Abohar, Gurdaspur and Ballowal Saunkhri (**Table 4**). However, imazethapyr 75 g/ha PoE at 15 DAS at Faridkot and imazethapyr 75 g/ha PoE at 25 DAS at Bathinda recorded the maximum number of seeds/pod in greengram. Imazethapyr 50 g/ha PoE at 15 DAS at Ludhiana, imazethapyr 50 g/ha PoE at 25 DAS at Abohar, imazethapyr 75 g/ha PoE at 15 DAS at Faridkot and Gurdaspur, imazethapyr 75 g/ha PoE at 25 DAS at Bathinda and imazethapyr 50 g/ha PE recorded the highest seed index of greengram (**Table 4**).

The highest grain yield of greengram was recorded with HW twice at 4 and 6 WAS at all locations, except Bathinda, where, imazethapyr 75 g/ha PoE at 25 DAS gave the highest grain yield (**Table 5**). At Ludhiana, application of imazethapyr 50 and 75 g/ha PoE at 15 DAS, at Abohar imazethapyr 75 g/ha PoE at 25 DAS, and at Ballowal Saunkhri imazethapyr 75 g/ha PE produced grain yields statistically at par with HW twice. Similarly, at Gurdaspur, Faridkot, and Bathinda, the herbicidal treatments were on par with two HW. On an average, HW twice at 4 and 6 WAS, imazethapyr 75 g/ha PoE at 15 and 25 DAS recorded statistically similar grain yield of greengram and significantly higher than the other treatments. HW twice, imazethapyr 75 g/ha PoE at 15 and 25 DAS enhanced grain yield of greengram by 71.4, 60.2 and 58.5% over weedy check, respectively. Punia *et al.* (2017) also reported significant yield enhancement in greengram with the application of imazethapyr 70 g/ha applied at 3-4 leaf stage. The superior yield performance with HW twice and herbicidal treatments can be attributed to their effective weed control (**Tables 1** and **2**), thereby improving light interception, nutrient uptake, and moisture availability for the crop (Singh *et al.* 2018).

Economics

The HW twice at 4 and 6 WAS recorded maximum gross return, which were significantly higher than weedy check and other treatments, but at par with imazethapyr 75 g/ha PoE at 15 and 25 DAS (**Table 5**). Imazethapyr 75 g/ha PoE at 15 DAS recorded the highest net return followed by imazethapyr 75 g/ha at 25 DAS. The slightly lower net return with under HW twice was due to the higher

Table 4. Number of seeds/pod and seed index of summer greengram as influenced by weed control treatments (pooled mean)

Treatment	Seeds/pod						Mean	Seed index (g)						Mean
	LDH	ABH	GSP	BS	FDK	BTD		LDH	ABH	GSP	BS	FDK	BTD	
Weedy check	11.5	10.5	10.4	10.1	7.00	8.3	9.6	3.93	3.89	3.14	3.55	3.74	3.03	3.65
Hand weeding twice at 4 and 6 WAS	11.9	11.8	11.2	11.8	8.85	11.0	10.8	3.93	3.97	4.04	4.06	4.05	3.05	3.92
Imazethapyr 50 g/ha PoE at 15 DAS	11.8	11.2	11.0	11.4	9.05	10.0	10.5	4.12	3.92	3.87	3.97	4.12	3.13	3.93
Imazethapyr 50 g/ha PoE at 25 DAS	11.9	11.3	10.9	11.1	8.65	11.0	10.5	4.08	4.05	3.83	3.96	4.10	3.2	3.95
Imazethapyr 75 g/ha PoE at 15 DAS	12.0	11.5	11.2	11.5	9.08	10.3	10.6	4.09	3.88	4.07	3.96	4.21	3.23	3.97
Imazethapyr 75 g/ha PoE at 25 DAS	11.9	11.7	11.2	11.5	8.60	11.1	10.6	4.01	4.02	3.94	4.01	4.13	3.25	3.96
Imazethapyr 50 g/ha PE	12.0	10.8	10.8	10.8	8.85	10.5	10.4	4.02	3.80	3.80	4.19	4.07	3.13	3.88
Imazethapyr 75 g/ha PE	11.7	10.7	10.8	10.9	8.60	10.3	10.3	4.09	3.75	3.83	3.99	3.95	3.15	3.85
LSD (p=0.05)	NS	NS	NS	NS	0.42	1.3	0.3	0.20	0.26	0.24	NS	0.19	NS	0.12

Abbreviation used: LDH: Ludhiana; ABH: Abohar; GSP: Gurdaspur; BS: Ballowal Saunkhri; FDK: Faridkot; BTD: Bathinda; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing

Table 5. Effect of weed management treatments on grain yield and economics of summer greengram (pooled mean)

Treatment	Greengram grain yield (t/ha)							Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
	LDH	ABH	GSP	BS	FDK	BTD	Mean				
Weedy check	1.44	0.94	0.99	0.56	1.01	0.20	0.86	29038	86299	57261	1.97
Hand weeding twice at 4 and 6 WAS	1.94	1.67	1.57	1.13	1.50	1.01	1.47	49038	137783	88745	1.81
Imazethapyr 50 g/ha PoE at 15 DAS	1.89	1.32	1.39	0.84	1.43	0.94	1.30	29733	123371	93638	3.15
Imazethapyr 50 g/ha PoE at 25 DAS	1.73	1.43	1.38	0.69	1.40	0.95	1.26	29733	120940	91207	3.07
Imazethapyr 75 g/ha PoE at 15 DAS	1.90	1.42	1.54	0.93	1.39	1.06	1.37	30880	128407	97527	3.16
Imazethapyr 75 g/ha PoE at 25 DAS	1.72	1.57	1.54	0.76	1.41	1.16	1.36	30880	127625	96745	3.13
Imazethapyr 50 g/ha PE	1.75	1.24	1.28	1.05	1.33	0.79	1.24	30533	115905	85372	2.80
Imazethapyr 75 g/ha PE	1.79	1.09	1.28	1.10	1.29	0.82	1.23	30880	113647	82767	2.68
LSD (p=0.05)								-	12220	12220	0.18

Abbreviation used: LDH: Ludhiana; ABH: Abohar; GSP: Gurdaspur; BS: Ballowal Saunkhri; FDK: Faridkot; BTD: Bathinda; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing

Table 6. Residue of imazethapyr in grains of greengram at harvest after its usage for weed management in summer greengram

Treatment	Residue in summer greengram (µg/g)
Imazethapyr 50 g/ha PoE at 15 DAS	<LOQ
Imazethapyr 50 g/ha PoE at 25 DAS	<LOQ
Imazethapyr 100 g/ha PoE at 25 DAS	0.018 ± 0.011
Imazethapyr 75 g/ha PoE at 15 DAS	<LOQ
Imazethapyr 75 g/ha PoE at 25 DAS	<LOQ
Imazethapyr 150 g/ha PoE at 25 DAS	0.049 ± 0.012
Imazethapyr 50 g/ha PE	<LOQ
Imazethapyr 75 g/ha PE	<LOQ
Imazethapyr 150 g/ha PE	0.027 ± 0.018

LOQ (Limit of Quantification) <0.01 µg/g; PoE: post-emergence application; PE: pre-emergence application DAS: days after sowing; WAS: weeks after sowing

labour costs involved, despite higher gross returns. Imazethapyr 75 g/ha PoE at 15 DAS gave the highest BC ratio (3.16) followed by imazethapyr 50 g/ha PoE at 15 DAS (3.15) and imazethapyr 75 g/ha PoE at 25 DAS (3.13) as reported by Singh *et al*. 2018 and Punia *et al*. 2017).

Herbicide residue in grains

The calibration curves of imazethapyr were linear with correlation coefficient R^2>0.99. Limit of detection (LOD) and limit of quantification (LOQ) of imazethapyr were 0.003 and 0.01 µg/g, respectively. The mean percent recoveries from greengram at fortification levels of 0.5, 0.1 and 0.01 µg/g ranged from 82.5 ± 2.21 to 94.3 ± 2.78. Inter day precision (percent RSD_R) and intraday precision (percent RSD_r) was assessed by repeating experiment three times a day and on three different days, respectively and were <10 percent. The harvest residues of imazethapyr in greengram when applied at 75 g/ha after 15 and 25 DAS, were below 0.01 µg g^{-1}. When imazethapyr was applied at 100 and 150 g/ha 25 DAS and at 150 g/ha as PE, residues corresponding to 0.018 ± 0.011, 0.049 ± 0.012 and 0.027 ± 0.018 µg/g, respectively were detected in greengram (**Table 6**). These results indicate that lower recommended doses of imazethapyr (50–75 g/ha) are safe for application in greengram, as the residues were below the limit of quantification (LOQ) as observed earlier by Punia *et al*. (2017) in greengram.

Conclusion

Imazethapyr 75 g/ha PoE at 15 and 25 DAS was found to be the most effective and economic approach for weed management to realise higher greengram productivity od summer greengram under different agro climatic zones of Punjab, India.

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