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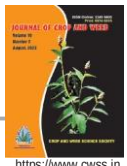

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Control of mixed weed flora with pre- and post-emergence imidazolinone herbicides in garden pea

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ABSTRACT

Vegetable pea is a cool season vegetable crop in northern India and frozen pea has vast export potential. It has slow initial growth and infestation of various grasses and broadleaf weeds lead to reduction in pod yield. Field experiment was conducted for consecutive three rabi seasons during 2014-15 to 2016-17 to study the bio-efficacy of different formulations of imidazolinone herbicides and standardize the dose of imazethapyr, pendimethalin plus imazethapyr and imazethapyr plus imazamox. All imidazolinone formulations were safe to crop and resulted in variable weed control efficiency. Pre-emergence application of pendimethalin plus imazethapyr 800-1000 g ha^{-1} resulted in 86-91% weed control efficiency at harvest. Cyperus rotundus, Medicago denticulata and Oenothera laciniata were not controlled with pendimethalin and premix of pendimethalin plus imazethapyr. Imazethapyr and imazethapyr plus imazamox 60-70 g ha^{-1} resulted in green pod yield of 15.8 t and 16.9 t ha^{-1}, respectively.

***Keywords*:** green pod yield, imazethapyr, imazethapyr + imazamox, pendimethalin + imazamox, pre-emergence, post-emergence

In northern India, frozen vegetable pea (green) is one of the vegetables amongst vegetable export basket. Garden pea (*Pisum sativum* L.) is a cool season vegetable crop and is known as weak competitors of weeds. The lower weed competitive ability of garden pea is due to its slow initial growth with less leaf area development and more utilization of energy in nodule formation and activity. Moreover, garden/vegetable pea is grown at wider row spacing which results into lower plant density per unit area leading to more space for weeds (Corre-Hellou *et al.*, 2011). The first picking take place around 85-90 days after sowing and crop season is over within 130-140 days after sowing. Weeds emerge along with crop and pose severe competition and pose a serious limitation to growth, yield and pod size of garden pea and uncontrolled weed growth also poses difficulties in pod harvesting. Weeds compete with the crop up to 70 days after sowing (Singh *et al*., 2016) and weed control during this critical period of crop-weed competition is essential for realizing maximum green pod yield and economic returns. Gogoi *et al.* (2022) observed that there are many gaps in adoption of improved production technology including seed rate and weed management which need to be minimized for enhancing productivity and sustainability in pulses production.

Various weed management strategies like cultural weed control practices (crop rotation, mulch, tillage), physical weed control methods (wheel hand hoe, hand weeding) and chemical weed control methods are employed for weed control. Manual weeding is easier but its time consuming, laborious and expensive. Due to unavailability of labour in Northern India, chemical weed control is the most preferred method. However, there are a few and costly herbicide options in pulses and pre-emergence herbicides are commonly used to control weeds. However, use of pre-emergence herbicides like pendimethalin keep weeds under check for initial 15-20 days period only, and weeds start appearing in the field after that and pose competition to the crop. Hence, one hand weeding has to be done after 30 days of herbicide application to keep the crop free from weeds at least during critical period of crop-weed competition. This hand weeding operation is costly and labour-intensive and this necessitates intervention of cost-effective alternative which is use of post-emergence herbicides for season long weed control.

Imidazolinone herbicides are group of herbicides with broad-spectrum action on grasses and broadleaf weeds in legume fields by inhibiting activity of acetolactate synthase enzyme. Imidazolinone herbicides show flexibility in time of application and it can be applied either as pre- or post-emergence herbicide option (Tan *et al*., 2005). Imazethapyr is available as (imazethapyr 10%) soluble liquid formulation and it can be applied as pre- or post-emergence. For broad-

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spectrum weed control, imazethapyr is also available as premix liquid formulation with pendimethalin (pendimethalin 30%+imazethapyr 2%) for use as pre-emergence, and with imazamox (imazethapyr 35%+imazamox 35%) as premix solid formulation for use as post-emergence. The efficacy of imazethapyr formulations available in market needs to be evaluated for weed control in garden pea under semi-tropical conditions and the tolerance in garden pea cv. Punjab 89 to imidazolinone herbicides need to be studied. With these objectives, an experiment was conducted for three consecutive seasons to evaluate the weed control efficacy of imidazolinone herbicides in garden pea.

MATERIALS AND METHODS

A field experiment was conducted consecutively for three *rabi* season (mid-October to mid-February) during 2014-15, 2015-16 and 2016-17 at Agronomy Research Farm, Punjab Agricultural University, Ludhiana. The soil of experimental site was sandy loam texture with 0.35% organic carbon and pH of 7.79 with 210, 32.75, 183.50 kg ha^{-1} of available N, P and K content, respectively. In each year of study, garden pea cultivar 'Punjab 89' was sown using seed rate of 75 kg ha^{-1} in mid-October at 30 cm × 10 cm spacing. Before sowing, 50 kg ha^{-1} nitrogen and 62.5 kg ha^{-1} phosphorus were applied. The experiment consisting of 12 weed control treatments and 4 replications was conducted in randomized complete block design. Treatments included pre-emergence application of pendimethalin 1000 g ha^{-1} and premix of pendimethalin plus imazethapyr 800, 900, 1000 g ha^{-1}; post-emergence application of imazethapyr 50, 60, 70 g ha^{-1} and premix of imazethapyr plus imazamox 50, 60, 70 g ha^{-1} along with unsprayed weedy and weed free control plots. The pre-emergence herbicides (pendimethalin and pendimethalin plus imazethapyr) were sprayed after 1 day of sowing (DAS) with battery-operated knapsack sprayer equipped with flat fan nozzle using 500 L water ha^{-1}. The first irrigation was applied at 15 DAS. The post-emergence herbicides (imazethapyr and imazethapyr plus imazamox) were sprayed at 25 DAS using spray volume of 375 L water ha^{-1} with battery-operated knapsack sprayer.

A quadrate of 50×50 cm was used in each plot (at two places) to determine the density of different species of grass and broadleaf weeds after 20 and 50 DAS. The biomass of grasses and broadleaf weeds from each plot was recorded after drying the weed samples at 70! for 48-72 hours at 50 DAS and at harvest. Weed control efficiency was calculated from weed biomass using the formula:

$$\text{WCE } (\%) = \frac{\text{Weed biomass in unsprayed plot} - \text{Weed biomass in herbicide treated plot}}{\text{Weed biomass in unsprayed plot}} \times 100$$

The green pod yield was recorded at crop harvest and green pods was picked thrice in January-February. The crop yield and weed data were subjected to the ANOVA using SPSS. Normality, homogeneity of variance and interactions of treatments and years were tested. To improve the normality and homogeneity of variance, square root transformation of weed data was done. The data was pooled over years and treatments means were compared using the Fisher's protected LSD at 5% probability.

RESULTS AND DISCUSSION

Weed flora: The experimental field was predominantly infested with broad leaf weeds. Among broadleaf weeds, *Oenothera laciniata* Hill, *Anagallis arvensis* L., *Chenopodium album* L., *Rumex dentatus* L., *Medicago denticulata* L., *Coronopus didymus* (L.) Sm., *Spergula arvensis* L. were present. *Cyperus rotundus* L. was observed up to 20 DAS but was not observed at later stages of crop growth. Among grasses, *Poa annua* L. and *Phalaris minor* Retz. were observed.

Effect on weeds: Pendimethalin 750 g ha^{-1} as pre-emergence application resulted in excellent control of all grasses and broadleaf weeds except *M. denticulata* and *O. laciniata* when observed at 20 DAS. The density of *M. denticulata* and *O. laciniata* in pendimethalin-treated plots was statistically similar to unsprayed weedy plots (Table 1). Similarly, pendimethalin plus imazethapyr resulted in complete control of grasses and broadleaf weeds except for *M. denticulata* and *O. laciniata*. It was observed that pendimethalin plus imazethapyr 1000 g ha^{-1} was effective in controlling these two weeds as compared to its lower doses (800 g and 900 g ha^{-1}). The pre-emergence herbicides (pendimethalin and its premix with imazethapyr) did not control *C. rotundus*. *Cyperus rotundus* is a summer-perennial and prefer warm weather and full sun conditions. Therefore, *C. rotundus* was not observed in experimental field at later stage of crop growth as the winter became harsh during end Novemeber-December.

Premix of pendimethalin plus imazethapyr 1000 g ha^{-1} resulted in reduced weed density than pendimethalin standalone treatment at 50 DAS (Table 2). Imazethapyr formulations were safe to the crop and differential weed control was observed with three formulations. Imazamox up to 40 g ha^{-1} was found to be safe with 90-95% weed control (Blackshaw, 1998). Weed density was significantly reduced with each successive increase in rate of imazethapyr with the highest weed control efficiency at imazethapyr 70 g ha^{-1}. However, weed

Table 1: Effect of pre-emergence herbicides on weed density at 20 DAS (pooled data of 3 years).

Herbicides	Weed density (No. m^{-2}) at 20 DAS									
(Dose g ha^{-1})	***Oenothera laciniata***	***Rumex dentatus***	***Anagallis arvensis***	***Medicago denticulata***	***Spergula arvensis***	***Coronopus didymus***	***Chenopodium album***	***Cyperus rotundus***	***Phalaris minor***	***Poa annua***
Pendimethalin 750	4.4 (19)	1.0 (0)	1.0 (0)	2.3 (4)	1.0 (0)	1.0 (0)	1.0 (0)	2.3 (4)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 800	2.4 (5)	1.0 (0)	1.0 (0)	2.0 (3)	1.0 (0)	1.0 (0)	1.0 (0)	2.3 (4)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 900	1.9 (3)	1.0 (0)	1.0 (0)	1.7 (2)	1.0 (0)	1.0 (0)	1.0 (0)	2.2 (4)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 1000	1.7 (2)	1.0 (0)	1.0 (0)	1.4 (1)	1.0 (0)	1.0 (0)	1.0 (0)	2.1 (3)	1.0 (0)	1.0 (0)
Unsprayed	4.7 (21)	1.7 (2)	4.1 (16)	2.3 (4)	2.8 (7)	2.2 (4)	3.5 (11)	2.3 (4)	2.3 (4)	1.9 (3)
LSD (0.05)	0.6	0.2	0.6	0.3	0.1	0.1	0.2	NS	0.1	0.1

Weed density data was subjected to square root transformation. Figure in parenthesis are means of original values

density was more in imazethapyr-treated plots as compared to premix of imazethapyr plus imazamox, indicating that imazethapyr standalone application was inferior in controlling weeds as compared to premix of imazethapyr plus imazamox. Kumar *et al*. (2016) observed that order of weed control efficacy of imazethapyr at 80-100 g ha^{-1} was grasses, sedges and broadleaf weeds in summer greengram. However, soil persistence of imazethapyr at this high dose in heavy-textured soils is sufficient to injure succeeding crops (such as oilseed/cucurbits crops) planted 1 year or later (Miller, 2003).

Weed biomass was significantly more in pendimethalin treated plots which reflected poor weed control efficacy by pendimethalin at 50 DAS (53% weed control efficiency) and at harvest (45% weed control efficiency). However, application of premix of pendimethalin plus imazethapyr 800-1000 g ha^{-1} as pre-emergence resulted in 96% weed control efficiency even up to 50 DAS. Premix of imazethapyr plus imazamox was superior in controlling the weeds and weed control efficiency of 66-86% and 72-85% was observed at 50 DAS and harvest, respectively (Table 3). It was better than standalone application of imazethapyr in which 60-74% and 69-73% control efficiency was observed at 50 DAS and at harvest, respectively. Sikkema *et al*. (2005) also observed that application of imazethapyr either as pre-emergence or post-emergence herbicide resulted in effective weed control in garden pea. It was observed by Rana *et al*. (2015) that post-emergence application of imazethapyr 50-100 g ha^{-1} and imazethapyr plus imazamox 50-90 g ha^{-1} resulted in lower weed biomass than unsprayed and pre-emergence herbicides (trifluralin and pendimethalin). However, lower germination percentage was recorded in plots receiving higher dose of imazethapyr plus imazamox 90 g ha^{-1} (Rana *et al*., 2015).

Effect on pod yield: All herbicidal treatments resulted in significantly higher green pod yield as compared to unsprayed weedy plots (Table 3). The lowest green pod yield was obtained in unsprayed weedy plots. The maximum green pod yield was obtained in weed free plot which was statistically at par with premix of imazethapyr plus imazamox 60-70 g ha^{-1} applied as post-emergence. The green pod yield where premix of pendimethalin plus imazethapyr 800-1000 g ha^{-1} was applied as pre-emergence, was also statistically at par with weed free plot. It was observed that standalone application of pendimethalin 750 g ha^{-1} lower rates of imazethapyr (50 g ha^{-1}) and premix of imazethapyr plus imazamox (50 g ha^{-1}) applied as post-emergence resulted in statistically similar yields as obtained with. Mawalia *et al*. (2016) also reported that more number of nodules and green pod yield was observed when pendimethalin

Table 2: Effect of pre- and post-emergence herbicides on weed density at 50 DAS (pooled data of 3 years).

Herbicides (Dose g ha^{-1})	Weed density (No. m^{-2}) at 50 DAS								
	Oenothera laciniata	***Rumex dentatus***	***Anagallis arvensis***	***Medicago denticulata***	***Coronopus didymus***	***Spergula arvensis***	***Chenopodium album***	***Phalaris minor***	***Poa annua***
Pendimethalin 750	7.8 (59)	3.3 (10)	3.4 (11)	3.9 (15)	2.6 (6)	2.0 (3)	3.8 (13)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 800	4.5 (20)	2.1 (3)	3.3 (10)	2.6 (6)	2.2 (4)	1.7 (2)	3.1 (9)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 900	4.3 (18)	1.7 (2)	3.0 (8)	2.2 (4)	1.9 (3)	1.5 (1)	2.7 (6)	1.0 (0)	1.0 (0)
Pendimethalin plus imazethapyr 1000	3.2 (9)	1.7 (2)	2.3 (4)	2.1 (4)	1.5 (1)	1.0 (0)	2.2 (4)	1.0 (0)	1.0 (0)
Imazethapyr 50	5.4 (28)	2.8 (7)	3.6 (12)	3.2 (9)	2.6 (6)	2.9 (7)	2.8 (7)	2.2 (4)	2.0 (3)
Imazethapyr 60	4.7 (21)	2.3 (4)	3.0 (9)	2.1 (4)	2.1 (3)	2.3 (5)	2.4 (5)	1.7 (2)	1.7 (2)
Imazethapyr 70	3.2 (9)	2.1 (3)	2.2 (4)	2.1 (4)	1.8 (2)	1.7 (2)	1.9 (3)	1.4 (1)	1.5 (1)
Imazethapyr plus imazamox 50	4.3 (17)	2.2 (4)	2.9 (7)	2.5 (5)	2.2 (4)	2.4 (5)	2.2 (4)	1.0 (0)	1.0 (0)
Imazethapyr plus imazamox 60	3.8 (14)	1.7 (2)	2.1 (4)	1.5 (1)	1.5 (1)	1.8 (2)	1.5 (1)	1.0 (0)	1.0 (0)
Imazethapyr plus imazamox 70	3.0 (8)	1.7 (2)	1.6 (2)	1.4 (1)	1.5 (1)	1.4 (1)	1.0 (0)	1.0 (0)	1.0 (0)
Weed free	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Unsprayed	8.1 (65)	4.3 (18)	4.5 (19)	4.1 (16)	3.5 (11)	2.9 (8)	4.1 (16)	2.6 (6)	3.7 (13)
LSD (0.05)	0.9	0.5	0.8	0.7	0.4	0.6	0.4	0.3	0.3

Weed density data was subjected to square root transformation. Figure in parenthesis are means of original values

Table 3: Effect of pre- and post-emergence herbicides on weed biomass and green pod yield at 50 DAS (pooled data of 3 years).

Herbicides (Dose g ha^{-1})	Weed biomass (g m^{-2}) at 50 DAS			Weed biomass (g m^{-2}) at harvest			Weed Control Efficiency (%)		Green pod yield (t ha^{-1})
	Grasses	Broadleaves	Total Weeds	Grasses	Broadleaves	Total Weeds	At 50 DAS	At harvest	
Pendimethalin 750	1.0 (0)	11.9 (141)	11.9 (141)	1.0 (0)	16.8 (282)	16.8 (282)	53.0	45.0	13.159
Pendimethalin plus imazethapyr 800	1.0 (0)	3.4 (10)	3.4 (10)	1.0 (0)	8.7 (74)	8.7 (74)	96.5	85.6	16.052
Pendimethalin plus imazethapyr 900	1.0 (0)	3.2 (9)	3.2 (9)	1.0 (0)	7.9 (61)	7.9 (61)	96.8	88.1	16.266
Pendimethalin plus imazethapyr 1000	1.0 (0)	3.0 (8)	3.0 (8)	1.0 (0)	6.7 (44)	6.7 (44)	97.4	91.5	16.461
Imazethapyr 50	2.2 (4)	10.8 (116)	11.0 (120)	4.1 (16)	12.0 (142)	12.6 (158)	60.0	69.2	13.781
Imazethapyr 60	1.8 (2)	10.1 (101)	10.2 (104)	3.2 (10)	11.9 (129)	11.7 (139)	65.3	70.2	15.044
Imazethapyr 70	1.5 (1)	8.8 (76)	8.8 (77)	2.6 (6)	10.8 (106)	10.8 (112)	74.2	73.2	15.823
Imazethapyr plus imazamox 50	1.0 (0)	10.1 (101)	10.1 (101)	2.6 (6)	11.8 (140)	12.1 (146)	66.2	71.6	14.001
Imazethapyr plus imazamox 60	1.0 (0)	8.7 (75)	8.7 (75)	1.0 (0)	10.4 (108)	10.4 (108)	74.8	79.0	16.929
Imazethapyr plus imazamox 70	1.0 (0)	6.4 (40)	6.4 (40)	1.0 (0)	8.8 (77)	8.8 (77)	86.6	85.0	16.939
Weed free	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	100.0	100.0	16.961
Unsprayed	3.1 (9)	17.1 (290)	17.3 (299)	5.2 (27)	22.1 (487)	22.7 (514)	-	-	9.681
LSD (p=0.05)	0.4	0.7	0.7	0.4	1.0	1.0	-	-	2.027

Weed biomass data was subjected to square root transformation. Figure in parenthesis are means of original values

1000 g ha^{-1} was integrated with hand weeding or post-emergence application of imazethapyr plus imazamox 60 g ha^{-1}.

It is concluded that pre-emergence application of pendimethalin plus imazethapyr 800-1000 g ha^{-1} resulted in early-season and effective control of grass and broad leaf weeds except *Medicago denticulata* and *Oenothera laciniata*. The standalone application of imazethapyr 60-70 g ha^{-1} as post-emergence resulted in moderate weed control. Imazethapyr plus imazamox 60-70 g ha^{-1} as post-emergence herbicide (at 20-25 DAS) was effective for control of mixed weed flora in garden pea and resulted in maximum green pod yield.

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