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Bioefficacy of Imazethapyr Applied Alone and in Combination with other Herbicides in Black Gram and their Residual Effect on Succeeding Pearl-millet and Sorghum Crops

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ABSTRACT

Background: Weeds are one of the major constraints in achieving yield potential of black gram. Due to slow initial growth of black gram, weeds compete effectively and caused reduction in growth as well as yield of black gram. Hand weeding is neither practicable nor economical due to unpredictability of weather and high labour cost, respectively. Therefore, application of herbicides is considered as the best approach for efficient weed control in black gram.

Method: A field experiment was conducted at Research Farm of Department of Agronomy, CCSHAU, Hisar during *summer* and *kharif* 2017 to evaluate the effect of different weed control treatments in black gram and their residual effect on succeeding pearl millet and sorghum crops. Total of fourteen weed control treatments were replicated thrice in randomized complete block design (RCBD).

Result: *Dactyloctenium aegyptium* (37%), *Trianthema portulacastrum* (34%), *Cyperus rotundus* (21%) and *Digera arvensis* (8%) were the major weed flora associated with black gram at 30 DAS. Both at 30 and 60 DAS, PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} provided 100% control of *D. aegyptium* and *T. portulacastrum*. PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} was the most significant herbicide treatment (90% control of weeds) at 30 DAS however, 3-4 leaf stage application of imazethapyr + imazamox at 70 g/ha recorded with highest control of weeds (89%) at 60 DAS. Maximum seed yield (912 kg ha^{-1}) and yield attributes of black gram were obtained in weed free treatment which was statistically at par with two hoeing performed at 20 and 40 DAS (895 kg ha^{-1}) and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (878 kg ha^{-1}). Imazethapyr and its RM combination with imazamox applied at 3-4 leaf stage had phytotoxic effects on black gram at 30 DAS which suppressed the growth and caused yield penalty. Residual effect or phytotoxicity was not observed on succeeding pearl millet and sorghum crops.

Key words: Black gram, Hand hoeing, Imazethapyr, Pearl millet, Phytotoxicity, Sorghum, Weed control efficiency (WCE), Weed density.

INTRODUCTION

Black gram [*Vigna mungo* (L.) Hepper] belongs to family leguminoseae is one of the important pulse crops with high nutritional values. It contains 59.6% carbohydrates, 24% protein, 1.4% fat, 3.2% minerals and significant amount of calcium and phosphorous. It has also the ability to fix atmospheric nitrogen symbiotically into the soil, thus improves and maintains the fertility and health status of soil. India annually produces 30.60 lakh tones of black gram with productivity of 546 kg ha^{-1} over an area of 56.02 lakh ha (Anonymous, 2020). The area, production and productivity of black gram in Haryana is 1000 ha, 400 tones and 400 kg ha^{-1} respectively and generally cultivated in Ambala, Panchkula, Yamunanagar, Karnal and Kurukshetra districts. Due to slow initial growth of black gram it is subjected to severe competition from variety of weeds resulting in yield reduction up to an extent of 30-50 % (Mishra, 1997). Major weed species infesting black gram are *Echinochloa colona, Dactyloctenium aegyptium, Eleusine indica, Digitaria sanguinalis*, *Celosia argentea, Phyllanthus niruri, Cleome viscosa, Cyperus rotundus* and *C. iria* whereas during the summer season *E. colonum, D. aegyptium, Physalis minima, Portulaca quadrifida* and *C. rotundus* infested black gram field (Singh *et al.,* 1991). Weeds put enormous stress on black gram, especially during initial period of 20-40 days (Saraswat and Mishra, 1993) and further season long weed competition drastically reduced black gram yield to the extent of 87% depending upon type and intensity of weed flora (Singh *et al.,* 2002). The reduction in seed yield of black gram due to weeds can be as high as 77% (Kumar *et al.,* 2015). Therefore, it is of utmost important to remove the weeds from the field at appropriate time using an effective method for achieving the potential yield of black gram.

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Weeds can be controlled by adopting cultural and mechanical measures but they are not always practicable due to high cost involved, non-availability of labour at appropriate time, long window of weed emergence and unpredictable weather conditions. Thus, application of herbicides offers best alternative for possible effective control of weeds in black gram.

Imazethapyr is a new herbicide of imidazolinone group and is applied as pre-plant incorporation (PPI), pre-emergence (PE) and post-emergence (PoE) to control grasses and broadleaved weeds in pulse crops. Quantification of herbicide persistence in soil at applied rate will be helpful in determining phyto-toxicity of herbicide to sensitive rotational crops. Shaner and Hornford (2005) reported that imazethapyr and imazamox are applied as early post emergence, they have residual activity. Likewise, Jordan *et al.* (1998) reported that prevailing condition of low soil moisture and low temperature resulted in accumulation of high level residue of imazethapyr in top 10 cm of soil for duration of 90 days. However, Sangwan *et al.* (2016) assessed the performance of imazethapyr and its mixture with imazamox and pendimethalin in cluster bean and their carryover effect on mustard crop raised in rotation, but no residual carry over effect of these herbicides on succeeding mustard crop was visible and it was due to presence of high rainfall and temperature conditions throughout growing season. Keeping in view the above facts, the present investigation was carried out to study the bioefficacy of imazethapyr applied alone and in combination with other herbicides in black gram and their residual effect on succeeding pearl-millet and sorghum crops.

MATERIALS AND METHODS

A field experiment was conducted during *summer* and *kharif* 2017 at Research Farm of Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar (29°10′ N Latitude, 75°46′ Longitude and 215.20 meters Altitude). Agro-ecologically field of experiment is characterized by semi-arid climate with very hot and dry summer and severe cold winter. The soils of the experimental field was sandy loam with 55% sand, 34% silt and 11% clay, medium in fertility with 0.4% organic carbon, slightly alkaline (pH 8.0), sufficient in N content (320 kg ha^{-1}), medium in P (17 kg ha^{-1}) and high K content (307 kg ha^{-1}). The experiment was laid out in randomized complete block design (RCBD) with three replication and 14 treatments *viz.* imazethapyr 70 g ha^{-1} pre-plant incorporation (PPI), imazethapyr 70 g ha^{-1} pre-emergence (PE), imazethapyr 80 g ha^{-1} (PE), imazethapyr 70 g ha^{-1} post-emergence (PoE), imazethapyr 80 g ha^{-1} PoE, ready mix imazethapyr + imazamox 70 g ha^{-1} (PE), RM imazethapyr + imazamox 80 g ha^{-1} (PE), RM imazethapyr + imazamox 70 g ha^{-1} (PoE), RM imazethapyr + imazamox 80 g ha^{-1} (PoE), pendimethalin 1000 g ha^{-1} (PE), RM imazethapyr + pendimethalin 1000 g ha^{-1} (PE), weedy check, two hoeing at 20 and 40 DAS and weed free. Black gram variety UH-1 was sown on March 4, 2017 in a plot size of 6.0 x 6.0 m^2, at row spacing of 30 cm using 15 kg seed per hectare. The crop was fertilized with 20 kg N/ha and 40 kg P_2O_5/ha Application of different PPI, PE and PoE herbicides in black gram were performed using flat fan nozzle mounted on backpack sprayer, calibrated to spray at a discharge of 250 lt/ha and pressure of 42 p.s.i.

Species wise weed density and total dry weight of weeds were recorded at 30 and 60 DAS with the help of 0.5 x 0.5 m^2 quadrate placed thrice at random in each plot. The weed control efficiency (WCE) was worked out both at 30 and 60 DAS by using the formula derived by Kondap and Upadhyay (1985).

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy check plots} - \text{Dry weight of weeds in treated plots}}{\text{Dry weight of weeds in weedy check plots}}$$

The growth and yield attributes of black gram were recorded from five selected plants in each treatment plot. Above ground weed biomass was sampled at 30 and 60 DAS by randomly placing a quadrate (0.5 x 0.5 m^2) in each plot. Plant material was dried at 65°C for 48 hours before determining the dry weight. Quantification of phyto-toxicity to black gram was done at 15, 30, 45 and 60 DAS on a scale of 0 to 100 (where 0 indicate no effect and 100 indicate complete mortality).

After harvesting of black gram on 30th May 2017, the remaining crop residue were collected and removed from the field. Afterwards, slight disking of the field was performed without disturbing the original layout (RCBD). Pearl millet variety HHB 67 was sown in half of the treatment plot (6.0 x 3.0 m^2) with row spacing of 30 cm using seed rate of 7.5 kg/ha and rest half plot was sown with sorghum crop (HC 171) spaced apart at 25 cm row using seed rate of 30 kg/ha. Both of succeeding crops were raised for fodder purpose and supplied with basal dose of 50 kg N and 15 kg P_2O_5 per ha. For evaluating the residual effects of herbicides applied in black gram on succeeding pearl millet and sorghum crops, data on number of plants per meter row length at 20 DAS, plant height and number of leaves at 45 DAS and fodder yield of pearl millet and sorghum at harvest was recorded. Before statistical analysis, square root transformation ($\sqrt{x+1}$) on data of weed density and total dry weight of weeds and arcsine transformation on data of crop-phytotoxicity were imposed in order to make their distribution normal. For evaluating the comparative performance of different treatments, data were subjected to one-way analysis of variance (ANOVA) and means were separated with critical difference at 5% level of probability.

RESULTS AND DISCUSSION

Weed density

Major weed species infesting the experimental plots were *Dactyloctenium aegyptium*, *Trianthema portulacastrum, Cyperus rotundus* and *Digera arvensis* (Table 1). At 30 DAS, *Dactyloctenium aegyptium* and *Trianthema portulacastrum* were the dominated weeds with relative density of 37% and 34% respectively but at 60 DAS, *Cyperus rotundus* and

Table 1: Effect of various weed control treatments on weed density of different weeds and total dry weight of weeds in black gram.

Treatment	Dose (g/ha)	Time of application	Weed Density (No./m^2)								Total dry weight (g/m^2)	
			Dactyloctenium aegyptium		*Trianthema portulacastrum*		*Cyperus rotundus*		*Digera arvensis*			
			30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Imazethapyr	70	PPI	4.12 (16.0)	3.55 (11.7)	2.28 (5.3)	2.97 (8.0)	3.25 (9.7)	5.10 (25.3)	3.03 (8.3)	2.51 (5.3)	5.50 (29.3)	7.70 (58.3)
Imazethapyr	70	PE	4.02 (15.3)	3.62 (12.3)	3.90 (14.7)	2.43 (5.3)	4.25 (17.3)	5.90 (34.0)	3.35 (10.3)	2.76 (6.7)	5.71 (31.6)	7.42 (54.1)
Imazethapyr	80	PE	3.73 (13.3)	3.65 (12.3)	2.95 (8.0)	2.75 (6.7)	3.68 (12.7)	5.85 (33.3)	3.15 (9.0)	2.56 (5.7)	5.17 (25.7)	6.33 (39.1)
Imazethapyr	70	3-4 leaf stage	10.07 (100.7)	3.89 (14.3)	9.35 (86.7)	2.08 (4.0)	6.62 (43.3)	8.33 (68.7)	4.55 (20.0)	1.14 (0.3)	10.22 (103.7)	9.04 (80.9)
Imazethapyr	80	3-4 leaf stage	10.31 (105.3)	3.81 (13.7)	8.61 (73.3)	1.00 (0)	6.25 (38.3)	7.87 (61.0)	4.50 (19.3)	1.38 (1.0)	8.43 (70.1)	8.01 (63.2)
Imazethapyr + imazamox (RM)	70	PE	4.12 (16.0)	3.92 (14.7)	4.41 (18.7)	4.71 (21.3)	5.68 (31.3)	7.43 (54.3)	3.52 (11.7)	2.74 (6.7)	7.39 (53.7)	9.51 (89.4)
Imazethapyr + imazamox (RM)	80	PE	4.02 (15.3)	3.54 (11.7)	3.19 (9.3)	2.97 (8.0)	5.00 (24.3)	6.87 (46.3)	3.35 (10.3)	2.76 (6.7)	6.87 (46.3)	8.04 (63.7)
Imazethapyr + imazamox (RM)	70	3-4 leaf stage	10.04 (100.0)	4.34 (18.0)	9.83 (96.0)	1.00 (0)	6.89 (46.7)	8.98 (79.7)	4.71 (21.3)	1.00 (0)	10.28 (105.2)	5.21 (26.2)
Imazethapyr + imazamox (RM)	80	3-4 leaf stage	8.45 (70.7)	3.58 (12.0)	9.14 (82.7)	1.00 (0)	6.73 (44.3)	8.84 (77.3)	4.44 (19.3)	1.00 (0)	9.54 (90.1)	5.54 (29.7)
Pendimethalin	1000	PE	5.12 (25.3)	6.16 (37.0)	2.09 (4.0)	3.29 (10.0)	7.22 (51.3)	9.41 (87.7)	4.12 (16.0)	3.40 (10.7)	10.40 (107.3)	9.57 (90.7)
Imazethapyr + pendimethalin (RM)	1000	PE	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	2.87 (7.3)	4.74 (21.7)	2.22 (4.3)	1.47 (1.3)	4.51 (19.7)	6.06 (35.7)
Weedy check	-	-	11.03 (120.7)	8.84 (77.7)	10.55 (110.7)	9.07 (81.3)	8.38 (69.3)	10.07 (100.7)	5.26 (26.7)	4.03 (15.3)	14.01 (196.0)	15.08 (226.6)
Two hoeing	-	20 and 40 DAS	1.73 (2.3)	1.55 (1.7)	1.24 (0.7)	1.58 (1.7)	1.75 (2.7)	3.01 (8.3)	1.58 (1.7)	1.28 (0.7)	3.22 (9.4)	3.93 (14.4)
Weed free	-	-	1.00 (0)	1.00 (0)	1.00	1.00 (0)	1.00 (0)	1.00 (0.0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
SE (m) ±			0.26	0.29	0.37	0.29	0.30	0.26	0.31	0.18	0.31	0.15
CD at 5%			0.75	0.85	1.09	0.84	0.89	0.77	0.90	0.52	0.90	0.44

*Original data given in parenthesis were subjected to square root $\sqrt{x+1}$ transformation before analysis.

Trianthema portulacastrum were the dominated weeds with relative density of 37% and 30% respectively. At 30 DAS, pre-plant incorporation (PPI) and pre-emergence (PE) application of imazethapyr and its ready mix (RM) combination with imazamox and pendimethalin at various doses were the most effective treatment resulting in significant reduction of all the weeds in comparison to weedy check. Almost 100 % control of *Dactyloctenium aegyptium* and *Trianthema portulacastrum* was recorded in plots applied with PE imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (Table 1). At 60 DAS, 3-4 leaf stage application of imazethapyr alone and its ready mix combination with imazamox resulted in significant reduction in all the weed species except *Cyperus rotundus.* Among the herbicide treatments, both at 30 and 60 DAS, lowest weed density of *Cyperus rotundus* (7.3 and 21.7 per m^2, respectively) were recorded with PE imazethapyr + pendimethalin (RM) applied at 1000 g ha^{-1} (Table 1). PE pendimethalin applied at 1000 g ha^{-1} was almost ineffective against *Cyperus rotundus and Digera arvesis* as it gave poorest control comparable to weedy check. At later stages of crop (60 DAS), effect of 3-4 leaf stage application of imazethapyr + imazamox at 70 and 80 g ha^{-1} became more visible as density of *Trianthema portulacastrum* and *Digera arvensis* recorded were almost nil in corresponding plots (Table 1).

Total dry weight of weeds

During all black gram growing stages two hoeing employed at 20 and 40 DAS recorded significantly lower dry weight of weeds. Among the herbicidal treatments at 30 DAS, significantly lower dry weight of weeds (19.7 g m^{-2}) was recorded with PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} which was at par with PE application of imazethapyr at 80 g ha^{-1} (Table 1). Although all herbicide treatment caused significant reduction in dry matter accumulation of weeds at 60 DAS but RM formulation of imazethapyr + imazamox applied at 3-4 leaf stage at 70 g ha^{-1} was recorded with significant lowest dry weight of weeds (26.2 g m^{-2}) which was at par with 3-4 leaf stage application of imazethapyr + imazamox at 80 g ha^{-1} (Table 1). The weedy check plot was registered with maximum dry weight of weeds. Similar results were reported by Gupta *et al.* (2017).

Weed control efficiency (%)

Both at 30 and 60 DAS maximum weed control efficiency (95 and 94 % respectively) was recorded with two hoeing performed at 20 and 40 DAS (Fig 1). Among the herbicidal treatments at 30 DAS, PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} gave highest weed control efficiency (90 %), followed by PE application of imazethapyr at 80 g ha^{-1} and PPI application of imazethapyr at 70 g ha^{-1}. At 60 DAS, 3-4 leaf stage application of imazethapyr + imazamox (RM) at 70 g/ha gave highest (89 %) weed control efficiency, followed by 3-4 leaf stage application of imazethapyr + imazamox (RM) at 80 g ha^{-1} (Fig 1). Higher weed control efficiency and per cent control of weeds was initially attributed due to root and shoot inhibiting action of pendimethalin on weeds (Appleby and Valverde, 1988 and Gilliam *et al.,* 1993) and at later stages due to the higher persistence of imazethapyr as half-life of imazethapyr varies from 78-270 days (Goetz *et al.,* 1990). Verma and Kushwaha (2020) reported similar findings in green gram.

Visual phyto-toxicity (%) on black gram and its dry weight

Neither of PPI nor of the PE herbicides caused phyto-toxicity to black gram crop. Application of imazethapyr and its ready mix combination with imazamox at 70 and 80 g ha^{-1} at 3-4 leaf stage exhibited phyto-toxicity in forms of chlorosis and stunting of black gram to the tune of 16.3-30.3 % at 30 DAS which was mitigated within two weeks after application as it is evident by visual phyto-toxicity recorded at 45 and 60 DAS. At 30 DAS, higher phyto-toxicity (30.3 %) was observed with 3-4 leaf stage application of imazethapyr + imazamox (RM) at 80 g ha^{-1} which was at par with 3-4 leaf stage application of imazethapyr + imazamox (RM) at 70 g ha^{-1} (Table 2).

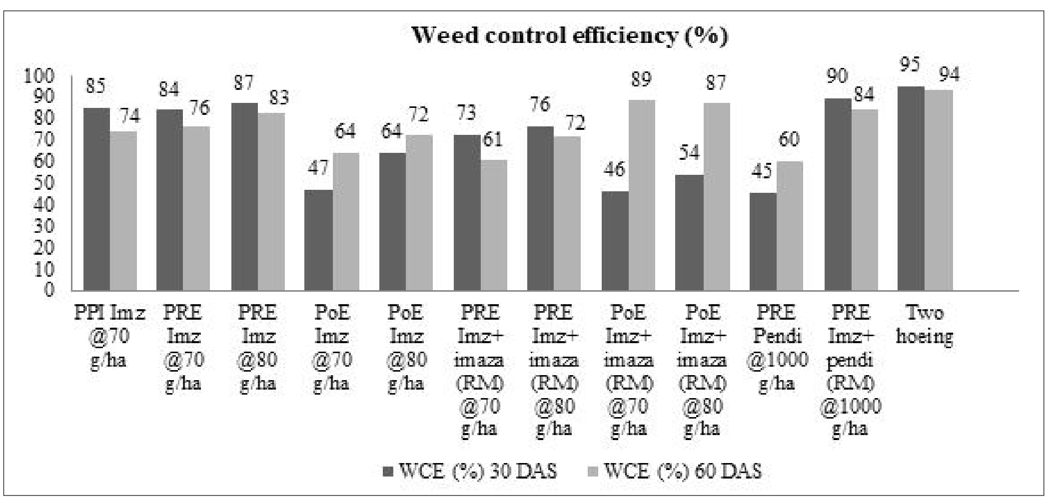

Fig 1: Weed Control Efficiency (%) of various herbicidal treatments at 30 and 60 DAS in black gram.

Table 2: Effect of various weed control treatments on plant dry weight and visual phytotoxicity (0 to 100 scale) on black gram.

Treatment	Dose (g/ha)	Time of application	Phyto-toxicity (%) 15 DAS	30 DAS	45 DAS	60 DAS	Dry weight (g/plant) 30DAS	60DAS	At harvest
Imazethapyr	70	PPI	0	0.0 (0)	0	0	1.05	12.01	18.38
Imazethapyr	70	PE	0	0.0 (0)	0	0	0.90	11.64	17.64
Imazethapyr	80	PE	0	0.0 (0)	0	0	1.01	12.16	18.04
Imazethapyr	70	3-4 leaf stage	0	23.5 (16.3)	0	0	0.46	11.23	17.54
Imazethapyr	80	3-4 leaf stage	0	27.9 (22.1)	0	0	0.53	11.57	17.97
Imazethapyr + imazamox (RM)	70	PE	0	0.0 (0)	0	0	0.77	12.25	18.05
Imazethapyr + imazamox (RM)	80	PE	0	0.0 (0)	0	0	0.92	12.90	18.22
Imazethapyr + imazamox (RM)	70	3-4 leaf stage	0	32.5 (28.9)	0	0	0.66	10.67	17.34
Imazethapyr + imazamox (RM)	80	3-4 leaf stage	0	33.4 (30.3)	0	0	0.72	11.32	17.88
Pendimethalin	1000	PE	0	0.0 (0)	0	0	0.73	12.13	17.30
Imazethapyr + pendimethalin (RM)	1000	PE	0	0.0 (0)	0	0	1.29	12.60	19.00
Weedy check	-	-	0	0.0 (0)	0	0	0.47	10.33	15.87
Two hoeing	-	20 and 40 DAS	0	0.0 (0)	0	0	1.36	13.00	19.28
Weed free	-	-	0	0.0 (0)	0	0	1.35	13.70	20.16
SE (m) ±			-	0.9	-	-	0.04	0.42	0.62
CD at 5%			-	2.6	-	-	0.12	1.24	1.80

*Original data given in parenthesis were subjected to arcsine transformation before statistical analysis.

At 30 DAS, experimental plots engaged with two hoeing employed at 20 and 40 DAS registered maximum plant dry weight (1.36 g plant^{-1}) which was at par with weed free (1.35 g plant^{-1}) and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (1.29 g plant^{-1}) (Table 2). At 60 DAS, the plots which were remained weed free throughout growing season produced maximum plant dry weight (13.70 g plant^{-1}) and results were at par with treatment plots performed with hoeing twice at 20 and 40 DAS, PE application of imazethapyr + imazamox (RM) at 80 g ha^{-1} and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1}. Likewise, at harvesting stage, maximum dry matter accumulation (20.16 g plant^{-1}) was recorded from weed free plots which was at par with two hoeing given at 20 and 40 DAS and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (Table 2).

Black gram yield and its attributes

In comparison to weedy check, all weed control treatments contributes towards achieving significantly higher number of yield attributing characters of black gram *viz.* number of branches plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1} and biological as well as seed yield of black gram. It was because of reduction in competition of crop plants from weeds for nutrients, sunlight and space as both above and below ground area. The experimental plots free of weeds throughout the growing season were recorded with maximum number of branches plant^{-1}, number of pods plant^{-1} and number of seeds pod^{-1} which was at par with two hoeing employed at 20 and 40 DAS and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (Table 3). Although, 100-seeds weight of black gram was non-significant between different weed control treatments. PE application of imazethapyr alone or in combination with other herbicides were superior then application of same molecules at later stages, in producing the higher yield attributes of black gram. This might be due to the successful control of weeds at initial stages by pre-emergence herbicides and furthermore imidazolinone herbicides applied at later stages also caused some phyto-toxicity on black gram. The significantly higher grain yield and biological yield (912 kg ha^{-1} and 3864 kg ha^{-1}, respectively) was recorded in weed free plot and was statistically at par with two hoeing given at 20 and 40 DAS (895 kg ha^{-1} and 3605 kg ha^{-1}, respectively) and PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} (878 kg ha^{-1} and 3675 kg ha^{-1}, respectively) (Table 3). Among the herbicidal treatments, PE application of pendimethalin at 1000 g ha^{-1} recorded the lowermost seed yield (505 kg ha^{-1}) of black gram (Table 3). A reduction of 80% in seed yield of black gram was observed in weedy check plot in comparison to best herbicide treatment which is PE application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1}. This was due to unchecked and abundant growth of weeds in weedy check that competes efficiently with black gram for moisture, nutrient, space and sunlight. The results are in analogous to those reported by Gogoi *et al.* (1992) and Kumar *et al.* (2015).

Residual effects of herbicides applied in black gram on succeeding pearl-millet and sorghum crops

The survival of the plants of succeeding pearl millet and sorghum crops did not differ significantly by residual carryover effect of various herbicides applied in black gram as the number of plants per meter row length, plant height, number of leaves plant^{-1} and fodder yield of above crops were non-significant among different weed control treatments (Table 4). Furthermore, neither pearl millet nor sorghum crop showed any phyto-toxic effect at any stage of

Table 3: Yield and yield attributes of black gram as affected due to different weed control measures.

Treatment	Dose (g/ha)	Time of application	No. of branches per plant	No. of pods/ plant	No. of seeds /pod	100-seeds weight	Biological yield (Kg/ha)	Seed yield (Kg/ha)	Harvest index (%)
Imazethapyr	70	PPI	14.0	32.3	4.18	3.4	3,515	805	22.9
Imazethapyr	70	PE	13.0	30.0	4.09	3.3	3,324	754	22.7
Imazethapyr	80	PE	13.7	30.7	4.20	3.2	3,556	784	22.0
Imazethapyr	70	3-4 leaf stage	13.3	24.7	3.79	2.9	2,686	630	23.5
Imazethapyr	80	3-4 leaf stage	12.3	26.3	3.80	3.2	2,968	656	22.1
Imazethapyr + imazamox (RM)	70	PE	13.6	27.7	3.89	3.6	3,025	740	24.5
Imazethapyr + imazamox (RM)	80	PE	13.9	29.3	4.00	3.5	3,128	766	24.5
Imazethapyr + imazamox (RM)	70	3-4 leaf stage	12.0	22.3	3.60	3.8	2,345	510	21.7
Imazethapyr + imazamox (RM)	80	3-4 leaf stage	11.7	23.7	3.68	3.6	2,469	538	21.8
Pendimethalin	1000	PE	11.6	20.7	3.60	3.7	2,294	505	22.0
Imazethapyr + pendimethalin (RM)	1000	PE	14.7	35.0	4.41	3.5	3,675	878	23.9
Weedy check	-	-	9.9	14.7	3.50	3.1	898	185	20.6
Two hoeing	-	20 and 40 DAS	15.3	35.7	4.30	3.4	3,605	895	24.8
Weed free	-	-	15.6	38.3	4.60	3.6	3,864	912	23.6
SE (m) ±			0.5	1.6	0.14	0.3	104	20	0.6
CD at 5%			1.3	4.6	0.40	NS	305	57	1.7

Table 4: No. of plants/m.r.l., plant height, no. of leaves and fodder yield of succeeding pearl-millet and sorghum crops as affected by residual carryover effect of different herbicide treatments applied in preceding black gram.

Treatment	Dose (g/ha)	Time of application	No. of plants/ m.r.l. at 20 DAS		Plant height (cm)		No. of leaves		Fodder yield kg/ha)	
			Pearl millet	Sorghum	Pearl millet	Sorghum	Pearl millet	Sorghum	Pearl millet	Sorghum
Imazethapyr	70	PPI	20.7	21.7	152.1	163.9	11.2	13.8	3,983	4,283
Imazethapyr	70	PE	20.3	21.3	155.0	165.5	11.8	13.8	3,972	4,269
Imazethapyr	80	PE	19.3	20.0	152.9	159.3	11.6	12.7	3,903	4,213
Imazethapyr	70	3-4 leaf stage	19.0	21.3	150.0	161.3	11.0	12.9	3,900	4,205
Imazethapyr	80	3-4 leaf stage	18.7	21.7	147.9	160.6	10.5	12.5	3,873	4,200
Imazethapyr + imazamox (RM)	70	PE	18.7	22.0	152.8	166.3	11.6	13.8	3,953	4,225
Imazethapyr + imazamox (RM)	80	PE	18.3	21.3	148.0	164.3	11.1	13.1	3,925	4,253
Imazethapyr + imazamox (RM)	70	3-4 leaf stage	19.3	23.0	151.1	160.3	10.9	12.9	3,897	4,197
Imazethapyr + imazamox (RM)	80	3-4 leaf stage	18.7	20.3	149.0	162.0	10.6	12.5	3,885	4,180
Pendimethalin	1000	PE	21.3	22.0	150.6	161.3	11.7	13.9	3,973	4,285
Imazethapyr+ pendimethalin (RM)	1000	PE	20.3	21.0	152.9	159.3	11.5	13.7	3,923	4,247
Weedy check	-	-	19.3	21.7	154.0	163.7	11.9	12.9	3,870	4,258
Two hoeing	-	20 and 40 DAS	20.0	22.3	151.9	162.0	11.0	13.0	3,917	4,295
Weed free	-	-	20.7	21.3	153.8	162.7	11.8	13.4	3,970	4,253
SE (m) ±			0.7	0.8	2.5	2.8	0.3	0.4	135	145
CD at 5%			NS	NS	NS	NS	NS	NS	NS	NS

crop development. This might be due to enhanced microbial degradation of these herbicides due to the application of three flood irrigation in black gram and occurrence of 341 mm rainfall between the time of application of herbicides and sowing of pearl millet and sorghum crops. Silva *et al*. (1999) supported the above results where they reported that imazamox applied at 50 and 100 g ha^{-1} in soybean have no influence on development of sorghum at 120 days after application. Similarly, Babu *et al.* (2013) reported no residual injury of imazethapyr at 100 g ha^{-1} on succeeding crops such as pearl millet and sunflower crops. Similar results were obtained on succeeding mustard crop by Tomar *et al.* (2014) and Kumar *et al.* (2015), however Punia *et al.* (2011) reported residual carryover injury on succeeding mustard crop due to imazethapyr applied at 100 g ha^{-1} preceding cluster bean crop.

CONCLUSION

From the present investigation, it can be concluded that either of two hoeing employed at 20 and 40 DAS or pre-emergence application of imazethapyr + pendimethalin (RM) at 1000 g ha^{-1} should be adopted for better control of weeds without any phyto-toxicity on black gram and also does not exhibits any adverse effect on succeeding pearl millet and sorghum crops.

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