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Effect Of Post Emergence Herbicides On Photosynthetic Pigments, Antioxidant Enzyme Activity And Yield Of Blackgram

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ABSTRACT
The present investigation was undertaken at Agricultural College Farm, Bapatla during kharif, 2015. The experiment was laid out in Randomised Block Design with ten treatments replicated thrice. The post emergence herbicides viz., imazethapyr 10% EC @ 50 g a.i ha^{-1} and acifluorfen sodium 16% EC + clodinafop propargyl 8% EC (24% EC) @ 180, 240 and 300 g a.i ha^{-1} were sprayed at 15 and 25 DAS. Hand weeding and weedy check were also included for comparison. Statistical analysis of the data showed that all the parameters were affected by herbicides. Potosynthetic pigments viz., total chlorophyll and carotenoid contents in weed free check and acifluorfen sodium + clodinafop propargyl @ 300 and 240 g a.i ha^{-1} applied at 15 DAS were increased by 34.3, 28.7 and 27.2 per cent and by 10.3, 9.4 and 8.7 per cent, respectively, over weedy check at 40 DAS (i.e. 25 days after herbicide application (DAHA)). Higher superoxide dismutase (SOD) activity was recorded during first 5 days after herbicide application with acifluorfen sodium + clodinafop propargyl @ 300 and 240 g a.i ha^{-1} at 15 DAS, which helped in the mitigation of herbicide injury. Weed free check and acifluorfen sodium + clodinafop propargyl @ 300 and 240 g a.i ha^{-1} at 15 DAS increased the yield attributes and seed yield of blackgram. These three treatments increased the seed yield by 77.6, 69.4 and 67.8 per cent, respectively, over unweeded control. The favourable economic benefit interms of benefit-cost ratio was observed by the application of acifluorfen sodium + clodinafop propargyl @ 240 g a.i ha^{-1} at 15 DAS.
Key words: *Chlorophyll, Days after herbicide application (DAHA), Post emergence herbicides, Superoxide dismutase (SOD)*

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INTRODUCTION

Blackgram [*Vigna mungo* (L.) Hepper)] is an important legume crop cultivated worldwide in tropical and subtropical regions and is valued for high protein in its seeds. India is the largest producer and consumer of blackgram in the world. As a pulse crop, blackgram plays an important role in Indian diet. The protection of crops from weeds and other vegetation which inhibit crop growth is a constantly recurring problem in agriculture. Blackgram, being a short duration and initially slow growing, suffers heavily due to infestation of weeds. Depending upon intensity and nature of weed flora, an average yield reduction of 30-50 per cent has been reported due to weed competition (Mishra, 1997). *Echinochloa colona* alone, one of the major weed in blackgram, may reduce the seed yield to the extent of 49 per cent (Rao and Rao, 2003).

Control of weeds during critical period of crop weed competition is very important to avoid severe yield losses. The manual and mechanical methods of weed control, besides being less effective, are costly and time consuming. Moreover, many times labour is not available at the critical period of weed removal. In such situations, herbicides offer most ideal, practical, effective and economical means of reducing early weed competition and crop production losses. Selective herbicides kill specific targets while leaving the desired crop relatively unharmed. Some of these act by interfering with the growth of the weed and are often synthetic "imitation" of plant hormones. The herbicides selectivity is based on the plant's ability to rapidly metabolize the herbicide, forming non-phytotoxic compounds. However, there is a differential selectivity between species and the genetic makeup of the species or cultivar may determine varying degrees of tolerance or susceptibility to herbicides.

The use of herbicides, even in tolerant cultivars, can generate stress conditions, evidenced by the increase in phytotoxicity, which affects growth, development and productivity. The negative effect of stress is often mediated by the oxidative damage initiated by reactive oxygen species (ROS). The herbicides selectivity can be visually assessed by means of the phytotoxicity symptoms in plants, and also by the change in photosynthetic pigments and yield parameters. Also, it is important to check the herbicides efficiency in the target weed control and the effects on productivity, as there are products that reduce crop productivity without visual symptoms and others that cause sharp injuries, but they allow the crop to fully express its productive potential. Recently, some new post emergence herbicides *viz.,* imazethapyr, acifluorfen sodium and clodinafop propargyl *etc.* are being marketed with the assurance of selective control of weeds in blackgram. Although these are recommended for blackgram, there are field reports of phytotoxicity in the crop after the application of imazethapyr, acifluorfen sodium and clodinafop propargyl. Therefore, the present investigation was undertaken to study the effect of post emergence herbicides on photosynthetic pigments, antioxidant enzyme activity and yield of blackgram.

MATERIALS AND METHODS

A field experiment was conducted at "Northern" block of Agricultural College Farm, Bapatla, on a sandy clay loam soil in *Kharif* season, 2015. The experiment was laid out in a Randomized Block Design with three replications. The crop was fertilized with nitrogen and phosphorus @ 20 kg N ha^{-1} in the form of urea and 50 kg P_2O_5 ha^{-1} in the form of single super phosphate before sowing of crop. The post emergence herbicides *viz.,* imazethapyr 10% EC @ 50 g a.i ha^{-1} and acifluorfen sodium 16% EC + clodinafop propargyl 8% EC (24% EC) @ 180, 240 and 300 g a.i ha^{-1} were sprayed at 15 and 25 DAS using knapsack sprayer fitted with flat fan nozzle at spray volume of 500 L ha^{-1}.

The observations on photosynthetic pigments (total chlorophyll, and carotenoid contents in leaves) estimated colorimetrically by dimethyl sulphoxide (DMSO) method as described by Hiscox and Stam (1979) and superoxide dismutase activity (SOD) was assayed as per Dhindsa *et al*.(1981) in leaves before herbicide application and 5, 10 and 15 DAHA. Yield parameters like number of pods per plant, number of seeds per pod, pod weight per plant, 100 seed weight and yield were taken at harvest.

RESULTS AND DISCUSSION

Total chlorophyll and carotenoid contents in blackgram leaves

The data pertaining to the total chlorophyll and carotenoid contents of blackgram leaves as influenced by post emergence herbicides are furnished in Table 1 and 2 respectively. At 15 DAS i.e. before spraying, significant differences were not observed among the treatments.

At 5 DAHA (i.e. at 20 DAS), imazethapyr at 50 g ha^{-1} and acifluorfen sodium + clodinafop propargyl at 300, 240 and 180 g a.i ha^{-1} sprayed at 15 DAS recorded lesser total chlorophyll (1.272, 1.278, 1.294 and 1.312 mg g^{-1}, respectively) and carotenoid contents (0.321, 0.324, 0.326 and 0.318 mg g^{-1}) over unweeded control. These results indicated that the effect of post emergence herbicides on total chlorophyll and carotenoid content followed a dose-dependent manner, *i.e*. the content of pigments was reduced gradually as the concentration of acifluorfen sodium + clodinafop propargyl increased from 180 to 300 g a.i ha^{-1} during early stages of crop growth *i.e.* at 20 DAS. This is due to phytotoxicity of these herbicides during initial stages. Weed free check recorded the highest total chlorophyll (1.557 mg g^{-1}) and carotenoid content (0.411 mg g^{-1}) over other weed control treatments. The treatments T_2, T_4, T_6 and T_8 were on par with control.

At 25 DAS, weed free check recorded higher total chlorophyll content (1.626 mg g^{-1} respectively) which was statistically at par with post emergence herbicides acifluorfen sodium + clodinafop propargyl at 300, 240 and 180 and imzethapyr 50 g a.i ha^{-1} sprayed at 15 DAS (1.585, 1.582, 1.578 and 1.579 mg g^{-1},respectively). Acifluorfen sodium + clodinafop propargyl @ 300 and 240 g a.i ha^{-1} applied at 15 DAS recorded higher carotenoid contents (0.469 and 0.467 mg g^{-1}), which were statistically at par with weed free check and superior over un weeded control and other weed control treatments. Though, these herbicides caused injury to blackgram plants at their respective concentrations during initial stages, but the crop recovered at later growth stages and increased the pigments content significantly.

In the treatments, where herbicides acifluorfen sodium + clodinafop propargyl were applied at 25 DAS @ 180, 240 and 300 g a.i ha^{-1} and imzethapyr at 50 g ha^{-1} significantly reduced the total chlorophyll and carotenoid contents compared to the control. This is due to phytotoxicity exhibited by these herbicides at their respective concentrations at 30 DAS. Highest total chlorophyll and carotenoid contents were recorded with hand weeding at 15 and 30 DAS treatment (1.937 and 0.485 mg g^{-1} respectively), which was statistically at par with 240 and 300 g a.i ha^{-1} of acifluorfen sodium + clodinafop propargyl applied at 15 DAS.

At 35 and 40 DAS, higher total chlorophyll and carotenoid contents were obtained with weed free check (1.969 and 2.166; 0.487 and 0.492 mg g^{-1}, respectively). Among the post emergence herbicides, acifluorfen sodium + clodinafop propargyl at 300 and 240 g a.i ha^{-1} at 15 DAS recorded significantly higher total chlorophyll and carotenoid contents and these were statistically at par with weed free check and superior over other herbicidal treatments. Unweeded control recorded lesser total chlorophyll and carotenoid contents (1.542 and 1.613; 0.440 and 0.446 mg g^{-1} respectively). Shaban *et al.* (2004) reported that higher values of chlorophyll a, chlorophyll b, carotenoids and total pigments were obtained with hand weeding and clodinafop propargyl at 225 or 315 g a.i ha^{-1}.

Regarding the results obtained in the present investigation, it was found that these herbicide treatments (T_5 and T_7 treatments) have caused phytotoxicity only at 5 DAHA (i.e. during initial stages) and the blackgram plants recovered at later growth stages and maintained higher total chlorophyll and carotenoid contents. The treatment with acifluorfen sodium + clodinafop propargyl at 300 g a.i ha^{-1} applied at 25 DAS (T_8) showed damage to the blackgram crop up to 40 DAS (i.e. up to 15 DAHA) and recorded lesser total chlorophyll and carotenoid contents compared to other herbicidal treatments.

Superoxide dismutase (SOD) activity in blackgram leaves

The data pertaining to SOD activity in blackgram leaves as affected by post emergence herbicides are presented in Table 3. At 15 DAS i.e., before spraying, no significant differences were noted among the treatments.

At 20 DAS (i.e. 5DAHA), the highest SOD activity was detected with acifluorfen sodium + clodinafop propargyl @ 300 g a.i ha^{-1} at 15 DAS (28.61units mg^{-1} protein h^{-1}) followed by 240 g ha^{-1} at 15 DAS (27.90 units mg^{-1} protein h^{-1}), when compared to the control and other treatments. The highest SOD activity in blackgram leaves due to herbicide treatments is an indicative of increased detoxification of Reactive Oxygen Species (ROS) which are produced in response to stress caused by these herbicides at early stages of crop growth. Treatments with the herbicide clodinafop have induced oxidative stress in wheat, maize and rye plants (Lukatkin *et al*., 2013). Agostinetto *et al.* (2016) reported that there was an increased SOD activity in wheat plants exposed to clodinafop herbicide at 5 days after spraying the herbicide compared to control and other treatments. Weed free check recorded lowest SOD activity (19.26 units mg^{-1} protein h^{-1}) because of no weed competition (i.e. no stress). Weedy check also recorded higher values of SOD (23.48 units mg^{-1} protein h^{-1}) and it was at par with T_2, T_4, T_6 and T_8 treatments. This is due to the competition of weeds with blackgram for moisture, nutrients, light and space which might have resulted oxidative stress in blackgram.

At 25 DAS, lower SOD activity was observed with acifluorfen sodium + clodinafop propargyl at 300 and 240 g a.i ha^{-1} and imazethapyr at 50 g ha^{-1} applied at 15 DAS (23.14, 23.25 and 24.16 units mg^{-1} protein h^{-1}, respectively), which were statistically at par with weed free check (22.13 units mg^{-1} protein h^{-1}), and significantly lower than control (weedy check) and other treatments. This might be due to the recovery of blackgram plants from the herbicide injury through the lesser generation of ROS, especially of $O^{\cdot}{}_2^-$ (superoxide anions). Weedy check recorded highest SOD activity due to weed competition and it was at par with T_2, T_4, T_6 and T_8 treatments.

At 30 DAS, among the post emergence herbicides, acifluorfen sodium + clodinafop propargyl @ 300, 240 and 180 g a.i ha^{-1} and imazethapyr at 50 g ha^{-1} sprayed at 25 DAS recorded higher SOD activity than other weed control treatments. The higher SOD activity in blackgram plants during the first five days after herbicide application has been correlated with tolerance to oxidative stress. Whereas acifluorfen sodium + clodinafop propargyl @ 300 and 240g and imazethapyr @ 50 g a.i ha^{-1} at 15 DAS recorded SOD activity at par with weed free check, due to complete recovery of blackgram plants, an indication of no stress.

At 35 and 40 DAS, weedy check (T_{10}) recorded highest SOD activity (46.28 and 43.26 units mg^{-1} protein h^{-1}, respectively). This might be due to stress created due to weed competition in blackgram which increased the activation of SOD enzyme, indicating greater generation of ROS, especially of $O^{\cdot}{}_2^-$ which serves as a substrate for SOD. Among the post emergence herbicides, acifluorfen sodium + clodinafop propargyl @ 300 g a.i ha^{-1} applied at 25 DAS recorded higher SOD activity (46.24 and 42.14 units mg^{-1} protein h^{-1}, respectively) followed by 240 g a.i ha $^{-1}$ 25 DAS (45.28 and 41.14 units mg^{-1} protein h^{-1}, respectively). In these treatments, injury due to these herbicides continued up to 40 DAS (i.e. 15 days after herbicide application) and an increased activation of SOD was observed, which may represent a condition of oxidative stress that finally resulted in lesser growth attributes and yield. Whereas, acifluorfen sodium + clodinafop propargyl @ 240 and 300 g a.i ha^{-1} applied at 15 DAS recorded SOD activity (31.56 and 30.01 units mg^{-1} protein h^{-1}) and (31.98 and 30.12 units mg^{-1} protein h^{-1}) similar to that of weed free check (32.30 and 30.13 units mg^{-1} protein h^{-1}), respectively at 35 and 40 DAS. This might be due to quick recovery of blackgram from the herbicide stress and the crop resumed to normal condition by 25 DAS, which resulted in the lesser generation of ROS, and hence lesser activation of SOD enzyme.

The effects of post emergence herbicides, acifluorfen sodium + clodinafop propargyl @ 240 and 300 g a.i ha^{-1} applied at 15 DAS on the SOD activity (*i.e.* antioxidant activity) seem to be more evident in the first five days after application, indicating a condition of oxidative stress in blackgram due to herbicide injury. But by 25 DAS, the crop recovered from the herbicide stress and exhibited lesser SOD activity compared to unweeded control and other treatments, indicating lesser oxidative stress in blackgram. From this study, it can be concluded that initially, acifluorfen sodium + clodinafop propargyl @ 240 and 300 g a.i ha^{-1} at 15 DAS caused oxidative stress (up to 20 DAS), but the blackgram crop recovered the negative condition afterwards and exhibited superior performance in terms of growth and yield.

Table.1. Effect of post emergence herbicides on total chlorophyll content (mg g^{-1}) of blackgram leaves

TREATMENTS	Total Chlorophyll (mg g^{-1})					
	15DAS	20DAS (5DAHA)	25DAS (10DAHA)	30DAS (15DAHA)	35DAS (20DAHA)	40DAS (25DAHA)
T1 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 15DAS	1.030	1.272	1.579	1.636	1.813	1.892
T2 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 25DAS	1.026	1.392	1.501	1.445	1.601	1.698
T3 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180g a.i ha^{-1} at 15DAS	1.010	1.312	1.578	1.624	1.802	1.887
T4 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180 g a.i ha^{-1} at 25DAS	1.034	1.382	1.492	1.431	1.598	1.732
T5 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@240g a.i ha^{-1} at 15DAS	0.996	1.294	1.582	1.899	1.934	2.052
T6 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@240g a.i ha^{-1} at 25DAS	0.996	1.404	1.504	1.456	1.613	1.741
T7 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@300g a.i ha^{-1} at 15DAS	0.996	1.278	1.585	1.924	1.978	2.076
T8 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@300g a.i ha^{-1} at 25DAS	0.986	1.389	1.498	1.436	1.623	1.724
T9 Weed free check (Hand weeding at 15and 30 DAS)	0.978	1.557	1.626	1.937	1.969	2.166
T10 Un weeded control	0.968	1.401	1.502	1.539	1.542	1.613
SEm+	0.014	0.012	0.025	0.023	0.041	0.050
CD	NS	0.035	0.074	0.069	0.122	0.149
CV (%)	2.5	1.47	3.6	2.5	4.9	4.6

Table.2. Effect of post emergence herbicides on carotenoids content (mg g^{-1}) of blackgram leaves

TREATMENTS	Carotenoids (mg g^{-1})					
	15DAS	20DAS (5 DAHA)	25DAS (10 DAHA)	30DAS (15 DAHA)	35DAS (20 DAHA)	40DAS (25 DAHA)
T1 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 15DAS	0.068	0.321	0.456	0.462	0.475	0.477
T2 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 25DAS	0.063	0.363	0.428	0.408	0.439	0.441
T3 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180g a.i ha^{-1} at 15DAS	0.066	0.318	0.451	0.468	0.472	0.476
T4 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180 g a.i ha^{-1} at 25DAS	0.066	0.358	0.426	0.396	0.431	0.456
T5 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@240g a.i ha^{-1} at 15DAS	0.064	0.326	0.467	0.472	0.480	0.485
T6 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@240g a.i ha^{-1} at 25DAS	0.066	0.361	0.422	0.398	0.434	0.450
T7 Acifluorfen Sodium 16%EC + Clodinafop propargyl	0.066	0.324	0.469	0.480	0.483	0.488

8%EC (24%EC)@300g a.i ha^{-1} at 15DAS						
T8 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@300g a.i ha^{-1} at 25DAS	0.066	0.355	0.419	0.381	0.412	0.448
T9 Weed free check (Hand weeding at 15and 30 DAS)	0.063	0.411	0.471	0.485	0.487	0.492
T10 Un weeded control	0.065	0.360	0.420	0.434	0.440	0.446
SEm±	0.001	0.006	0.004	0.004	0.009	0.002
CD	NS	0.018	0.013	0.013	0.027	0.007
CV (%)	3.5	1.6	1.8	1.8	3.5	1.0

Table .3. Effect of post emergence herbicides on superoxide dismutase (SOD) (unit mg^{-1} protein h^{-1}) of blackgram leaves

TREATMENTS	SOD (unit mg^{-1} protein h^{-1})					
	15DAS	20DAS (5DAHA)	25DAS (10DAHA)	30DAS (15DAHA)	35DAS (20DAHA)	40DAS (25DAHA)
T1 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 15DAS	16.70	26.42	24.16	27.19	36.12	35.12
T2 Imazethapyr 10% EC @ 50g a.i ha^{-1} at 25DAS	18.30	23.32	28.10	37.18	44.18	42.14
T3 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180g a.i ha^{-1} at 15DAS	17.20	26.58	25.10	28.01	35.13	34.13
T4 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180 g a.i ha^{-1} at 25DAS	17.70	22.98	27.82	38.28	46.28	41.14
T5 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@240g a.i ha^{-1} at 15DAS	16.90	27.90	23.25	25.98	31.56	30.12
T6 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@240g a.i ha^{-1} at 25DAS	17.80	23.18	28.10	40.76	44.56	40.18
T7 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@300g a.i ha^{-1} at 15DAS	16.80	28.61	23.14	26.01	31.98	30.01
T8 Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@300g a.i ha^{-1} at 25DAS	17.20	23.24	27.96	44.16	45.28	41.12
T9 Weed free check (Hand weeding at 15and 30 DAS)	17.50	19.26	22.13	25.32	32.30	30.13
T10 Un weeded control	0.065	23.48	28.12	32.10	46.24	43.26
SEm±	0.168	0.365	0.730	0.843	0.365	0.365
CD	NS	1.085	2.19	2.505	1.085	1.085
CV (%)	5.0	2.7	4.4	4.2	1.5	2.3

Table .4. Effect of post emergence herbicides on yield components, yield and economics of blackgram

TREATMENTS	No. of pods plant^{-1}	No. of seeds Pod^{-1}	Pod weight (g plant^{-1})	100 Seed weight (g)	Seed yield (kg ha^{-1})	B:C Ratio
T1 Imazethapyr 10% EC@50g a.i ha^{-1} at 15 DAS	23.4	3.4	15.55	3.81	740.74	1.04
T2 Imazethapyr 10% EC@50g a.i ha^{-1} at 25 DAS	19.2	3.5	14.64	3.95	768.25	1.12
Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180g a.i ha^{-1} at 15DAS	25.6	4.2	15.28	4.34	771.60	1.08
Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@180 g a.i ha^{-1} at 25DAS	18.7	4.4	14.82	4.23	632.09	0.70

Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@240g a.i ha^{-1} at 15DAS	27.8	4.8	17.53	4.51	987.60	1.59
Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@240g a.i ha^{-1} at 25DAS	24.6	4.3	15.22	4.18	925.90	1.43
Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC (24%EC)@300g a.i ha^{-1} at 15DAS	28.9	4.9	17.96	4.92	1001.60	1.56
Acifluorfen Sodium 16%EC + Clodinafop propargyl 8%EC(24%EC)@300g a.i ha^{-1} at 25DAS	23.4	4.1	14.38	4.53	655.50	0.68
Weed free check (Hand weeding at 15and 30 DAS)	30.2	5.2	18.16	4.92	1050.20	1.37
T10 Un weeded control	18.2	3.0	11.65	3.59	591.23	0.73
SEm±	0.5	0.04	0.769	0.02	41.13	
CD	1.5	0.12	2.286	0.06	123.4	
CV (%)	2.8	2.05	8.8	1.01	11.6	

Yield attributes and yield

Different weed control treatments increased the number of pods per plant from 2.7 to 65.9 per cent compared to weedy check (Table 4). Weed free check and post emergence application of acifluorfen sodium + clodinafop propargyl @ 300 and 240 g a.i ha^{-1} at 15 DAS increased the pods per plant by 65.9, 58.8 and 52.7 per cent, respectively, over unweeded control. The highest number of seeds per pod (5.2) was recorded under hand weeding twice at 15 and 30 DAS, followed by post emergence application of acifluorfen sodium + clodinafop propargyl @ 300 (4.9) and 240 (4.8) g a.i ha^{-1} at 15 DAS.

Post emergence application of acifluorfen sodium 16% EC + clodinafop propargyl 8% EC (24% EC) @ 240, 300 g a.i ha^{-1} at 15 DAS and weed free treatment increased the pod weight by 40.0, 41.6 and 42.6 per cent , respectively, over un weeded control. There was a significant increase in 100 seed weight (test weight) due to weed control treatments. The maximum 100- seed weight observed was 4.92 g versus control (3.50 g) as a result of combined application of acifluorfen sodium + clodinafop propargyl @ 300 g a.i ha^{-1} at 15 DAS and this treatment is at par with weed free check (4.92 g) and superior over other herbicidal treatments. These two treatments increased the 100- seed weight by 37 per cent over unweeded control.

The highest seed yield was recorded with weed free check (T_9 –1050.20 kg ha^{-1}), where yield attributes were also higher. Among different herbicides, post emergence application of acifluorfen sodium 16% EC + clodinafop propargyl 8% EC (24% EC) @ 300 g a.i ha^{-1} at 15 DAS recorded higher seed yield (T_7 – 1001.60 kg ha^{-1}) which was statistically at par to its 240 g ha^{-1} at 15 DAS (T_5 – 987.60kg ha^{-1}) due to better yield attributes. These two treatments were at par with weed free check. This significant increase in yield due to these treatments may be because of reduced crop-weed competition at critical stages as reflected by significantly low weed population and drymatter, resulting in better accumulation of photosynthates. Remaining herbicidal treatments (i.e. T_1, T_2, T_3, and T_6) were significantly superior over un weeded control. Weedy check (T_{10}) recorded lowest seed yield (591.23 kg ha^{-1}) due to heavy infestation of weeds. All the weed control treatments increased the seed yield of blackgram by 6.9 to 77.6 per cent over weedy check (Table 4). Weed free check and post emergence application of acifluorfen sodium 16% EC + clodinafop propargyl 8% EC (24% EC) @ 300 and 240 g a.i ha^{-1} at 15 DAS increased the seed yield by 77.6, 69.4 and 67.8 per cent, respectively, over un weeded control. Though, imazethapyr @ 50 g ha^{-1} at 15 and 25 DAS recorded significant increase in yield (25.3 and 29.9 per cent, respectively) over un weeded control, but these two treatments were inferior over the combined use of acifluorfen sodium + clodinafop propargyl at 240 and 300 g a.i ha^{-1} at 15 DAS.

ECONOMICS

The highest benefit cost ratio was recorded with acifluorfen sodium + clodinafop propargyl @ 240 g a.i ha^{-1} (i.e. 1.59) and this was closely followed by acifluorfen sodium + clodinafop propargyl @ 300 g a.i ha^{-1} (i.e. 1.56) and hand weeding at 15 and 30 DAS with 1.37, indicating the cost effectiveness of herbicides, whereas weed free treatment involved highest labour cost and cost of cultivation, which leads to decreased net returns.

CONCLUSION

From this study, it can be concluded that post emergence application of acifluorfen sodium + clodinafop propargyl @ 240 g a.i ha^{-1} at 15 DAS is recommended for weed control in blackgram as it improved the contents of photosynthetic pigments, SOD enzyme activity and yield of blackgram.

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