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New Generation Herbicides Effectively Control Weeds and Enhance Greengram (*Vigna radiata* L.) Yield

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ABSTRACT

A field experiment was conducted at Agronomy Main Research Farm, Odisha University of Agriculture and Technology, Bhubaneswar, India during the summer season of 2021 by taking cv *Nayagarh local* as test variety. The experiment was laid out in a Randomized Block Design consisting of 10 treatment combinations with three replications viz., T_1: Pendimethalin 38.7 EC @ 0.678 kg ha^{-1} as PE, T_2: Oxyfluorfen @ 140 g ha^{-1} as post-emergence (PE), T_3: Pendimethalin 30 EC + Imazethapyr 2 EC ready mix (RM) @ 1 kg ha^{-1} as PE, T_4: Pendimethalin @ 1 kg ha^{-1} followed by Quazifop-p-ethyl @ 50 g ha^{-1} as post-emergence (PoE), T_5: Pendimethalin @ 1 kg ha^{-1} followed by Propaquizafop @ 50 g ha^{-1} PoE, T_6: Topramezone @ 25.2 g ha^{-1} as early PoE (EPoE), T_7: Propaquizafop 2.5% @ 50 g ha^{-1} + Imazethapyr 3.75% (RM) @ 75g ha^{-1} as EPoE, T_8: Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE, T_9: Mechanical weeding at 20 and 40 DAS, T_{10}: Farmers' practice i.e., hand weeding at 20 DAS. The results revealed that Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE recorded minimum total weed count (47.1) with minimum weed dry weight (3.14 g m^{-2}) and maximum seed yield (866 kg ha^{-1}) with the highest benefit to cost ratio (2.46) that ultimately resulted in the highest net return ha^{-1} (Rs 40,702/-). However, the maximum weed dry weight was recorded in farmers' practice i.e., hand weeding at 20 DAS (22.25 g m^{-2}).

Keywords Fluazifop-p-butyl, Fomesafen, Imazethapyr, Post-emergence, Propaquizafop.

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INTRODUCTION

Pulses are recognized as an important part of the Indian diet and protein supplements, particularly for vegetarians, due to their high protein and necessary amino acid content, and cheaper price as compared to animal protein. Pulses are farmed on an area of 807.54 million hectares worldwide, and they account

for a production of 730 million tonnes with a productivity of 892 kg ha^{-1}. Greengram (*Vigna radiata* L.) one of the most important pulse crops in south and Southeast Asia, is also known as golden gram, mash bean, celera bean, and green bean. It is India's third most significant pulse crop in terms of production, area, and productivity after chickpea and pigeon pea. Depending on cultivars, soil type, soil moisture level, and other environmental factors, uncontrolled weeds can lower greengram production by 50-90% (Kumar *et al.* 2006). Intensive research is needed to determine the key time of crop-weed competition to develop a suitable weed control program.

Although the application of Pendimethalin as a pre-emergence spray can suppress early emerging weeds i.e., annual grassy weeds (Gurjar *et al.* 2001 and Chauhan *et al*. 2002). But, if the farmers failed to apply this herbicide for whatever reasons, the only alternative left to them is to apply a post-emergence herbicide. Due to the lack of knowledge on weed control in greengram, particularly the use of post-emergence herbicides, an attempt was made to test evaluate Pendimethalin and Quazifop or Propaquizafop as post-emergence herbicides, since they have shown promising results in other pulses. Combined application of herbicides of pre and post-emergence in a sequential mode in a short-duration crop like greengram, not only increases the cost of production but also increases drudgery in its multiple application. Many novel compounds have been created in recent years that have a high degree of action at low doses, greater weed control effectiveness, and shorter half-life, but are less hazardous to mammals. These herbicides are classified as new generation herbicides with broad spectrum weed control ability and are environmentally less hazardous due to their extremely low application rates. Keeping the above facts in view, an investigation was planned to elucidate the most promising chemical weed management options in greengram (*Vigna radiata* L.) with the new generation herbicides.

MATERIALS AND METHODS

The experiment was conducted in the summer of 2021 at Agronomy Main Research farm, Odisha University of Agriculture and Technology, Bhubaneswar (20^0 30'N, 85^0 64' E, and 58 m above the MSL). The initial soil of the experimental site was sandy loam in texture. The soil pH and organic carbon (OC) were 5.58 (1:2) and 3.8 g ha^{-1}, and the available nitrogen, phosphorus, and potassium were 189, 23.8, and 12.7 kg ha^{-1}, respectively. The total rainfall, maximum and minimum air temperature (average), day and night time relative humidity prevailed during the crop growth period were 46.2 mm, 33.1 and 26.1 ^{0}C, and 93.5% and 73.4 %, respectively (Fig. 1). A promising

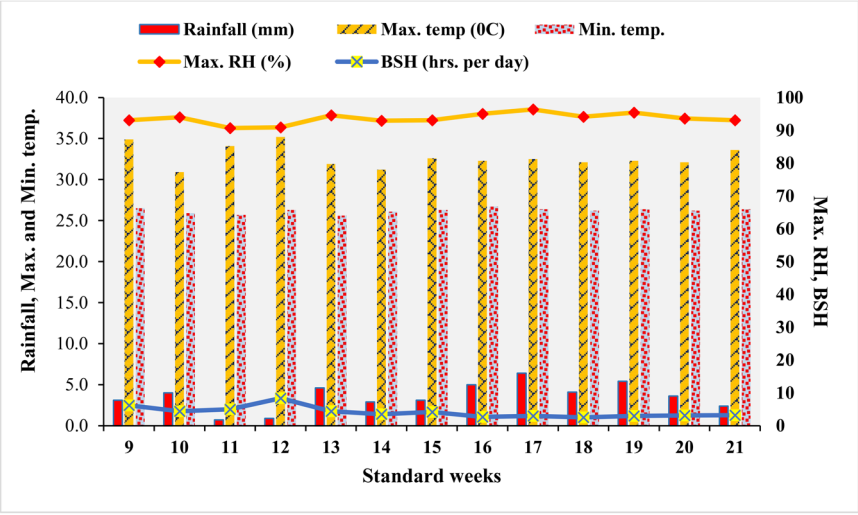

Fig. 1. Weather condition prevailed during the cropping season.

local cultivar of greengram "*Nayagarh local*" was adopted as a test variety for this experiment. Sowing was done with a seed rate of 25 kg ha^{-1} in lines on a well pulverised field after treatment with rhizobium + phosphorus solubilizing bacteria @ 20 g kg^{-1} seeds. The crop was fertilized with Urea (20 kg N ha^{-1}), DAP (40 kg P_2O_5 ha^{-1}), and MOP (20 kg K_2O ha^{-1}) to meet its fertilizer requirements. Irrigation was given three times viz., a pre-sowing, at 21 DAS and flowering stage. Harvesting and threshing were done manually.

Treatment details and imposition of treatments

This replicated experiment was laid out in a Randomised Block Design consisting of 10 treatment combinations viz., T_1: Pendimethalin 38.7 EC @ 0.678 kg ha^{-1} as pre-emergence (PE), T_2: Oxyfluorfen @ 140 g ha^{-1} as PE, T_3: Pendimethalin 30 EC + Imazethapyr 2 EC ready mix (RM) @ 1 kg ha^{-1} as PE, T_4: Pendimethalin 38.7 EC @ 1 kg ha^{-1} followed by Quazifop-p-ethyl @ 50 g ha^{-1}, T_5: Pendimethalin 38.7 EC @ 1 kg ha^{-1} followed by Propaquizafop @ 50 g ha^{-1} as post-emergence (PoE), T_6: Topramezone @ 25.2 g ha^{-1} as early post emergence (EPoE), T_7: Propaquizafop 2.5% @ 50 g ha^{-1} + Imazethapyr 3.75% (RM) @ 75 g ha^{-1} as EPoE, T_8: Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE, T_9: Mechanical weeding at 20 and 40 DAS, and T_{10}: Farmer practice i.e., hand weeding at 20 DAS. The pre-emergence, post emergence herbicides, mechanical, and hand weeding were done as per the schedule.

Parameters recorded

The weed density m^{-2} was recorded using a quadrant and then by removing and counting the weeds from that quadrant. Weed dry weight was recorded by the destructive sampling of weeds from 1 m^2 area. The plant height from ground level to the tip of the main shoot from 10 tagged plants from each treatment was measured using a wooden scale. The number of branches $plant^{-1}$ was counted from tagged plants and converted to per m^{-2} area. The number of the effective nodules and their fresh weight from the uprooted plants were recorded and the average was worked out to get the nodule $plant^{-1}$. Seed yield was recorded by separating seeds from the pods after cleaning and was expressed as kg ha^{-1}. Similarly, haulm yield was recorded and expressed in terms of kg ha^{-1}. The economic yield was expressed as a percentage of its harvested biomass yield and was reported as the harvest index. Treatment-wise production economics was calculated to get the cost of cultivation, gross and net return, and benefit-cost ratio. Statistical analyses were done by using R-studio version 4.2.1 to elucidate the treatment effects.

RESULTS AND DISCUSSION

Pendimethalin @ 1 kg ha^{-1} as PE followed by (fb) Quazifop-p-ethyl @ 50 g ha^{-1} as PoE (T_4) recorded the lowest (25.9) weed density m^{-2} at 45 DAS which was at par with Pendimethalin @ 1 kg ha^{-1} (PE) fb Propaquizafop @ 50 g ha^{-1} as PoE (T_5) (Table 1). But at 60 DAS and harvest, Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (PoE) (T_8) recorded the lowest weed density i.e. 47.1 and 67, respectively. A similar trend was followed for total weed dry weight. Fluazifop-p-butyl inhibits acetyl CoA carboxylase, an enzyme that catalyses an early step in the fatty acid synthesis. The acid might have been transported in phloem and might have accumulated in the meristems where it would have disrupted the synthesis of lipids in susceptible species (Urano 1982, Erlingson 1988). Fomesafen controls weeds by inhibiting the protoporphyrinogen oxidase (PPO) enzyme in plants. PPO inhibitors interfere with an enzyme involved in chlorophyll and heme biosynthesis (Sayadon and Lowe 2017). The quick knock-down effect of both the chemical might be the reason for efficient control of weeds in greengram. Chandrakar *et al.* (2014), Singh and Singh (2016) and Verma *et al.* (2017) have also reported similar findings.

Mechanical weeding (at 20 and 40 DAS) recorded maximum plant height (42.1 cm) at harvest which was followed by Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE (T_8) i.e., 40.1 cm at harvest. At 45 DAS, the maximum (6.4) number of branches per plant was observed in T_8 among all herbicidal treatments (Table 2) and the same result was obtained at 60 DAS also. There was a negative correlation between plant height and weed density ($r = -0.64$, $P \leq 0.01$), total weed dry weight ($r = -0.64$, $P \leq 0.01$) (Fig. 2). This indicated that lesser weed density and weed dry weight helped increase

Table 1. Effect of different weed management practices on the weed density and total weed dry weight in greengram.

Treatments	Weed density m^{-2}			Total weed dry weight (g m^{-2})		
	45 DAS	60 DAS	Harvest	45 DAS	60 DAS	Harvest
T_1: Pendimethalin @ 0.678 kg ha^{-1} (PE)	7.93 (62.33)	13.53 (182.49)	14.44 (208.13)	1.98 (3.46)	3.56 (12.17)	4.22 (17.34)
T_2: Oxyfluorfen @ 140 g ha^{-1} (PE)	9.39 (87.71)	14.81 (218.76)	15.71 (246.38)	2.32 (4.87)	3.88 (14.58)	4.59 (20.53)
T_3 Pendimethalin + Imazethapyr (RM) @ 1 kg ha^{-1}	7.43 (54.70)	12.44 (154.20)	13.32 (176.92)	1.88 (3.04)	3.28 (10.28)	3.90 (14.74)
T_4: Pendimethalin 1 kg ha^{-1} (PE) fb Quazifop-p-ethyl @ 50 g ha^{-1} (PoE) at 20-25 DAS	5.14 (25.96)	10.68 (113.59)	12.30 (150.79)	1.39 (1.44)	2.84 (7.57)	3.62 (12.57)
T_5: Pendimethalin 1 kg ha^{-1} (PE) fb Propaquizafop @ 50 g ha^{-1} (PoE)	5.79 (33.07)	12.89 (165.75)	13.91 (192.93)	1.53 (1.84)	3.40 (11.05)	4.07 (16.08)
T_6: Topramezone @ 25.2 g ha^{-1} at 20-25 DAS (EPoE)	10.03 (100.05)	15.17 (229.74)	15.74 (247.28)	2.46 (5.56)	3.98 (15.32)	4.59 (20.61)
T_7: Propaquizafop @ 50 g ha^{-1} fb Imazethapyr @ 75 g ha^{-1} 20-25 DAS (EPoE)	8.45 (70.85)	14.32 (204.48)	15.26 (232.37)	2.11 (3.94)	3.76 (13.63)	4.46 (19.36)
T_8: Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (PoE)	7.87 (61.40)	6.90 (47.17)	8.22 (67.08)	1.98 (3.41)	1.91 (3.14)	2.46 (5.59)
T_9 : Mechanical weeding at 20 and 40 DAS	7.69 (58.67)	7.42 (54.51)	9.81 (95.78)	1.94 (3.26)	2.03 (3.63)	6.11 (36.80)
T_{10}: Farmer practice (hand weeding at 20 DAS)	13.97 (194.65)	18.28 (333.82)	21.02 (441.65)	3.36 (10.81	4.77 (22.25)	4.06 (16.05)
SEm (±)	0.52	0.66	1.24	0.25	0.30	0.32
CD (p=0.05)	1.551	1.964	3.691	0.575	0.894	0.952

Original values are given in parenthesis, which were transformed to √(x+0.5). *Data statistically not analyzed.

plant height.Chandrakar *et al.*(2014), Singh and Singh (2016), and Verma *et al.* (2017) also reported similar findings. At 45 and 60 DAS, the maximum number of trifoliate leaves per plant (21.6 and 38.6, respectively) was observed in Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE (T_8) (Table 2). The highest number of nodules $plant^{-1}$ at 45 DAS and 60 DAS (37.5 and 26.1, respectively) was observed in mechanical weeding done at 20 and 40 DAS. This was at par with Fluazifop-p-butyl + Fomesafen (RM)

Table 2. Effect of different weed management practices on the different growth traits of greengram.

Treatments	Plant height (cm)	No. of branches $plant^{-1}$		No of trifoliate leaves $plant^{-1}$			Nodules $plant^{-1}$
	At Harvest	45 DAS	60 DAS	45 DAS	\ 60 DAS	45 DAS	60 DAS
T_1: Pendimethalin @ 0.678 kg ha^{-1} (PE)	37.65	4.8	7.0	21.2	31.2	27.3	15.6
T_2: Oxyfluorfen @ 140 g ha^{-1} (PE)	39.16	5.3	6.5	17.3	32.6	29.2	14.5
T_3 : Pendimethalin + Imazethapyr (RM) @ 1 kg ha^{-1}	37.86	4.6	7.4	23.6	32.0	312	19.8
T_4: Pendimethalin 1 kg ha^{-1} (PE) fb Quazifop-p-ethyl @ 50 g ha^{-1} (PoE) at 20-25 DAS	38.0	3.1	7.7	19.8	35.3	31.6	20.1
T_5: Pendimethalin 1 kg ha^{-1} (PE) fb Propaquizafop @ 50 g ha^{-1} (PoE)	33.9	3.3	6.7	17.3	29.9	34.1	21.5
T_6: Topramezone @ 25.2 g ha^{-1} at 20-25 DAS (EPoE)	38.7	4.8	6.6	16.6	26.6	23.4	22.4
T_7: Propaquizafop @ 50 g ha^{-1} fb Imazethapyr @ 75 g ha^{-1} 20-25 DAS (EPoE)	36.9	5.1	7.5	20.4	34.0	30.1	23.1
T_8: Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (PoE)	40.1	6.4	8.0	21.6	38.6	35.0	25.2
T_9 : Mechanical weeding at 20 and 40 DAS	42.1	4.6	7.8	19.8	37.1	37.5	26.1
T_{10}: Farmer practice (hand weeding at 20 DAS)	35.4	5.4	5.4	16.2	24.4	23.7	14.8
SEm (±)	1.29	0.31	0.36	1.15	1.54	1.23	1.59
CD (p=0.05)	3.7	0.9	1.1	3.4	4.5	3.6	4.7

Fig. 2. Correlogram and correlation coefficients of different traits of greengram.

@ 125 g ha^{-1} as PoE (T_8) with 35 and 25.2 nodules plant^{-1} at both stages, respectively. The increase in nodule number probably was due to increased aeration of the rhizosphere in loosened soil conditions coupled with no chemical application. Besides this, there was a positive correlation ($r = 0.63$, $P \leq 0.01$)

Table 3. Effect of different weed management practices on the yield and yield attributing traits.

Treatments	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index*
T_1: Pendimethalin @ 0.678 kg ha^{-1} (PE)	13.4	11.3	3.01	716.3	3272.0	17.96
T_2: Oxyfluorfen @ 140 g ha^{-1} (PE)	11.9	9.8	3.07	645.3	2961.3	18.09
T_3: Pendimethalin + Imazethapyr (RM) @ 1 kg ha^{-1}	13.6	11.9	3.03	741.6	3374.3	18.02
T_4: Pendimethalin 1 kg ha^{-1} (PE) fb Quazifop-p-ethyl @ 50 g ha^{-1} (PoE) at 20-25 DAS	15.2	12.5	2.90	835.0	3605.0	18.80
T_5: Pendimethalin 1 kg ha^{-1} (PE) fb Propaquizafop @ 50 g ha^{-1} (PoE)	14.7	12.3	2.97	840.3	3593.3	18.95
T_6: Topramezone @ 25.2 g ha^{-1} at 20-25 DAS (EPoE)	12.5	11.2	2.90	682.0	3177.6	17.68
T_7: Propaquizafop @ 50 g ha^{-1} fb Imazethapyr @ 75 g ha^{-1} 20-25 DAS (EPoE)	12.2	10.8	3.17	695.0	3146.0	18.08
T_8: Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (PoE)	15.8	14.7	3.30	866.3	3634.3	19.25
T_9 : Mechanical weeding at 20 and 40 DAS	14.4	12.2	3.10	793.6	3466.3	18.63
T_{10}: Farmer practice (hand weeding at 20 DAS)	11.1	9.65	3.03	614.0	2755.6	18.27
SEm (±)	0.85	0.85	0.21	12.42	30.78	
CD (p=0.05)	2.5	2.4	0.64	36.9	91.4	

Table 4. Effect of different weed management practices on the production economics of greengram.

Treatments	Cost of cultivation (ha^{-1})*	Net return (ha^{-1})*	B:C ratio*
T_1 : Pendimethalin @ 0.678 kg ha^{-1} (PE)	26917	30259	2.12
T_2 : Oxyfluorfen @ 140 g ha^{-1} (PE)	27592	24592	1.89
T_3 : Pendimethalin + Imazethapyr (RM) @ 1 kg ha^{-1}	28867	30360	2.05
T_4 : Pendimethalin 1 kg ha^{-1} (PE) fb Quazifop-p-ethyl @ 50 g ha^{-1} (PoE) at 20-25 DAS	27767	38596	2.39
T_5 : Pendimethalin 1 kg ha^{-1} (PE) fb Propaquizafop @ 50 g ha^{-1} (PoE)	28267	38443	2.36
T_6 : Topramezone @ 25.2 g ha^{-1} at 20-25 DAS (EPoE)	28567	25985	1.91
T_7 : Propaquizafop @ 50 g ha^{-1} fb Imazethapyr @ 75 g ha^{-1} 20-25 DAS (EPoE)	29757	25697	1.86
T_8 : Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (PoE)	27967	40702	2.46
T_9 : Mechanical weeding at 20 and 40 DAS	27567	35594	2.29
T_{10} : Farmer practice (hand weeding at 20 DAS)	25917	21170	1.82

*Data statistically not analzsed.

established between a number of trifoliate leaves and nodule numbers which indicates a higher number of trifoliate leaves helped in the production of more nodules $plant^{-1}$. The results corroborate with the findings of Choudhary *et al.* (2012), Aggarwal *et al.* (2014) and Das *et al.* (2014).

Application of Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} as PoE (T_8) recorded the maximum number of pods $plant^{-1}$ (15.8) and was at par with Pendimethalin @ 1 kg ha^{-1} as PE fb Propaquizafop @ 50 g ha^{-1} as PoE (T_5) (14.7) (Table 3). Fluazifop-p-butyl + Fomesafen (RM) (T_8) recorded the maximum number of seeds pod^{-1} (14.7). This was at par with Pendimethalin @ 1 kg ha^{-1} as PE fb Quazifop-p-ethyl @ 50 g ha^{-1} as PoE (T_4) (12.5) and Pendimethalin @ 1 kg ha^{-1} as PE fb Propaquizafop @ 50 g ha^{-1} as PoE (T_5) (12.3). The same trend was followed for the seed index. The highest seed yield (866.3 kg ha^{-1}) was recorded in Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} treatment (T_8), which remained at par with Pendimethalin @ 1 kg ha^{-1} as PE fb Propaquizafop @ 50 g ha^{-1} as PoE (T_5) (840.3 kg ha^{-1}) and Pendimethalin @ 1 kg ha^{-1} as PE fb Quazifop-p-ethyl @ 50 g ha^{-1} as PoE (T_4) (835 kg ha^{-1}) (Table 3). The next best treatment in registering higher seed yield was mechanical weeding at 20 and 40 DAS (793.6 kg ha^{-1}) followed by treatment of Pendimethalin + Imazethapyr (RM) as PE (741.6 kg ha^{-1}) and pendimethalin 38.7 EC as PE (716.3 kg ha^{-1}). The highest yield in T_8 could be due to the effective control of the ready mix combination of two herbicides having a different modes of action which controlled the mixed and diverse weed flora present in the experimental site. Seed yield had positive correlation with plant height at harvest ($r = 0.21$, $P \leq 0.01$), number of branches at 60 DAS ($r = 0.73$, $P \leq 0.01$), number of trifoliate leaves at 60 DAS ($r = 0.42$, $P \leq 0.01$), pods $plant^{-1}$ ($r = 0.98$, $P \leq 0.01$), seeds $plant^{-1}$ ($r = 0.92$, $P \leq 0.01$) (Fig. 2). These traits directly contributed to the yield of greengram. Besides this, seed yield had a negative correlation with weed density and weed dry matter at 60 DAS ($r = -0.84$, $P \leq 0.01$). These findings conform with Gupta *et al.* (2017). But the voluminous weed growth in T_{10} i.e. farmers' practice (hand weeding at 20 DAS) resulted in severe crop weed competition, thereby siphoning of resources like nutrients, water, solar radiation, CO_2 by weeds. Severe weed competition in this treatment reduced yield to the extent of 65.2% in this treatment. Sahoo (2014) and Mansoori *et al*. (2015) also reported similar findings due to uncontrolled weed growth. The highest haulm yield (3634.33 kg ha^{-1}) was recorded in Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (T_8) treatment, which remained at par with Pendimethalin 1 kg ha^{-1} as PE fb Quazifop-p-ethyl @ 50 g ha^{-1} as PoE (T_4) (3605 kg ha^{-1}) and Pendimethalin 1 kg ha^{-1} as PE fb Propaquizafop @ 50 g ha^{-1} as PoE (T_5) (3593 kg ha^{-1}).

The maximum cost of cultivation of Rs 29,757/- occurred in Propaquizafop 2.5% fb Imazethapyr 3.75% (EPoE) (T_7). But, Fluazifop-p-butyl + Fomesafen (RM) (T_8) fetched highest net return (Rs 40,702/- ha^{-1}) followed by Pendimethalin @ 1 kg ha^{-1} as PE fb Quazifop-p-ethy1 @ 50 g ha^{-1} (T_4) at 20-25

DAS (38,596/- ha^{-1}) (Table 4). The best benefit to cost ratio was found in treatment Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (T_8) (2.46) followed by Pendimethalin @ 1 kg ha^{-1} as PE fb Quazifop-p-ethy1 @ 50 g ha^{-1} (T_4) at 20-25 DAS (2.39). The benefit to cost ratio were recorded in the application of Fluazifop-p-butyl + Fomesafen (RM) @ 125 g ha^{-1} (T_8) treatment. These findings conform with Gupta *et al.* (2017).

CONCLUSION

Our study revealed that Fluazifop-p-butyl + Fomesafen (RM), which is a new generation herbicide, when applied as post-emergence @ 125 g ha^{-1}, could effectively control the diverse weed flora in greengram which can turn out to be the best in terms of getting higher grain yield as well as net and gross profits.

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