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Effect of nanoparticles in combination with pendimethalin and hydrogen peroxide on growth parameters and nodulation of blackgram (*Vigna mungo* L.)

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Abstract
Field experiments were conducted at the Agricultural College and Research Institute, Madurai, Tamil Nadu Agricultural University, Tamil Nadu, during *kharif* and *rabi* season of 2017 - 2018, to study the effect of nanoparticles in combination with herbicides and hydrogen peroxide on weed and crop plants. The experiments were laid out in randomized block design with twelve treatments and replicated thrice using blackgram MDU 1 as a test variety. The observation on growth parameters of plant height, leaf area index (LAI) and dry matter production (DMP) were taken at 20, 40 DAS and at harvest stage. The number of root nodules and their dry weight were taken at 30 and 60 DAS. Among the different treatments, weed free plot recorded higher dry matter production, number of nodules and dry weight of nodules, followed by application of H_2O_2 fb pendimethalin @ 0.75 kg ai. ha^{-1} + ZnO nanoparticles (Nps) registered maximum plant height and leaf area index. However, it was at par with weed free plot. Next to the best treatments application of pendimethalin @ 0.75 kg ai. ha^{-1} + hand weeding at 35 DAS registered higher dry matter production, crop growth rate, number of root nodules and dry weight of nodules.

Keywords: Blackgram, zinc oxide and silver nanoparticles, hydrogen peroxide, pendimethalin, nodulation, growth parameters

Introduction
India is the largest producer and consumer of pulses in the world accounting for 33.6 per cent of the world area and 24 per cent of the world production (Pramanik and Bera., 2012) [6]. Among the pulse crops, blackgram is an important legume crop cultivated worldwide in tropical and subtropical regions. In India, it occupies an area of 3.06 m.ha. with a production of 1.70 million tonnes and average productivity of 555 kg ha^{-1}. In Tamil Nadu, it is cultivated in 365.1 lakh hectares, with the productivity of 851 kg ha^{-1}. Even though cultivated area is higher, the productivity of pulses in India is low. Among the various factors responsible for the lower yield of blackgram, heavy weed infestation is one of the predominant reasons (Rao *et al*., 2010) [9]. The crop is not a very good competitor against the weeds and therefore weed control initiatives are essential to ensure proper crop growth, particularly in the early growth period. The enlargement of weed seed bank is considered as a serious problem for the subsequent crops. Exhausting the weed seed bank reduces the crop weed competition and improves the growth and yield of crops. Several pre and post emergence herbicides were used for controlling weeds in pulses. However the newly emerging science, the nanotechnological approach throws some light to manage some weeds with the help of nanoparticles (Gum *et al*., 2009) [2]. Hydrogen peroxide is a biocide commonly used for sterilizing soil borne pathogens (Linley *et al*, 2012) [3]. An attempt has been made to study the effect of herbicides in combination with nanoparticles and hydrogen peroxide on growth and nodulation of blackgram to improve the weed control as well as to increase the yield.

Materials and Methods
Field experiment was conducted at 'B block' of Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, during *kharif* and *rabi* season of 2017-2018. The site was located at $9^0.54$' N latitude and $78^0.80$' E longitude at an altitude of 147 m above mean sea level. The region falls under southern zone of Tamil Nadu.

The experimental site is situated in semi-arid tropical region**.** The mean annual rainfall is 856 mm out of which 39.8 per cent is distributed during south west monsoon, 42 per cent during north east monsoon, 2.1 per cent during winter and 16.2 per cent during summer. The soil of the experimental field is sandy clay loam in texture. The fertility status was low in available nitrogen (231 kg ha^{-1}), medium in available phosphorus (16.4 kg ha^{-1}), medium in available potassium (294.8 kg ha^{-1}), organic carbon (0.34 %), pH (1:2 soil water suspension) (7.1).

The experiment was laid out in randomized block design, replicated thrice using MDU 1 blackgram as the test variety. The experiment was carried out with the following treatments i.e., H_2O_2 30 ml m^{-2} alone (T_1) and it was in combination with Ag Nps @ 500 ppm m^{-2} (T_2), ZnO Nps @ 500 ppm m^{-2} (T_3), Pre-emergence application of pendimethalin @ 0.75 kg a.i ha^{-1} alone (T_4). For T_5 H_2O_2 fb pendimethalin @ 0.75 kg a.i ha^{-1} and T_6, T_7 consists of pendimethalin with Ag Nps and ZnO Nps, respectively. T_8 and T_9 consist of H_2O_2 fb pendimethalin + Ag Nps, ZnO Nps, respectively. T_{10}, T_{11} and T_{12} comprises of pendimethalin + hand weeding @ 35 DAS, weed free check and unweeded check, respectively.

Hydrogen peroxide (H_2O_2) applied in soil one day before sowing of the seeds. The recommended dose of fertilizer viz., 25:50:25 kg N, P_2O_5 and K_2O ha^{-1} was applied as basal to all the plots. The N was applied in the form of urea (46 % N), P was applied in the form of single super phosphate (16 % P_2O_5) and K was applied in the form of Muriate of Potash (60 % K_2O). For improving the growth and flower initiation of the crop foliar spray of 2% DAP applied @ 35 DAS.

The observation on growth parameters (Plant height, Leaf Area Index (LAI) and Dry matter production), crop growth rate were taken at 20, 40 DAS and at harvest stage. The number of root nodules and nodule dry weight were taken at 30 DAS and 60 DAS.

Result and Discussion

Plant height

Application of nanoparticle herbicide combination significantly influenced the plant height (Table 1) of blackgram. Weed free plot (T_{11}) produced taller plants at all the three stages of observations in both the seasons. The plant height of 26.4, 38.4 and 49.9 cm recorded at 20, 50 DAS and at harvest in *kharif* and 24.5, 36.2 and 48.2 cm was recorded at 20, 50 DAS and at harvest stage in *rabi* respectively. This might be due to continuous weed removal by manual weeding results in weed free environments throughout the crop period. The similar results were reported by Balyan *et al*. (2016) [1]. Application of H_2O_2 fb pendimethalin + ZnO Nps (T_9) equally produced higher plant height of 25.3, 36.5 and 47.8 cm recorded at 20, 50 DAS and at harvest stage in *kharif* and the plant height of 23.6, 34.7 and 46.4 cm recorded at 20, 50 DAS and at harvest stage in *rabi*, respectively and comparable with the best treatment T_{11}. Increased plant height might be attributed due to the weed free environment accelerated the enzyme activity and auxin metabolism in plants, which promote the growth of the crop. Further it can also be attributed due to improved absorption of ZnO nanoparticles influenced the plant growth under this treatment. The results are in agreement with the earlier findings of Petosa *et al*. (2017) [5]. Shorter plants (16.1, 20.6 and 27.0 cm in *kharif* and 15.4, 19.5 and 25.5 cm in *rabi*, respectively.) were observed in control plot (T_{12}) and it was significantly differed from other treatments. This might be due to the emergence of large number of weeds and higher crop-weed competition. These results are similar to the findings of Vivek *et al*. (2008) [10].

Leaf Area Index

Among the treatments the weed free plot (T_{11}) recorded the highest LAI (Table 1) of 3.94 and 5.01 in *kharif* and 3.91 and 4.83 in *rabi* at 20 and 50 DAS, respectively. This might be due to continuous hand weeding which creates less crop-weed competition and increases the number of leaves. The similar results were reported by Nirala *et al*. (2016)[4]. Followed by application of H_2O_2 fb pendimethalin + ZnO Nps (T_9) recorded the highest leaf area index of 3.76 and 4.87 in *kharif* and 3.85 and 4.71 at 20 and 50 DAS in *rabi*, respectively and on par with the best treatment T_{11}. Next to this treatment, application of pendimethalin + ZnO nanoparticles (T_7) and pendimethalin + hand weeding at 35 DAS (T_{10}) showed better results. This might be due to the combined activity of pendimethalin, which creates less weed competition for crops and ZnO nanoparticles which improves the leaf area expansion in plants, size and number of leaves. These results were agreed with the findings of Zafar *et al*. (2016). The lowest LAI was recorded in control (T_{12}) at all stages of crop growth in both seasons. This may due to the higher crop-weed competition, the leaf area and number gets reduced. This is in agreement with the findings of Vivek *et al*. (2008) [10].

Dry matter production

Dry matter production (Table 2) was significantly influenced by the weed management practices at all the three stages of observation. Weed free plot (T_{11}) produced significantly more dry matter of 960, 1635 and 2945 kg ha^{-1} in *kharif* and 987, 1719 and 3175 kg ha^{-1} at 20, 50 DAS and harvest stage in *rabi*, respectively. These results were attributed due to the weed free condition prevailed during the entire crop growth period favoured the crop to use natural the resources effectively. Pendimethalin + hand weeding at 35 DAS (T_{10}) performed better after weed free when compared to other treatments. The dry matter gets increased due to the activity of pendimethalin in early stages and hand weeding maintains the field in weed free condition during flowering and early stages of pod set. This coincides with the findings of Raju *et al*, (2017) [8]. The dry matter production was significantly reduced in control (T_{12}) at all the stages of crop in both seasons.

Crop Growth Rate

Crop growth rate (Table 2) was markedly influenced by the weed control treatments. Crop growth rate was increased along with age of crop and highest CGR was recorded at 50 DAS to harvest. Weed free plot (T_{11}) recorded significantly the highest CGR of 33.8 and 65.5 kg ha^{-1} in *kharif* and 36.6 and 72.8 kg ha^{-1} at 20-50 DAS and 50 DAS harvest in *rabi*, respectively. The increase in crop growth rate was due to effective weed management from the early crop growth stages and higher dry matter accumulation. These results were agreed with the findings of Nirala *et al*, (2016) [4]. It was followed by the application pendimethalin + hand weeding at 35 DAS (T_{10}) registered 31.2 and 61.1 kg ha^{-1} in *kharif* and 34.1 and 64.0 kg ha^{-1} at 20-50 DAS and 50 DAS harvest in *rabi*, respectively. The lowest CGR was recorded in control when compared with rest of other treatments with numerical of 16.1 and 22.8 kg ha^{-1} in *kharif* and 17.4 and 25.8 kg ha^{-1} at 20-50 DAS and 50 DAS-harvest in *rabi*, respectively.

Nodulation

Significantly higher numbers of root nodules (Table 3) were recorded in weed free plot (T_{11}) (27.93 and 26.57 in *kharif* and 28.85 and 27.51 at 30 and 60 DAS in *rabi*, respectively). Next to this treatment, pendimethalin + hand weeding at 35 DAS (T_{10}) recorded higher number of root nodules. The lowest number of root nodules recorded in control plot (T_{12}) and this is at par with H_2O_2 treated plots (T_1, T_2, T_3, T_5, T_8 and T_9). The reduction of nodules from the roots might be due to higher weed competition. This is in acceptance with the report of Raghavendra and Gundappagol (2017) [7].

Nodule dry weight

The dry weight of root nodule (Table 3) was recorded significantly highest in weed free plot (T_{11}). The dry weight of 3.15 and 2.81 mg plant^{-1} in *kharif* and 3.47 and 3.29 mg plant^{-1} were recorded at 30 and 60 DAS in *rabi*, respectively. This might be due to free of weeds and increased aeration by frequent hand weedings. Pendimethalin + hand weeding at 35 DAS (T_{10}) had better root nodule dry weight next to weed free plot (T_{11}) which recorded dry weight of 2.93 and 2.47 mg plant^{-1} *kharif* and 3.14 and 2.88 mg plant^{-1} at 30 and 60 DAS in *rabi*, respectively. However the lowest nodule dry weight was recorded in control plot (T_{12}) and this treatment is at par with treatments applied with H_2O_2 (T_1, T_2, T_3, T_5, T_8 and T_9) as part in recommendation. Due to the higher crop-weed competition for nutrients, the number of nodules gets decreased. Thus, it directly affects the nodule dry weight. Similar findings were reported by Linley *et al*, (2012) [3].

Table 1: Effect of Effect of nanoparticles in combination with pendimethalin and hydrogen peroxide on Plant height (cm) and Leaf area Index of blackgram

T. No	Plant height (cm)						Leaf area index			
	Kharif			*Rabi*			*Kharif*		*Rabi*	
	20 DAS	50 DAS	At harvest	20 DAS	50 DAS	At harvest	20 DAS	50 DAS	20 DAS	50 DAS
T_1	17.2	22.6	29.7	16.9	21.2	28.2	2.66	3.52	2.31	3.22
T_2	17.6	22.9	30.2	17.0	21.6	28.6	2.68	3.59	2.31	3.27
T_3	17.8	23.0	30.7	17.3	22.1	29.1	2.63	3.64	2.44	3.30
T_4	19.1	25.2	33.5	18.4	24.3	32.2	2.96	3.91	2.79	3.62
T_5	20.3	27.6	36.5	19.2	26.4	35.4	3.20	4.22	3.10	3.92
T_6	20.9	28.5	37.3	19.5	26.9	36.3	3.21	4.28	3.17	3.98
T_7	24.0	34.1	44.3	22.4	32.6	43.4	3.51	4.60	3.51	4.38
T_8	21.2	29.4	39.0	20.1	28.3	37.8	3.24	4.31	3.19	4.01
T_9	25.3	36.5	47.8	23.6	34.7	46.4	3.76	4.87	3.85	4.71
T_{10}	22.9	31.8	41.8	21.2	30.7	40.6	3.49	4.58	3.48	4.35
T_{11}	26.4	38.4	49.9	24.5	36.2	48.2	3.94	5.01	3.91	4.83
T_{12}	16.1	20.6	27.0	15.4	19.5	25.5	2.03	3.12	2.02	2.91
SEd	0.52	1.03	1.30	0.41	0.94	1.25	0.10	0.11	0.12	0.15
CD (p=0.05)	1.12	2.14	2.63	0.92	1.91	2.56	0.23	0.24	0.27	0.29

Table 2: Effect of nanoparticles in combination with pendimethalin and hydrogen peroxide on dry matter production (Kg ha^{-1}) and crop growth rate (Kg ha^{-1})

T. No	Dry matter production (kg ha^{-1})						Crop growth rate (kg ha^{-1})			
	Kharif			*Rabi*			*Kharif*		*Rabi*	
	20 DAS	50 DAS	At harvest	20 DAS	50 DAS	At harvest	30-50 DAS	50-At harvest	30-50 DAS	50-At harvest
T_1	615	954	1534	635	1012	1716	17.0	29.0	18.9	35.2
T_2	650	990	1654	681	1042	1885	17.0	33.2	18.1	42.2
T_3	637	976	1621	646	1026	1754	17.0	32.3	19.0	36.4
T_4	695	1084	1834	743	1160	2100	19.5	37.5	20.9	47.0
T_5	786	1265	2214	829	1340	2421	24.0	47.5	25.6	54.1
T_6	771	1210	2110	853	1294	2343	22.0	45.0	22.1	52.5
T_7	744	1185	2074	821	1269	2286	22.1	44.5	22.4	50.9
T_8	862	1438	2542	870	1500	2710	28.8	55.2	31.5	60.5
T_9	835	1365	2425	878	1449	2612	26.5	53.0	28.6	58.2
T_{10}	910	1534	2756	928	1610	2890	31.2	61.1	34.1	64.0
T_{11}	960	1635	2945	987	1719	3175	33.8	65.5	36.6	72.8
T_{12}	569	891	1346	576	924	1440	16.1	22.8	17.4	25.8
SEd	21	46	73	29	52	89	0.73	1.28	0.80	1.46
CD (p=0.05)	44	89	145	56	106	176	1.45	2.62	1.61	2.89

Table 3: Effect of nanoparticles in combination with pendimethalin and hydrogen peroxide on number of nodules plant^{-1} nodule dry weight (mg plant^{-1})

T. No	Number of nodules plant^{-1}				Nodule dry weight mg plant^{-1}			
	Kharif		*Rabi*		*Kharif*		*Rabi*	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1	17.79	17.00	20.74	19.10	2.28	1.96	2.33	2.07
T_2	17.86	17.02	20.97	19.42	2.30	1.24	2.36	2.09
T_3	17.92	17.11	21.29	19.70	2.34	1.28	2.39	2.10
T_4	21.25	20.89	23.63	23.00	2.66	1.69	2.68	2.39
T_5	18.21	17.33	21.33	19.75	2.35	1.31	2.40	2.12
T_6	21.84	21.12	23.85	23.26	2.69	2.21	2.79	2.44
T_7	22.58	21.93	24.67	24.36	2.71	2.27	2.82	2.53
T_8	18.52	17.64	21.50	19.87	2.37	1.34	2.46	2.11
T_9	18.84	17.88	21.82	20.06	2.40	1.36	2.43	2.16
T_{10}	25.34	25.12	26.43	26.03	2.93	2.47	3.14	2.88
T_{11}	27.93	26.57	28.85	27.51	3.15	2.81	3.47	3.29
T_{12}	19.56	18.21	22.14	20.42	2.41	1.68	2.49	2.18
SEd	0.87	0.65	0.72	0.69	0.08	0.04	0.09	0.05
CD (p=0.05)	1.78	1.31	1.43	1.37	0.16	0.14	0.18	0.15

Conclusion

From the results it could be concluded that weed free plot recorded higher growth parameters, dry matter production, number of nodules and dry weight of nodules. Among the weed control treatments application of H_2O_2 *fb* pendimethalin @ 0.75 kg ai.ha^{-1} + ZnO nanoparticles (Nps) registered maximum plant height and leaf area index and it was at par with weed free plot.

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