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Synthesizing Nanoencapsulated Sulfentrazone Herbicide and Optimizing Time and Dose for Season Long Weed Management in Irrigated Blackgram (*Vigna mungo* L.)

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ABSTRACT

Background: Pulses are nutritious edible seeds of leguminous plants, have become an essential part of the human diet. Among the pulses, blackgram (*Vigna mungo* L.) is an important legume crop cultivated in tropical and subtropical regions of the world. Even though there are so many factors responsible for the lower yield of blackgram, weeds play a major role. Sulfentrazone is a broad spectrum herbicide belongs to the family of phenyl triazolinone. Sulfentrazone has high persistence and mobility with mean partition coefficient K_{oc} = 43 and sorption coefficient K_d < 1 and also has high horizontal and vertical leaching potential. Even though generally used herbicides in blackgram like pendimethalin, imazethapyr and quizalofop-ethyl are helpful in managing weeds, they have to apply multiple times or have to integrate with other methods of weed management which is expensive. So as to reduce the usage of multiple herbicides, to avoid manual weeding and to achieve season long weed control without affecting the environment the nano-encapsulated sulfentrazone is the better alternative and it gives better solution for the above constraints besides increasing the productivity.

Methods: Laboratory and field experiments were conducted in the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during 2019-2020. Laboratory experiment was conducted to prepare nano-encapsulated sulfentrazone herbicide using solvent evaporation method. Screening trial was conducted in field with 17 treatments in randomized block design. Main trial was conducted with nine treatments of randomized block design by selecting the best performing treatments in screening trial. A confirmatory trial was also conducted by using same treatments.

Result: The encapsulated sulfentrazone particles were characterized in SEM (Scanning electron microscope) and also analysed with EDAX (Energy dispersive X-ray analysis) for elemental analysis, which is followed by particle size analysis and zeta potential to know the size and stability respectively. All these tests concluded that the sulfentrazone particles were encapsulated correctly and might be useful for slow release of the particle and also for reducing vertical and horizontal leachability. The field trials revealed that sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation applied at 1 DBS is better alternative for the season long weed management in blackgram without affecting the soil and ground water, as well as increasing the productivity.

Key words: Blackgram, Encapsulation, Solvent evaporation, Sulfentrazone, Weed.

INTRODUCTION

Pulses are nutritious edible seeds of leguminous plants, have become an essential part of the human diet. Among the pulses, blackgram (*Vigna mungo* L.) is an important legume crop cultivated in tropical and subtropical regions of the world. Even though there are so many factors responsible for the lower yield of blackgram weeds play a major role. Weeds are silent slayers of the crop because initially they grow along with crop, at certain stage they dominate crop and reduce the yield in a drastic way.

Sulfentrazone is a herbicidal molecule belongs to the family of phenyl triazolinone which controls the weeds by the process of protoporphyrinogen oxidase (PPO) inhibition. It can be applied as pre plant, pre-emergence or post-emergence for broad spectrum weed control (Dayan *et al*. 1996). Sulfentrazone has high persistence and mobility with mean partition coefficient K_{oc} = 43 and sorption coefficient K_d < 1 and also has high horizontal and vertical leaching potential (Martinez *et al.*, 2008). It has high Groundwater Ubiquity Score (GUS) of 6.75 which is far more than broad spectrum herbicides like pendimethalin and glyphosate which are having GUS of 0.66 and 0.42 respectively (Gustafson, 1989).

Even though generally used herbicides in blackgram like pendimethalin, imazethapyr and quizalofop-ethyl are

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helpful in managing weeds, they have to apply multiple times or have to integrate with other methods of weed management which is expensive. So as to reduce the usage of multiple herbicides, to avoid manual weeding and to achieve season long weed control without affecting the environment the nano-encapsulated sulfentrazone is the better alternative and it gives better solution for the above constraints besides increasing the productivity.

MATERIALS AND METHODS

Preparation of encapsulated sulfentrazone

One g of sulfentrazone (a.i) [*i.e*. 2.525 ml of commercial formulation] was mixed with 10 ml of ultrapure water and stirred it using magnetic stirrer for 5 min. Then separately 2 ml of polyethylene glycol as polymer and 8 ml of dichloromethane were taken, mixed and stirred for 5 min using magnetic stirrer. Both the solutions were mixed and stirred for another 5 min thus organic phase was formed. After that 4 % starch solution was taken and stirred with magnetic stirrer for 1 hour thus formed the aqueous phase. Finally organic phase containing polymer with herbicide was added drop by drop to aqueous phase and stirred again with magnetic stirrer for 12 hours. Thus produced nanoparticles were collected as such (liquid formulation) in a vial or centrifuged it for 15 min at 5000 rpm then dried the solid particles in vacuum desiccator to get dried powder.

All the field experiments were conducted at wetland farms, Tamil Nadu Agricultural University, Coimbatore during the year 2019-20 in randomized block design with three replications. The screening trial comprised of seventeen different treatments *viz*., sulfentrazone with and without encapsulation of two different concentrations @ 0.30 and 0.40 kg a.i. ha^{-1} and absolute control. The main field trial I and II comprised of nine treatments of which four best performed treatments were selected from the screening trial. Other treatments were pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* quizalofop-ethyl @ 50 g a.i. ha^{-1} and imazethapyr @ 50 g a.i. ha^{-1} at 20 DAS, pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* 1 HW at 20 DAS, HW twice at 15 and 30 DAS, Weed free check and absolute control.

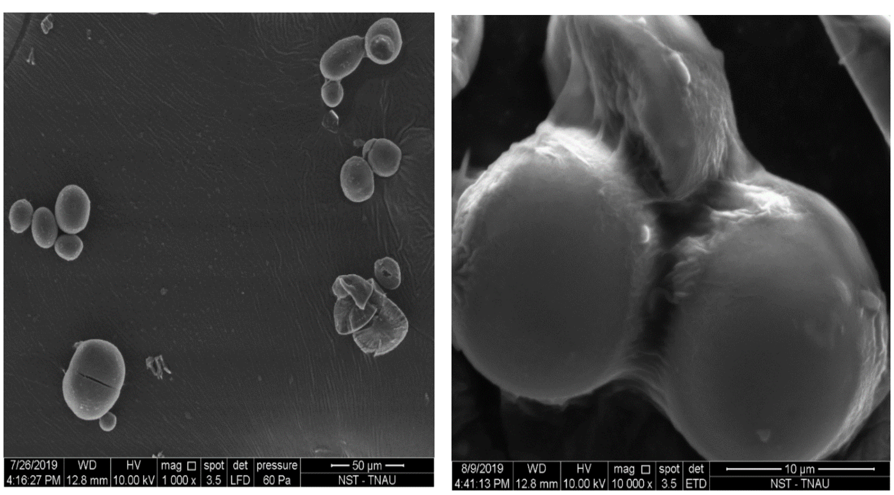
RESULTS AND DISCUSSION

Lab experiment

The encapsulated sulfentrazone particles were characterized in SEM (Fig 1) and also analysed with EDAX (Energy dispersive X-ray analysis) which is used for elemental analysis or chemical characterization of a sample. SEM images (Fig 1) were clearly showing that spherical or round particles which were encapsulated by the starch molecules. In the organic phase because of mixing and continuous stirring the polyethylene glycol polymerized and mixed with herbicide molecules in the presence of solvent dichloromethane. Similar results were observed by Mohanraj and Chen (2006). In the same way covalent bonding ability, mixing during preparation or surface adsorption ability of PEG was explained by Hans and Lowman (2002). Reis *et al*. (2006) explained in similar way about solvents used in organic phase as encapsulant and observed nano encapsulated particles were obtained by dispersion (Fig 1).

The SEM-EDAX image (Fig 2) is showing that presence of carbon and oxygen peak and also presence of little amounts of fluorine, Sulphur and chlorine confirmed the presence of active ingredient of sulfentrazone in the encapsulated herbicide. Dayan *et al*. (1998) given structure of sulfentrazone in the similar way which supports the above elemental composition. The spherical nanoparticles with smooth and shining surface is showing that herbicide was encapsulated with starch molecules (Fig 1).

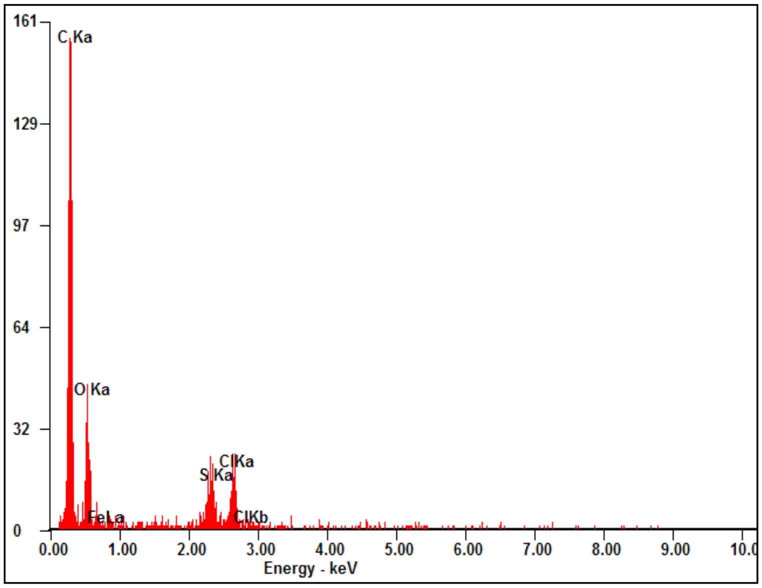
In the particle size analyzer it was tested to know the size of encapsulated particles and zeta potential of the particles. The average particle size of encapsulated sulfentrazone and normal sulfentrazone were 186.9 nm (Fig 3) and 626.9 nm (Fig 4) respectively which were clearly



A B

Fig 1: SEM images at different magnifications of 1000x and 10000x (A and B respectively).

showing that encapsulated herbicidal particle size was far less than normal herbicide because of using solvent evaporation method by the processes of polymerization, dissociation and dispersion by the presence of polyethylene glycol, dichloromethane and starch. The zeta potential of encapsulated sulfentrazone was -38.1 mV (Fig 5). Zeta potential is a measure of surface charges present on the nano particles. Zeta potential shows the stability of the



Element	Wt%	At%
CK	66.06	78.26
OK	16.32	14.51
FK	01.21	00.31
SK	07.80	03.46
ClK	08.62	03.46
Matrix	Correction	ZAF

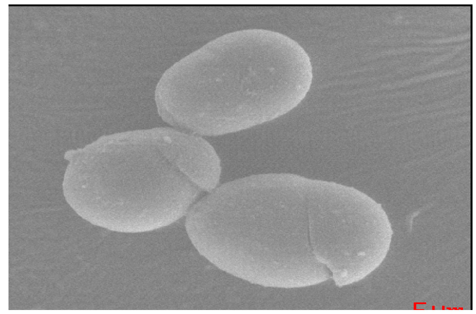


Fig 2: SEM – EDAX values of encapsulated sulfentrazone herbicide.

Measurement Results

Date	: Tuesday, August 20, 2019
Measurement Type	: Particle Size
Sample Name	: sulfendrazone 0.3
Scattering Angle	: 90
Temperature of the holder	: 25.1 ℃
T% before meas.	: 22170
Viscosity of the dispersion medium	: 0.893 mPa·s
Form Of Distribution	: Standard
Representation of result	: Scattering Light Intensity
Count rate	: 115 kCPS

Calculation Results

Peak No.	S.P.Area Ratio	Mean	S. D.	Mode
1	1.00	190.1 nm	14.3 nm	186.9 nm
2	---	--- nm	--- nm	--- nm
3	---	--- nm	--- nm	--- nm
Total	1.00	190.1 nm	14.3 nm	186.9 nm

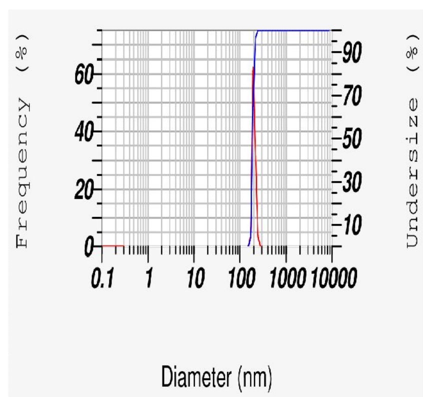


Fig 3: Particle size analyzer values for encapsulated sulfentrazone herbicide

Measurement Results

Date	: Tuesday, August 20, 2019
Measurement Type	: Particle Size
Sample Name	: normal sulfendrazone
Scattering Angle	: 90
Temperature of the holder	: 25.1 ℃
T% before meas.	: 31025
Viscosity of the dispersion medium	: 0.893 mPa·s
Form Of Distribution	: Standard
Representation of result	: Scattering Light Intensity
Count rate	: 45 kCPS

Calculation Results

Peak No.	S.P.Area Ratio	Mean	S. D.	Mode
1	1.00	649.8 nm	93.5 nm	626.9 nm
2	---	--- nm	--- nm	--- nm
3	---	--- nm	--- nm	--- nm
Total	1.00	649.8 nm	93.5 nm	626.9 nm

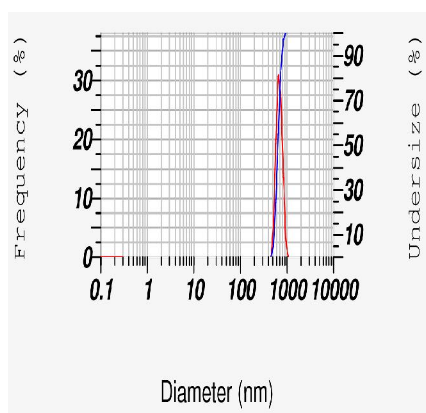


Fig 4: Particle size analyzer values of sulfentrazone (without encapsulation) herbicide

colloids. Nano particles with zeta potential above (+/-) 30 mV have been considered to be stable in suspension, as the charge on the surface of particles prevents aggregation. As the zeta potential of encapsulated sulfentrazone was -38.1 mV which is more than (+/-) 30 mV, thus the encapsulated sulfentrazone herbicide is stable. This stability might be useful for slow release of the particle and also for reducing vertical and horizontal leachability.

Field experiment

Weed flora

Weed species vegetation in the screening trial consists of *Dinebra retroflexa, Echinochloa colonum, Amaranthus viridis, Calotropis gigantea, Corchorus trilocularis, Euphorbia thymifolia, Malachra capitata, Parthenium hysterophorus, Portulaca oleracea, Trianthema portulacastrum.* All these weeds were occurred in main field trial I and II also except *Calotropis gigantea* and *Parthenium hysterophorus.* Among these most dominant weed species were grasses. Similar findings were observed by Dayan *et al.* (1996).

Screening trial

Effect of weed management treatments on weeds

The higher weed density was observed in unweeded control respectively at 20, 40 and 60 DAS. Lower weed density was noticed in the treatments T_7 (Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^+$ at 2 DAS) and T_8 (Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^+$ at 3 DAS) at 20 and 40 DAS respectively. But at 60 DAS

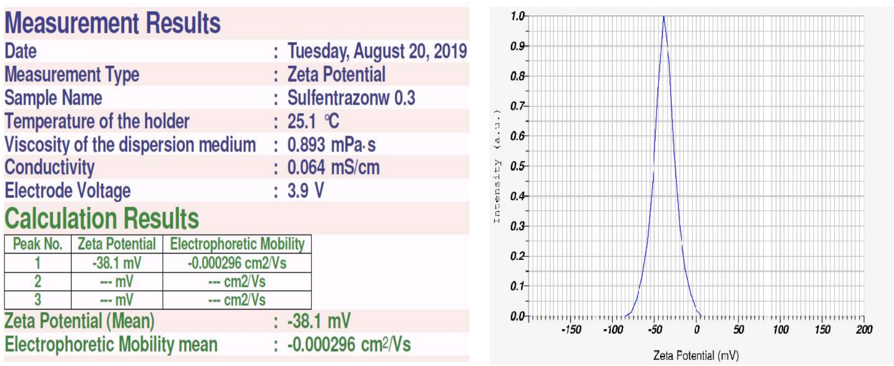


Fig 5: Zeta potential values for encapsulated sulfentrazone herbicide.

Table 1. Effect of weed management treatments on total weed density, Seed, Hull and Haulm yield of blackgram in screening trial.

T. No	Treatments	Total weed density (No. m^{-2})			Seed yield (kg ha^{-1})	Hull yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
		20 DAS	40 DAS	60 DAS			
T_1	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^+$ at 1 DBS	1.46 (1.67)	1.56 (2.00)	1.86 (3.00)	1349	587	3851
T_2	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^+$ at 1 DAS	4.74 (22.00)	5.37 (28.33)	6.12 (37.00)	809	352	2337
T_3	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^+$ at 2 DAS	1.68 (2.33)	1.86 (3.00)	2.54 (6.00)	1276	555	3646
T_4	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^+$ at 3 DAS	1.56 (2.00)	1.77 (2.67)	2.65 (6.67)	1062	462	3366
T_5	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^+$ at 1 DBS	1.34 (1.33)	1.46 (1.67)	1.77 (2.67)	1355	589	3842
T_6	Sulfentrazone @ 0.40 kg a.i.ha^{-1} e$^+$ at 1 DAS	4.41 (19.00)	5.01 (24.67)	5.76 (32.67)	783	341	2292
T_7	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^+$ at 2 DAS	0.71 (0.00)	0.88 (0.33)	2.19 (4.33)	1095	476	3238
T_8	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^+$ at 3 DAS	0.71 (0.00)	0.88 (0.33)	2.34 (5.00)	1099	478	3250
T_9	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^-$ at 1 DBS	2.04 (3.67)	2.41 (5.33)	3.31(10.67)	1249	543	3562
T_{10}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^-$ at 1 DAS	5.18 (26.33)	5.84 (33.67)	6.74 (45.00)	761	331	2238
T_{11}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^-$ at 2 DAS	2.34 (5.00)	2.48 (5.67)	3.17 (9.67)	1182	514	3338
T_{12}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e$^-$ at 3 DAS	2.18 (4.33)	2.41 (5.33)	3.26 (10.33)	945	411	2734
T_{13}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^-$ at 1 DBS	1.66 (2.33)	1.93 (3.33)	3.02 (8.67)	1184	515	3353
T_{14}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^-$ at 1 DAS	4.84 (23.00)	5.52 (30.00)	6.41 (40.67)	706	307	2061
T_{15}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^-$ at 2 DAS	2.04 (3.67)	2.20 (4.33)	2.95 (8.33)	795	346	2309
T_{16}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e$^-$ at 3 DAS	2.11 (4.00)	2.20 (4.33)	3.02 (8.67)	825	359	2422
T_{17}	Absolute control	9.19 (84.00)	10.17 (103.00)	11.08 (122.33)	328	142	1434
	SEd	0.20	0.17	0.22	49	21	191
	CD (P= 0.05)	0.40	0.35	0.45	100	44	389

Data subjected to square root ["(X + 0.5)] transformation. Values in parenthesis are means of original values

e$^+$ - with encapsulation e$^-$ - without encapsulation DBS – Day before sowing DAS – Day(s) after sowing.

lower weed density was noticed in T_1 (Sulfentrazone @ 0.30 kg a.i.ha^{-1} e^+ at 1 DBS) and T_5 (Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^+ at 1 DBS) (Table 1). The results were in conformity with the findings of Srivastava (2003). He proved that in hand weeded plot weed density was 43.53 m^{-2} whereas in the sulfentrazone (0.8 L ha^{-1}) treated plot the weed density was only 0.90 m^{-2}.

Effect of weed management treatments on blackgram crop

Plant height (cm) was lesser in all the sulfentrazone applied treatments compared to absolute control (15.87 and 49.73)

Table 2: Effect of weed management treatments on plant height and plant dry weight of blackgram in screening trial.

T. No	Treatments	Plant height (cm)			Plant dry weight (g plant^{-1})		
		20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
T_1	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^+ at 1 DBS	13.27	43.60	54.27	1.88	7.73	16.83
T_2	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^+ at 1 DAS	13.77	42.70	49.73	1.76	4.26	10.35
T_3	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^+ at 2 DAS	13.43	43.77	54.73	1.87	7.22	15.95
T_4	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^+ at 3 DAS	12.93	40.83	50.57	1.78	6.92	14.73
T_5	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^+ at 1 DBS	13.13	43.03	53.50	1.86	7.71	16.90
T_6	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^+ at 1 DAS	13.53	42.47	49.47	1.75	4.14	10.04
T_7	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^+ at 2 DAS	12.87	38.83	48.50	1.65	5.82	14.11
T_8	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^+ at 3 DAS	12.83	38.53	47.40	1.65	6.04	14.19
T_9	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^- at 1 DBS	13.10	41.10	53.63	1.84	7.46	15.63
T_{10}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^- at 1 DAS	13.70	41.83	47.87	1.75	4.17	9.77
T_{11}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^- at 2 DAS	13.30	42.03	53.50	1.83	7.16	14.83
T_{12}	Sulfentrazone @ 0.30 kg a.i. ha^{-1} e^- at 3 DAS	12.33	37.83	42.83	1.61	6.03	11.98
T_{13}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^- at 1 DBS	12.77	41.57	49.63	1.83	7.10	14.84
T_{14}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^- at 1 DAS	13.20	37.17	42.53	1.75	4.00	9.11
T_{15}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^- at 2 DAS	12.13	30.37	38.27	1.58	6.16	10.18
T_{16}	Sulfentrazone @ 0.40 kg a.i. ha^{-1} e^- at 3 DAS	12.07	31.90	40.53	1.56	5.39	10.54
T_{17}	Absolute control	15.87	49.73	55.07	1.79	3.44	6.23
	SEd	0.70	2.28	2.56	0.18	0.40	0.72
	CD (P= 0.05)	1.42	4.64	5.22	NS	0.81	1.47

Table 3. Effect of weed management treatments on density of total weeds (No. m^{-2}) in main trial I and II.

T. No.	Treatments	Main trial I			Main trial II		
		20DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
T_1	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e^+ at 1 DBS	0.71 (0.00)	1.39 (1.67)	2.03 (3.67)	0.71 (0.00)	1.47 (2.00)	1.77 (2.67)
T_2	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e^- at 1 DBS	1.10 (1.00)	1.93 (3.33)	2.66 (6.67)	1.00 (0.67)	2.02 (3.67)	2.32 (5.00)
T_3	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e^+ at 2 DAS	2.60 (6.33)	2.74 (7.33)	3.76 (13.67)	2.83 (7.67)	3.19 (9.67)	3.74 (13.67)
T_4	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e^- at 2 DAS	2.73 (7.00)	2.91 (8.00)	4.22 (17.33)	3.00 (8.67)	3.69 (13.33)	4.22 (17.33)
T_5	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* Quizalofop-ethyl @ 50 g a.i. ha^{-1} and Imazethapyr @ 50 g a.i. ha^{-1} at 20 DAS	4.13 (16.67)	2.73 (16.67)	4.29 (7.00)	5.04 (18.00)	3.02 (25.00)	4.14 (8.67)
T_6	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* 1 HW at 20 DAS	4.11 (16.67)	3.39 (11.00)	3.71 (13.33)	4.90 (23.67)	3.62 (12.67)	3.87 (14.67)
T_7	HW twice at 15 and 30 DAS	0.71 (0.00)	1.77 (2.67)	3.56 (12.33)	0.71 (0.00)	1.93 (3.33)	3.62 (12.67)
T_8	Weed free check	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T_9	Absolute control	9.99 (99.33)	10.67 (113.33)	11.68 (136.00)	11.70 (136.67)	12.38 (153.00)	12.65 (159.67)
	SEd	0.29	0.28	0.27	0.37	0.33	0.27
	CD(P= 0.05)	0.62	0.59	0.56	0.78	0.70	0.57

Data subjected to square root [“(X + 0.5)] transformation. Values in parenthesis are means of original values.

at 20 and 40 DAS. But at 60 DAS the plant height was on par in T_1, T_3, T_4, T_5, T_9 and T_{11} with the control (55.07) (Table 2). In case of plant dry weight (g plant^{-1}) at 20 DAS there was no significant difference among the treatments. At 40 and 60 DAS more dry weight was noticed in T_1, T_3, T_5, T_9 and T_{11} compared to unweeded control (Table 2).

Seed yield, hull yield and haulm yield (kg ha^{-1}) of blackgram were higher in sulfentrazone @ 0.30 (T_1) and 0.40 (T_5) kg a.i. ha^{-1} at 1 DBS which are 1349, 587 and 3851 kg ha^{-1} in T_1 and 1355, 589 and 3842 kg ha^{-1}, respectively (Table 1). Similar results were recorded by Krausz *et al*. (1998) in soybean when sulfentrazone applied @ 0.42 kg a.i. ha^{-1}.

Main trial I and II

Effect of weed management treatments on weeds

Zero weed density was noticed with the application of encapsulated sulfentrazone at 1 DBS (T_1), hand weeding at 15 and 30 DAS (T_7) and weed free plot (T_8) in both the trials at 20 DAS. Very low weed density was observed in T_1 and T_2 (sulfentrazone without encapsulation applied at 1 DBS) and T_7 in both the trials at 40 and 60 DAS. All the other treatments also noticed lower weed population compared to absolute control in both main trials (Table 3). The results were in conformity with the findings of Srivastava (2003). In case of pendimethalin similar weed density was observed by Gupta *et al*. (2013).

Effect of weed management treatments on blackgram crop

In plant dry matter at 20 DAS there was no significant difference among the treatments. At 40 and 60 DAS more plant dry weight was noticed in all the treatments compared to control (Table 4). Seed yield, hull yield and haulm yield of blackgram were higher in T_1, T_2, T_5, T_7 and T_8 in both trials (Table 5). There was no significant difference in harvest

Table 4. Effect of weed management treatments on dry matter production (g plant^{-1}) of blackgram in main trial I and II.

T. No.	Treatments	Main trial I			Main trial II		
		20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
T_1	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 1 DBS	1.73	6.43	14.63	1.79	6.67	15.43
T_2	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 1 DBS	1.73	6.37	14.50	1.77	6.61	15.34
T_3	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 2 DAS	1.69	6.29	14.33	1.72	6.53	15.18
T_4	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 2 DAS	1.68	6.24	14.07	1.69	6.48	14.98
T_5	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* Quizalofop-ethyl @ 50 g a.i. ha^{-1} and Imazethapyr @ 50 g a.i. ha^{-1} at 20 DAS	1.72	6.38	14.41	1.77	6.63	15.27
T_6	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* 1 HW at 20 DAS	1.73	6.35	14.37	1.76	6.59	15.24
T_7	HW twice at 15 and 30 DAS	1.75	6.45	14.76	1.78	6.70	15.60
T_8	Weed free check	1.77	6.51	14.84	1.82	6.76	15.73
T_9	Absolute control	1.71	2.69	5.41	1.74	2.80	5.77
	SEd	0.16	0.30	0.82	0.20	0.31	0.74
	CD(P= 0.05)	NS	0.64	1.74	NS	0.66	1.57

Table 5. Effect of weed management treatments on seed yield (kg ha^{-1}), hull or bhusa yield (kg ha^{-1}), haulm yield (kg ha^{-1}) and harvest index of blackgram in main trial I and II.

T. No.	Treatments	Main trial I				Main trial II			
		Seed yield	Hull yield	Haulm yield	Harvest index	Seed yield	Hull yield	Haulm yield	Harvest index
T_1	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 1 DBS	1229	539	3588	0.23	1303	564	3687	0.23
T_2	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 1 DBS	1214	533	3555	0.23	1272	551	3666	0.23
T_3	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 2 DAS	1123	493	3514	0.22	1177	510	3628	0.22
T_4	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 2 DAS	1095	480	3451	0.22	1134	491	3578	0.22
T_5	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* Quizalofop-ethyl @ 50 g a.i. ha$^-$ and Imazethapyr @ 50 g a.i. ha^{-1} at 20 DAS	1218	534	3534	0.23	1231	533	3649	0.23
T_6	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* 1 HW at 20 DAS	1150	505	3524	0.22	1192	516	3640	0.22
T_7	HW twice at 15 and 30 DAS	1282	563	3620	0.24	1327	575	3726	0.24
T_8	Weed free check	1301	571	3640	0.24	1388	601	3758	0.24
T_9	Absolute control	381	167	1362	0.20	374	162	1375	0.20
	SEd	120	53	201	0.02	123	53	172	0.02
	CD(P= 0.05)	255	112	427	NS	261	113	365	NS

Table 6. Effect of weed management treatments on economics of blackgram in main trial I and II

T. No.	Treatments	Main trial I and II*			
		Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 1 DBS	27685	92233	64548	3.33
T_2	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 1 DBS	27135	90063	62928	3.32
T_3	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^+$ at 2 DAS	27685	84064	56379	3.04
T_4	Sulfentrazone @ 0.3 kg a.i. ha^{-1} e$^-$ at 2 DAS	27135	81513	54378	3.00
T_5	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* Quizalofop-ethyl @ 50 g a.i. ha^{-1} and Imazethapyr @ 50 g a.i. ha^{-1} at 20 DAS	28385	89314	60929	3.15
T_6	Pendimethalin @ 1.0 kg a.i. ha^{-1} at 2 DAS *fb* 1 HW at 20 DAS	31925	85535	53610	2.68
T_7	HW twice at 15 and 30 DAS	33895	95005	61110	2.80
T_8	Weed free check	36175	97812	61637	2.70
T_9	Absolute control	24775	27808	3033	1.12

* Average values of main trial I and II were taken for calculating economics

Data not statistically analysed.

index of all the treatments (Table 5). Higher gross returns (92,233 Rs ha^{-1}), net returns (64,548 Rs ha^{-1}) and B:C ratio (3.33) were acquired in T_1 followed by T_2 and least Gross returns (27,808 Rs ha^{-1}) and net returns (3,033 Rs ha^{-1}) and B:C ratio (1.12) were acquired in absolute control (Table 6). The results were supported by the findings of Shruthi and Salakinkop (2015).

CONCLUSION

In the laboratory experiment nano-encapsulated sulfentrazone herbicide was synthesized and characterized by using SEM and PSA which proved that the sulfentrazone was encapsulated perfectly and the size also reduced much compared to non-encapsulated (normal) sulfentrazone. In addition the zeta potential of encapsulated one is in correct range which made that powerful and stable. Then the synthesized encapsulated sulfentrazone was tested in the field experiment for its selectivity, efficacy and to optimize time and dosage of application. On the basis of both laboratory and field experiment (screening trial) it might be concluded that sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation and without encapsulation applied at 1 DBS and 2 DAS were produced lesser weed density and higher plant dry weight, seed yield. Even though both T_1 and T_5 are giving better results, T_1-sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation applied at 1 DBS is economically feasible to the farmer for getting higher gross returns, net returns and B:C ratio. These better performing treatments in screening trial were compared with other herbicides and weeding methods in main field trial I and II. These trials revealed that sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation applied at 1 DBS was given lower weed density and higher seed yield, gross returns (92233 Rs ha^{-1}), net returns (64,548 Rs ha^{-1}) and B:C ratio (3.33). This concluded that sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation applied at 1 DBS is better alternative for the season long weed management in blackgram without affecting the soil and ground water, as well as increasing the productivity.

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