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Enhancing Zn nutrition uptake efficiency in groundnut with *Pseudomanas chloraphis* in zinc deficient soil under rainfed and irrigated condition

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Abstract
The experiment trial was conducted at Oilseeds Research Station, Tindivanam during 2021– 2023, to evaluate the response of *Pseudomonas Chloraphis* in enhancing Zinc uptake efficiency in Groundnut crop in Zinc deficient soil under rainfed and irrigated condition. In this study Zinc solubilising bacteria *Pseudomonas Chloraphis* was applied in Groundnut as seed treatment 1 kg/ha and soil application 2 kg/ha with different levels of $ZnSO_4$ *viz*., 100 % (25 kg $ZnSO_4$), 75 %(18.5 kg $ZnSO_4$), 50 % (12.5 kg $ZnSO_4$) as basal application. The results revealed that the application of recommended dose of fertilizer along $ZnSO_4$ (12.5 kg/ha) + Zinc solubilizing bacteria (ZSB15) recorded significant increase in plant height with 52.7 cm respectively and nodule count with 83.0 respectively on par with application of recommended dose of fertilizer $ZnSO_4$ (25 kg/ha) + Zinc solubilizing bacteria (ZSB15)) with 86.6. The *Rhizobium* population was enumerated and the maximum population of 29.5 $x10^3$ cfu/ml was recorded with application of Zinc solubilising bacteria (T_4). The yield attributes the number of pods and pod yield was recorded significant in the treatments with application of Zn solubilising bacteria with $ZnSO_4$. Maximum yield of 18.63 and 1758 kg/ha respetively, was recorded with application of $ZnSO_4$ - 12.5 kg/ha with Zinc solubilising bacteria in seed treatment and for soil application. Exogenous application of zinc sources, similar to fertilizer application has been advocated to various crops. This causes transformation of about 96 to 99 percent of applied available zinc to various unavailable forms. The zinc thus, made unavailable can be reverted back to available form by inoculating bacterial strain capable of solubilizing it. Since zinc is a limiting factor in crop production, this study on zinc solubilization by bacteria has an immense importance in zinc nutrition to plant.

Keywords: Groundnut, zinc deficient soil, ZSB 15, *Pseudomonas Chloraphis*, rainfed, irrigated

Introduction
India is blessed with the agro-ecological condition favourable for growing nine major oilseeds including seven edible oilseed namely groundnut, rapeseed, mustard, soybean, sunflower, safflower, sesame and niger and two non-edible sources, namely castor and linseed, apart from wide range of other minor oilseeds and oil bearing species. Among all the oilseed crops, groundnut occupies the first place in India accounting for more than 28% of acerage and 32% of production in the country. However, except for castor, the productivity of oilseed crops in India is one of the lowest in the world. In India, the major cause for increased zinc deficiency is the adoption of intensive cultivation, imbalanced nutrient application generally devoid of zinc and dispensing with organic manures and the very nature of soils predominated with high pH, calcareous and low in organic matter content (Behera *et al*., 2011) [2]. In this context, there should be a paradigm shift toward developing strategies to overcome zinc deficiency, increasing crop yields and improve human health. Zinc deficiency is currently listed as a major risk factor for human health and cause of death globally. Zinc is known to occur in a number of discreet chemical forms varying in their solubility and availability to crop plants. These includes presence in soil solutions as ionic or organically complexed species, exchange sites of soil organic and inorganic colloids, complexed with organic matter, occluded in oxides and hydrous oxides of Fe, Al and Mn, and entrapped in primary and secondary silicate minerals (Han *et al*., 2011; Behera *et al*., 2011) [8, 2]. To increase zinc availability, fertilization of food crops with Zn represents a short-term and complementary strategy, which is necessary to build the Zn pool for uptake or

translocation (Cakmak, 2008) [3], whereas, plant breeding strategy (genetic biofortification) appears to be a most sustainable, affordable and cost-effective approach useful in improving Zn concentrations in grain. In this context, the use of beneficial rhizosphere microorganisms as bio-inoculants to increase availability of native zinc to crop assimilation and achieve the objective of low-input and sustainable agriculture (He *et al*., 2010) [9] and to overcome zinc malnutrition in human populations (Mäder *et al*., 2010) [12] could be a viable option. Among the bacterial species, strains belonging to the genera Acinetobacter, Bacillus, Gluconacetobacter and Pseudomonas have been reported (Fasim *et al*., 2002) [5] as zinc solubilizers, fertilizers and manures, to enhance soil fertility and crop productivity has often negatively affected the complex biogeochemical cycles (Steinshamn *et al*., 2004) [13]. Exogenous application of zinc sources, similar to fertilizer application has been advocated to various crops. This causes transformation of about 96 to 99 percent of applied available zinc to various unavailable forms. The zinc thus, made unavailable can be reverted back to available form by inoculating bacterial strain capable of solubilizing it. Since zinc is a limiting factor in crop production, this study on zinc solubilization by bacteria has an immense importance in zinc nutrition to plant. Thus, keeping this in the view, the present study has planned on Effect of Zinc Solublizing Bacteria enhancing Zinc use efficiency and yield of Summer Groundnut.

Materials and Methods

The field experiment were conducted in Oilseeds Research Station, Tindivanam in Groundnut crop (TMV 13) during 2021-22 and 2022-23 under rainfed and irrigated condition in Groundnut in randomized block design with four replication on the soil deficient in Zinc (0.69 ppm). The experiment is fixed with six treatments and four replications and the design was RBD. The treatments were T_1 – RDF (STCR) + 100 % of $ZnSO_4$ (25 kg/ha) + Zn Biofertilizer (ZSB15), T_2 – RDF (STCR) + 75 % of $ZnSO_4$ (18.75 kg/ha) + Zn Biofertilizer (ZSB15), T_3- RDF (STCR) + 50% of $ZnSO_4$ (12.5 kg/ha) + Zn Biofertilizer (ZSB15), T_4 - RDF (STCR) + Zn Biofertilizer (ZSB15), T_5 – RDF (STCR) + $ZnSO_4$ (25 kg/ha), T_6 – RDF (STCR) (Control).

The Zinc solubilsing bacteria applied as Zinc solubilising bacteria @ 1 kg/ha as seed treatment and 2kg/ha for soil application. The culture Zinc solubilising bacteria – *Pseudomonas chlororaphis* was obtained from Department of Agricultural Microbiology. Two packets of each biofertilizers were used for seed treatment and for soil application 2kg of each biofertilizer was mixed with 25 kg and applied before sowing. Biometric observation *viz*., plant stand, plant height, number of branches, nodule count and at harvest stage was recorded. Yield attributes *viz*., no of pods per plant, pod yield was recorded. The data were statistically analyzed.

The experimental trial was conducted in soil with sandy clay loam in nature with 6.9 pH, EC 0.25 dSm^{-1}, Available N – 185 kg/ha, Available P – 23 kg/ha, Available K – kg/ha, available Zn content is 0.68 ppm with the same set of treatments. Observations on plant stand, growth and yield attributes were recorded. The microbial population and soil nutrient analysis were done at different stages of growth to analyse the Zn use efficiency and the results are furnished in the Table (1-5).

Results and Discussion

Effect of Pseudomonas Chlororaphis on enhancing plant growth in Groundnut

Zinc solubilising bacteria *Pseudomonas Chloraphis* was applied in Groundnut as seed treatment 1 kg/ha and soil application 2 kg/ha with different levels of $ZnSO_4$ *viz*., 100 % (25 kg $ZnSO_4$), 75 %(18.5 kg $ZnSO_4$), 50 % (12.5 kg $ZnSO_4$) as basal application. The results revealed that the application of recommended dose of fertilizer along $ZnSO_4$ (12.5 kg/ha) + Zinc solubilizing bacteria (ZSB15) recorded significant increase in plant height with 52.7 cm respectively and nodule count with 83.0 respectively on par with application of recommended dose of fertilizer $ZnSO_4$ (25 kg/ha) + Zinc solubilizing bacteria (ZSB15)) with 86.6. The *Rhizobium* population was enumerated and the maximum population of 29.5 $x10^3$ cfu/ml was recorded with application of Zinc solubilising bacteria (T_4).

Effect of Pseudomonas Chlororaphis on enhancing Pod count and yield in Groundnut

The yield attributes the number of pods and pod yield was recorded significant in the treatments with application of Zn solubilising bacteria with $ZnSO_4$. Maximum yield of 18.63 and 1758 kg/ha respetively, was recorded with application of $ZnSO_4$ - 12.5 kg/ha with Zinc solubilising bacteria in seed treatment and for soil application. In Groundnut application of Zinc solubilising bacteria @ 1 kg/ha as seed treatment and 2kg/ha for soil application along with 12.5 kg/ha $ZnSO_4$ with STCR based fertilizer recommendation under rainfed condition, recorded maximum pods/plant (18.8) and pod yield with 1758 kg/ha (23%) over NPK alone and under irrigated condition pod yield with 2450 kg/ha with 24% increase in yield over NPK alone. In sesame crop application of Zinc solubilising bacteria @ 1 kg/ha as seed treatment and 2kg/ha for soil application along with 12.5 kg/ha $ZnSO_4$ with STCR based fertilizer recommendation under rainfed condition, recorded maximum capsules of 109.5/plant and yield with 808 kg/ha (15.5 %) over control and under irrigated condition recorded recorded maximum capsules of 109.5/plant and yield with 842 kg/ha with 14% increase in yield over NPK alone.The exogenous application of zinc sources, similar to fertilizer application has been advocated to various crops. This causes transformation of about 96 to 99 percent of applied available zinc to various unavailable forms. The zinc thus, made unavailable can be reverted back to available form by inoculating bacterial strain capable of solubilizing it.

Zinc use efficiency

Zinc use efficiency of groundnut influenced by different treatments are presented in table 5 which revealed that highest zinc use efficiency was recorded in treatment T_3 (8.1 g g^{-1}) and T_4 (6.34 g g^{-1}). The increased in nutrient use efficiency may be due to solubilizing of Zn from Zinc sulphate by Zn solubilizing bacteria which reflected on increased in uptake of total N, P, K, Fe, Zn, Mn and Cu by groundnut.

Table 1: Effect of Zinc solubilising bacteria on growth & yield of Groundnut under Rainfed condition (I - Crop) (2021-22)

Treatment	Plant stand/20 m^2	Plant height (cm)	No. of branches	No of nodules/plant	*Rhizobium* population (10^5 cfu/ml)	No. of pods/plant	Pod yield (kg/ha)	BC ratio
T_1 – RDF (STCR) + $ZnSO_4$ (25 kg/ha) + Zn Biofertilizer (ZSB15)	609	47.0	4.6	69.8	20.9	15.2	1763	2.05
T_2- RDF (STCR) + $ZnSO_4$ (18.5 kg/ha) + Zn Biofertilizer (ZSB15)	607.5	45.7	5.0	71.5	21.5	15.0	1765	2.14
T_3 – RDF (STCR) + $ZnSO_4$ (12.5 kg/ha) + Zn Biofertilizer (ZSB15)	609.5	45.3	5.2	69.0	23.4	15.5	1771	2.32
T_4 - RDF (STCR) + Zn Biofertilizer (ZSB15)	602	44.7	4.7	68.5	25.5	14.0	1645	1.85
T_5 – RDF (STCR) + $ZnSO_4$ (25 kg/ha)	599	43.3	4.5	62.5	20.5	14.0	1675	1.72
T_6 – RDF (STCR) (Control)	583	43.75	4.2	53.5	19.3	11.0	1512	1.14
Mean	601.17	44.96	4.70	65.80	21.85	14.15	1688.5	
SEd	13.09	2.75	0.26	13.25		0.93	8.18	
CD(0.05)	45.43	8.47	0.79	40.20		2.79	24.66	

Table 2: Effect of Zinc solubilising bacteria on growth & yield of Groundnut under Irrigated condition (I - Crop) (2021-22)

Treatment	Plant stand/20 m^2	Plant height (cm)	No. of branches	No of nodules/plant	*Rhizobium* population (10^5cfu/ml)	No. of pods/plant	Pod yield (kg/ha)	BC ratio
T_1 – RDF (STCR) + $ZnSO_4$ (25 kg/ha) + Zn Biofertilizer (ZSB15)	645	51.2	5.8	72.6	23.3	26.5	2543	1.97
T_2- RDF (STCR) + $ZnSO_4$ (18.5 kg/ha) + Zn Biofertilizer (ZSB15)	629	50.5	6.0	78.5	23.5	25.7	2545	2.01
T_3 – RDF (STCR) + $ZnSO_4$ (12.5 kg/ha) + Zn Biofertilizer (ZSB15)	635	52.9	6.2	79.0	25.4	26.2	2552	2.04
T_4 - RDF (STCR) + Zn Biofertilizer (ZSB15)	626	47.7	5.7	72.5	24.5	18.5	2387	1.90
T_5 – RDF (STCR) + $ZnSO_4$ (25 kg/ha)	612	50.3	5.5	62.5	22.5	21.4	2435	1.86
T_6 – RDF (STCR) (Control)	605	48.75	4.7	60.5	20.3	14.5	2158	1.85
Mean	625.33	50.23	5.65	70.93	23.25	22.13	2466	
SEd	0.29	0.11	0.28	4.91	0.29	1.12	74.35	
CD(0.05)	NS	NS	NS	10.32	NS	2.75	156.2	

Table 3: Effect of Zinc solubilising bacteria on growth & yield of Groundnut under Rainfed condition (II - Crop) (2022-23)

Treatment	Plant stand/20 m^2	Plant height (cm)	No. of branches	No of nodules/plant	*Rhizobium* population (10^5cfu/ml)	No. of pods/plant	Pod yield (kg/ha)	BC ratio
T_1 – RDF (STCR) + $ZnSO_4$ (25 kg/ha) + Zn Biofertilizer (ZSB15)	612.5	47.15	4.6	72.95	19.25	18.05	1749	2.3
T_2- RDF (STCR) + $ZnSO_4$ (18.5 kg/ha) + Zn Biofertilizer (ZSB15)	610.5	46.52	4.4	75.13	20.88	18.25	1737	2.3
T_3 – RDF (STCR) + $ZnSO_4$ (12.5 kg/ha) + Zn Biofertilizer (ZSB15)	611.0	48.35	4.8	76.25	26.40	18.63	1758	2.4
T_4 - RDF (STCR) + Zn Biofertilizer (ZSB15)	607.5	46.57	4.4	77.88	29.38	15.75	1557	1.9
T_5 – RDF (STCR) + $ZnSO_4$ (25 kg/ha)	592.0	42.25	4.6	68.13	22.63	16.25	1546	1.7
T_6 – RDF (STCR) (Control)	590.5	40.36	4.6	62.13	16.13	13.50	1419	1.3
Mean	604.00	45.20	4.57	72.08	22.45	16.74	1646	
SEd	7.52	8.09	0.39	2.79		0.52	82.98	
CD(0.05)	NS	NS	NS	5.86		1.12	176.86	

Table 4: Effect of Zinc solubilising bacteria on growth & yield of Groundnut under Irrigated condition (II - Crop) (2022-23)

Treatment	Plant stand/20 m^2	Plant height (cm)	No. of branches	No of nodules/plant	*Rhizobium* population (10^5cfu/ml)	No. of pods/plant	Pod yield (kg/ha)	BC ratio
T_1 – RDF (STCR) + $ZnSO_4$ (25 kg/ha) + Zn Biofertilizer (ZSB15)	647.5	47.6	5.6	86.6	21.5	21.6	2375	2.05
T_2- RDF (STCR) + $ZnSO_4$ (18.5 kg/ha) + Zn Biofertilizer (ZSB15)	642.4	48.3	6.3	84.3	25.3	21.2	2363	2.10
T_3 – RDF (STCR) + $ZnSO_4$ (12.5 kg/ha) + Zn Biofertilizer (ZSB15)	645.5	52.7	5.6	86.3	27.5	23.6	2450	2.55
T_4 - RDF (STCR) + Zn Biofertilizer (ZSB15)	634.2	52.2	6.3	94.6	29.5	23.5	2175	1.94
T_5 – RDF (STCR) + $ZnSO_4$ (25 kg/ha)	623.5	53.2	5.3	75.6	21.5	22.7	2137	1.84
T_6 – RDF (STCR) (Control)	616.5	43.7	5.3	69.3	19.3	18.5	1975	1.56
Mean	634.93	49.62	5.73	84.45	24.106	21.85	2245.83	
SEd	0.29	0.11	0.28	4.91		1.12	130.06	
CD(0.05)	1.04	NS	NS	10.32		2.75	277.22	

Conclusion

The application of Pseudomonas chlororaphis, a zinc-solubilizing bacteria, significantly enhanced plant growth, pod count, and yield in groundnut. The treatment combining $ZnSO_4$ at 12.5 kg/ha with the bacteria resulted in the highest plant height, nodule count, and Rhizobium population. Moreover, this combination led to a substantial increase in pod yield (23%) under rainfed conditions and 24% under irrigated conditions compared to NPK alone. Additionally, zinc use efficiency improved, with the highest recorded at 8.1 g/g in the T_3 treatment. These results highlight the potential of using zinc-solubilizing bacteria to improve nutrient uptake, enhance growth, and increase yield in groundnut cultivation.

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