DoI: https://doi.org/10.58537/jorangrau.2025.53.5.04

J. Res. ANGRAU 53 (5) 15-25, 2025

RESPONSE OF COLOURED RICE CULTIVARS TO ZINC NUTRITION

K. HIMASRI, K. ANNY MRUDHULA*, MANUKONDA SRINIVAS and A.J. SUVARNA LATHA

Agricultural College, Bapatla - 522101,
Acharya N.G. Ranga Agricultural University, Guntur, Andhra Pradesh, India

Date of Receipt : 26.09.2025 Date of Acceptance : 05.11.2025

ABSTRACT

An experiment was conducted in the Farm of agricultural college, Bapatla, during *kharif,* 2023 to examine the response of zinc foliar fertilisation on the growth, yield attributes, yield and nutrient uptake of coloured rice (*Oryza sativa* L.). The experiment was laid by using split-plot design with three replications. The main plot contained four rice cultivars: M_1- Navara, M_2- BPT-2858, M_3- BPT-2841 and M_4- Kujipatalia. In the sub-plots, $ZnSO_4$ foliar spraying was done at various stages: S_1- No zinc, S_2- Application of $ZnSO_4$ @ 0.2% at tillering stage, S_3- Application of $ZnSO_4$ @ 0.2% at tillering and panicle initiation stages and S_4- Application of $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting stages. The results indicated that the Kujipatalia variety (M_4) produced the maximum number of tillers, dry matter accumulation, productive tillers per square meter, panicle length, total grains per panicle, grain yield (4480 kg ha^{-1}), straw yield, harvest index, and nutrient uptake. Foliar application of ZnSO„ at 0.2% during the tillering, panicle initiation, and booting stages (S_4) was found to be significantly superior to other treatments, except for S_3. Conversely, the Navara variety (M_1), when not received foliar zinc application, recorded the lowest values of all the parameters of coloured rice cultivars. However, it displays Kujipatalia variety shows highest yield and yield attributes relative to the other cultivars.

Keywords: Coloured rice; Growth; Nutrient uptake; Yield; Zinc fertilization.

INTRODUCTION

Rice has gained notable prominence in recent years, particularly among individuals who emphasize nutritional benefits (Mrudula *et al.,* 2023) while also appreciating its cultural and traditional significance. Among the coloured rice cultivars, different shades of black rice and red rice cultivars are popular in cultivation and germplasm improvement programmes. Black rice has a profound impact on culinary traditions and cultural activities, starting from its roots in Asia and continuing to its current comeback in world cuisine. Black rice had gained significant interest among coloured rice cultivars due to its sensory attributes (Ito and Lacerda, 2019).

Continuous use of primary nutrients alone has resulted in zinc (Zn) deficit in the majority of the rice-growing soils of the worldand in particular Andhra Pradesh, leading to inadequate zinc supplementation. The Zn deficiency in rice-eating regions like Andhra Pradesh is at risk from inadequate Zn intake.

**Corresponding author email id:* anny.mrudula@gmail.com

The levels of zinc in both polished and unpolished rice are naturally insufficient to fulfil the human body's requirements for this essential mineral . Zn deficiency also limits rice yields (Mrudula *et al*., 2023) and its availability is limited under high soil pH and bicarbonate conditions.

In addition to the non-coloured cultivars, coloured rice cultivars are evaluated for insufficient Zn to alleviate Zn malnutrition (Rakotondramanana *et al*., 2024).Enhancing the zinc concentration in rice can be addressed through foliar fertilisation. Foliar fertilization contributes more than soil application for increasing Zn concentration in rice, as assessed by immediate crop response to applied nutrients.Different cultivars of rice showed wide variation in grain and straw yield, uptake both with and without Zn application (Prakash *et al*., 2018) and in different environments (Wissuwa *et al*.,2008. Researchers worked on the time of application to correct the Zn deficiency and yield enhancement and concluded that correcting the zinc deficiency and application time at heading, flowering, and early milk stage (Fongfon *et al*., 2021) enhanced the yield. Limited research was reported on black-coloured rice cultivars response to different foliar nutrition of Zn on growth, yield attributes, and grain nutrient uptake and their effect on grain yield of rice. Hence the present study was under taken.

MATERIAL AND METHODS

The experiment was conducted during the *Kharif* season of 2023 at the Agricultural College Farm, Bapatla, Andhra Pradesh, India. The experimental site is situated at a longitude of 80.30^0 East and a latitude of 15.54^0 North, with an elevation of 5.49 metres. The soil at the experimental site is classified as sandy clay loam, with a pH of 7.2 and an electrical conductivity of 0.21 dS m^{-1}. It contains medium levels of organic carbon (0.45%) and phosphorus (38.2 kg ha^{-1}), but is deficient in nitrogen (235.2 kg ha^{-1}) and zinc (0.29 ppm). The mean maximum temperature recorded during the cropping period was 33.2ºC, while the average minimum temperature was 23.7ºC. In 2023, the cumulative rainfall recorded during the cropping season was 900.8 mm. The study was conducted using a split-plot design with three replications. The main plot included four different rice cultivars: M_1- Navara, M_2- BPT-2858, M_3- BPT-2841, and M_4- Kujipatalia. In the sub-plots, foliar application of $ZnSO_4$ at various stages. S_1 - No zinc; S_2- application of $ZnSO_4$ at a concentration of 0.2% during the tillering stage; S_3 - application of $ZnSO_4$ at a concentration of 0.2% during the tillering and panicle initiation stages; and S_4 - application of $ZnSO_4$ at a concentration of 0.2% during the tillering, panicle initiation, and booting stages were individually evaluated. Twenty-five-day-old seedlings were transplanted at a spacing of 20 cm × 15 cm. The recommended fertilizer dose of 120:60:40 kg N, P_2O_5 and K_2O ha^{-1} was applied in split doses at the basal, tillering, and panicle initiation stages. Other crop management practices were followed as per standard recommendations. The recorded data were subjected to statistical analysis using Fisher's method of analysis of variance as described by Panse and Sukhatme (1978).

RESULTS AND DISCUSSION

Table 1 indicated that at harvest, the Navara variety exhibited significantly greater plant height (138.8 cm) compared to all other varieties, except BPT-2841. The tallest plants were observed under the application of $ZnSO_4$ during the tillering, panicle initiation, and booting stages (S_4), whereas the shortest plants were recorded under the control treatment without zinc application (S_1). Mandal and Ghosh (2021) reported that zinc enhances plant height through its role in chlorophyll synthesis, enzyme activation, and stomatal

Table 1. Plant height (cm) of coloured rice varieties at harvest influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				
	S_1: No zinc	S_2 : Tillering stage	S_3:Tillering and panicle stages	S_4: Tillering, panicle initiation and booting stages	Mean initiation
M_1: Navara	127.1	138.4	143.0	146.8	138.8
M_2: BPT-2858	118.9	127.9	130.5	138.4	128.9
M_3: M_3: BPT-2841	117.2	123.6	124.5	128.4	123.4
M_4: Kujipatalia	118.6	123.0	124.5	127.5	123.4
Mean 120.5	128.2	130.6	135.3		
SEm+	CD (0.05)	CV (%)			
Main plot	3.4	11.6	9.0		
Sub plot4.6	13.6	12.5			
(M X S)					
S at same M	8.0	23.5			
M at same or different S	7.5	21.1			

regulation. Adequate zinc availability promotes enzymatic activity and auxin metabolism, thereby contributing to increased plant height. The maximum plant height was achieved with the Navara variety in combination with $ZnSO_4$ application

As presented in Table 2, among the colored rice cultivars tested, Kujipatalia produced the highest drymatter, followed by BPT-2858 and Navara. The maximum drymatter accumulation was observed when $ZnSO_4$ was applied at the tillering, panicle initiation, and booting stages, followed by its application at the tillering and panicle initiation stages. Zinc supplementation enhanced the synthesis of tryptophan and indole-3-acetic acid (IAA), which are key factors contributing to both fresh and dry biomass production (Tetarwal *et al.* 2011).No zinc application treatment recorded the lowest drymatter. Suresh and Salakinkop (2016) observed that Zn increased photosynthetic rate and nutrient uptake, thereby increasing plant drymatter production. The highest drymatter production was recorded with Kujipatalia variety with $ZnSo_4$ @ 0.2% application at tillering, panicle initiation and booting stages and the lowest drymatter production was recorded with navara variety with no zinc application.

Cultivars and zinc fertilisation significantly affected productive tiller number (Table 3). The Kujipatalia (319 m^{-2}) reported maximum productive tillers, followed by the BPT-2841 variety (312m^{-2}), BPT-2858 variety (273m^{-2}) and Navara variety (245m^{-2}). Zinc fertilization applied at the tillering, panicle initiation, and booting stages resulted in the highest number of productive tillers (304 m^{-2}), followed by 294 m^{-2} and 285 m^{-2} in the subsequent treatments. Mustafa *et al.,* (2011) reported that adequate zinc supply enhances the uptake and availability of essential nutrients, thereby improving plant metabolic processes and overall crop growth. In the

Table 2. Drymatter production (kg ha^{-1}) of coloured rice varieties at harvest influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	7338	7325	7300	7373	7334
M_2: BPT-2858	9150	9439	10013	10698	9825
M_3: M_3: BPT-2841	8746	9625	10167	10692	9808
M_4: Kujipatalia	9408	9513	9835	10951	9927
Mean 8660	8976	9329	9929		
SEm+	CD (0.05)	CV (%)			
Main plot	238.0	823	8.9		
Sub plot 318.4	657	8.5			
(M X S)					
S at same M	551.5	1138			
M at same or different S	559.5	1097			

Table 3. Number of productive tillers (m^{-2}) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	234	248	243	253	245
M_2: BPT-2858	262	271	277	283	273
M_3: M_3: BPT-2841	270	308	327	344	312
M_4: Kujipatalia	299	312	327	337	319
Mean 266	285	294	304		
SEm+	CD (0.05)	CV (%)			
Main plot	6.9	24	8.4		
Sub plot 7.4	22	9.0			
(M X S)					
S at same M	12.8	37			
M at same or different S	12.6	35			

Table 4. Panicle length (cm) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	20.3	21.1	21.8	22.3	21.4
M_2: BPT-2858	20.7	21.3	21.9	22.6	21.6
M_3: BPT-2841	20.9	21.6	22.9	23.3	22.1
M_4: Kujipatalia	21.4	22.0	23.2	23.5	22.5
Mean	20.8	21.5	22.5	22.9	
SEm+	CD (0.05)	CV (%)			
Main plot	0.45	NS	8.1		
Sub plot 0.34	1.0	9.3			
(M X S)					
S at same M	0.58	1.7			
M at same or different S	0.64	2.9			

absence of zinc application, the number of productive tillers was significantly lower (266 m^{-2}). The interaction effect between zinc fertilization and colored rice cultivars was also significant. The Kujipatalia variety, when supplemented with $ZnSO_4$ at tillering, panicle initiation and booting had at the tillering, panicle initiation, and booting stages, recorded the highest number of productive tillers (404 m^{-2}), whereas the lowest count was observed in the Navara variety under the control treatment without zinc application.

Panicle length did not alter significantlyamong the coloured rice cultivars, but zinc fertilisation influenced panicle length. With zinc fertilisation at tillering, panicle initiation and booting produced the longest panicles (22.5 cm)as presented in Table 4. Welch and Graham (2008) suggested that zinc's role in protein synthesis, membrane function, and cell elongation may explain the increase in panicle length. Welch *et al.* (2008) reported that the improvement in panicle length might be attributed to the vital role of zinc in maintaining the structural ability of cell membranes and its use in protein synthesis, membrane function and cell elongation. The Kujipatalia variety with $ZnSO_4$at tillering, panicle initiation and booting had the longest panicles, while the Navara variety with no zinc had the shortest panicles.

Coloured rice cultivars and Zinc fertilisation increased number of grains $panicle^{-1}$. Kujipatalia cultivar (255) had recorded the highest grains $panicle^{-1}$ followed by BPT-2841 (250) and BPT-2858 (244).Zinc fertilization at different growth stages significantly increased the number of grains per panicle. The application of ZnSO□ at the tillering, panicle initiation, and booting stages produced the highest grain count per panicle (249). Fergany (2018) reported that foliar application of zinc at three intervals resulted in the maximum number of grains per panicle.

Table 5.Total no. of grains panicle[-1] of coloured rice varieties influenced by zinc Fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	178	182	186	190	184
M_2: BPT-2858	229	239	246	263	244
M_3: M_3: BPT-2841	235	242	254	269	250
M_4: Kujipatalia	241	245	259	274	255
Mean	221	227	236	249	
SEm+	CD (0.05)	CV (%)			
Main plot	3.7	13	9.6		
Sub plot4.0	11	10.0			
(M X S)					
S at same M	7.0	20			
M at same or different S	6.8	19			

Table 6.Spikelet sterility (%) of coloured rice varieties influenced byzinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	17.8	16.9	17.1	16.4	17.0
M_2: BPT-2858	16.0	15.2	14.2	12.5	14.4
M_3: M_3: BPT-2841	14.1	13.3	12.5	11.7	12.9
M_4: Kujipatalia	14.2	13.4	12.4	11.7	12.9
Mean	15.5	14.7	14.1	13.1	
SEm+	CD (0.05)	CV (%)			
Main plot	0.2	0.7	8.3		
Sub plot0.3	0.8	9.9			
(M X S)					
S at same M	0.5	1.5			
M at same or different S	0.5	2.9			

Table 7. Test weight (g) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				Mean
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	
M_1: Navara	18.5	18.5	18.5	18.6	18.5
M_2: BPT-2858	12.1	12.1	12.2	12.2	12.1
M_3: M_3: BPT-2841	13.1	13.5	13.6	13.8	13.5
M_4: Kujipatalia	14.6	14.8	14.8	14.9	14.8
Mean	14.6	14.7	14.8	14.9	
SEm+	CD (0.05)	CV (%)			
Main plot	0.24	0.8	5.7		
Sub plot 0.41	NS	9.6			
(M X S)					
S at same M	0.71	2.1			
M at same or different S	0.65	2.9			

The Kujipatalia cultivar with $ZnSO_4$ at tillering, panicle initiation and booting hadat tillering, panicle initiation and booting had the higher grains panicle^{-1}, while the Navara cultivar with no zinc had the lowest grains panicle^{-1}.

Data in Table 6 shows that the spikelet sterility varied significantly on both the coloured rice varieties and zinc fertilization.In case of varieties, Kujipatalia variety (12.9%) and BPT-2841(12.9%) variety has recorded significantly thelowest spikelet sterility percent while,significantlythe highest spikelet sterility percent was recorded with Navara variety (17.0%).

Among the zinc fertilization treatments, the lowest spikelet sterility percentage (13.1%) was recorded with the foliar application of ZnSO„ at 0.2% during the tillering, panicle initiation, and booting stages. In contrast, the highest sterility percentage (15.5%) was observed under the control treatment without zinc application. Foliar application of zinc has been reported to enhance pollen grain viability, thereby reducing sterility (Karim *et al.,* 2012). Similar findings were documented by Kandil *et al*. (2022). The interaction between rice cultivars and zinc fertilization was also significant. The Kujipatalia variety, when supplied with ZnSO„ at the critical growth stages, exhibited the lowest spikelet sterility, whereas the Navara variety under the control treatment without zinc application recorded the highest sterility percentage.

As per Table 7, test weight differed significantly only by cultivar but not by zinc fertilisation.The cultivar Navara (18.5 g) and BPT-2858 (12.1 g) had the highest and lowest test weights, respectively. There was no statstically significant difference in zinc fertilisation treatments. The Navara variety with $ZnSO_4$ @ 0.2% at tillering, panicle initiation and booting had the highest test weight, while the BPT-2858 variety with no zinc had the lowest.

Table 8.Grain yield (kg ha^{-1}) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	Foliar application of $ZnSo_4$ @ 0.2%				
	S_1: No zinc	S_2: Tillering stage	S_3:Tillering and panicle initiation stages	S_4: Tillering, panicle initiation and booting stages	Mean
M_1: Navara	2980	3330	3474	3489	3318
M_2: BPT-2858	3426	3461	4114	4470	3868
M_3: M_3: BPT-2841	3327	4300	4459	4661	4187
M_4: Kujipatalia	4201	4387	4640	4694	4480
Mean 3484	3869	4172	4328		
SEm+	CD (0.05)	CV (%)			
Main plot	100.90	349	8.8		
Sub plot 103.39	302	9.0			
(M X S)					
S at same M	179.08	523			
M at same or different S 178.01		493			

Grain yield (Table 8) was significantly influenced by colored rice cultivars, zinc fertilization, and their interaction. The Kujipatalia variety recorded the highest grain yield (4480 kg ha^{-1}), which was statistically comparable to BPT-2841 (4187 kg ha^{-1}), while the Navara variety produced the lowest yield (3318 kg ha^{1}. The maximum grain yield (4328 kg ha^{-1}) was obtained with foliar application of $ZnSO_4$ at tillering, panicle initiation and booting hadat 0.2% during the tillering, panicle initiation, and booting stages, which was on par with $ZnSO_4$ at tillering, panicle initiation and booting had application at the tillering and panicle initiation stages (4172 kg ha^{-1}). In contrast, the minimum yield (3484 kg ha^{-1}) was observed under the control treatment without zinc application. Wang *et al.* (2023) reported that foliar zinc application significantly enhances grain yield by increasing spikelet number per panicle, filled grain percentage, and 1000-grain weight. Similar findings were also documented by Xia *et al.* (2018) and Chen *et al*. (2022). The highest yield was achieved with the Kujipatalia variety in combination with $ZnSO_4$ at tillering, panicle initiation and booting had application at all three critical stages, whereas the lowest yield was recorded with the Navara variety under the control treatment.

Straw yield was significantly influenced by colored rice cultivars and zinc fertilization. The maximum straw yield was obtained with the Kujipatalia variety (5374 kg ha^{-1}), followed by BPT-2841 (5255 kg ha^{-1}), while Navara variety recorded the lowest yield (4116 kg ha^{-1}). Among the zinc fertilization treatments, the highest straw yield (5221 kg ha^{-1}) was achieved with $ZnSO_4$ application at the tillering, panicle initiation and booting stages, which was statistically comparable to $ZnSO_4$ application at the tillering and panicle initiation stages (5071 kg ha^{-1}). In contrast, the lowest straw yield

Table 9.Straw yield (kg ha^{-1}) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	**Foliar application of $ZnSo_4$ @ 0.2%**				**Mean**
	S_1: No zinc	**S_2: Tillering stage**	**S_3:Tillering and panicle initiation stages**	**S_4: Tillering, panicle initiation and booting stages**	
M_1: Navara	3739	4006	4364	4354	4116
M_2: BPT-2858	4460	4276	5082	5385	4801
M_3: M_3: BPT-2841	4805	5185	5473	5557	5255
M_4: Kujipatalia	5231	5313	5363	5589	5374
Mean	4559	4695	5071	5221	
SEm+	CD (0.05)	CV (%)			
Main plot	94.6	327	8.9		
Sub plot 98.9	289	9.2			
(M X S)					
S at same M	171.2	500			
M at same or different S	169.4	470			

Table 10. Harvest index (%) of coloured rice varieties influenced by zinc fertilization

Coloured rice varieties	**Foliar application of $ZnSo_4$ @ 0.2%**				**Mean**
	S_1: No zinc	**S_2: Tillering stage**	**S_3:Tillering and panicle initiation stages**	**S_4: Tillering, panicle initiation and booting stages**	
M_1: Navara	43.7	44.0	44.1	44.5	44.1
M_2: BPT-2858	43.4	44.6	44.7	46.0	44.7
M_3: BPT-2841	41.0	45.4	45.6	45.6	44.4
M_4: Kujipatalia	44.5	45.2	46.2	46.3	45.6
Mean	43.2	44.8	45.1	45.6	
SEm+	CD (0.05)	CV (%)			
Main plot	0.4	1.0	3.1		
Sub plot 0.51	1.0	4.0			
(M X S)					
S at same M	0.89	2.67			
M at same or different S	0.84	2.52			

(4559 kg ha^{-1}) was observed under the control treatment without zinc application. Singh *et al.* (2021) reported that zinc application positively influences vegetative growth by enhancing plant height, tiller number, leaf area, and dry matter accumulation, thereby contributing to higher straw yield. A significant interaction was also observed between rice cultivars and zinc fertilization. The Kujipatalia variety, when supplied with $ZnSO_4$ at all three critical stages, produced the highest straw yield, whereas the Navara variety under the control treatment recorded the lowest.

The harvest index (Table10) was significantly influenced by colored rice cultivars and zinc fertilization. The highest harvest index was recorded in the Kujipatalia variety (45.6%), while the lowest was observed in the Navara variety (44.1%). With respect to zinc fertilization, the maximum harvest index (45.6%) was obtained under ZnSO□ application at 0.2% during the tillering, panicle initiation, and booting stages, which was statistically comparable to $ZnSO_4$ application at the tillering and panicle initiation stages (45.1%) and at the tillering stage alone (44.8%). In contrast, the lowest harvest index (43.2%) was recorded under the control treatment without zinc application. Mohapatra *et al.* (2021) reported that zinc application significantly enhances the harvest index of rice. A significant interaction effect was also observed between cultivars and zinc fertilization. The Kujipatalia variety, when combined with $ZnSO_4$ application at all three critical stages, recorded the highest harvest index, whereas the BPT-2841 variety under the control treatment without zinc application exhibited the lowest.

CONCLUSION

The results revealed that the maximum grain yield (3,489 kg ha^{-1}) and straw yield (4,364 kg ha^{-1}) were obtained with Kujipatalia variety while, foliar zinc fertilization at all three stages *viz.,* tillering, panicle initiation and booting stages was an effective approach to increase yield of coloured rice cultivars through $ZnSO_4$ application which reduces the problem of zinc deficiency.

REFERENCES

Chen, M. R., White, P. J., Hammond, J. P., Zelko, I and Lux, A. 2022. Zinc in plants. New Phytologist,173: 677-702.

Fongfon, S., Prom-u-thai, C., Pusadee, T. and Jamjod, S. 2021. Responses of purple rice genotypes to nitrogen and zinc fertilizer application on grain yield, nitrogen, zinc, and anthocyanin concentration. Plants, 10(8): 1717. doi:10.3390/plants10081717.

Ito, V.C. and Lacerda, L.G. 2019. Black rice (*Oryza sativa* L.): a review of its historical aspects, chemical composition, nutritional and functional properties and applications and processing technologies. Food Chemistry, 301: 125304. doi:10.1016/ j.foodchem.2019.125304.

Karim, H. C., Cakmak, I and Graham, R. D. 2012. Effect of different levels of zinc on growth and uptake ability in rice zinc contrast lines (*Oryza Sativa* L.). Plant and Soil*,* 192: 191-197.

Mandal, S. and Ghosh, G.K. 2021. Response of rice (*Oryza sativa* L.) to soil and foliar application of nano-ZnO and bulk Zn-fertilizer in red acidic soil of West Bengal, India. Egyptian Journal of Soil Science, 61(2): 287–310. doi:10.21608/ EJSS. 2020. 47255. 1394.

Mohapatra, K.K., Singh, S.K. and Patra, A. 2021. Influence of varying levels of zinc on yield and zinc biofortification in hybrid rice (*Oryza sativa* L.) grown in moderate zinc soil. Journal of Indian Society of Soil Science, 69(2): 220–223.

Mrudula, A.K., Krishnaveni, B., Suneetha, Y., Sunil, K.M. and Naik, B.S.S. 2023. Effect of nutrient management on growth, yield and quality parameters of black rice. Ecology Environment & Conservation, 29: 181–186.

Mustafa, G., Ehsanullah, N., Akbar, S.A., Qaisrani, A., Iqbal, H. and Khan, Z. 2011. Effect of zinc application on growth and yield of rice (*Oryza sativa* L.). International Journal of Agricultural Sciences and Veterinary Medicine, 5(6): 530–535.

Panse, V.G. and Sukhatme, V.G. 1978. Statistical Methods for Agricultural Workers. 2nd Edn. Indian Council of Agricultural Research.

Prakash Chand, G., Shivay, Y.S., Pooniya, V., Choudhary, M. and Verma, R.K. 2018. Zinc partitioning in basmati rice varieties as influenced by Zn fertilization. The Crop Journal, doi:10.1016/j.cj.2017.09.001.

Rakotondramanana, M., Wissuwa, M., Ramanankaja, L., Razafimbelo, T., Stangoulis, J. and Grenier, C. 2024. Stability of grain zinc concentrations across lowland rice environments favors zinc bio-fortification breeding. Frontiers in Plant Science, 15: 1293831.

Singh, A., Singh, N.B., Afzal, S., Singh, T. and Hussain, I. 2021. Zinc oxide nanoparticles: A review of their biological synthesis, antimicrobial activity, uptake, translocation, and biotransformation in plants. Journal of Materials Science, 53: 185–201. doi:10.1007/s10853-020-05197-1.

Suresh, S. and Salakinkop, S.R. 2016. Growth and yield of rice as influenced by biofortification of zinc and iron. Journal of Farm Sciences, 29(4): 443–448.

Tetarwal, S., Khamparia, R. S and Singh, S. 2011. Effect of zinc and organic manures on yield attributes and yield of rice. Journal of Bioinfolet, 10 (3A): 879-881.

Wang, R., Mi, K., Yuan, X., Chen, J., Pu, J., Shi, X., Yang, Y., Zhang, H and Zhang, H. 2023. Zinc oxide nanoparticles foliar application effectively enhanced zinc and aroma content in rice (*Oryza sativa* L.). Rice, 16: 36.

Welch, R.M. and Graham, R.D. 2008. Breeding strategies for biofortified staple plant foods to reduce micronutrient malnutrition globally. Journal of Nutrition, 132: 495–499. doi:10.1093/jn/132.3.495.

Wissuwa, M., Ismail, A.M. and Graham, R.D. 2008. Rice grain zinc concentrations as affected by genotype, native soil-zinc availability and zinc fertilization. Plant and Soil, 306: 37–48.

Xia, H., Xue, Y., Liu, D., Kong, W., Xue, Y., Tang, Y., Li, J., Li, D and Mei, P. 2018. Rational application of fertilizer nitrogen to soil in combination with foliar Zn spraying improved Zn nutritional quality of wheat grains. Frontier in Plant Sciences,9:677.

Himasri, K., Mrudhula,A.K., Srinivas,M. and Latha,S.A..2025. Response of coloured rice cultivars to zinc nutrition. The Journal of Research ANGRAU,53(5): 15-25