Response of Traditional Aromatic Rice (*Oryza Sativa* L.) Cultivars to Zinc Fertilization Strategies under Eastern Himalayan Region

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***Abstract*—** *The present study aimed to evaluate the effect of zinc fertilization strategies on growth, yield, and nutrient uptake in two traditional aromatic rice cultivars, Tulaipanji and Kalonunia, under acidic soil conditions of North Bengal. The field experiment was conducted during the kharif seasons of 2022 and 2023 at Uttar Banga Krishi Viswavidyalaya, Pundibari, using a Split Plot Design with three replications. The main plot comprised two varieties, while the sub-plot included six zinc management treatments, involving combinations of soil-applied, foliar-applied, and nano zinc sources.*

Results revealed significant varietal differences, with Kalonunia consistently outperforming Tulaipanji in terms of plant height, number of tillers, chlorophyll index, grain yield, and nutrient uptake. Among zinc treatments, the integrated application of 2.5 kg Zn ha^{-1} *as basal + 100 ppm nano Zn foliar at panicle initiation + 0.5% Zn foliar spray at grain filling* (Z_3) *showed superior performance across both years.* Z_3 *recorded the highest grain yield (2.77 t ha*$^{-1}$*), grain number per panicle (121.69), and maximum uptake of nitrogen, phosphorus, potassium, and zinc in straw. This enhanced performance is attributed to improved zinc bioavailability and the synergistic action of multiple application timings and forms.*

The findings emphasize the efficacy of integrated zinc management, particularly involving nano and foliar zinc application, in enhancing yield and nutritional quality of aromatic rice cultivars. Such strategies hold promises for sustainable crop production and combating micronutrient malnutrition in zinc-deficient regions.

Keywords*— *Aromatic rice, nano zinc, biofortification, zinc fertilization, nutrient uptake, yield enhancement, Kalonunia, Tulaipanji.

I. INTRODUCTION

Rice is a staple food for the Asia-Pacific region, contributing approximately 21% of global energy and 15% of protein requirements (Sengupta *et al.,* 2019). Among rice types, aromatic rice occupies a niche segment known for its aroma, fine grain, and superior cooking quality. West Bengal holds a rich diversity of traditional aromatic landraces, including Tulaipanji and Kalonunia, which are medium-grained types valued both domestically and for export potential (Mondal *et al.,* 2011).

Despite its importance, rice is nutritionally poor, particularly in micronutrients like zinc (Zn) and iron (Kumar *et al.,* 2020). Micronutrient malnutrition or "hidden hunger" is widespread among resource-poor populations, largely due to low Zn bioavailability in cereal-based diets (Bouis and Saltzman, 2017). Zinc plays a vital role in numerous physiological and biochemical processes including enzyme activity, gene expression, photosynthesis, and stress tolerance (Hefferon, 2019). Moreover, higher Zn in rice straw is crucial for livestock nutrition in developing countries.

Agronomic biofortification, especially using Zn fertilizers, has emerged as a strategy to improve Zn content in grains, thereby enhancing both human and animal nutrition (WHO, 2002). Ahmed *et al.,* 2021 also found tallest plant and maximum leaves of maize with soil application of 10 kg Zn ha $^{-1}$. Recent advances advocate the use of zinc nanoparticles (ZnNPs), which offer controlled nutrient release, improved uptake efficiency, environmental safety, and economic benefits (Iqbal *et al.*, 2020). Thus, ZnNPs hold promise for enhancing rice yield and nutritional quality, particularly in aromatic cultivars with export value. Based on above mentioned fact present study was undertaken at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar during two consecutive *kharif* 2022 and 2023 to study the comparative response of zinc fertilization on traditional aromatic cultivars.

II. MATERIALS AND METHODS

Present research was conducted at the instructional farm of Uttar Banga Krishi Viswavidyalya, Pundibari, Cooch Behar, West Bengal during the *kharif* season of 2022 and 2023. The experiment was fitted out in Split Plot Design with three replications. The main plot included two variety: V_1- Tulaipanji and V_2 - Kalonunia and sub plot treatment consisting of Z_1 - 5 kg Zn (soil) as basal, Z_2 - 2.5 kg Zn (soil) as basal + 2.5 kg (soil) maximum tillering, Z_3 - 2.5 kg Zn (soil) as basal+100 ppm nano Zn at PI + 0.5% Zn FA at grain filling, Z_4 - 0.5% Zn FA at PI + 0.5% FA at grain filling, Z_5 -100 ppm nano Zn at PI + 100 ppm nano Zn at grain filling, Z_6 - Control. Soil of the experimental field was acidic in reaction having pH value 5.84 with medium in organic carbon (0.69%), low in available nitrogen (169.27 kg ha^{-1}), medium in available phosphorus (18.91 kg ha^{-1}), potassium (140.82 kg ha^{-1}) and available zinc (0.77 mg kg^{-1}). The both varieties used in the experiment sown in 23rd July and 28th July during 2022 & 2023 respectively, with a row to row and plant to spacing of 25 x 20 cm. Plot size of 5 m x 4 m was maintained along with seed rate @ 30 kg ha^{-1}. Vermicompost @ 3 t ha^{-1} was applied as basal in each plot. Weather conditions of the experimental period included a total rainfall of 2602.50 mm and 3169.30 mm for 2022 and 2023 respectively, and an average maximum and minimum temperature range of 33.56 °C to 8.49°C in 2022 and 32.86°C to 12.70 °C in 2023 during the June to December.

Soil application of zinc through Zinc Sulphate Heptahydrate (21% Zn), foliar application through Chelated Zinc (Zinc EDTA 12% Zn) and nano zinc refers to a product from Sisco Research Laboratories (SRL) that involves zinc nanoparticles, specifically zinc oxide nanoparticles (ZnO NPs, 50nm, 99.9%). Standard agronomic practices were followed to keep the field devoid of weeds, insects and fungi.

Key growth parameters including plant height, number of tillers m^{-2} and chlorophyll were recorded 30 days interval starting from 30 days after sowing to harvest. Among the yield attributes total no of grain panicle^{-1}, spikelet sterility was recorded at harvest from randomly selected plants. Grain from the corresponding net plot area were sun dried for 4 days and then threshing was done. The grain weight of individual plot was recorded and was converted to tonnes ha^{-1}. The experimental data were analysed using statistical software SPSS version-20. For determination of critical difference at 5% level of significance Fisher and Yates (1963) table was consulted.

TABLE 1
RESPONSE OF ZINC FERTILIZATION ON GROWTH ATTRIBUTES OF AROMATIC RICE CULTIVARS

Treatments	Plant Height (cm)				No of tiller m^{-2}				Chlorophyll Index			
	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT
Variety												
V_1	64.14	108.70	119.54	127.28	223.91	330.81	280.29	257.40	213.04	168.98	101.49	67.83
V_2	68.33	122.73	133.05	138.04	298.37	383.06	320.14	294.05	220.28	183.43	105.12	70.33
SE m (±)	0.81	1.07	1.43	1.47	4.21	4.06	4.27	4.82	4.57	3.18	1.32	0.77
CD (P=0.05)	3.17	4.19	5.62	5.79	16.53	15.93	16.77	18.38	17.94	12.50	5.21	3.01
Zinc management												
Z_1	70.84	117.78	124.26	128.91	276.70	377.70	279.92	260.33	230.96	179.17	99.26	64.92
Z_2	68.06	120.25	125.72	130.97	264.94	386.61	290.49	268.82	219.41	184.89	102.86	69.04
Z_3	67.79	115.74	130.54	139.15	263.81	366.40	332.76	300.61	217.92	175.61	109.40	77.04
Z_4	64.03	114.28	128.65	136.62	255.97	342.91	319.28	290.13	212.20	173.32	107.93	72.75
Z_5	63.95	113.37	127.19	134.56	252.94	335.51	307.99	283.87	210.34	172.70	107.11	71.90
Z_6	62.75	112.87	121.42	125.73	252.50	332.49	270.84	250.61	209.12	171.55	93.27	58.84
SE m (±)	1.10	1.98	1.95	2.08	4.22	5.88	4.57	7.49	3.58	2.62	2.02	1.13
CD (P=0.05)	3.13	5.69	5.57	5.93	12.07	16.80	13.06	21.40	10.22	7.49	5.76	3.22

III. RESULTS AND DISCUSSION

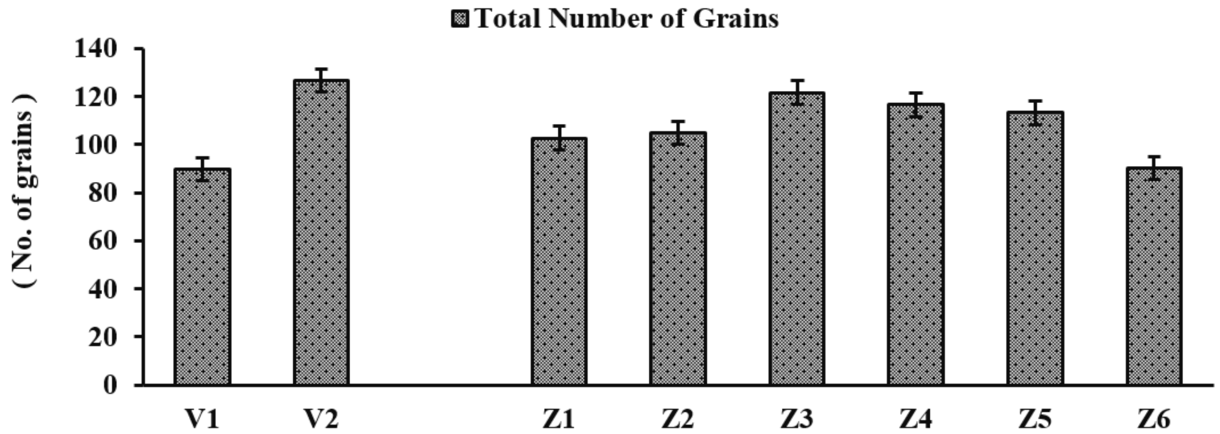
3.1 Growth parameters:

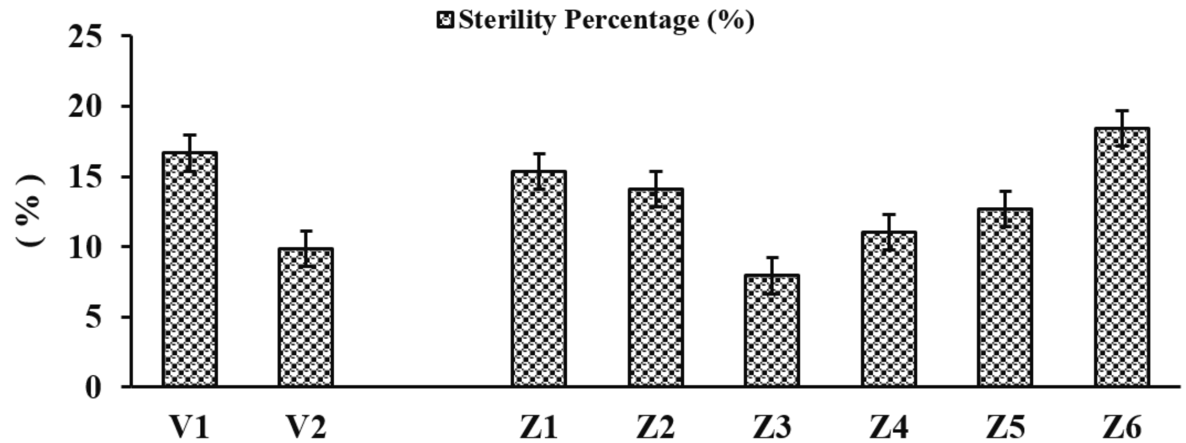
Plant height (cm), no of tiller m^{-2} is a critical agronomic trait directly associated with the overall biomass accumulation, photosynthetic potential, and sink capacity of cereal crops like rice. Based on the pooled results, a significant varietal influence on plant height, no of tiller and chlorophyll index was observed across all growth stages of aromatic rice. Kalonunia (V_2) consistently recorded greater plant height, no of tiller and chlorophyll index than Tulaipanji (V_1), demonstrating its superior vegetative vigour and growth potential (Table 1). This consistent superiority in plant stature observed in Kalonunia can be attributed to its intrinsically robust plant architecture, better nutrient responsiveness, and efficient translocation of assimilates.

Among the level of zinc at 30 days after transplanting (DAT), Z_1 (5 kg Zn ha^{-1} as basal) resulted the highest plant hight (70.84 cm), no of tiller m^{-2} (276.70) and chlorophyll index (230.96). At 60 DAT, the tallest plant hight (120.25 cm), highest no of tiller m^{-2} (386.61) and chlorophyll index (184.89) were recorded under Z_2. At 90 DAT and harvest stage, the highest plant height (130.54 cm and 139.15 cm, respectively), no of tiller m^{-2} (332.76 and 300.61) and chlorophyll index (108.40 and 77.04) was obtained in Z_3 followed by Z_4 (0.5% foliar Zn at PI + grain filling), while Z_6 registered the lowest values. These treatments help delay senescence, improve nutrient mobilization, and support assimilate partitioning, which collectively sustain productive tillers through to maturity, (Broadley *et al.,* 2007). These findings underscore the importance of foliar and nano zinc application during the panicle initiation and grain filling stages. Zinc is known to improve chlorophyll synthesis and delay senescence, thus prolonging the photosynthetic duration and promoting further growth (Fageria *et al.,* 2002).

3.2 Yield attributes and yield:

Yield components such as total no of grain $panicle^{-1}$, grain yield (t ha^{-1}), sterility % a significant variation was observed as influenced by varietal differences (Fig. 1). Among the two aromatic rice cultivars, Kalonunia (V_2) exhibited higher grain count $panicle^{-1}$ (126.78) and grain yield (2.48 t ha^{-1}), whereas Tulaipanji recorded highest sterility (16.66%). Better responsiveness of Kalonunia to zinc fertilization may be attributed to improved nutrient uptake and assimilate partitioning towards reproductive structures, thereby resulting in greater yield.





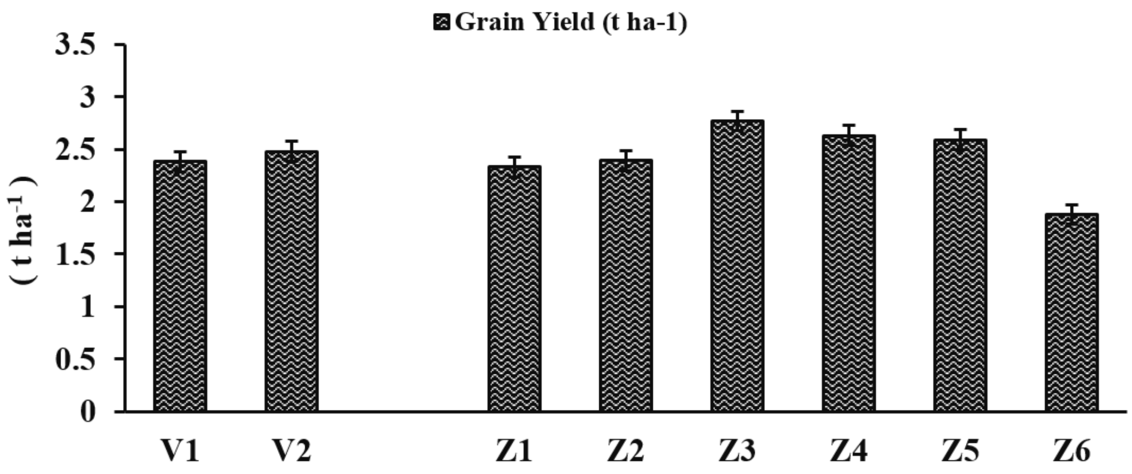


FIGURE 1: Response of Zinc Fertilization on Yield Attributes and Yield of Aromatic Rice Cultivars

Among the various zinc management treatments, the treatment Z_3 (2.5 kg Zn (soil) as basal + 100 ppm nano Zn at PI + 0.5% Zn FA at grain filling) resulted the highest no of grain panicle^{-1} (121.69) and grain yield (2.77 t ha^{-1}) this was followed by Z_4 (116.64 and 2.63 t ha $^{-1}$), Z_5 (113.26 and 2.59 t ha^{-1}). The markedly lower yield observed under the control treatment Z_6. Whereas the higher sterility percentage obtained from the Z_6 treatment (18.45 %) followed by Z_1 and Z_2. The superior performance of Z_3 can be attributed to the synergistic effect of basal, nano, and foliar zinc applications, which likely improved zinc availability during key phenological stages, enhanced enzymatic activities, and promoted efficient assimilate translocation and spikelet fertility, culminating in higher grain yield (Alloway, 2008; Cakmak, 2008).

3.3 Uptake of nitrogen, phosphorus, potassium and zinc in straw:

In case of nutrient uptake V_2 (Kalonunia) obtained highest nitrogen (31.08 & 38.32 kg ha^{-1}), phosphorus (6.45 & 8.64 kg ha^{-1}), potassium (53.60 & 64.28 kg ha^{-1}) and zinc (125.89 & 156.04 g ha^{-1}) uptake respectively during 2022 and 2023 over V_1 (Tulaipanji) (Table 2). This enhanced uptake capacity in Kalonunia may be attributed to its superior nutrient remobilization efficiency and enhanced translocation dynamics which enhance the nutrient uptake in straw.

TABLE 2
RESPONSE OF ZINC FERTILIZATION ON NUTRIENT UPTAKE BY AROMATIC RICE CULTIVARS

Treatments	Nitrogen uptake by straw (kg ha^{-1})		Phosphorus uptake by straw (kg ha^{-1})		Potassium uptake by straw (kg ha^{-1})		Zinc uptake by straw (g ha^{-1})	
	2022	2023	2022	2023	2022	2023	2022	2023
Variety								
V_1	26.74	32.71	6.02	8.22	49.48	60.61	104.19	136.48
V_2	31.08	38.32	6.45	8.64	53.60	64.28	125.89	156.04
SE m (±)	1.11	1.49	0.04	0.05	0.32	0.42	1.37	2.71
CD (P=0.05)	NS	NS	0.26	0.30	1.94	2.53	8.33	16.47
Zinc management								
Z_1	26.40	32.39	6.02	8.29	48.00	59.76	94.28	126.02
Z_2	27.68	34.22	6.04	8.35	49.58	60.72	106.60	140.59
Z_3	35.77	41.96	6.65	8.94	58.63	69.54	164.70	198.31
Z_4	32.14	39.27	6.42	8.63	55.16	65.85	134.31	164.12
Z_5	30.24	38.08	6.38	8.58	54.44	64.67	121.30	151.73
Z_6	21.21	27.17	5.90	7.81	43.41	54.15	69.06	96.79
SE m (±)	1.07	1.27	0.20	0.18	1.84	1.03	6.36	5.71
CD (P=0.05)	3.15	3.76	0.59	0.77	5.43	3.04	18.75	16.85

Application of 2.5 kg Zn (soil) as basal + 100 ppm nano Zn at PI + 0.5% Zn FA at grain filling (Z_3) recorded significantly highest nitrogen (35.77 & 41.96 kg ha^{-1}), phosphorus (6.65 & 8.94 kg ha^{-1}), potassium (58.63 & 69.54 kg ha^{-1}) and zinc (164.70 & 198.31 g ha^{-1}) uptake respectively during 2022 and 2023 followed by Z_4 (0.5% Zn FA at PI + 0.5% at grain filling) and Z_5 (100 ppm nano Zn at PI + 100 ppm nano Zn at grain filling). The use of nano zinc, in particular, is known to increase zinc bioavailability due to its higher surface area and reactivity, enabling more efficient nutrient uptake and utilization by plant tissues (Dimkpa & Bindraban, 2016).

IV. CONCLUSION

The present investigation demonstrated that varietal differences and zinc management practices significantly influenced the growth, yield, and nutrient uptake of aromatic rice under acidic soil conditions of North Bengal. Among the two tested cultivars, Kalonunia (V_2) consistently outperformed Tulaipanji (V_1) in terms of plant height, tiller number, chlorophyll index, grain yield, and nutrient uptake, highlighting its superior vegetative vigor and efficient resource use.

Zinc application strategies significantly enhanced growth parameters and yield components. The integrated treatment involving basal soil application of zinc along with foliar and nano zinc application at critical phenological stages (Z_3: 2.5 kg Zn ha^{-1} as basal + 100 ppm nano Zn at panicle initiation + 0.5% Zn foliar spray at grain filling) was found to be the most effective. This treatment consistently recorded the highest grain yield, grain count $panicle^{-1}$, and uptake of nitrogen, phosphorus, potassium, and zinc in both years of study. The effectiveness of Z_3 may be attributed to improved zinc bioavailability and synergistic effects of multiple application modes, enhancing enzymatic activity, spikelet fertility, and nutrient translocation during critical growth stages.

The findings underscore the potential of nano and foliar zinc fertilization, in conjunction with conventional soil application, to boost the productivity and nutritional quality of aromatic rice cultivars especially those like Kalonunia with strong genetic potential. These results support the use of integrated zinc management as a sustainable agronomic approach for improving rice yield and addressing zinc malnutrition in resource-poor regions.

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