DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007 *Int. J. Exp. Res. Rev.*, **Special Vol. 40: 90-103 (2024)**

Original Article | *Peer Reviewed* | *Open Access*

International Journal of Experimental Research and Review (IJERR)
© Copyright by International Academic Publishing House (IAPH)
ISSN: 2455-4855 (Online)
www.iaph.in

Impact of Agronomic Zinc Biofortification on Yield Attributes, Yield and Micronutrient Uptake of Rice (*Oryza sativa* L.) in Southern Odisha

Swarnajit Pal[1], Tanmoy Shankar[1*], Sitabhra Majumder[1], Rahul Adhikary[2] and Subhajit Pal[3]

[1]Department of Agronomy and Agroforestry, M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, 761 211, Odisha, India; [2]Department of Soil Science, M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, 761 211, Odisha, India; [3]Department of Soil Science, Faculty of Agriculture, Bidhan Chandra Krishi Vishwavidyalaya, Mohanpur, Nadia, 741252, West Bengal, India

E-mail/Orcid Id:

SP, swarnajitpal1234@gmail.com, https://orcid.org/0009-0008-2241-0103; *TS*, tanmoy.shankar125@gmail.com, https://orcid.org/0000-0003-1888-9912; *SM*, sitabhra.majumder@cutm.ac.in, https://orcid.org/0009-0004-3587-2818; *RA*, rahul.adhikary@cutm.ac.in, https://orcid.org/0000-0003-0020-4161; *SP*, pelosubhajit@rediffmail.com, https://orcid.org/0000-0002-9044-9930

Article History:

Received: 24th Jan., 2024
Accepted: 16th June, 2024
Published: 30th June, 2024

Keywords:

Split application, yield attributes, yield, zinc

How to cite this Article:

Swarnajit Pal, Tanmoy Shankar, Sitabhra Majumder, Rahul Adhikary and Subhajit Pal (2024). Impact of Agronomic Zinc Biofortification on Yield Attributes, Yield and Micronutrient Uptake of Rice (*Oryza sativa* L.) in Southern Odisha. *International Journal of Experimental Research and Review*, *40(spl.)*, 90-103.

DOI:
https://doi.org/10.52756/ijerr.2024.v40spl.007

Abstract: Cereal crops are low in micronutrients primarily due to Iron and Zinc deficiency in soil. Iron, being the cofactor of various enzymes, performs basic functions in the human body, while its absence causes anaemia. Symptoms of Zn-deficiency appearing in the human body includes retarded growth, hypogonadism, immune dysfunction and cognitive impairment. In rice plants, their deficiency results in stunted growth and poor plant development, leading to yield reduction. Consumption of milled rice containing very low levels of iron and zinc, is one of the principal reasons for widespread malnutrition among rice consumers. Health of millions of people around the world, including India, is directly or indirectly affected due to 'Hidden Hunger' or 'Malnutrition' of iron and zinc. The current study was conducted in the summer season of 2022 at the Post Graduate Research Farm, M.S. Swaminathan School of Agriculture, comprising 8 treatments of zinc (foliar and basal) applications on rice. Influence of these treatments on grain and straw yield of rice was ascertained by measuring Pearson correlation coefficient and different multivariate tests viz., Multiple Regression, Multilayer Perceptron Neural Analysis (MPN) and Principal Component Analysis (PCA), which indicated that grain zinc and iron content, was highly influenced by the zinc application. Analysis of generated data indicated that basal application of 5 kg Zn ha^{-1} along with foliar application of 0.25% Zn at maximum tillering and at booting stage produced the highest grain yield (6.80 t ha^{-1}) and superior outcomes on different yield attributes, nutrient uptake and straw yield of hybrid rice as compared to other treatments, (MARVEL 1011) in the soil of Southern Odisha.

Introduction

Rice (*Oryza sativa* L.), with a global area of 165 million hectares, a production of approximately 513 million tons and productivity of 4620 kg/ha (USDA, 2022), provides staple food for over 50% of the world's population (De and Dey, 2021, 2022; Majumder et al., 2023), is a crucial cereal crop. India ranks first with 46.38 million hectares under rice cultivation and the second largest producer with a production level of 130.29 million tonnes and a productivity of 2809 kg/ha (Government of India, 2022). In the state of Odisha, rice covers approximately 3.77 million hectares, producing 6.55 million tonnes and a productivity rate of 1739 kg/ha (Government of Odisha, 2021).

***Corresponding Author:** tanmoy.shankar125@gmail.com

Rice grains are a major source of carbohydrates, proteins, etc., and inherently contain low amounts of Fe and Zn (Chaudhuri et al., 2018). The nutrient content of rice is lower compared to wheat. In milled rice, protein content is 6-7%, with a low-fat content of 2-2.5%. Cereal crops are primarily low in micronutrients, mainly Iron and Zinc (Biswas and Ghosh, 2016; Bera and Choudhury, 2023). Iron, being the cofactor of various enzymes, performs basic functions in the human body, while its absence causes anaemia. On the other hand, Zn-deficiency symptoms include retarded growth, hypogonadism, immune dysfunction, and cognitive impairment. Some other deficiency symptoms are yield reduction, stunted growth, and poor plant development. Various research reports have established that about 2 billion people in poorer countries are suffering from malnutrition caused by micronutrients, including Zn (Wakeel et al., 2018; Verma, 2015).

The micronutrient Zn is needed for the growth and development of plants as well as humans. Zinc plays a vital role in the proper functioning of the immune system and helps in a child’s physical and mental changes (Kinash et al., 2021; Shukla et al., 2018). Zinc also plays a key role in immune cells and is necessary for smell and taste receptors. In plants, Zinc acts as a regulatory cofactor for various enzymatic reactions (Praharaj et al., 2021). Zinc is also required for the metabolism of carbohydrates, protein synthesis, pollen formation, maintenance of structural and functional accuracy of cell membranes, and resistance to pathogenic infection. Hence, Zinc has an overall impact on our human body (Wessels et al., 2021).

Millions of people around the world, including in India, are suffering from ‘Hidden Hunger’ or ‘Malnutrition’, which directly or indirectly affects individual health. Micronutrient malnutrition is a serious problem in India and across the world (Haridas et al., 2022). Consumption of milled rice, which has very low iron and zinc concentrations, is one of the principal reasons for the widespread prevalence of malnutrition among rice consumers (Mohidem et al., 2022). In order to tackle the problem, several approaches, including nutritional supplementation, nutritional fortification, and biofortification have been proposed and deployed. Among these, biofortification, particularly ‘Agronomic biofortification,’ helps in a promising way to increase the nutritional quality of rice grains.

The three major key benefits of biofortification in alleviating malnutrition are:

i) Improvement of the nutritional content of staple foods that poor people largely consume. Biofortification plays a major role in a sustainable way to supply micronutrients to overcome the malnutrition problem using preferred food items.

ii) It is an effective means of reducing malnutrition among rural people who live under poverty with limited access to supplements. Commercially marketed fortified foods can overcome this. iii) Instead of recurring costs of fortified food consumption, a biofortified crop can be developed with a single-time investment, encouraging farmers to grow it in subsequent years (Praharaj et al., 2021). The multiplier effect of biofortification over time and space makes it a cost-effective investment with low recurrent expenditure for maintaining a high status of micronutrients in crops. Hence, biofortification is believed to be the process of augmenting the micronutrient status in crops and has gained attention as a promising strategy to combat micronutrient deficiencies. In the case of zinc, biofortification offers a potential solution to address zinc deficiency in rice-consuming regions (Birol and Bouis, 2023).

The major approach to zinc biofortification is the foliar and soil application of zinc. Foliar application of Zn involves spraying a zinc solution directly onto the leaves of the rice plants. Soil application of $ZnSO_4$ as a source of Zinc has little effect on grain biofortification, but it is recommended to apply zinc to improve paddy fields as well as deficiencies in the initial stages of rice growth (Zulfiqar et al., 2021; Zou et al., 2012). Various sources of Zn-fertilizer can do zinc application. Band placement of $ZnSO_4$ has been proved more effective than broadcasting, whereas broadcasting of ZnO showed a better response than any other method of application (Nayak et al., 2022). By applying both soil and foliar applications of Zinc in rice plants, it can significantly enhance crop yields as well as the zinc concentration in grains for better nutritional quality.

Foliar application of zinc has emerged as a practical and effective method to enhance Zn status in kharif paddy, as this micronutrient moves faster within the plant body. However, the re-translocation of Zn is triggered by the nutritional status of plants. By bypassing the soil uptake constraints, this approach allows for the direct and efficient absorption of zinc by the rice plants. It can significantly improve the nutritional quality of rice and contribute to better human health, particularly in regions where zinc deficiency-related disorders are prevalent (Saikh et al., 2022).

As all living beings require zinc as a trace element, a sufficient amount of zinc is good for normal health and development. In developing countries, food items high in Zn content are essential for human health, as the supplementation of food rich in essential minerals is often difficult to supply. However, Zn-deficiency in the soil leads to stunted growth and reduced yields of crops. This deficiency not only decreases the nutritional quality of rice but also poses a major threat to food security. Therefore, to increase the micronutrient content of crops, we are applying the biofortification process, which has become a major strategy to defend against micronutrient malnutrition (Younas et al., 2023).

Materials and Methods

The experiment consisted of eight treatments, including one control, one soil treatment, three foliar treatments and three combined (soil foliar) treatments. The control group represented the conventional approach, where chemical fertilizers at recommended dose of 80:40:40::N:P_2O_5:K_2O kg/ha through urea, single super phosphate, and muriate of potash were applied. The treatments combinations comprised; T_1: No application of Zn (control); T_2: Foliar application @ 0.5% Zn at maximum tillering stage;T_3: Foliar application @ 0.5% Zn at booting stage; T_4: Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn at booting stage; T_5: Basal application @ 5 kg Zn ha^{-1}; T_6: Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at maximum tillering stage; T_7: Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at the booting stage; and T_8: Basal application @ 5 kg Zn ha^{-1} + Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage. Each treatment was replicated 3 times and laid out in the field following a Randomized Complete Block Design (RBD) in 24 plots, measuring 5 m × 4 m. The transplanting of rice crop (Hybrid, MARVEL 1011) was done on 5th August, 2023 and all the recommended agronomic practices were followed for the successful raising of crop. Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$), obtained from Total Agri Care Concern Pvt. Ltd., was utilized as the sole source of zinc application either by foliar or basal. The crop was harvested by the month of November, the grain and straw were separated and washed in de-ionised water, dried, grinded and kept in polythene packets, isolated according to the treatments applied, for further nutrient analysis. The iron and zinc content in the grain and straw was determined in the Atomic Absorption Spectrophotometer (PinAAcle Perkin Elmer 900F) after digesting the samples in a mixture of Nitric acid, Perchloric acid and Sulphuric acid. Statistical analysis of the data collected from the field and laboratory was carried out with the help of standard ANOVA techniques and the difference between the treatment means was calculated in order to find out their statistical significance with appropriate critical difference (CD) values at 5% level of significance (Gomez and Gomez, 1984). Correlation coefficient values among different plant parameters were also calculated. Multivariate analysis viz., Multiple Regression (Wang, 2016), Multilayer Perceptron Neural Analysis (Popescu et al., 2009) and Principal Component Analysis (Jolliffe and Cadima, 2016) were performed for identification of the most important plant parameters that exerted influence on crop growth and yield. All the statistical analysis were performed using statistical software viz., MS Excel, SPSS 23.0 and Origin Pro 2019 version.

Result and Discussion

Effect of split application of zinc on the yield (t/ha) of hybrid rice

One important characteristic that directly affects the productivity and output potential of rice crops is the number of panicles per unit area. Number of panicles m^{-2} varies significantly among the different treatments. As the Zn doses increases from the control treatment to other treatments, the number of panicles m^{-2} also increases. The maximum number of panicle m^{-2} was recorded in the soil application of 5 kg Zn ha^{-1} with two equal splits of foliar application of 0.25% at maximum tillering and booting stage (254.4) respectively and was statistically at par with treatment receiving one basal application of 5kg Zn ha^{-1} with 0.5% $ZnSO_4.7H_2O$ foliar application at maximum tillering stage (252.6) and with the application of equal doses of 0.25% at maximum tillering and same doses at booting stage (250.2), respectively. The percent increase over control (T_1) to soil application of 5 kg Zn ha^{-1} with two equal splits of foliar application of 0.25% at maximum tillering and booting stage, respectively, treatment receiving one basal application of 5kg Zn ha^{-1} with 0.5% $ZnSO_4.7H_2O$ foliar application at maximum tillering stage and two splits of foliar spray at an application of 0.25% Zn at maximum tillering and 0.25% Zn booting stage was 6.31%, 5.55% and 4.30%, respectively. The lowest was recorded (239.3) in the control treatment, where no zinc was applied. Similar observations were also recorded by Shivay et al. (2013), where it was observed that applying zinc increases yield attributes like panicles number spikelets panicle^{-1}. The number of spikelet panicles^{-1} was counted and statistically analyzed in table 4.6. However highest (164) was observed in the treatment that received soil application of 5 kg Zn ha^{-1} with two equal splits of foliar application of 0.25% at maximum tillering and booting stage, respectively and also observed in soil application of 5 kg Zn ha^{-1} with foliar application of 0.5% at maximum tillering stage (164). However, the lowest was received in the control plot. Zinc plays an important role in enzymatic reaction thereby increasing in spikelet numbers. Similar observations were also observed by Das et al. (2019). Islam et al. (2021) also found that yield attributes like spikelets panicle^{-1} were increased with different methods of Zn application over control and no significant difference were found among the various methods. From the above table, it has been noticed that filled grain per panicle varied significantly among the different treatment combinations. The highest filled grains per panicle were recorded in the T_8 treatment (146.6), which was statistically at par with T_6 (145.7) and T_4 (141). The lowest filled grain was recorded in the control plot (129.7). The percent increase of T_8, T_6 and T_4 was 13.03%, 12.33% and 8.71%, respectively, over the T_1 treatment. Similar observations were also recorded by Shivay et al. (2013) and also by Islam et al. (2021). The data on the percentage of filled grain per panicle were recorded after harvest and were statistically analyzed and presented in table 4.6. From the table, it has been observed that the percentage of filled grain per panicle did not vary significantly among the different treatments. However, the highest was noted in T_8 with the combined application of soil @ 5kg ha^{-1} with two equal splits of foliar spray of 0.25% at maximum tillering and booting stage, respectively. As expected, the control plot resulted in the lowest. Similar observations were also found by Das et al. (2019). One crucial quality attribute of rice that directly affects yield potential is the length of the panicles. From table 4.6, it has been noticed that panicle length varied significantly among the different treatment combinations. However, the maximum (29 cm) was noticed in the treatment, which received soil application of 5kg ha^{-1} with two equal splits of foliar spray of 0.25% at maximum tillering and booting stage, respectively. The T_8 treatment was statistically at par with T_4, T_6 and T_7 and the values were 28.8 cm, 28.2 cm, and 28.6 cm, respectively. The lowest was recorded at the control plot (24.7cm), where no zinc was applied. Similar findings were also noticed by Sudha (2020) and Kandil et al. (2022). However, it did not vary significantly among the different treatment combinations. Besides, a Similar trend of observation was also seen in the percentage of filled grain. Due to various management techniques, the test did not vary significantly, as it is a genetically influenced character.

Effect of split application of zinc on the zinc content (%) and uptake (kg/ha) of hybrid rice

Zinc uptake in both grain (202.0 g ha^{-1}) and straw (350.2 g ha^{-1}) were maximum in treatment that received one soil application of 5 kg Zn ha^{-1} with two splits of foliar application of 0.25% at maximum tillering and booting stage, respectively and is presented in table 4.10 (b). The increased Zn availability to plants in treated plots compared to control (T_1) plots may also have contributed to the improvement in rice quality parameters following Zn fertilization, leading to an increase in Zn uptake, ultimately leading to higher photosynthates translocation to reproductive parts observed by Shivay et al. (2015) and Alloway et al. (2008). Applying fertilizers containing micronutrients directly can improve the ability of grain to absorb and transfer minerals more efficiently. Consequently, foliar Zn management is thought to be an effective approach, together with other micronutrients, to address Zn deficiency in cereal grains. A similar trend of observation was also discovered in Fe uptake and values of different treatments are presented in table 4.10 (b). Due to the synergetic effects of both nutrients, increasing Zn levels in rice plants may positively affect iron uptake, transport and accumulation in different plant parts, including grain and straw. In all cases, the maximum was recorded at T_8 treatment, which was statistically at par with T_6 and T_4 whereas the lowest was recorded in the control plot. The percent increases over T_1 to T_4, T_6 and T_8 were 22.51%, 25.02%, and 26.37% in, respective to the grain uptake.

Multivariate analysis

The Pearson correlation coefficient values (Table 4) indicated a significant positive correlation (at $p < 0.05$) between rice grain yield with straw yield (r=0.930**), number of panicles per m^2 (r=0.861**), number of filled grains per panicle (r=0.927**), zinc uptake in grains (r=0.868**), zinc uptake in straw (r=0.856**), iron uptake in grains (r=0.992**), iron uptake in straw (r=0.954**); and rice straw yield with grains per panicle (r=0.804**), number of filled grains per panicle (r=0.756*), zinc uptake in grains (r=0.722*), zinc uptake in straw (r=0.712*), iron uptake in grains (r=0.888**), iron uptake in straw (r=0.997**).

A Multiple Regression analysis using the Backward elimination technique (Wang, 2016) was performed to evaluate the changes in grain yield and straw yield (dependent variable) under the influence of these plant parameters (independent variable) (Table 5 and 6) and to identify the most influencing variables (predictors) within the probability range of F (0.05 to 0.10). While the Durbin-Watson value within the range of 1.5 to 2.5 needs no auto-correction, in the present analysis, values of 2.413 (Grain yield) and 3.066 (Straw yield) indicated that the used models were perfect to explain the relationship. In the case of rice grain yield, a significant influence of the number of filled grains per panicle, Fe uptake in straw and harvest index exerted significant influence. In the case of straw yield, the number of filled grains per panicle, iron uptake in gains, Fe uptake in straw and number of grains per panicle significantly influenced the changes. In both cases, these relationships could explain the variation perfectly (R^2=1.00**).

The influences of the identified independent variables (predictors) are more specifically depicted by Multilayer Perceptron Neural (MPN) Network analysis (Popescu et al., 2009). The role played by other independent variables that might act as moderators (in the hidden layers) is also analysed. A MPN model was drawn (Figure 2 and 4), taking the dependent variable in the output layer and the predictors estimated in the multiple regression process in the input layer. The blue lines (Figure 2 and 4) through the hidden layers acted as moderators. Positive values in the parameter estimates (Table 7 and 8) indicated a positive influence towards the output. The thicker and darker lines indicated a stronger relationship. The sensitivity analysis (Figure 3 and 5) showed the percentages of normalized importance among the contributing variables towards the dependent variable (Yield).

Four independent parameters that influenced rice grain yield in the order of importance were Fe uptake in straw (0.372) > harvest index (0.230) > number of filled grains per panicle (0.225) > number of panicles per m^2 (0.172) (Table 7). The sensitivity analysis (Figure 3, Table 7) indicated the normalized importance (%) of these variables towards the dependent variable (Grain yield).

Five independent parameters Fe uptake in straw (0.421) > Fe uptake in grain (0.278) > number of filled grains per panicle (0.158) > number of panicles per m^2 (0.087) > Zn uptake in straw (0.056) were seen to influence rice straw yield (Table 8, Fig

Table 1. Effect of Agronomic zinc biofortification on yield attributes of hybrid rice.

Treatments		**Yield Attributes**					
		Number of panicles m^2	**Spikelet $panicle^{-1}$**	**Filled grains $panicle^{-1}$**	**Percentage of filled grain (%)**	**Panicle length (cm)**	**Test weight (g)**
T_1	No application of Zn (control)	239.3	155.9	129.7	83.2	24.7	22.1
T_2	Foliar application @ 0.5% Zn at maximum tillering stage	243.1	160.1	137.2	85.7	27.0	23.4
T_3	Foliar application @ 0.5% Zn at booting stage	240.7	157.5	132.1	86.9	26.3	22.2
T_4	Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage	250.2	162.2	141.0	86.9	28.8	23.6
T_5	Basal application @ 5 kg Zn ha^{-1}	241.3	160.5	136.5	85.1	27.5	22.1
T_6	Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at maximum tillering stage	252.6	164.0	145.7	88.8	28.2	23.6
T_7	Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at booting stage	247.5	161.0	139.8	86.8	28.6	23.7
T_8	Basal application @ 5 kg Zn ha^{-1} + Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage	254.4	164.0	146.6	89.4	29.0	23.5
S.Em. (±)		1.4	1.2	0.9	1.6	0.8	1.1
CD (P=0.05)		4.27	3.63	2.77	NS	2.33	NS

4). The sensitivity analysis (Figure 5, Table 8) indicated the normalized importance (%) of these variables towards the dependent variable (straw yield). This study was further supported by the Principal Component Analysis (Jolliffe and Cadima, 2016) that identified the patterns in the dataset, highlighting their similarities and differences through the distances among themselves. The main contributing plant parameters influencing rice grain and straw yield were then identified according to their contribution to the component loadings (Table 9). Scatter Plot diagrams were created to understand the role of each sampling point with respect to the dependent variables (grain and straw yield) and the predictors were observed. The ability of each treatment in relation to grain yield and straw yield has also been highlighted. Scatterplot diagrams (Figure 6, 7) with regression lines further explained the positions of the treatments applied in context with the rice grain-straw yield. In the scatter plot diagrams, treatment numbers associated with highest grain yield along with higher value of the desired plant parametric traits have been identified.

Two Principal Components explaining 98.62% variability in grain yield were identified. While the 1st component could explain 74.53% of the variability, the 2nd component explained 24.09% additional variability (Table 9). With respect to straw yield, 96.58% of the variability could be explained by two identified Principal Components (Table 10). Among the different independent variables, the impact on rice grain yield through loadings under PC1 followed the order: number of filled grains (0.51) > number of panicles (0.50) >Fe uptake in straw (0.44) > harvest index (0.21). In case of variation in rice straw yield through loadings under PC1 follow the order: Fe uptake in grain (0.431) > number of grains per panicle (0.417) > number of filled grains (0.413) > Fe uptake in straw (0.407) > Zn uptake in straw (0.385). The highest positive loading with respect to grain yield (1.226 through PC1) and with respect to straw yield (1.142 through PC1) could be observed under treatment no. 8 and thus could be designated as the best treatment.

DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007

Table 2. Effect of Agronomic zinc biofortification on yield of hybrid rice.

Treatments	Zn uptake (g ha^{-1})			Fe uptake (g ha^{-1})		
	Grain	Straw	Total uptake	Grain	Straw	Total uptake
T_1	97.5	155.4	252.90	207.4	1598.9	1806.3
T_2	123.5	195.8	319.27	239.5	1908.3	2147.7
T_3	133.3	215.0	348.32	228.5	1827.9	2056.3
T_4	158.8	262.7	421.53	254.1	1918.4	2172.5
T_5	131.8	207.4	339.20	237.5	1866.6	2104.1
T_6	185.4	289.5	474.87	259.3	1920.3	2179.6
T_7	192.1	313.5	505.59	248.0	1918.9	2166.9
T_8	202.0	350.2	552.13	262.1	2032.1	2294.1
S.Em. (±)	2.7	2.9	3.2	3.1	6.3	2.9
C. D. (P=0.05)	8.09	8.55	9.4	9.22	18.58	8.7

T_1-No application of Zn (control);T_2-Foliar application @ 0.5% Zn at maximum tillering stage;T_3-Foliar application @ 0.5% Zn at booting stage;T_4-Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage; T_5-Basal application @ 5 kg Zn ha^{-1};T_6Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at maximum tillering stage;T_7Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at booting stage;T_8Basal application @ 5 kg Zn ha^{-1} + Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage

Table 3. Effect of agronomic zinc biofortification on micronutrient uptake of grain and straw of hybrid rice.

Treatments		Yield		
		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1	No application of Zn (control)	5.67	7.33	43.6
T_2	Foliar application @ 0.5% Zn at maximum tillering stage	6.40	8.70	42.4
T_3	Foliar application @ 0.5% Zn at booting stage	6.21	8.37	42.6
T_4	Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage	6.70	8.70	43.5
T_5	Basal application @ 5 kg Zn ha^{-1}	6.41	8.53	42.9
T_6	Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at maximum tillering stage	6.77	8.67	43.8
T_7	Basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at booting stage	6.60	8.73	43.0
T_8	Basal application @ 5 kg Zn ha^{-1} + Foliar application @ 0.25% Zn at maximum tillering and 0.25% Zn booting stage	6.80	9.17	42.6
S.Em. (±)		0.12	0.2	0.5
CD (P=0.05)		0.36	0.56	NS

Table 4. Pearson Correlation Coefficient of grain yield and straw yield with other plant parameters.

	GY	SY	H_ Index	Pan / m2	G/ Pan	Filled_ Gr	Zn_Upt _Gr	Zn_Upt _Str	Fe_Upt _Gr	Fe_Upt _Str
GY	1	.930**	0.185	.861**	.953**	.927**	.868**	.856**	.992**	.954**
SY	.930**	1	-0.189	0.642	.804*	.756*	.722*	.712*	.888**	.997**

Table 5. Regression of rice grain yield with other plant parameters.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-10.723	0.37		-29.22	0.00
H_Index	0.279	0.01	0.39	23.83	0.00
Filled_Gr	-0.005	0.00	-0.09	-3.09	0.05
Fe_Upt_Str	0.004	0.00	1.11	50.56	0.00

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin -Watson
1.000^c	1.000	1.000	0.005056	2.413
Predictors: (Constant), H_Index, Filled_Gr, Fe_Upt_Str,				
Dependent Variable: GY				

Table 6. Regression of rice straw yield with other plant parameters.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-2.423	0.720		-3.367	0.078
G/Pan	0.034	0.007	0.200	4.718	0.042
Filled_Gr	-0.017	0.003	-0.214	-5.728	0.029
Zn_Upt_Str	0.000	0.000	0.044	3.700	0.066
Fe_Upt_Gr	-0.005	0.001	-0.196	-4.467	0.047
Fe_Upt_Str	0.005	0.000	1.148	68.819	0.000

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1.000	1.000	1.000	0.004866	3.066
Predictors: (Constant), G/Pan, Filled_Gr, Zn_Upt_Str, Fe_Upt_Gr, Fe_Upt_Str				
Dependent Variable: SY				

Table 7. Importance of different independent variables on rice grain yield.

Independent Variable Importance		
	Importance	Normalized Importance
Fe_Upt_Str	0.372	100.0%
H_Index	0.230	61.9%
Pan/ m2	0.172	46.1%
Filled_Gr	0.225	60.5%

Table 8. Importance of different independent variables on rice straw yield.

Independent Variable Importance		
	Importance	Normalized Importance
Fe_Upt_Str	0.421	100.0%
Zn_Upt_Str	0.056	13.3%
G/?Pn	0.087	20.7%
Filled_Gr	0.158	37.5%
Fe_Upt_Gr	0.278	65.9%

Table 9. Component loadings of Principal Components explaining variation in rice grain yield.

PC No	Eigen values	% of Variance	Cumu -lative (%)	Parameters	Loadings Loadings		Obser- vations	Scores	
					PC1	PC2		PC1	PC2
1	3.73	74.53	74.53	GY	0.50	-0.21	1	-1.686	1.679
2	1.20	24.09	98.62	Fe_Upt_Str	0.44	-0.46	2	-0.301	-1.426
3	0.04	0.88	99.50	H_Index	0.21	0.83	3	-0.876	-0.799
4	0.02	0.50	100.00	Pan/ m2	0.50	0.21	4	0.638	0.269
5	0.00	0.00	100.00	Filled_Gr	0.51	0.07	5	-0.379	-0.568
							6	1.074	0.858
							7	0.304	-0.442
							8	1.226	0.429

Table 10. Component loadings of Principal Components explaining variation in rice straw yield.

PC No	Eigen values	% of Variance	Cumu -lative (%)	Parameters	Loadings Loadings		Obser- vations	Scores	
					PC1	PC2		PC1	PC2
1	5.336	88.93	88.93	SY	0.394	0.603	1	-1.980	-1.377
2	0.459	7.65	96.58	Fe_Upt_Str	0.407	0.502	2	-0.090	1.411
3	0.193	3.22	99.80	Zn_Upt_Str	0.385	-0.424	3	-0.711	0.926
4	0.007	0.12	99.92	G/Pan	0.417	-0.234	4	0.499	0.140
5	0.005	0.08	100.00	Filled_Gr	0.413	-0.384	5	-0.199	0.744
				Fe_Upt_Gr	0.431	-0.053	6	0.868	-0.859
							7	0.471	-0.013
							8	1.142	-0.973

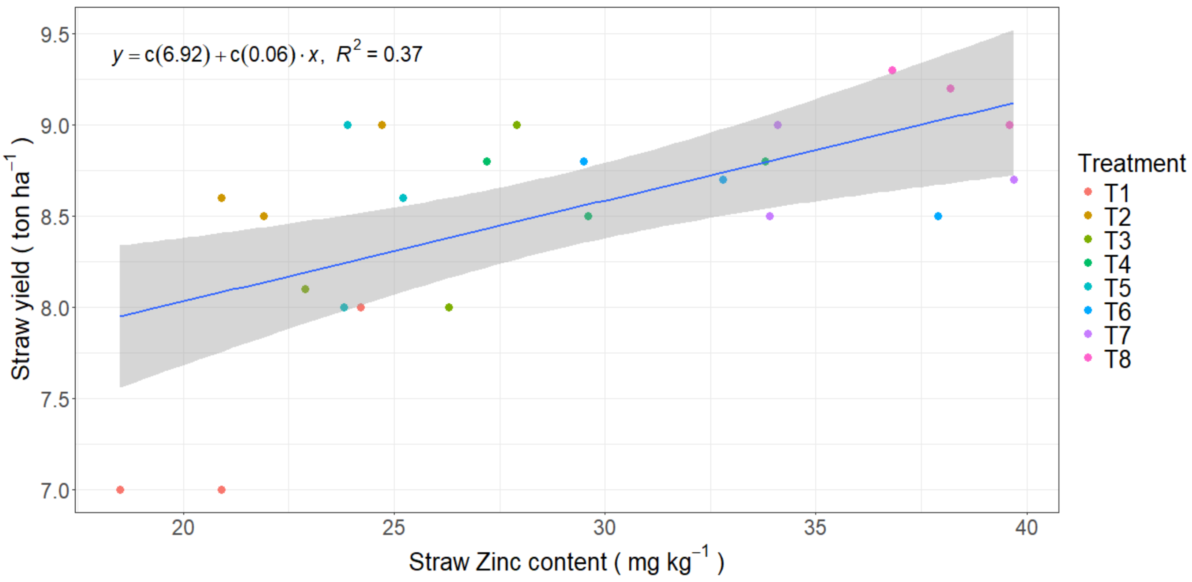

Figure 1. Correlation graph between straw yield and straw zinc content.

DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007

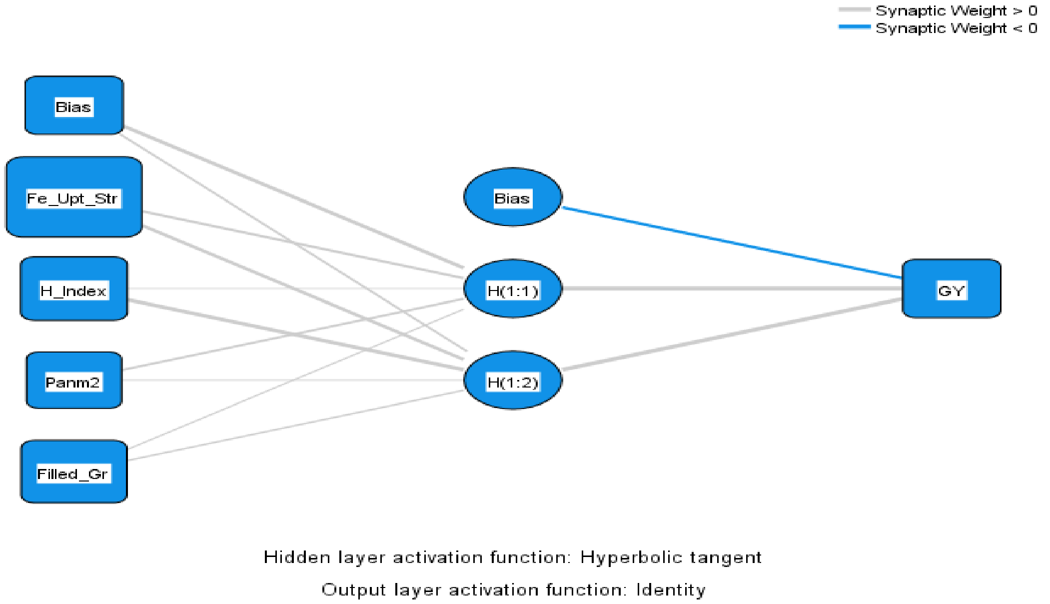

Figure 2. Effect of independent variables on grain yield identified through Multilayer Perceptron.

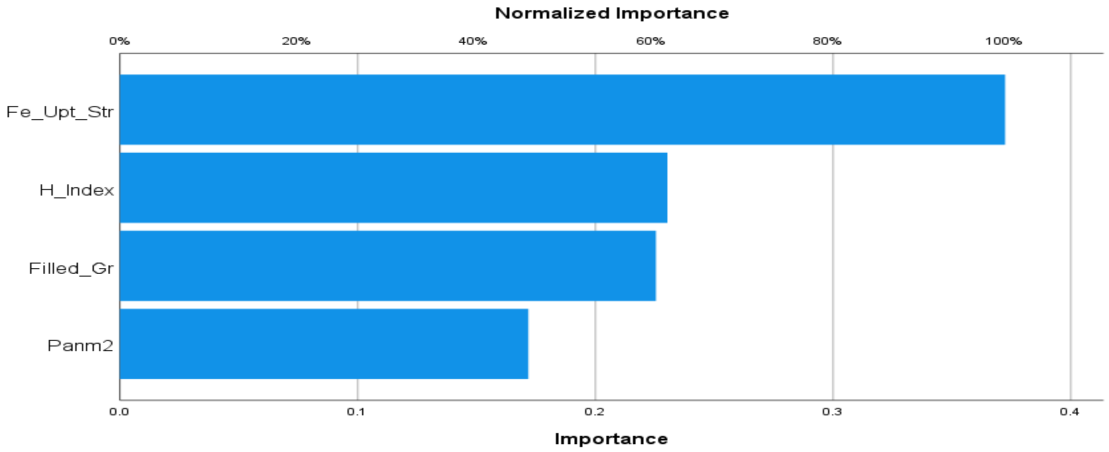

Figure 3. Normalised importance of independent variables on rice grain Yield.

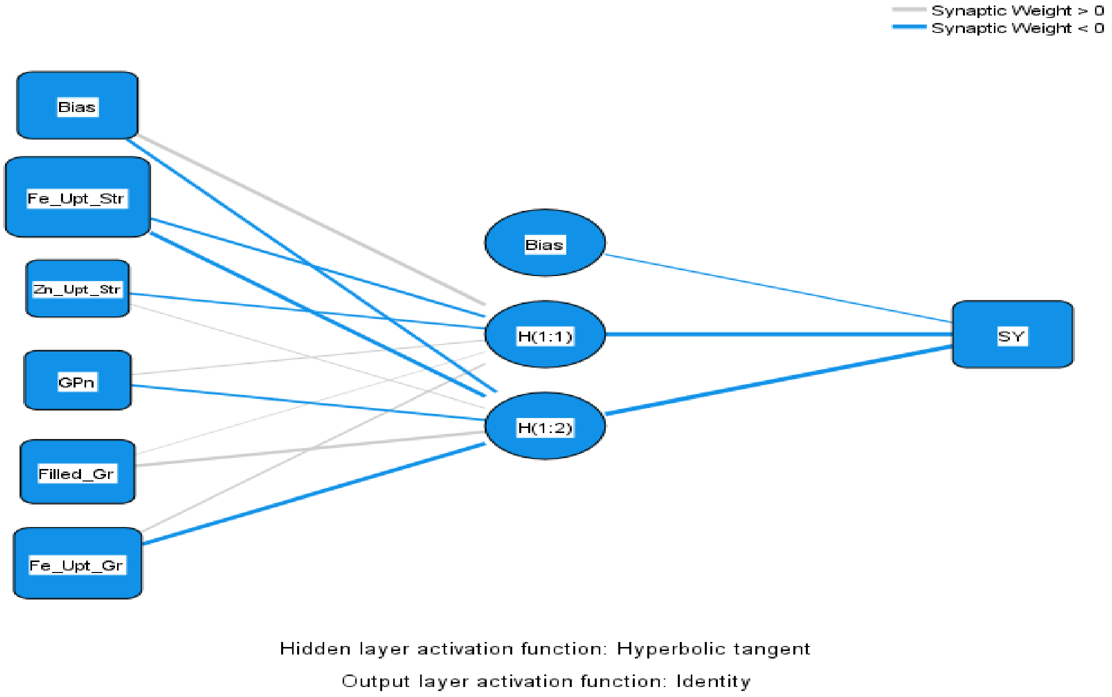

Figure 4. Effect of independent variables on straw yield identified through Multilayer Perceptron Neural Analysis.

DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007

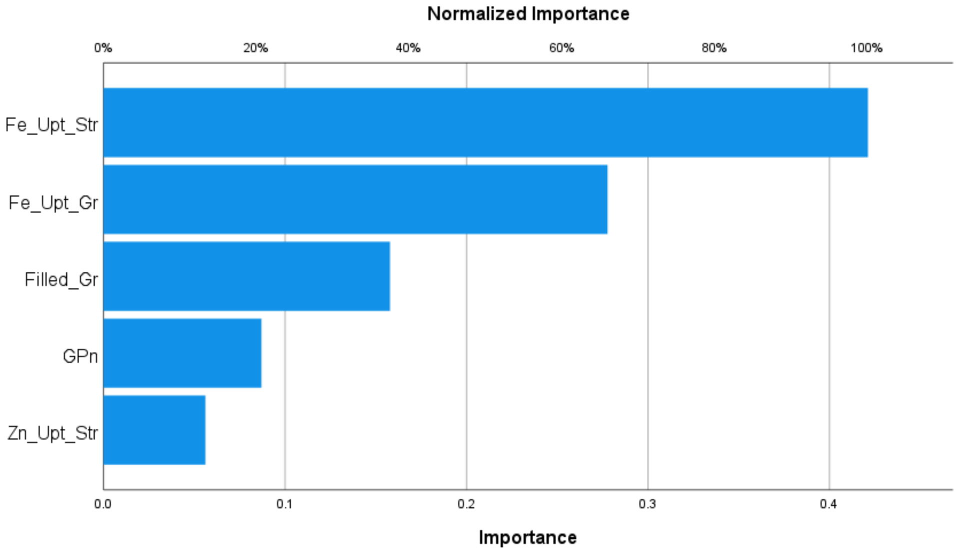

Figure 5. Normalized importance of independent variables on rice Straw Yield.

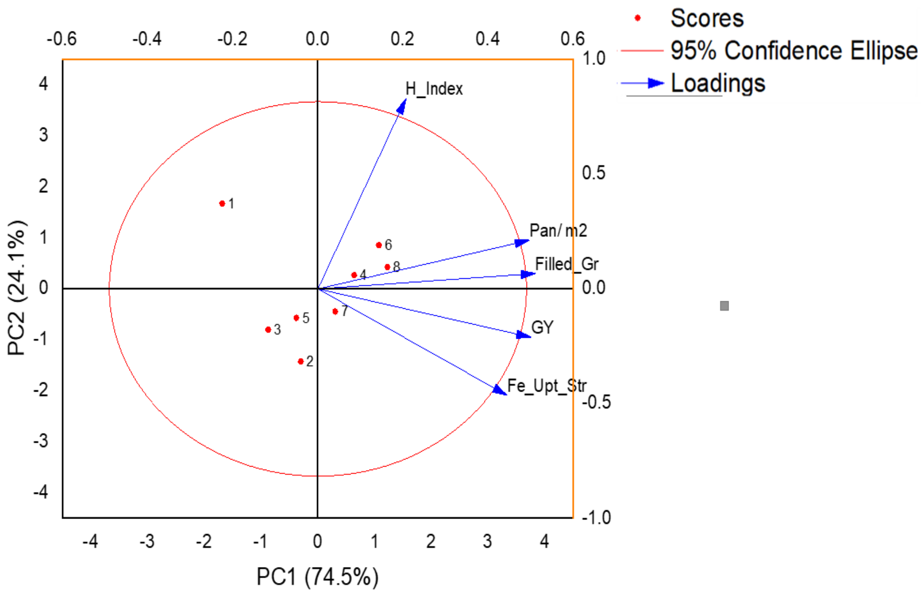

Figure 6. PCA biplot of grain yield.

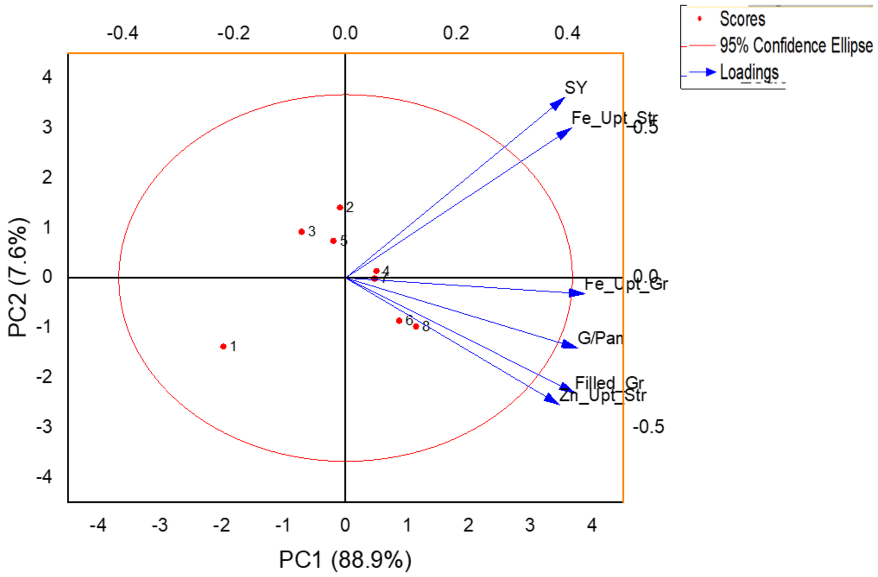

Figure 7. PCA Biplot of rice straw yield.

DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007

Conclusion

Based on the experimental findings, it may be concluded that the basal application @ 5 kg Zn ha^{-1} + Foliar application @0.5% Zn at maximum tillering stage also showed favourable results on yield attribute, yield and uptake. Combined application of soil and Foliar application of zinc sulphate (T_6 and T_8) significantly influenced grain yield. Under low Zn soil conditions, foliar application of Zn exhibited a significant positive effect on yield parameters and yield. Foliar application of 0.25% solution of Zn during maximum tillering and booting stage, along with basal application of 5 kg Zn ha^{-1} could be recommended for getting maximum grain yield of hybrid rice. Thus, by zinc application farmers could be benefited by getting higher yields and alleviating zinc deficiency within the grain.

Acknowledgement

The authors acknowledge the M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, India and the Department of Soil Science, Bidhan Chandra Krishi Vishwavidyalaya, West Bengal, India for providing all the facilities necessary to carry out this study.

Conflict of Interest

The authors declare no conflict of interest.

References

Alloway, B. J. (2008). Micronutrients and Crop Production: An Introduction. In *Springer eBooks*, pp. 1–39. https://doi.org/10.1007/978-1-4020-6860-7_1

Bera, A., & Choudhury, B. (2023). Arsenic Uptake, Transport, Accumulation in Rice and Prospective Abatement Strategies – A Review. *Int. J. Exp. Res. Rev.*, *30*, 388-401. https://doi.org/10.52756/ijerr.2023.v30.036

Birol, E., & Bouis, H. E. (2023). Role of socio-economic research in developing, delivering and scaling new crop varieties: the case of staple crop biofortification. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/fpls.2023.1099496

Biswas, P., & Ghosh, R. (2016). Effective weed management practices to control complex weed flora in different cultivars of hybrid and high yielding varieties of rice (*Oryza sativa* L.). *Int. J. Exp. Res. Rev.*, *2*, 14-19. https://doi.org/10.52756/ijerr.2016.v2.004

Das, A., Singh, S., Kumar, M., & Kumar, O. (2019). Evaluation of Different Methods of Zinc Application on Growth, Yield and Biofortification of Zinc in Rice (Oryza sativa L.). *Journal of the Indian Society of Soil Science*, *67*(1), 92. https://doi.org/10.5958/0974-0228.2019.00010.0

De, M., & Dey, S. (2021). Variation in agronomic characters among traditional rice varieties of Cooch Behar, West Bengal: A Case Study. *Int. J. Exp. Res. Rev.*, *25*, 1-8. https://doi.org/10.52756/ijerr.2021.v25.001a

De, M., & Dey, S. (2022). Numerical Taxonomic analysis for the estimation of Genetic Diversity among some traditional rice (*Oryza sativa* L.) varieties of West Bengal. *Int. J. Exp. Res. Rev.*, *29*, 48-54. https://doi.org/10.52756/ijerr.2022.v29.005

Gomez, K.A., & Gomez, A.A. (1984). Statistical Procedures for Agriculture Research. John Wiley and Sons Publishers, NewYork. 357-423

Government of India. (2022). *Agricultural Statistics at a Glance*. Ministry of Agriculture & Farmers Welfare Department of Agriculture & Farmers Welfare Economics and Statistics Division, New Delhi.

Government of Odisha. (2021). 5-*decades of Odisha agriculture statistics*. Directorate of Agriculture and Food production, Government of Odisha, India.

Haridas, S., Ramaswamy, J., Natarajan, T., & Nedungadi, P. (2022). Micronutrient interventions among vulnerable population over a decade: A systematic review on Indian perspective. *Health Promotion Perspectives*, *12*(2), 151–162. https://doi.org/10.34172/hpp.2022.19

Islam, M. R., Sultana, A., Jahiruddin, M., & Islam, S. (2021). Effect of soil application of zinc on growth, yield and zinc concentration in rice varieties. *European of Agriculture and Food Sciences*, *3*(6), 117–122. https://doi.org/10.24018/ejfood.2021.3.6.425

Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: a review and recent developments. *Philosophical Transactions - Royal Society. Mathematical, Physical and Engineering Sciences/Philosophical Transactions - Royal Society. Mathematical, Physical and Engineering Sciences*, *374*(2065), 20150202. https://doi.org/10.1098/rsta.2015.0202

Kandil, E. E., El-Banna, A. a. A., Tabl, D. M. M., Mackled, M. I., Ghareeb, R. Y., Al-Huqail, A. A., Ali, H. M., Jebril, J., & Abdelsalam, N. R. (2022).

Zinc Nutrition Responses to Agronomic and Yield Traits, Kernel Quality, and Pollen Viability in Rice (*Oryza sativa* L.). *Frontiers in Plant Science*, *13*. https://doi.org/10.3389/fpls.2022.791066

Kinash, M., Boyarchuk, O., & Dobrovolska, L. (2021). Zinc: its impact on immune function in children. *Pediatria Polska*, *96*(4), 263–269. https://doi.org/10.5114/polp.2021.112401

Majumder, S., Shankar, T., Maitra, S., Adhikary, R., & Sairam, M. (2023). Effect of nutrient omission on growth and productivity of *rabi* rice. *Crop Research*, *VOLUME 58*(ISSUE 3 AND 4 (MAY AND JUL) 2023). https://doi.org/10.31830/2454-1761.2023.cr-11166

Mohidem, N. A., Hashim, N., Shamsudin, R., & Man, H. C. (2022). Rice for Food Security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*, *12*(6), 741. https://doi.org/10.3390/agriculture12060741

Nayak, S., Mandi, S., Baral, K., Prasanna, R., & Shivay, Y. S. (2022). Agronomic approaches for biofortification of staple food crops. In *Springer eBooks* (pp. 483–517). https://doi.org/10.1007/978-981-16-3280-8_19

Popescu, M., Balas, V. E., Perescu-Popescu, L., & Mastorakis, N. (2009). Multilayer perceptron and neural networks. *WSEAS Transactions on Circuits and Systems Archive*, *8*(7), 579–588. https://doi.org/10.5555/1639537.1639542

Praharaj, S., Skalicky, M., Maitra, S., Bhadra, P., Shankar, T., Brestic, M., Hejnak, V., Vachova, P., & Hossain, A. (2021). Zinc biofortification in food crops could alleviate the zinc malnutrition in human health. *Molecules/Molecules Online/Molecules Annual*, *26*(12), 3509. https://doi.org/10.3390/molecules26123509

Saikh, R., Murmu, K., Sarkar, A., Mondal, R., & Jana, K. (2022). Effect of foliar zinc application on growth and yield of rice (Oryza sativa) in the Indo-Gangetic Plains of India. *Nusantara Bioscience*, *14*(2). https://doi.org/10.13057/nusbiosci/n140208

Shivay, Y. S., Prasad, R., & Pal, M. (2013). Zinc fortification of oat grains through zinc fertilisation. *Agricultural Research*, *2*(4), 375–381. https://doi.org/10.1007/s40003-013-0078-2

Shivay, Y. S., Prasad, R., Singh, R. K., & Pal, M. (2015). Relative efficiency of zinc-coated urea and soil and foliar application of zinc sulphate on yield, nitrogen, phosphorus, potassium, zinc and iron biofortification in grains and uptake by basmati rice (*Oryza sativa* L.). *The Journal of Agricultural Science*, ***7***(2), 161–173.

Shukla, A. K., Behera, S. K., Pakhre, A., & Chaudhari, S. K. (2018). Micronutrients in soils,plants, animals and humans. Indian Journal of Fertilisers, 14(3), 30-54.

Singh, K., Verma, G., & Manchanda, J. (2020). Soil and foliar zinc application for enhancing grain zinc content of aromatic rice genotypes grown on zinc deficient and sufficient soil. *Journal of Soil and Water Conservation in India/Journal of Soil and Water Conservation, India*, *19*(2), 223. https://doi.org/10.5958/2455-7145.2020.00030.2

Sudha, S. (2020). Agronomic biofortification of zinc in different rice genotypes. *International Journal of Chemical Studies*, *8*(5), 05–08. https://doi.org/10.22271/chemi.2020.v8.i5a.10973

USDA. United States Department of Agriculture. (2022). *World Agricultural Production*. Circular Series.

Verma, A. (2015). Food fortification: A complementary strategy for improving micronutrient malnutrition (MNM) status. *Food Science Research Journal*, *6*(2), 381–389. https://doi.org/10.15740/has/fsrj/6.2/381-389

Wakeel, A., Farooq, M., Bashir, K., & Ozturk, L. (2018). Micronutrient Malnutrition and Biofortification: Recent advances and future perspectives. In *Elsevier eBooks*. pp. 225–243. https://doi.org/10.1016/b978-0-12-812104-7.00017-4

Wang, K., & Chen, Z. (2016). Stepwise regression and all possible subsets regression in education. *Electronic International Journal of Education, Arts, and Science*, *2*. http://eijeas.com/index.php/EIJEAS/article/download/83/90

Wessels, I., Fischer, H. J., & Rink, L. (2021). Dietary and physiological effects of zinc on the immune system. *Annual Review of Nutrition*, *41*(1), 133–175. https://doi.org/10.1146/annurev-nutr-122019-120635

Younas, N., Fatima, I., Ahmad, I. A., & Ayyaz, M. K. (2023). Alleviation of zinc deficiency in plants and humans through an effective technique; biofortification: A detailed review. *Shengtai Xuebao*, *43*(3), 419–425. https://doi.org/10.1016/j.chnaes.2022.07.008

Zou, C. Q., Zhang, Y. Q., Rashid, A., Ram, H., Savasli, E., Arisoy, R. Z., Ortiz-Monasterio, I., Simunji, S., Wang, Z. H., Sohu, V., Hassan, M., Kaya, Y., Onder, O., Lungu, O., Mujahid, M. Y., Joshi, A. K., Zelenskiy, Y., Zhang, F. S., & Cakmak, I.

(2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil*, *361*(1–2), 119–130. https://doi.org/10.1007/s11104-012-1369-2

Zulfiqar, U., Hussain, S., Maqsood, M., Ishfaq, M., & Ali, N. (2020). Zinc nutrition to enhance rice productivity, zinc use efficiency, and grain biofortification under different production systems. *Crop Science*, *61*(1), 739–749. https://doi.org/10.1002/csc2.20381

How to cite this Article:

Swarnajit Pal, Tanmoy Shankar, Sitabhra Majumder, Rahul Adhikary and Subhajit Pal (2024). Impact of Agronomic Zinc Biofortification on Yield Attributes, Yield and Micronutrient Uptake of Rice (*Oryza sativa* L.) in Southern Odisha. *International Journal of Experimental Research and Review*, *40*(spl.), 90-103.

DOI: https://doi.org/10.52756/ijerr.2024.v40spl.007