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Effect of Zn, Fe and FYM on Interaction between Zn and Fe on Nutrient Content, Uptake and Yield of Different Varieties of Rice (Oryza sativa L.)

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ABSTRACT

The field experiment were carried out using split plot design with three replication during kharif 2006-07 and 2007-08 to investigate the effect of varieties and Zn, Fe and FYM on nutrient content, uptake and yield of rice (Oryza sativa). The experiment consisted of two level of varieties (V1:NDR-359, V2:HUBR-2-1) and two fertilizer source (F1:RFD100, F2:RFD50+FYM50) in main plot and nine level of micronutrient combination (M0:0, M1:Zn-EDTA1, M2:Zn-EDTA0.5, M3:Fe-EDTA1, M4:Fe-EDTA0.5, M5:Zn-EDTA1+Fe-EDTA1, M6:Zn-EDTA0.5+Fe-EDTA0.5, M7:Zn-EDTA1+Fe-EDTA0.5, M8:Fe-EDTA1+Zn-EDTA0.5) allotted in sub-plot. Among the different testing varieties, V1:(NDR-359) recorded highest yield and NPK content in grain, while significant content of Zn and Fe recorded in HUBR-2-1. Among different fertilizer sources, nutrient supplied through RFD75+FYM25 was record improvement in Zn and Fe content and uptake in grain and straw of rice. The significantly high content of Zn and their uptake in grain recorded under supply through the micronutrient level M7 (Zn:EDTA1+Fe-EDTA0.5). Whereas foliar application of M2:Fe-EDTA0.5 at 15 DAT and 50% panicle initiation significantly increased Fe content and uptake in grain and straw. Interaction effect of HUBR-2-1 and RFD75+FYM25 with single application of Zn-EDTA1 through soil recorded significant zinc content in grain. It can be concluded that the NDR-359 was found the high yielding rice cultivar responding to RFD75+FYM25 along with supply of micronutrient as Zn-EDTA1+Fe-EDTA0.5 in alluvial soil of Uttar Pradesh.

Keywords
Rice, Fertilizer, Micronutrient, Yield and uptake.

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Introduction

Rice (Oryza sativa L.) cultivated in 114 of the 193 countries of the world and considers one of the most important cereal crops in India. The amount needed from it is greater than that locally produced. Therefore, increasing its productivity as well as cultivated area is highly recommended. Plants require specific amount of certain nutrients in specific form at appropriate time, for their growth and development. In India rice productivity is still very low. During the last few decades, though country has witnessed some increase in productivity but to meet our expected demand of 140 MT by the end of 2020, it warrants further intensified efforts to increase the production and productivity of the crops. However, imbalanced use of nutrients, giving much emphasis to supplement the soil with the micronutrients, may lead to widespread deficiencies of other nutrients, particularly micronutrients under intensive cultivation. The deficiency of micronutrients has become
major constraints to productivity, stability, sustainability and fertility of soil. Large variation in the content of iron and zinc in grains of rice varieties, have been observed.

The aromatic cultivars have consistently higher concentration of iron and zinc in grain than the non-aromatic types (Graham et al., 1997). In general iron density in rice varied from 7-24 mg kg\(^{-1}\) and that of zinc between 16-58 mg kg\(^{-1}\). However, nearly in all the widely grown varieties content of Zn and Fe remained 12 and 22 mg kg\(^{-1}\) for iron and zinc respectively (Senadhira and Graham, 1999). Red rice genotypes showed higher iron and zinc concentration as compared to white rice. The role of N nutrition in biofortification of grain with Zn and Fe is a highly relevant issue in terms of designing new fertilizer programs for increasing Zn and Fe content in grain. Improving N nutrition of plants may contribute to grain Zn and Fe concentrations by affecting the levels of Zn-or Fe-chelating nitrogenous compounds required for transport of Zn and Fe within plants and/or the abundance of Zn and Fe transporters needed for root uptake and phloem loading of Zn and Fe. Finally, the results indicate that nitrogen management represents an effective agronomic tool to contribute to grain Zn and Fe concentrations (Ismail Cakmak, 2010).

Zinc-iron interaction has been reported in many crops. Lee et al., (1969) observed that completion sites exists between Fe\(^{3+}\) and Zn\(^{2+}\) while Brar and Sekhon (1976) reported that inhibitory effect of Fe on Zn absorption was non-competitive and translocation of Zn decreased with increased Fe levels. However, postulated that Zn may be bound in the soil through Fe/Al phosphate bridges, which are not readily available to plants. Few of such studies, refer to rice which, being physiologically different, responds differently to nutrient interactions. Under reduced conditions, increased availability of Fe and deficiency of Zn have been reported due to decreased absorption of Zn by plants (Rashid et al., 1976). Such soils are widely distributed in the states of Uttar Pradesh of these soils occasionally show toxic concentrations of available Fe and marginal concentrations of available Zn for rice and under such a situation liming is generally recommended to raise rice crop successfully. However, the effects of high content of Fe and application of lime on Zn availability in such soils are not fully known, particularly for upland conditions. Therefore, an attempt has been made in this paper to study interaction effects of rice for Zn and Fe on grain and straw yields and on Zn and Fe content in upland rice.

Under such conditions, soil application of micronutrients can be very expensive. The macro and micro-nutrients added to the soil, their availability will be affected by the soil environmental factors. Foliar feeding technique, as a particular way to supply these nutrients could avoid these factors and results in rapid absorption. Foliar feeding of micronutrients generally is more effective and less costly. It is well known that soil application of NPK fertilizers may lead to some losses of these fertilizers. The reported experiment was undertaken to study the effect of soil and foliar application of micronutrients on interaction between Zn and Fe content and uptake of rice crop to improve the nutritional status of plants.

**Materials and Methods**

The field experiments were conducted in SPD design during kharif 2006-07 and 2007-08, at the Department of Agronomy, Agricultural Research Farm, Institute of Agricultural Science, Banaras Hindu University Varanasi. The experiment consisted of two levels of varieties (\(V_1\):NDR-359, \(V_2\):HUBR-2-1), two level of fertilizer source (\(F_1\):RFD\(_{100}\),
F₂:RFD₇₅+FYM₃₅) arranged in main plot and nine level of micronutrient supply through soil and foliar application viz. M₀:0 (control), M₁:Zn-EDTA₁ (Zn as soil application through Zn-EDTA at 1.00 kg ha⁻¹), M₂:Zn-EDTA₀.₅ (Zn as foliar application through Zn-EDTA at 0.5 kg ha⁻¹), M₃:Fe-EDTA₁ (Fe as soil application through Fe-EDTA at 1.00 kg ha⁻¹), M₄:Fe-EDTA₀.₅ (Fe as foliar application through Fe-EDTA at 0.5 kg ha⁻¹), M₅:Zn-EDTA₁+Fe-EDTA₁ (Zn as soil application through Zn-EDTA at 1.00 kg ha⁻¹ + Fe as soil application through Fe-EDTA at 1.00 kg ha⁻¹), M₆:Zn-EDTA₀.₅+Fe-EDTA₀.₅ (Zn as foliar application through Zn-EDTA at 0.5 kg ha⁻¹ followed by Fe as foliar application through Fe-EDTA at 0.5 kg ha⁻¹), M₇:Zn-EDTA₁+Fe-EDTA₀.₅ (Zn as soil application through Zn-EDTA at 1.00 kg ha⁻¹ followed by Fe as foliar application through Fe-EDTA at 0.5 kg ha⁻¹), M₈:Fe-EDTA₁+Zn-EDTA₀.₅ (Fe as soil application through Fe-EDTA at 1.00 kg ha⁻¹ followed by Zn as foliar application through Zn-EDTA at 0.5 kg ha⁻¹) allotted in sub-plot design. There were 36 treatment combinations, each replicated for three times. One hundred eight plots were prepared and planted test crop on a spacing of 20 x 10 cm with two seedling hill-1.

For which the nursery beds was prepared on leveled and slightly raised ground (5 cm high) having a small plot of 22 m² for growing rice seedling. The healthy seed of test cultivar NDR-359 and HUBR-2-1 (Malviya Basmati-1) were sown separately by broad casting method at 25-30 kg ha⁻¹. As source of nutrients, 75% of recommended dose of 120 kg Nitrogen 60 kg P₂O₅ and 60 Kg K₂O from the source of urea, diammonium phosphate and muriate of potash respectively, and 50 Qtl FYM (25% N though organic manure. While Zn-EDTA and Fe-EDTA at 1 kg ha⁻¹ were incorporated thoroughly mixed into the soil whereas 0.5 kg ha⁻¹ Zn-EDTA and Fe-EDTA were applied as foliar application as per treatment. Half of N, total of quantity of phosphorus, potassium, FYM and Zn-EDTA, Fe-EDTA (as soil application) were applied as basal at the time of transplanting and the remaining half was top dressed in two equal amounts at maximum tillering and at flowering stages. The foliar application of Zn-EDTA and Fe-EDTA each at 0.5 kg ha⁻¹ were applied in two splits at 15 days after transplanting and at 50% at panicle initiation stage.

Soil of experimental field was alluvium, neutral in pH (7.3), low in available nitrogen (190.56 kg ha⁻¹), medium in available phosphorus (20.58 kg ha⁻¹) and exchangeable K (223.87 kg ha⁻¹). While content of Zn (0.89 kg ha⁻¹), and Fe (20.67 kg ha⁻¹) were deficient. Observation on nutrient content and uptake (Zn and Fe) were done at 90 days after transplanting. Estimation of N, P, K, Zn and Fe, respectively were done by the methods given by Zn and Fe (L’vov, 2005).

**Results and Discussion**

Data revealed that variety NDR-359 produced significantly higher grain yield and straw yield. Slight varietal differences were observed in N, P and K content of grain. Variety NDR-359 recorded higher N and P content than HUBR-2-1, but it recorded significantly higher K content in grain. In non-aromatic rice varieties, about 73% of N was translocated to grain and rest remained in the straw while in aromatic cultivars translocation of N to grain was only 47% (De *et al.*, 2002). Application of N, P, K with micronutrients Zn and Fe are known to increase the uptake or content of N, P, K, Zn and Fe (Ganghaib *et al.*, 1999). However, micronutrient (Zn and Fe) content of variety HUBR 2-1 proved significantly superior to NDR-359 (Table 1 and Fig. 1). Variety, HUBR 2-1 recorded maximum zinc and iron in grains because it is aromatic in nature
which supported the fact that zinc and iron concentrations remain higher in grains due to aromatic nature of the variety. These findings are strongly supported by Babu et al., 2005).

It is well known that the application of N,P, K, micronutrients along with FYM in proper combinations might increase and synthesize, various volatile aromatic compound found in rice, responsible for its aroma. Among which 2-Acetylene-1-Pyrroline (2-AP) is the most significant. Considerable improvement in grain quality of aromatic rice was recorded under combined use of organic and inorganic fertilizers as compared to 100% RFD through inorganic fertilizers (Sahu et al., 2007).

Application of 75% RFD through inorganic + 25% N through FYM recorded significantly higher grain yield of 5.40 t ha\(^{-1}\) over 100% RFD through inorganic (4.97 t ha\(^{-1}\)) (Table 2). Application of 75% RFD+25% N through FYM sources of fertilizers also produced relatively higher straw yield (7.54 t ha\(^{-1}\)) as compared to 100% recommended fertilizer dose sources of fertilizers at crop harvest (Table 2). It may be due to slow release of nutrients for a longer period after decomposition of FYM, which favored better plant growth and improved the yield components of rice. Improvement in all above yield attributes and yield has also been reported by Gupta et al., (2009). Application of 75% RFD through inorganic sources + 25% N through FYM proved significantly superior in increasing P, K, Zn and Fe content in grain over 100% RFD through inorganics whereas N content remained statistically at par with 100% recommended fertilizer dose (Table 3). The present results are in agreement with the findings of Srivastava et al., (2008) and Chandrapal et al., (2010). Organic sources also improved the content of Fe by supplying chelating agents, which helps in maintaining the solubility of micro-nutrients including Fe. The response of organic matter showed profound influence on the solubility of Fe in waterlogged soil by providing resistance to Fe chlorosis (Singh et al., 2010 and Das et al., 2010). It is thus apparent that application and maintenance of organic matter in the soil translates adequate long term availability of Fe. Improving N nutrition of plants may contribute to increase Zn and Fe concentration in grain by affecting the levels of Zn or Fe-chelating nitrogenous compound, required for transport of Zn and Fe within plants, which increased Zn and Fe transporters needed for its uptake by root and phloem loading. It indicates that nitrogen management is an effective agronomic tool to enhance grain Zn and Fe concentrations. The present results are in agreement with the findings of Cakmak (2010).

Application of Zn and Fe in combination with FYM and recommended dose of N, P, K significantly influenced the yield (Table 2; Fig. 2). Similarly combined application of Zn-EDTA at 1.00 Kg ha\(^{-1}\) followed by Fe-EDTA at 0.5 Kg ha\(^{-1}\) applied as foliar recorded significantly higher grain and straw yield over the single or combined application of Zn-EDTA and Fe-EDTA. Participation of Zn in biosynthesis of indole acetyl acid (IAA) and its role in initiation of primordial reproductive parts and partitioning of photosynthates towards them are responsible for increased yield (Takaki and Kushizaki, 1970). The favorable influence of applied Zn on yield may be due to its catalytic or stimulatory effect on most of the physiological and metabolic process of plants (Mandal et al., 2009). Iron as a constituent of the electron transport enzymes, like cytochromes and ferredoxin are actively involved in photosynthesis and mitochondrial respiration. It is also a constituent of the enzymes catalase and peroxidase, which catalyze the breakdown of H\(_2\)O\(_2\) (peroxide released during photorespiration) into H\(_2\)O and O\(_2\), preventing H\(_2\)O\(_2\) toxicity. Iron along with molybdenum,
is an element of the nitrite and nitrate reductase enzymes. Thus, iron helps in the utilization of nitrogen. All these physiological processes proved instrumental in increasing yield by application of iron. Incorporation of micronutrient (Zn-EDTA and Fe-EDTA) proved significantly superior to control in increasing N, P, K content in grains of rice (Table 3). Application of Zn-EDTA at 1 Kg ha\(^{-1}\) in soil followed by Fe-EDTA at 0.5 Kg ha\(^{-1}\) as foliar spray in two splits recorded maximum N, P and K content in grain of rice and proved superior over other treatments whereas, it remained at par with Zn-EDTA at 0.5 Kg ha\(^{-1}\) followed by 0.5 Kg ha\(^{-1}\) Fe-EDTA as foliar application. Rest of the treatment combinations remained almost on par. Increase in nutrient uptake with the increased fertility levels could be attributed to better availability of nutrients and their transport to the plant from the soil. Incorporation of Zn-EDTA at 1.00 Kg ha\(^{-1}\) as soil application showed significant superiority over all treatments in increasing Zn content in grain. The zinc and iron content in rice grains were recorded maximum with their separate application and minimum under control, whereas combined and sequential applications of Zn-EDTA and Fe-EDTA slightly decreased Zn and Fe concentrations in grains as compared to their separate applications reported by Verma and Tripathi (1983). Jana et al., (2010) also observed that soil application of Zn-EDTA led to higher content and uptake of N, P, K and Zn in grain and straw of rice. Alvarez et al., (2001) reported that when Zn was added as Zn-EDTA, the amounts of the most labile fractions (water-soluble plus exchangeable and organically complexed Zn) increased throughout the entire soil profile column, which enhanced the root-cell membrane function. Activity of carbonic anhydrase (CA) is closely related to Zn content in C3 plants (Pearson et al., 1995). Under extreme Zn deficiency, carbonic anhydrase activity remained almost absent. The labeled Zn rapidly accumulated in the roots of cereal crops upon immersion into the isotope solution. Root uptake and root-to-shoot transport of zinc and particularly internal utilization of zinc are equally important mechanism involved in the expression of zinc efficiency in cereal crops varieties. Since flag leaves are one of the sources of remobilized metals for developing seeds, the identification of the molecular players that might contribute to the process of metal transport from flag leaves to the seeds may be useful for biofortification purposes in relation to Zn and Fe (Sperotto et al., 2010). Foliar application of Fe in two splits produced highest Fe content in grain and proved significantly superior to all other combinations. Concurrently, incorporation of Zn-EDTA at 1 Kg ha\(^{-1}\) in soil and foliar application of Fe-EDTA at 0.5 Kg ha\(^{-1}\) showed next best affectivity in increasing Fe content over other treatments. Uptake of Zn or Fe, however, was reduced in combined soil as well as foliar applications of Zn and Fe which remarkably increased when applied to soil individually. This indicated antagonism between these two micronutrients when applied in combination. Further, Fe content improved due to application of N through organic sources which might be due to maintenance of better soil aeration and the solubility of micronutrients. Based on overall findings, it may be concluded that Zn-EDTA as soil and Fe-EDTA as foliar applied in rice contributed marked increase in yield associated with grain micronutrient content (Zn and Fe) along with their uptake as compared to other treatments and finally significantly balancing in ionic composition.

**Interaction effect between variety, fertilizer and micronutrient content in grain**

**On Zn content**

The significant interaction between variety and Zn content (V×M) was recorded in grain of rice (Table 1).
### Table 1 Effect of Zn, Fe and FYM on grain yield and straw yield of rice

| Treatments                        | 2006   | 2007   | Pooled | 2006   | 2007   | Pooled |
|-----------------------------------|--------|--------|--------|--------|--------|--------|
| **Varieties**                     |        |        |        |        |        |        |
| V1: NDR – 359                     | 54.50  | 55.61  | 55.05  | 73.78  | 76.25  | 75.01  |
| V2: HUBR 2-1                      | 47.22  | 50.27  | 48.75  | 70.93  | 73.76  | 72.34  |
| SEm±                              | 1.22   | 0.92   | 1.06   | 0.69   | 0.71   | 0.70   |
| CD (P = 0.05)                     | 4.23   | 3.18   | 3.66   | 2.39   | 2.47   | 2.42   |
| **Fertilizers**                   |        |        |        |        |        |        |
| F1: %RFD 100                      | 49.37  | 50.13  | 49.75  | 70.58  | 73.33  | 71.96  |
| F2: RFD 75 + FYM25                | 52.35  | 55.76  | 54.06  | 74.13  | 76.69  | 75.41  |
| SEm±                              | 1.22   | 0.92   | 1.06   | 0.69   | 0.71   | 0.70   |
| CD (P = 0.05)                     | NS     | 3.18   | 3.66   | 2.39   | 2.47   | 2.42   |
| **Micro-nutrient (Zn and Fe)**    |        |        |        |        |        |        |
| M0: Control                       | 42.89  | 44.13  | 43.49  | 64.72  | 65.14  | 65.83  |
| M1: Zn-EDTA at 1.00 kg ha\(^{-1}\) (S) | 52.20  | 54.33  | 53.25  | 72.88  | 76.41  | 74.65  |
| M2: Zn-EDTA at 0.5 kg ha\(^{-1}\) (F) | 50.27  | 52.84  | 51.60  | 70.88  | 75.34  | 73.11  |
| M3: Fe-EDTA at 1.00 kg ha\(^{-1}\) (S) | 49.36  | 52.07  | 50.71  | 70.55  | 74.01  | 72.28  |
| M4: Fe-EDTA at 0.5 kg ha\(^{-1}\) (F) | 51.81  | 53.62  | 52.72  | 72.73  | 76.05  | 74.39  |
| M5: Zn-EDTA at 1.00 kg ha\(^{-1}\) (S) + Fe-EDTA at 1.00kg (S) ha\(^{-1}\) | 51.89  | 53.80  | 52.85  | 73.61  | 76.23  | 74.92  |
| M6: Zn-EDTA at 0.5 kg ha\(^{-1}\) (F) fb Fe-EDTA at 0.5 kg ha\(^{-1}\) (F) | 52.39  | 54.57  | 53.48  | 74.64  | 76.51  | 75.58  |
| M7: Zn-EDTA 1.00 kg ha\(^{-1}\) (S) fb Fe-EDTA at 0.5 kg ha\(^{-1}\) (F) | 55.26  | 57.28  | 56.27  | 77.57  | 79.46  | 78.52  |
| M8: Fe-EDTA at 1.00 kg ha\(^{-1}\) (S) fb Zn-EDTA at 0.5 kg ha\(^{-1}\) (F) | 51.68  | 53.84  | 52.76  | 73.60  | 75.93  | 74.77  |
| SEm±                              | 0.89   | 0.79   | 0.83   | 0.64   | 0.67   | 0.65   |
| CD (P = 0.05)                     | 2.52   | 2.24   | 2.35   | 1.80   | 1.90   | 1.84   |

*RFD-Recommended Fertilizers Dose, S-Soil application, F-foliar application, fb-Followed by, NS-Non-significant*
Table.2a Interaction effect between variety and micronutrient (Zn and Fe) on zinc content (ppm) by grain of rice during 2006 and 2007

| Zn and Fe Application (V x M) | 2006 | 2007 |
|------------------------------|------|------|
|                              | V₁   | V₂   | V₁   | V₂   |
|                               | (NDR-359) | (HUBR-2-1) | (NDR-359) | (HUBR-2-1) |
| M₀: Control                   | 142.17 | 149.66 | 147.58 | 154.06 |
| M₁: Zn-EDTA at 1.00 kg ha⁻¹ (S) | 158.65 | 186.11 | 169.70 | 191.85 |
| M₂: Zn-EDTA at 0.5 kg ha⁻¹ (F) | 157.10 | 178.19 | 162.75 | 184.35 |
| M₃: Fe-EDTA at 1.00 kg ha⁻¹ (S) | 142.64 | 168.77 | 147.94 | 174.71 |
| M₄: Fe-EDTA at 0.5 kg ha⁻¹ (F) | 150.63 | 167.75 | 163.38 | 164.42 |
| M₅: Zn-EDTA at 1.00 kg ha⁻¹ (S) + Fe-EDTA at 0.5 kg ha⁻¹ (F) | 152.14 | 171.76 | 171.87 | 181.49 |
| M₆: Zn-EDTA at 0.5 kg ha⁻¹ (F) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 155.73 | 170.77 | 163.33 | 172.79 |
| M₇: Zn-EDTA at 1.00 kg ha⁻¹ (S) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 157.22 | 174.21 | 162.27 | 178.28 |
| M₈: Fe-EDTA at 1.00 kg ha⁻¹ (S) fb Zn-EDTA at 0.5 kg ha⁻¹ (F) | 144.95 | 154.15 | 150.98 | 172.38 |

SEM± CD (P = 0.05) SEM± CD (P = 0.05)

| M at same level of V | 1.76 | 4.98 | 1.85 | 5.22 |
| M at same level of M | 2.18 | 6.75 | 2.28 | 7.05 |

Table.2b Interaction effect between fertilizer and micronutrient on zinc content of rice grain (ppm) 2007

| Zn and Fe Application (F x M) | F₁   | F₂   |
|------------------------------|------|------|
| M₀: Control                   | 143.02 | 158.63 |
| M₁: Zn-EDTA at 1.00 kg ha⁻¹ (S) | 174.78 | 184.77 |
| M₂: Zn-EDTA at 0.5 kg ha⁻¹ (F) | 168.70 | 175.40 |
| M₃: Fe-EDTA at 1.00 kg ha⁻¹ (S) | 153.49 | 169.16 |
| M₄: Fe-EDTA at 0.5 kg ha⁻¹ (F) | 159.47 | 169.38 |
| M₅: Zn-EDTA at 1.00 kg ha⁻¹ (S) + Fe-EDTA at 1.00 kg ha⁻¹ (F) | 170.46 | 178.56 |
| M₆: Zn-EDTA at 0.5 kg ha⁻¹ (F) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 161.60 | 177.03 |
| M₇: Zn-EDTA at 1.00 kg ha⁻¹ (S) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 164.74 | 182.31 |
| M₈: Fe-EDTA at 1.00 kg ha⁻¹ (S) fb Zn-EDTA at 0.5 kg ha⁻¹ (F) | 157.21 | 168.06 |

M at same level of F | 1.85 | 5.23 |
F at same or different micronutrient (M) | 2.28 | 7.05 |
Table 2c Interaction between variety, fertilizer and micronutrient (Zn and Fe) on Zn content (ppm) by rice grain during 2006

| Zn and Fe Application (VxFxM) | V1F1  | V1F2  | V2F1  | V2F2  |
|-------------------------------|-------|-------|-------|-------|
| M0: Control                   | 135.630 | 148.710 | 141.490 | 157.830 |
| M1: Zn-EDTA at 1.00 kg ha⁻¹ (S) | 153.540 | 163.760 | 180.370 | 191.850 |
| M2: Zn-EDTA at 0.5 kg ha⁻¹ (F) | 151.350 | 162.840 | 170.840 | 185.530 |
| M3: Fe-EDTA at 1.00 kg ha⁻¹ (S) | 139.620 | 145.660 | 155.960 | 181.570 |
| M4: Fe-EDTA at 0.5 kg ha⁻¹ (F) | 136.420 | 164.830 | 161.680 | 173.820 |
| M5: Zn-EDTA at 1.00 kg ha⁻¹ (S) + Fe-EDTA at 0.5 kg ha⁻¹ (F) | 145.580 | 158.690 | 168.330 | 175.180 |
| M6: Zn-EDTA at 0.5 kg ha⁻¹ (F) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 147.890 | 163.560 | 168.700 | 172.840 |
| M7: Zn-EDTA at 1.00 kg ha⁻¹ (S) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 145.780 | 168.650 | 169.720 | 178.690 |
| M8: Fe-EDTA at 1.00 kg ha⁻¹ (S) fb Zn-EDTA at 0.5 kg ha⁻¹ (F) | 137.990 | 151.910 | 145.730 | 162.570 |

M at same level of V F  2.49  7.04
V F at same or different level of M  3.09  9.54

Table 3a Interaction effect between variety and micronutrient on Fe content (ppm) in grain of rice during 2006 and 2007

| Zn and Fe Application (V × M) | 2006 | 2007 |
|-------------------------------|------|------|
|                              | V1   | V2   | V1   | V2   |
|                              | (NDR-359) | (HUBR 2-1) | (NDR-359) | (HUBR 2-1) |
| M0: Control                   | 35.74 | 39.06 | 39.00 | 42.55 |
| M1: Zn-EDTA at 1.00 kg ha⁻¹ (S) | 40.85 | 45.64 | 43.50 | 47.41 |
| M2: Zn-EDTA at 0.5 kg ha⁻¹ (F) | 56.27 | 55.10 | 63.21 | 57.78 |
| M3: Fe-EDTA at 1.00 kg ha⁻¹ (S) | 42.53 | 49.74 | 48.35 | 51.46 |
| M4: Fe-EDTA at 0.5 kg ha⁻¹ (F) | 66.25 | 85.68 | 73.34 | 95.31 |
| M5: Zn-EDTA at 1.00 kg ha⁻¹ (S) + Fe-EDTA at 1.00 kg ha⁻¹ (S) | 53.80 | 59.24 | 59.55 | 60.97 |
| M6: Zn-EDTA at 0.5 kg ha⁻¹ (F) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 58.15 | 67.31 | 62.41 | 71.37 |
| M7: Zn-EDTA at 1.00 kg ha⁻¹ (S) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 53.38 | 76.91 | 55.35 | 82.27 |
| M8: Fe-EDTA at 1.00 kg ha⁻¹ (S) fb Zn-EDTA at 0.5 kg ha⁻¹ (F) | 51.61 | 67.71 | 56.29 | 70.72 |

M at same level of V  0.65  1.84  0.70  1.98
V at same or different level of M  0.78  2.40  0.84  2.59
Table 3b Interaction effect between fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006 and 2007

| Zn and Fe Application (F × M) | 2006   | 2007   |
|-------------------------------|--------|--------|
|                               | F₁     | F₂     | F₁     | F₂     |
| M₀: Control                   | 35.20  | 39.60  | 39.57  | 41.98  |
| M₁: Zn-EDTA at 1.00 kg ha⁻¹   | 39.79  | 46.70  | 40.90  | 50.02  |
| (S)                           |        |        |        |        |
| M₂: Zn-EDTA at 0.5 kg ha⁻¹(F) | 48.67  | 62.70  | 53.02  | 67.97  |
| (S)                           |        |        |        |        |
| M₃: Fe-EDTA at 1.00 kg ha⁻¹   | 44.19  | 48.09  | 47.38  | 52.42  |
| (S)                           |        |        |        |        |
| M₄: Fe-EDTA at 0.5 kg ha⁻¹(F) | 69.18  | 82.75  | 74.37  | 94.28  |
| (S)                           |        |        |        |        |
| M₅: Zn-EDTA at 1.00 kg ha⁻¹(F) | 54.32  | 58.72  | 58.28  | 62.24  |
| (F) + Fe-EDTA at 1.00kg(S) ha⁻¹ |        |        |        |        |
| M₆: Fe-EDTA at 0.5 kg ha⁻¹(F) | 57.20  | 68.25  | 57.71  | 76.07  |
| (F) fb Fe-EDTA at 0.5 kg ha⁻¹ |        |        |        |        |
| M₇: Zn-EDTA at 1.00 kg ha⁻¹(F) | 59.56  | 70.73  | 61.79  | 75.84  |
| (F) fb Zn-EDTA at 0.5 kg ha⁻¹ |        |        |        |        |
| M₈: Fe-EDTA at 1.00 kg ha⁻¹(F) | 62.53  | 75.83  | 60.88  | 76.07  |
| (F) fb Zn-EDTA at 0.5 kg ha⁻¹ |        |        |        |        |
| M at same level of F          | 0.65   | 1.84   | 0.70   | 1.98   |
| F at same or different level of M | 0.78   | 2.40   | 0.84   | 2.59   |

Table 3c Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006

| Zn and Fe Application (V×F×M) | 2006          | 2006          |
|-------------------------------|---------------|---------------|
|                               | V F₁₁         | V F₁₂         |
|                               | V F₂₁         | V F₂₂         |
| M₀: Control                   | 33.650        | 37.830        |
| M₁: Zn-EDTA at 1.00 kg ha⁻¹   | 37.820        | 43.870        |
| (S)                           | 41.750        | 49.520        |
| M₂: Zn-EDTA at 0.5 kg ha⁻¹(F) | 45.860        | 66.670        |
| (S)                           | 51.470        | 58.730        |
| M₃: Fe-EDTA at 1.00 kg ha⁻¹   | 40.480        | 44.580        |
| (S)                           | 47.890        | 51.590        |
| M₄: Fe-EDTA at 0.5 kg ha⁻¹(F) | 62.530        | 69.970        |
| (F)                           | 75.830        | 95.530        |
| M₅: Zn-EDTA at 1.00 kg ha⁻¹(F) | 51.960        | 56.640        |
| (F) fb Fe-EDTA at 0.5 kg ha⁻¹ | 56.680        | 61.800        |
| M₆: Zn-EDTA at 1.00 kg ha⁻¹(F) | 53.520        | 62.770        |
| (F) fb Fe-EDTA at 0.5 kg ha⁻¹ | 60.880        | 73.7300       |
| M₇: Zn-EDTA at 0.5 kg ha⁻¹(F) | 50.940        | 55.810        |
| (F) fb Zn-EDTA at 0.5 kg ha⁻¹ | 68.180        | 85.640        |
| M₈: Fe-EDTA at 1.00 kg ha⁻¹(F) | 48.330        | 54.880        |
| (F) fb Zn-EDTA at 0.5 kg ha⁻¹ | 63.780        | 71.630        |
| M at same level of V F        | 0.92          | 2.61          |
| V F at same or different level of M | 1.11          | 3.39          |
### Table 3d

Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2007

| Zn and Fe Application (V×F×M) | 2007          |          |          |          |
|------------------------------|---------------|----------|----------|----------|
|                               | $V_1F_{1,1}$  | $V_1F_{1,2}$ | $V_2F_{2,1}$ | $V_2F_{2,2}$ |
| $M_0$: Control                | 37.560        | 40.430   | 41.570   | 43.530   |
| $M_1$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) | 38.220        | 48.780   | 43.570   | 51.250   |
| $M_2$: Zn-EDTA at 0.5 kg ha$^{-1}$ (F) | 51.780        | 74.630   | 54.250   | 61.310   |
| $M_3$: Fe-EDTA at 1.00 kg ha$^{-1}$ (S) | 44.840        | 51.850   | 49.920   | 52.990   |
| $M_4$: Fe-EDTA at 0.5 kg ha$^{-1}$ (F) | 66.350        | 80.330   | 82.380   | 108.230  |
| $M_5$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) + Fe-EDTA at 1.00 kg ha$^{-1}$ (F) | 57.690        | 61.400   | 58.860   | 63.080   |
| $M_6$: Zn-EDTA at 0.5 kg ha$^{-1}$ (F) fb Fe-EDTA at 0.5 kg ha$^{-1}$ (F) | 56.320        | 68.500   | 59.100   | 83.630   |
| $M_7$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) fb Zn-EDTA at 0.5 kg ha$^{-1}$ (F) | 54.490        | 56.210   | 69.080   | 95.460   |
| M at same level of V F        | 0.99          | 2.80     |          |          |
| V F at same or different level of M | 1.19          | 3.36     |          |          |

### Table 3e

Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha$^{-1}$) by rice during 2006.

| Zn and Fe Application (V×F×M) | 2006          |          |          |          |
|------------------------------|---------------|----------|----------|----------|
|                               | $V_1F_1$      | $V_1F_2$ | $V_2F_1$ | $V_2F_2$ |
| $M_0$: Control                | 1.007         | 1.117    | 1.151    | 1.260    |
| $M_1$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) | 1.337         | 1.632    | 1.444    | 2.028    |
| $M_2$: Zn-EDTA at 0.5 kg ha$^{-1}$ (F) | 1.184         | 1.591    | 1.412    | 1.683    |
| $M_3$: Fe-EDTA at 1.00 kg ha$^{-1}$ (S) | 1.435         | 1.561    | 1.535    | 2.417    |
| $M_4$: Fe-EDTA at 0.5 kg ha$^{-1}$ (F) | 1.673         | 1.998    | 2.250    | 2.886    |
| $M_5$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) + Fe-EDTA at 1.00 kg ha$^{-1}$ (F) | 1.376         | 1.624    | 1.855    | 2.197    |
| $M_6$: Zn-EDTA at 0.5 kg ha$^{-1}$ (F) fb Fe-EDTA at 0.5 kg ha$^{-1}$ (F) | 1.475         | 1.837    | 2.086    | 2.623    |
| $M_7$: Zn-EDTA at 1.00 kg ha$^{-1}$ (S) fb Zn-EDTA at 0.5 kg ha$^{-1}$ (F) | 1.485         | 1.786    | 2.378    | 2.779    |
| M at same level of V F        | 0.01          | 0.04     |          |          |
| V F at same or different level of M | 0.02          | 0.05     |          |          |
Table 3f Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha⁻¹) by rice during 2007.

| Zn and Fe Application (V×F×M) | 2007 |
|-------------------------------|------|
|                               | V₁F₁ | V₁F₂ | V₂F₁ | V₂F₂ |
| M₀: Control                   | 1.071| 1.209| 1.259| 1.391|
| M₁: Zn-EDTA at 1.00 kg ha⁻¹ (S) | 1.455| 1.754| 1.582| 2.146|
| M₂: Zn-EDTA at 0.5 kg ha⁻¹ (F) | 1.372| 1.744| 1.549| 1.820|
| M₃: Fe-EDTA at 1.00 kg ha⁻¹ (S) | 1.535| 1.690| 1.710| 2.661|
| M₄: Fe-EDTA at 0.5 kg ha⁻¹ (F) | 1.813| 2.212| 2.523| 3.185|
| M₅: Zn-EDTA at 1.00 kg ha⁻¹ (S) + Fe-EDTA at 1.00 kg ha⁻¹ (S) | 1.482| 1.699| 1.945| 2.330|
| M₆: Zn-EDTA at 0.5 kg ha⁻¹ (F) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 1.563| 1.949| 2.183| 2.824|
| M₇: Zn-EDTA at 1.00 kg ha⁻¹ (S) fb Fe-EDTA at 0.5 kg ha⁻¹ (F) | 1.573| 1.870| 2.455| 2.952|
| M₈: Fe-EDTA at 1.00 kg ha⁻¹ (S) fb Zn-EDTA at 0.5 kg ha⁻¹ (F) | 1.367| 1.597| 2.358| 2.569|

M at same level of V F 0.01 0.04
V F at same or different level of M 0.02 0.05

**Fig. 1** Effect of Zn, Fe and FYM on grain yield and straw yield of rice

**Fig. 2** Interaction effect between variety and micronutrient (Zn and Fe) on zinc content (ppm) by grain of rice during 2006 and 2007
Fig. 3 Interaction effect between fertilizer and micronutrient on zinc content of rice grain (ppm) 2007

Fig. 4 Interaction between variety, fertilizer and micronutrient (Zn and Fe) on Zn content (ppm) by rice grain during 2006

Fig. 5 Interaction effect between variety and micronutrient on Fe content (ppm) in grain of rice during 2006 and 2007
**Fig. 6** Interaction effect between fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006 and 2007

**Fig. 7** Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006

**Fig. 8** Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2007
**Fig.9** Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha\(^{-1}\)) by rice during 2006.

![Graph showing interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha\(^{-1}\)) by rice during 2006.]

**Fig.10** Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha\(^{-1}\)) by rice during 2007.

![Graph showing interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha\(^{-1}\)) by rice during 2007.]

The combination of V\(_2\) (HUBR 2-1) with Zn-EDTA at 1.00 kg ha\(^{-1}\) through soil application recorded highest zinc content in grains than the other combinations but remained at par with Zn as foliar application through Zn-EDTA at 0.5 kg ha\(^{-1}\) during both the years of experimentation. This might be due to the efficiency of variety to absorb and store more zinc upon application reported by Tondon (1981).

On the combined application of fertilizer and micronutrient (Zn) had significant interaction in rice grain (Table 1b). Under interaction between fertilizer and micronutrient, Zn content was recorded significantly increased due to F\(_2\) x M\(_1\) (F2 -75% RFD through inorganics + 25% N through FYM) with soil application of Zn-EDTA at 1.00 kg ha\(^{-1}\) followed by application of Fe as foliar through Fe-EDTA at 0.5 kg ha\(^{-1}\) (M\(_7\)) during first year. Most probable reason for this interaction is to be appeared that efficiency of variety to absorb and store more fertilizer nutrient and zinc upon application reported by Nataraja et al., (2005).

Significant effect was recorded in interaction between variety, fertilizer and micronutrient on Zn content (VxFxM) in rice grain (Table 1b).

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Zn content under this interaction significantly increased in \( V_2 \times F_2 \times M_1 \) (\( V_2 \)-HUBR 2-1, \( F_2 \)-75\% RFD through inorganics + 25\% N through FYM, \( M_1 \)- Zn as soil application through Zn-EDTA at 1.00 kg ha\(^{-1}\)) closely followed by \( V_2 \times F_2 \times M_2 \) (\( M_2 \)-Zn as foliar application through Zn-EDTA at 0.5 kg ha\(^{-1}\)) during first year. It might be due to effective absorption of Zn by the variety (Yassen et al., 2010).

### On Fe content and uptake

Interaction of variety and micronutrient (Fe) showed significant increase in Fe content (\( V \times M \)) and its total uptake in rice grains during both the years. Higher Fe content and its total uptake in rice grains over control was recorded with HUBR 2-1(\( V_2 \)) when Fe was applied in the form of foliar spray (Fe-EDTA at 0.5 kg ha\(^{-1}\)) in two splits, one at 15 DAT and another at 50 \% panicle initiation stages (\( M_4 \)). This might be due to the efficiency of variety to absorb and accumulate higher Fe upon application (Table 2.1a) was reported by Tondon (1981).

Interaction effect of fertilizers (\( F_2 \)) and micronutrient (Fe) recorded significant on iron content (\( F \times M \)) and its total uptake in rice grains during both the years (Table 2.1b). Higher Fe content and its total uptake in rice grains was recorded due to foliar spray of Fe-EDTA at 0.5 kg ha\(^{-1}\) in two splits, \textit{i.e.} at 15 DAT and at 50 \% panicle initiation stages (\( M_4 \)). Other combinations remained almost at par. Similar findings were reported by Singh et al., (2002), and Nataraja et al., (2005).

The interaction effect of variety, fertilizers and micronutrient on Fe content in grain (\( V \times F \times M \)) and its total uptake was found significant during both years (Table 2.1c, d, and Table 2a,b). Higher Fe content and its total uptake in rice grains over control was recorded when Fe was applied foliarly through Fe-EDTA at 0.5 kg ha\(^{-1}\). Similarly significantly higher Fe content and total uptake in rice grain was recorded due to application of 75 \% RFD through inorganics + 25 \% N through FYM in combination with Fe as foliar application at 0.5 kg ha\(^{-1}\) than rest of the other treatment combinations during both the years of experimentation. Similar findings were reported by Singh et al., (2002) and Yassen et al., (2010).

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