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Enhancing nutrient content and uptake of Zn and Fe in aromatic rice through organic and inorganic sources of zinc and iron

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Abstract
Zinc (Zn) and iron (Fe) are important trace elements for people's health around the globe. A lot of people, especially children and women, are suffering from malnutrition caused by Zn and Fe deficiency. The deficiency are more pronounced in developing countries due to low income, which makes it difficult to afford meat or sea food that are rich in Zn and Fe. Biofortification of Zn and Fe in rice is the most economical and convenient way to supplement these micronutrients in the diet of poor people. A field experiment was carried out for "Enhancing nutrient content and uptake of Zn and Fe in aromatic rice through organic and inorganic sources of zinc and iron" during *kharif* 2019 at the Research Farm, Bihar Agricultural University, Sabour, Bhagalpur. The experiment was laid out with Randomized Complete Block design with ten treatments. Highest Zn content (35.74 mg kg^{-1}) and uptake (0.13 kg ha^{-1}) in grain as well as highest Zn content in straw (37.93 mg kg^{-1}) were recorded in treatment T_4 (RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering) while highest Zn uptake (0.21 kg ha^{-1}) in straw was recorded in treatment T_7 (RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of $FeSO_4$ @ 25 kg ha^{-1}). Fe content in grain (74.26 mg kg^{-1}) and straw (193.52 mg kg^{-1}) were found highest in T_6 (RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering) and T_8 (RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering) respectively while Fe uptake in grain (0.29 kg ha^{-1}) and straw (1.13 kg ha^{-1}) were found highest in treatment T_7 (RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of $FeSO_4$ @ 25 kg ha^{-1}).

Keywords: Aromatic rice, biofortification, foliar spray, nutrient content and uptake, $ZnSO_4$, $FeSO_4$

Introduction
Rice is a staple food and provides energy to almost half of the world's population, especially in Asia. Nutrient deficiency or malnutrition has affected at least 2 billion people (or 1 out of 3), mostly in Africa, South Asia, and Latin America (FA0, 2015) [4]. Micronutrient deficiency is a silent epidemic condition- it slowly weakens the immune system, stunts physical and intellectual growth, and even causes death. Under micronutrient deficiencies, zinc and iron deficiency are widespread and cause serious consequences. More than 24,000 people globally die daily owing to "hidden hunger" and malnutrition (Fiaz *et al*. 2019) [3]. Fe helps in the production of hemoglobin in human blood, which carries oxygen around the body; moreover, the immune system too needs Fe to work well. Zn deficiency can cause loss of appetite, poor growth, loss of hair, a poorly functioning immune system, poor wound healing and changes in taste sensation (IRRI, 2006) [7]. Polished rice contains an average of only 2 mg Fe kg^{-1} and 12 mg Zn kg^{-1}, whereas the recommended dietary intake of Fe for people is 10-15 mg; babies, children and teenagers require more Fe because they are growing rapidly; pregnant women need enough Fe for themselves and their growing baby, and this is particularly true toward the end of pregnancy when the baby is growing most rapidly; and girls and women who menstruate require more Fe due to blood loss. The recommended dietary intake of Zn is 12-15 mg (Welch and Graham 2004) [24] and currently, deficiency of Fe and Zn afflicts more than 50% of the world's population (Tucker 2003; Welch 2005) [20, 22]. Therefore, it has been suggested that increased levels of Zn and Fe in staple foods such as rice may play a major role in improving human health (Graham *et al*. 1999; Ruel and Bouis 1998; Welch and Graham 1999) [6, 14, 23].

Micronutrients, particularly Fe and Zn, have attained a great significance in today's intensive and

exploitive agriculture, which is aiming at increased crop productivity.

Bio-fortification is considered to be an effective process to increase the micronutrients in food crops including rice. It is also a sustainable and feasible strategy to alleviate micronutrient deficiencies for people who mainly consume rice and limited access to diversified food (or food markets) and good health facilities (Datta *et al*. 2000) [2]. Micronutrients (Zn and Fe) may be applied through different sources i.e, organic and inorganic sources. Zinc sulphate ($ZnSO_4$. $7H_2O$) containing 21% Zn and Iron sulphate ($FeSO_4$. $7H_2O$) containing 19% Fe may be used as an inorganic source. As an organic sources Panchagavya and Vermiwash are very effective and easy to handle may be used for biofortification of Fe and Zn. Panchagavya is an organic liquid fertilizer. One litre of it contains 28 mg Zinc and 87 mg Iron (Vajantha *et al*. 2012) [21] and is suitable for crop improvement in organic agriculture (Sangeetha and Thevanathan, 2010) [15]. Foliar application of Panchagavya has positive effect on growth and productivity of crops (Somasundaram *et al*. 2007) [19]. Vermiwash is a wonderful gift in the form of liquid obtained during the process of vermi-composting. It boosts up plant growth and yield safely, economically and in eco-friendly manner. It is a very nutritious and contains a lot of minerals, micronutrients, hormones, vitamins, antibiotics etc. in a form which is readily absorbable by plants. Vermiwash contains Zn (0.02 ppm) and Fe (0.06 ppm) (Manpreet *et al*. 2017) [10]. On application of vermiwash, plants become much more vigorous in growth and more resistant to pest and diseases (Jayashree *et al*. 2006) [9]. There are several potential approaches to increase the concentrations of Zn and Fe in staple foods, which include food biofortification either by plant breeding (genetic biofortification) or by the use of micronutrient fertilizers (agronomic biofortification). These deficiencies may be ameliorated by both soil and foliar applications of organic and inorganic sources of Zn and Fe. Keeping this in mind, an experiment was conducted for enhancing Zn and Fe content and uptake in aromatic rice through the organic and inorganic sources of Zn and Fe.

Materials and Methods

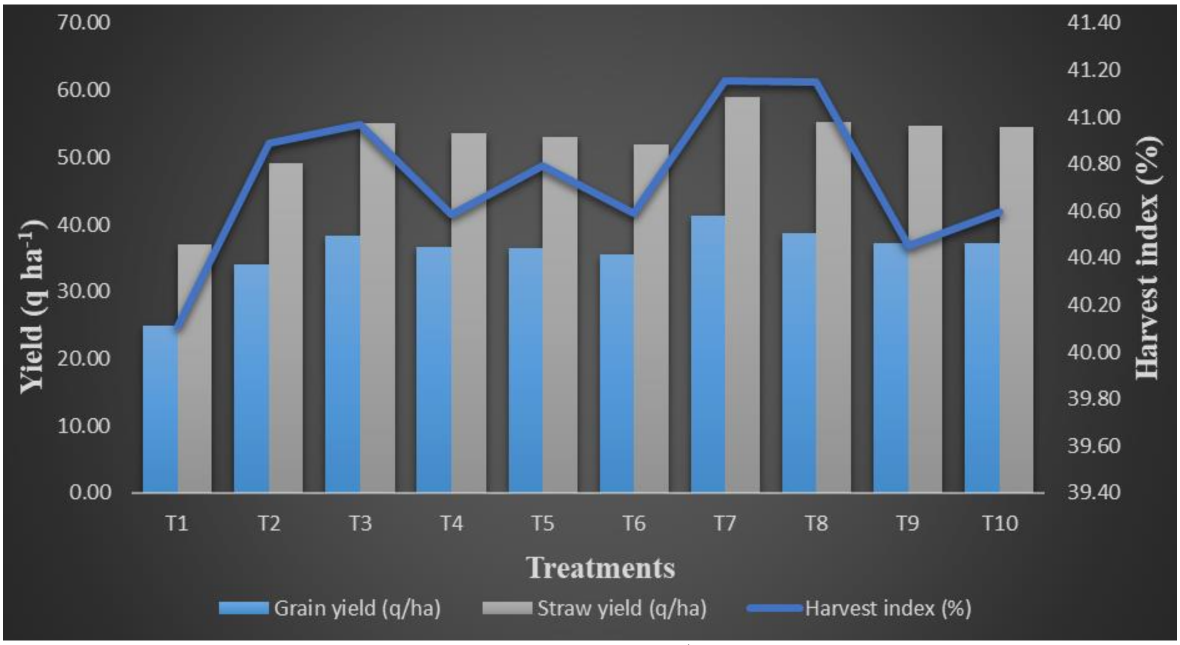
A field experiment on agronomic biofortification in aromatic rice through different sources of Zn and Fe was carried out at the agronomic research farm, Bihar Agricultural University, Sabour, Bhagalpur during *kharif* season of 2019. The latitude, longitude and altitude of this place are 25° 23' N, 78° 07' E and 37.19 meters above the mean sea level, respectively. Design of the experimental trial was Randomized Complete Block Design (RCBD) and replicated thrice with ten treatments (T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha^{-1}, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of $FeSO_4$ @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering) and plot size was 5.6 × 2.6 (14.56 m^2). Total number of plots were 30.

Yield was studied after harvesting as per investigation required. Crop was harvested at 15-20 per cent moisture in grain and plants showed physiological maturity. The total bio-mass harvested from each net plot was threshed, cleaned and weighed. Grain, thus obtained was weighed in terms of kg $plot^{-1}$ and then expressed in terms of q ha^{-1}. The straw yield for each plot was worked out by subtracting grain weight from total produce of individual net plot and it was computed in q ha^{-1}. Harvest index was calculated as ratio of economic yield to biological yield and expressed in percentage. Zinc and iron content were determined in an aliquat of the diacid digested extract by using atomic absorption spectrophotometer (AAS) method as described by (Lindsay and Follet 1969) [11].

Results and Discussion

Grain yield (q ha^{-1}), Straw yield (q ha^{-1}) and Harvest index (%)

An insight into the data clearly highlighted marked effect of all the treatments on grain and straw yield of aromatic rice (Fig. 1). It was clear from the graph that effect of bio-fortification through organic & inorganic sources of Zn & Fe on grain yield was found significant. Significantly higher grain yield of rice was recorded in treatment T_7 (41.30 q ha^{-1}) over all the treatments except T_8 (38.64 q ha^{-1}) and T_3 (38.25 q ha^{-1}) which were statistically at par with T_7. Further, the treatments T_8 and T_3 were also found comparable with T_{10} (37.26 q ha^{-1}) & T_9 (37.19 q ha^{-1}). In case of straw yield, treatment T_7 exhibited the maximum straw yield of 59.06 q ha^{-1} which was found superior to all, while the lowest straw yield was recorded with T_1 (37.02 q ha^{-1}). Among different treatments, the effect on harvest index was found non-significant. However, the maximum harvest index was recorded in treatment T_7 (41.16). Such an effects of micronutrients (Zn and Fe) application might be due to their critical role in crop growth, involving in photosynthesis process, respiration and biochemical and physiological activates and their importance in higher yield and biomass production, (Zeidan *et al*. 2010) [25]. The increase in yield could be due to adequate supply of Zn and Fe to plants as they take part in energy formation and translocation from sink to source. (Jat *et al*. 2011) [8] also obtained higher grain weight of rice by combined application of zinc and iron. These findings are in accordance with (Angelin *et al*. 2017) [16] and (Barua and Saikia 2018) [1].



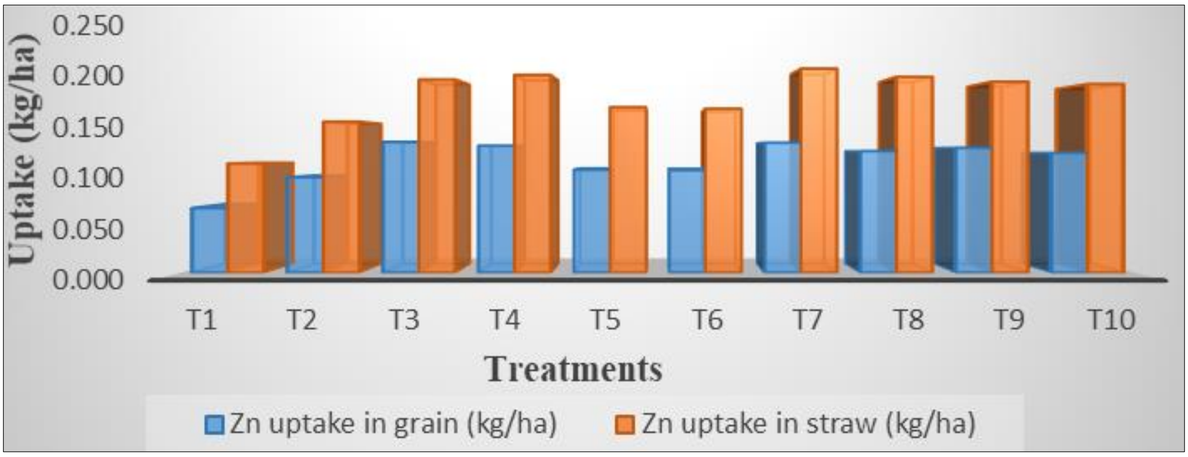
T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha -1, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of FeSO4 @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% FeS04 each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering.

Fig 1: Effect of bio-fortification through organic & inorganic sources of Zn & Fe on grain yield (q ha^{-1}), straw yield (q ha^{-1}) and harvest index of aromatic rice

Zinc content (mg kg^{-1}) and uptake (kg ha^{-1}) in grain and straw

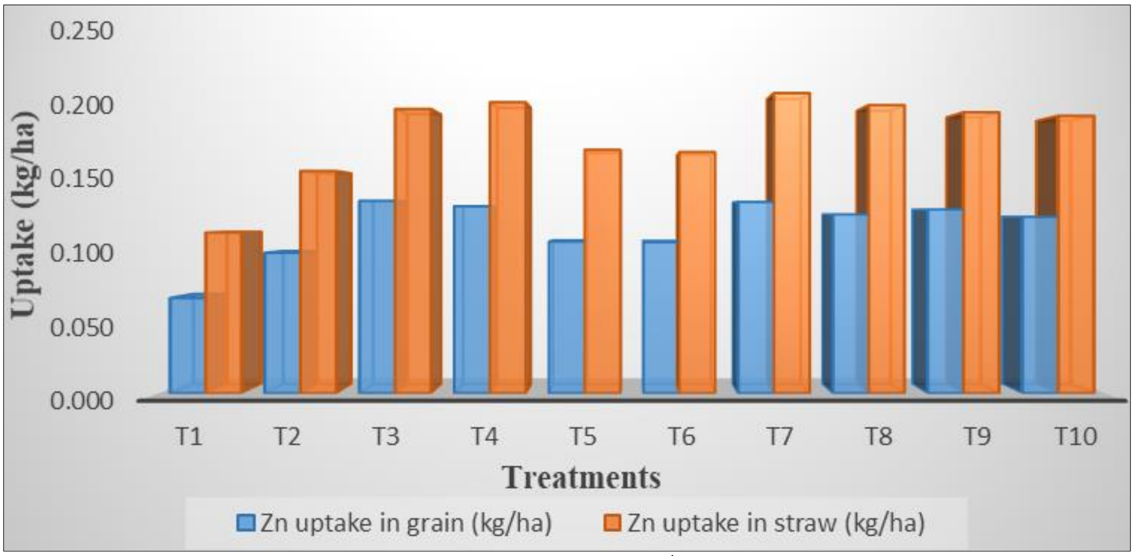
The close scanning of data shows that different treatments registered significant effect in Zn content in grain and straw (Fig 2). Among all the treatments highest content of Zn in grain (35.68 mg kg^{-1}) and straw (37.93 mg kg^{-1}) were recorded in treatment T_4 (RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering). While the lowest value of Zn content in grain (26.92 mg kg^{-1}) and straw (30.39 mg kg^{-1}) were found in T_1 (Absolute control).

Zinc uptake (kg ha^{-1}) in grain and straw indicates that different treatments shows marked variation on Zinc uptake in grain and straw (Fig. 3). The treatment T_4 (RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering) recorded the maximum value of Zinc uptake in grain (0.13 kg ha^{-1}) while the maximum uptake of Zn in straw (0.21 kg ha^{-1}) was recorded in T_7 (RDF + SA of $ZnSO_4$ @ 25 kg ha $^{-1}$ + SA of $FeSO_4$ @ 25 kg ha^{-1}) treatment. Lowest Zn uptake in grain (0.07 kg ha^{-1}) and straw (0.11 kg ha^{-1}) were recorded in T_1 (Absolute control). This might be due to foliar applied zinc which could be absorbed by leaf epidermis, and remobilized and transferred into the rice grains through phloem. Similar result was also reported by Gao *et al*. (2005) [5] and Slaton *et al*. (2001) [17].



T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha -1, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of FeSO4 @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering.

Fig 2: Effect of bio-fortification through organic & inorganic sources of Zn & Fe on zinc content (mg kg^{-1}) in grain and straw of plant after harvest of aromatic rice

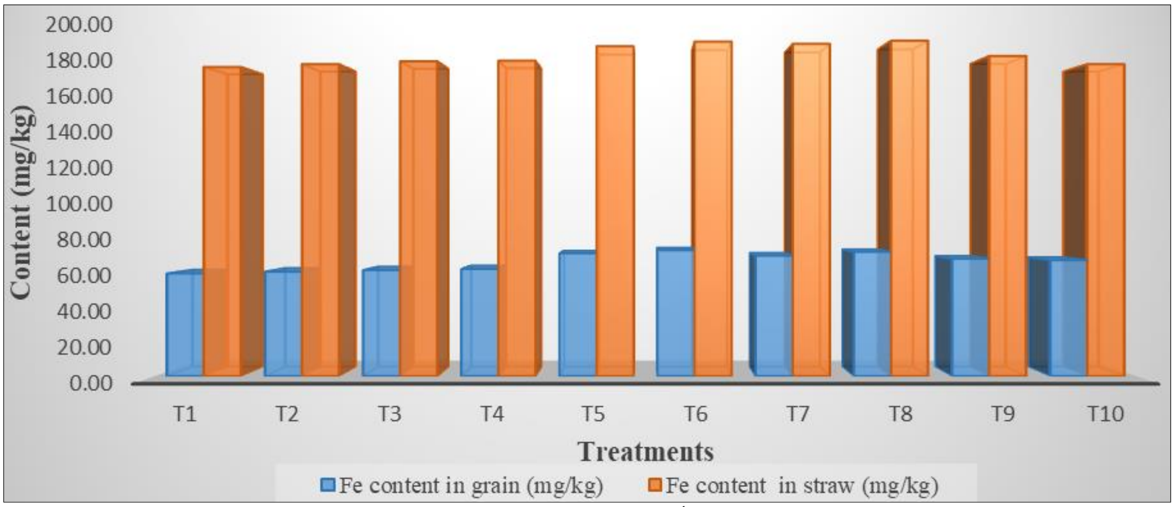


T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha -1, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of FeSO4 @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeS0_4$ each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering.

Fig 3: Effect of bio-fortification through organic & inorganic sources of Zn & Fe on zinc uptake (kg ha^{-1}) in grain and straw of plant after harvest of aromatic rice.

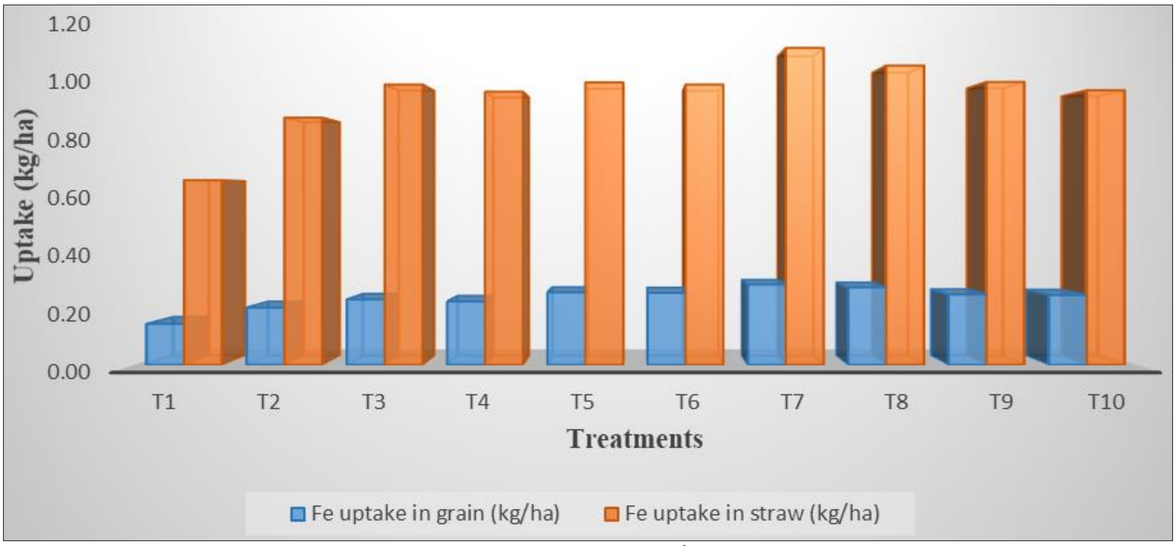
Iron content (mg kg^{-1}) and uptake (kg ha^{-1}) in grain and straw: Among different treatments highest content of Fe in grain (72.64 mg kg^{-1}) has recorded in treatment T_6 (RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering) while highest content of Fe in straw (193.52 mg kg^{-1}) has recorded in treatment T_8 (RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering) (Fig. 4).

Iron uptake in grain (kg ha^{-1}) was recorded highest in treatment T_7 (0.29 kg ha^{-1}) while in straw (kg ha^{-1}) was recorded highest in treatment T_7 (1.13 kg ha^{-1}) (Fig. 5). Increase in the Fe content of rice grain due to the application of Fe has been reported by several researchers (Sobramanyan and Mehta 1974) [18]. The increase in Zn and Fe uptake by the crop was associated with a corresponding increase in grain and straw yields of the crop (Meena and Bhaskaran 2005; Ramaiah *et al*. 1986) [12, 13].



T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha -1, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of FeSO4 @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeSO_4$ each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering.

Fig 4: Effect of bio-fortification through organic & inorganic sources of Zn & Fe on iron content (mg kg^{-1}) in grain and straw of plant after harvest of aromatic rice.



T_1: Absolute control, T_2: RDF, T_3: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1}, T_4: RDF + 2 FS of 0.5% $ZnSO_4$ at 25 DAT & 1 week after flowering, T_5: RDF + SA of $FeSO_4$ @ 25 kg ha^{-1}, T_6: RDF + 2 FS 0.5% $FeSO_4$ at 25 DAT & 1 week after flowering, T_7: RDF + SA of $ZnSO_4$ @ 25 kg ha^{-1} + SA of $FeSO_4$ @ 25 kg ha^{-1}, T_8: RDF + 2 FS of 0.5% $ZnSO_4$ & 2 FS of 0.5% $FeS0_4$ each at 25 DAT & 1 week after flowering, T_9: RDF + 3 FS of 3% Panch gavya at 25, 50 DAT & 1 week after flowering, T_{10}: RDF + 3 FS of vermi-wash at 25, 50 DAT & 1 week after flowering.

Fig 5: Effect of bio-fortification through organic & inorganic sources of Zn & Fe on iron uptake (kg ha^{-1}) in grain and straw of plant after harvest of aromatic rice

Conclusion

From the one year of experiment it can be concluded that highest Zn and Fe content as well as uptake of these micronutrients in aromatic rice will be achieved with the foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5% at 25 DAT and 1 week after flowering.

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